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Agriculture, Energy, Land and Water in GCAM

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The Global Change Assessment Model Team

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OVERVIEW

GCAM is an RCP-class integrated assessment model

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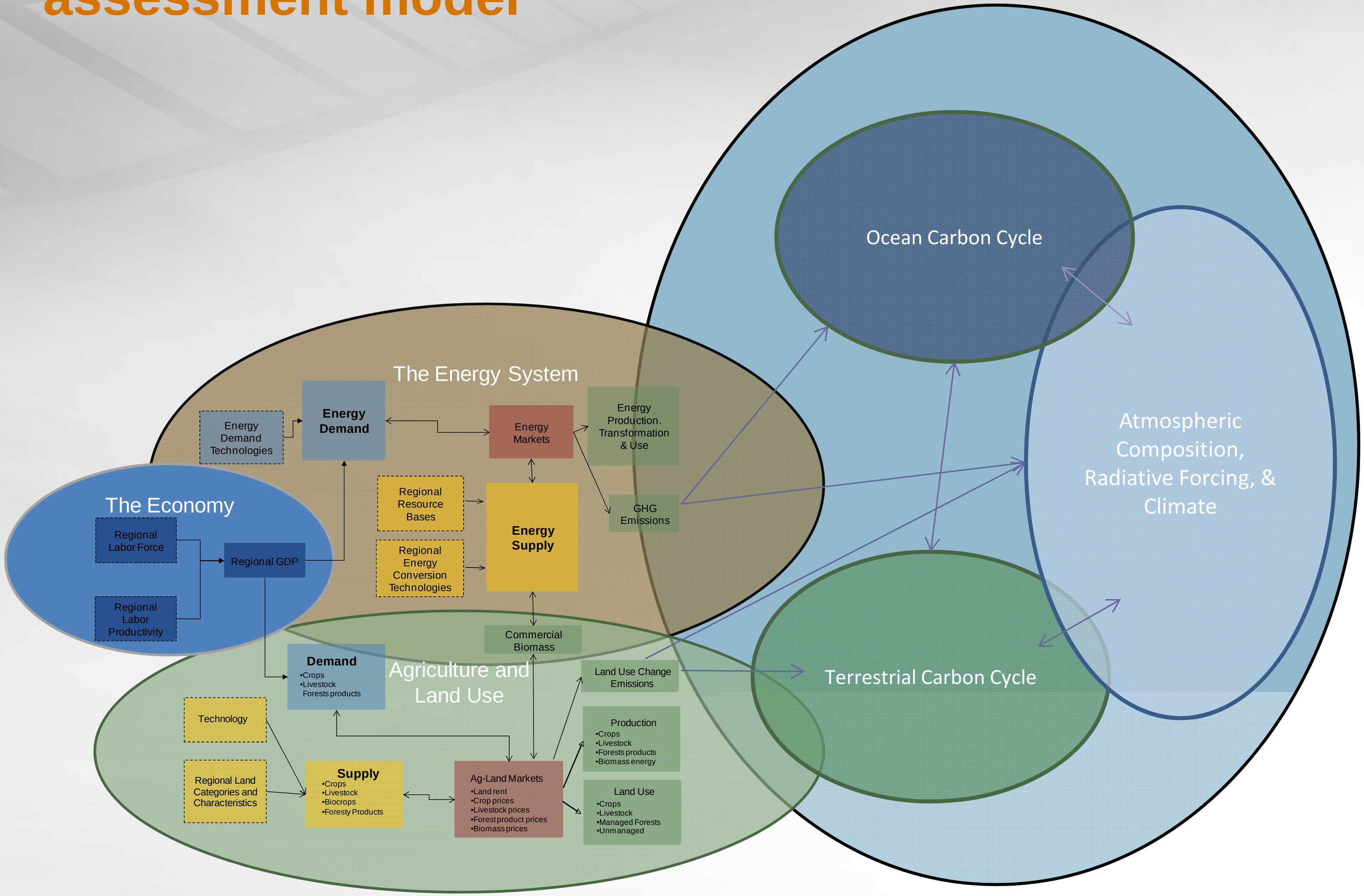

GCAM is an RCP class IAM

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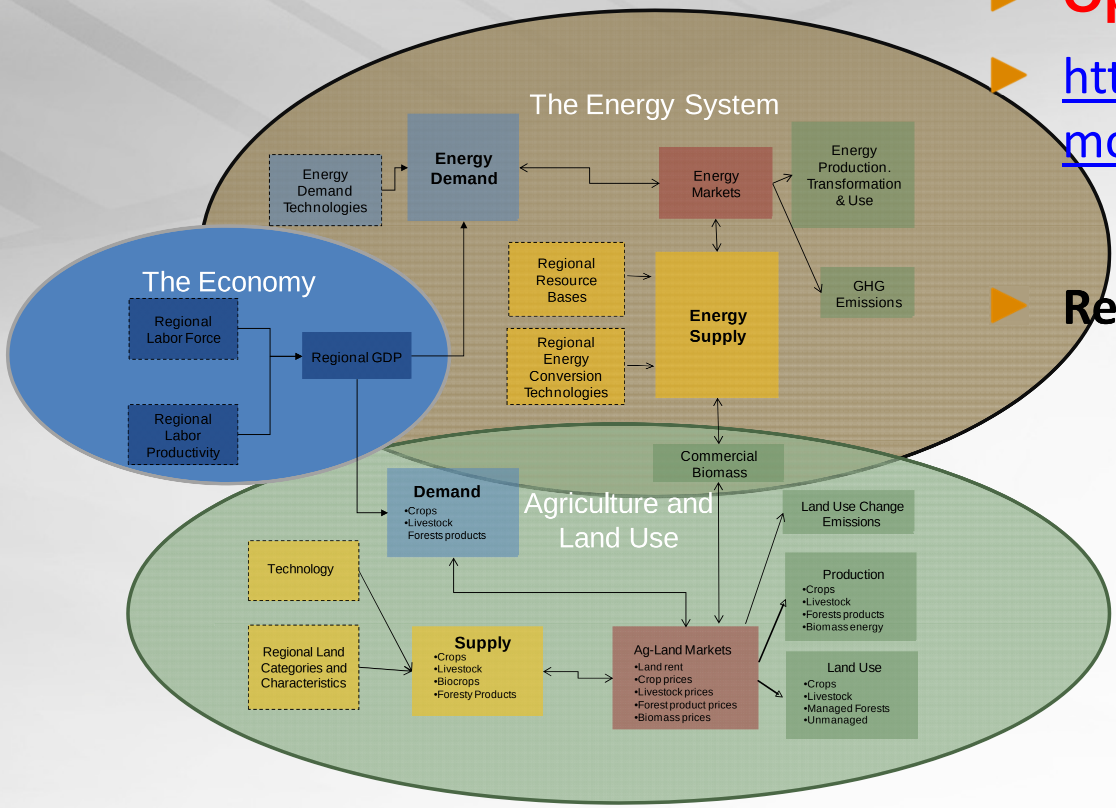
- **Open source model.**
- http://www.globalchange.umd.edu/models/gcam/download/
- **Research model.**



The GCAM human Earth systems

GCAM is an RCP-class IAM

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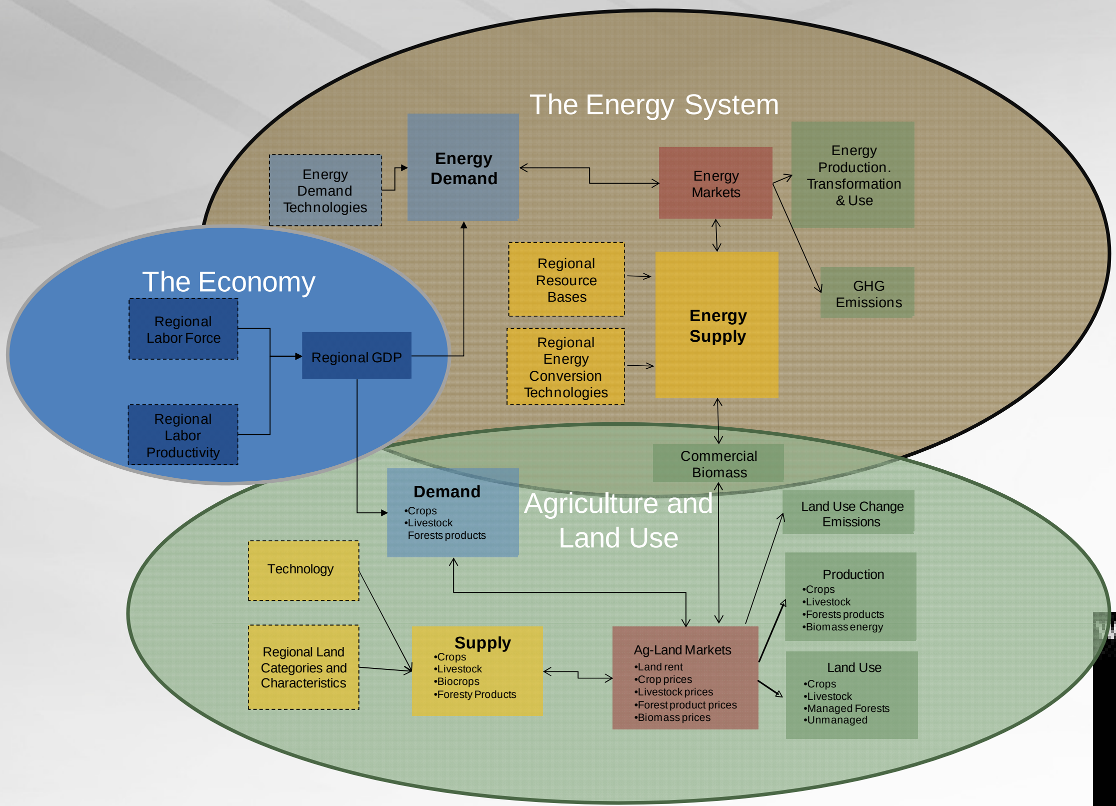
- Open source model.
- Research model.
- Use of GCAM by evil geniuses or terrorists organizations to take over the world is <u>STRICTLY PROHIBITED</u>.



The GCAM human Earth systems

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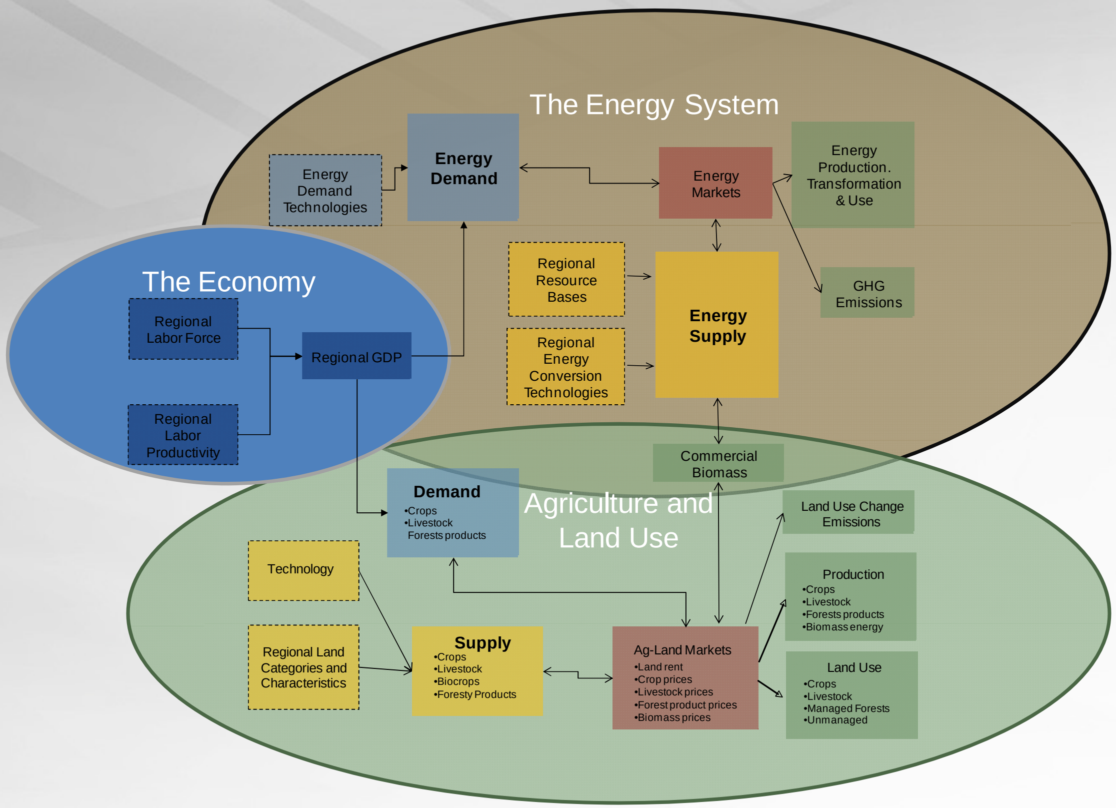
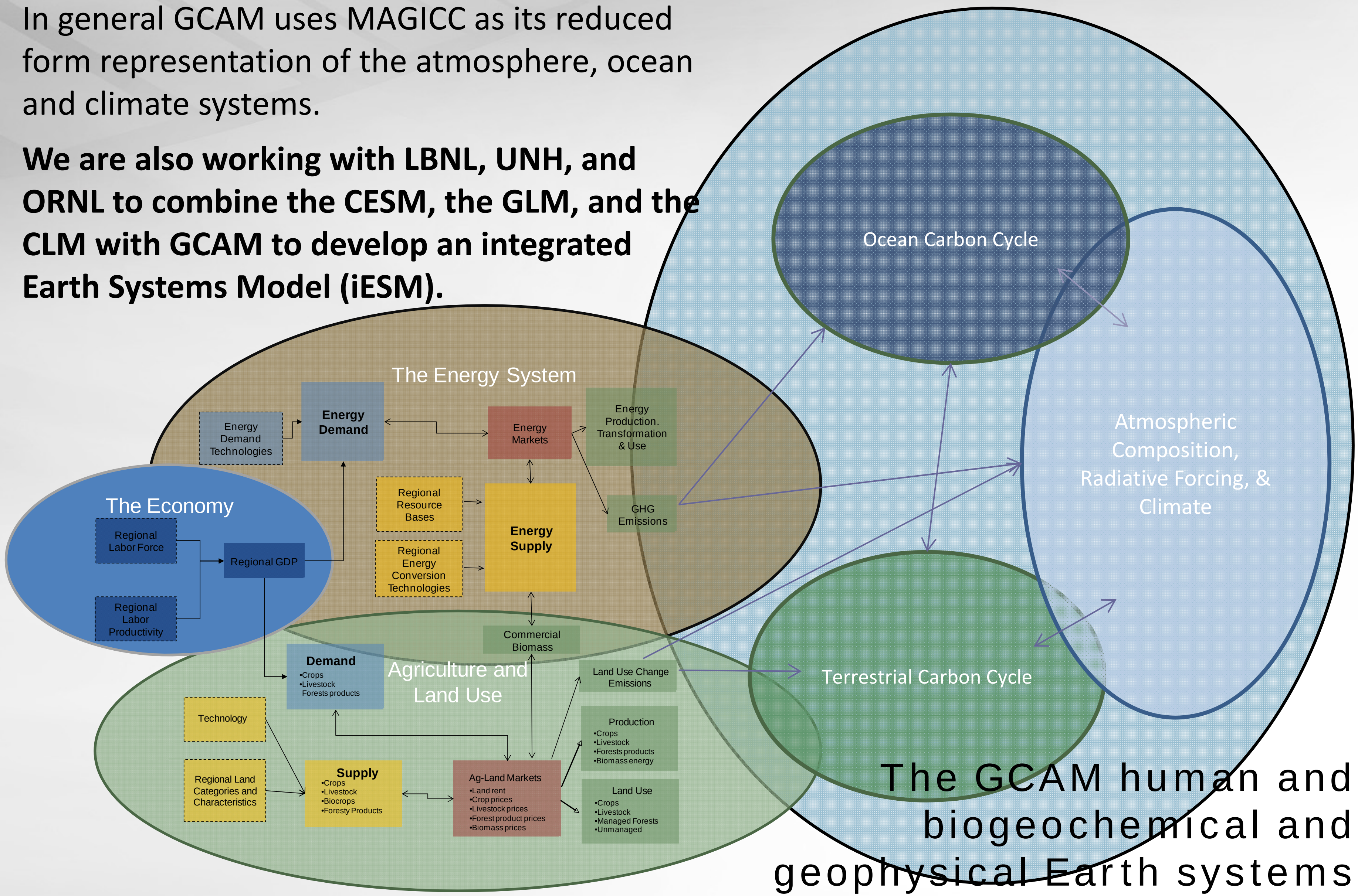


The GCAM human Earth systems

- **Open source model.**
- http://www.globalchange.umd.edu/models/gcam/download/
- Dynamic-recursive model.
- **The GCAM human Earth systems model has Economic, Energy and Land-use systems.**
- Technologically detail.
- Emissions of 16 greenhouse gases and short-lived species: CO_2, CH_4, N_2O, halocarbons, carbonacious aerosols, reactive gases, sulfur dioxide.
- 151 Agro-Ecological Zones (AEZ)
- **Runs through 2095 in 5-year time-steps (time step is variable).**

GCAM is an RCP-class IAM

- In general GCAM uses MAGICC as its reduced form representation of the atmosphere, ocean and climate systems.
- **We are also working with LBNL, UNH, and ORNL to combine the CESM, the GLM, and the CLM with GCAM to develop an integrated Earth Systems Model (iESM).**



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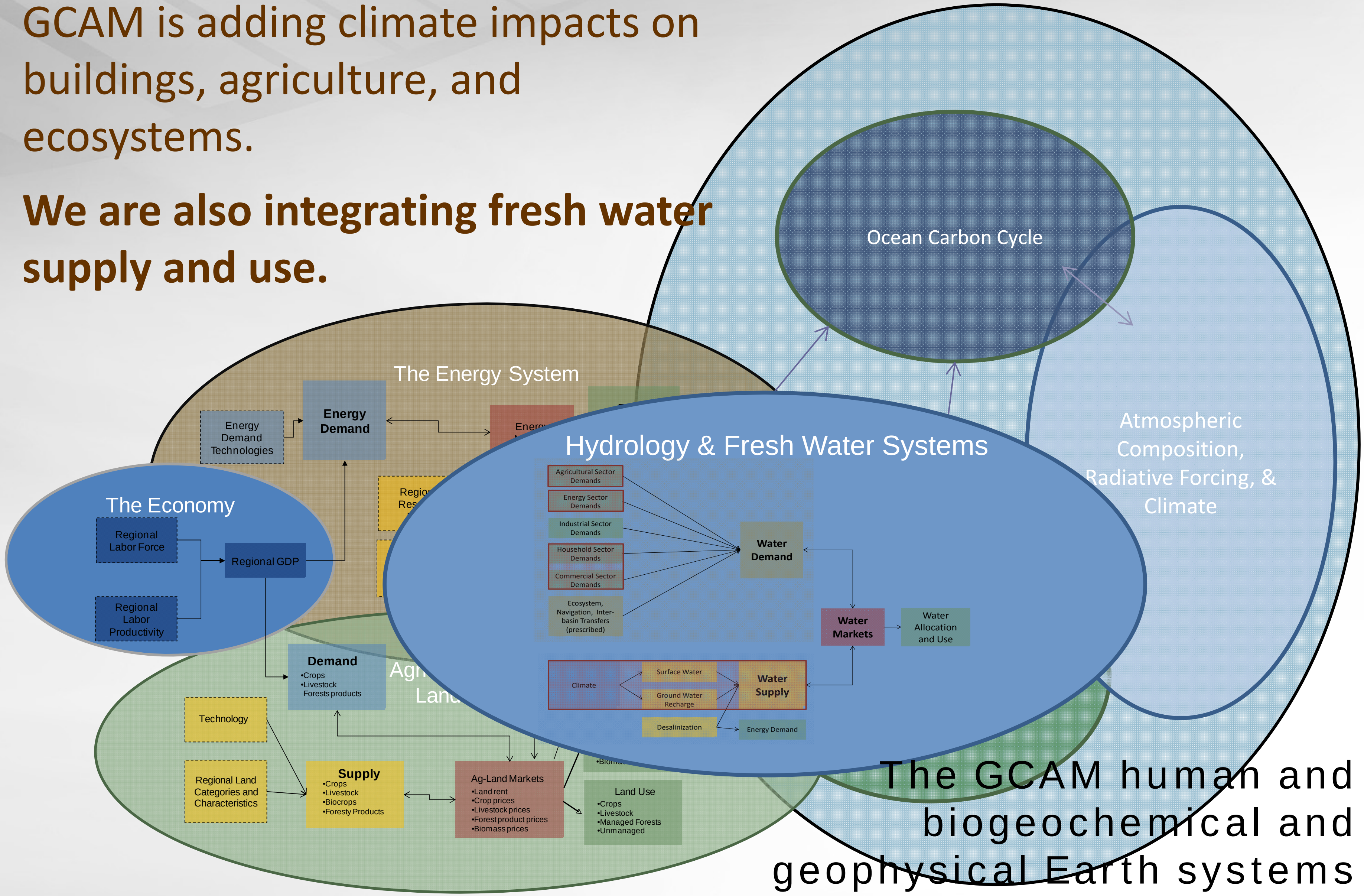
- GCAM is adding climate impacts on buildings, agriculture, and ecosystems.
- **We are also integrating fresh water supply and use.**



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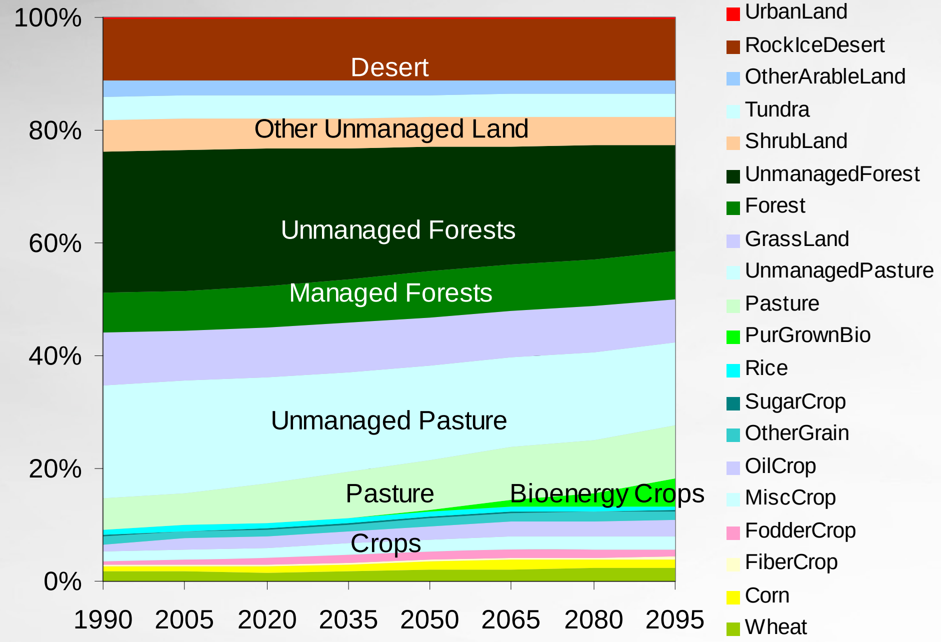
AGRICULTURE AND LAND USE

Agriculture and land-use play an important role in meeting climate goals

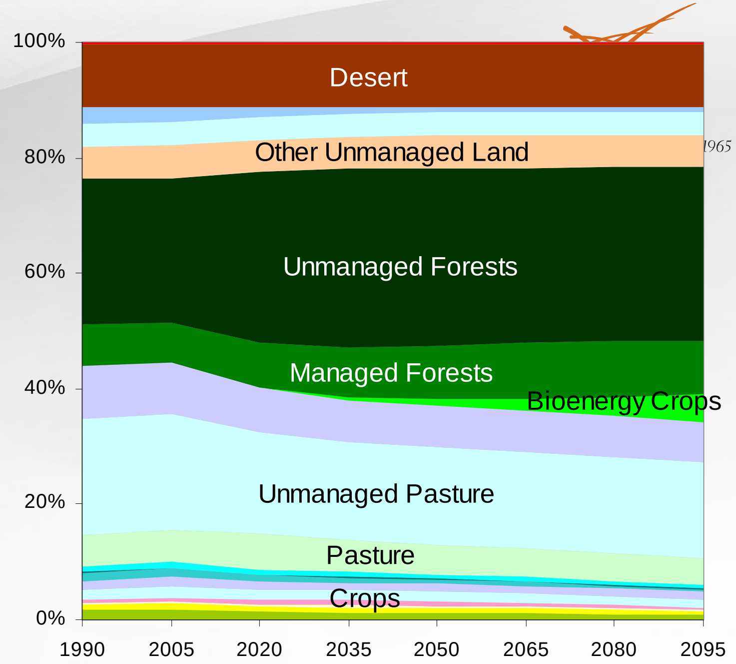
- Land-use policy can either be part of the problem or part of the solution (Wise, et al., 2009).
- Bioenergy can become one of the world's largest crops (Wise, et al., 2009).
- Sequestration potential is large, even compared with CCS. (Edmonds, et al., in review).
- Land-use leakage can be large relative to industrial leakage. (Calvin, et. al., 2009).

The Land Use Implications of Stabilizing at 450 ppm When Terrestrial Carbon is Valued

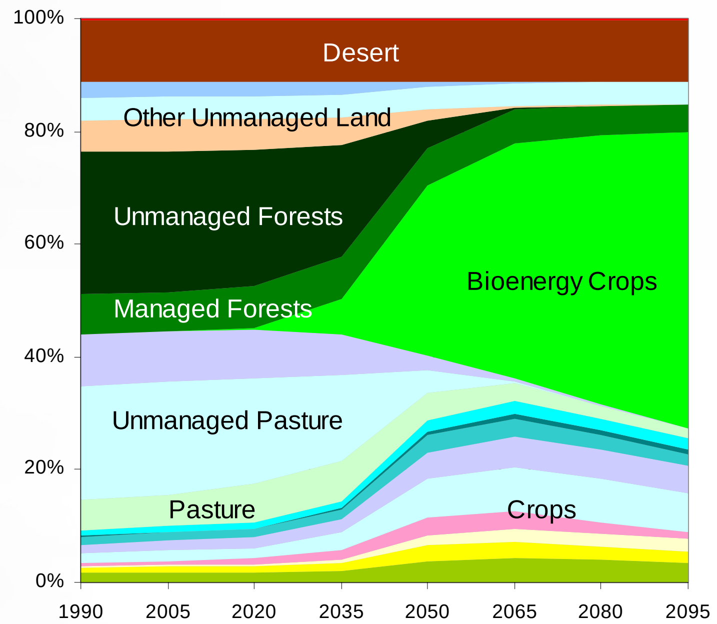


Reference Scenario

450 ppm Stabilization Scenario When ALL Carbon is Valued

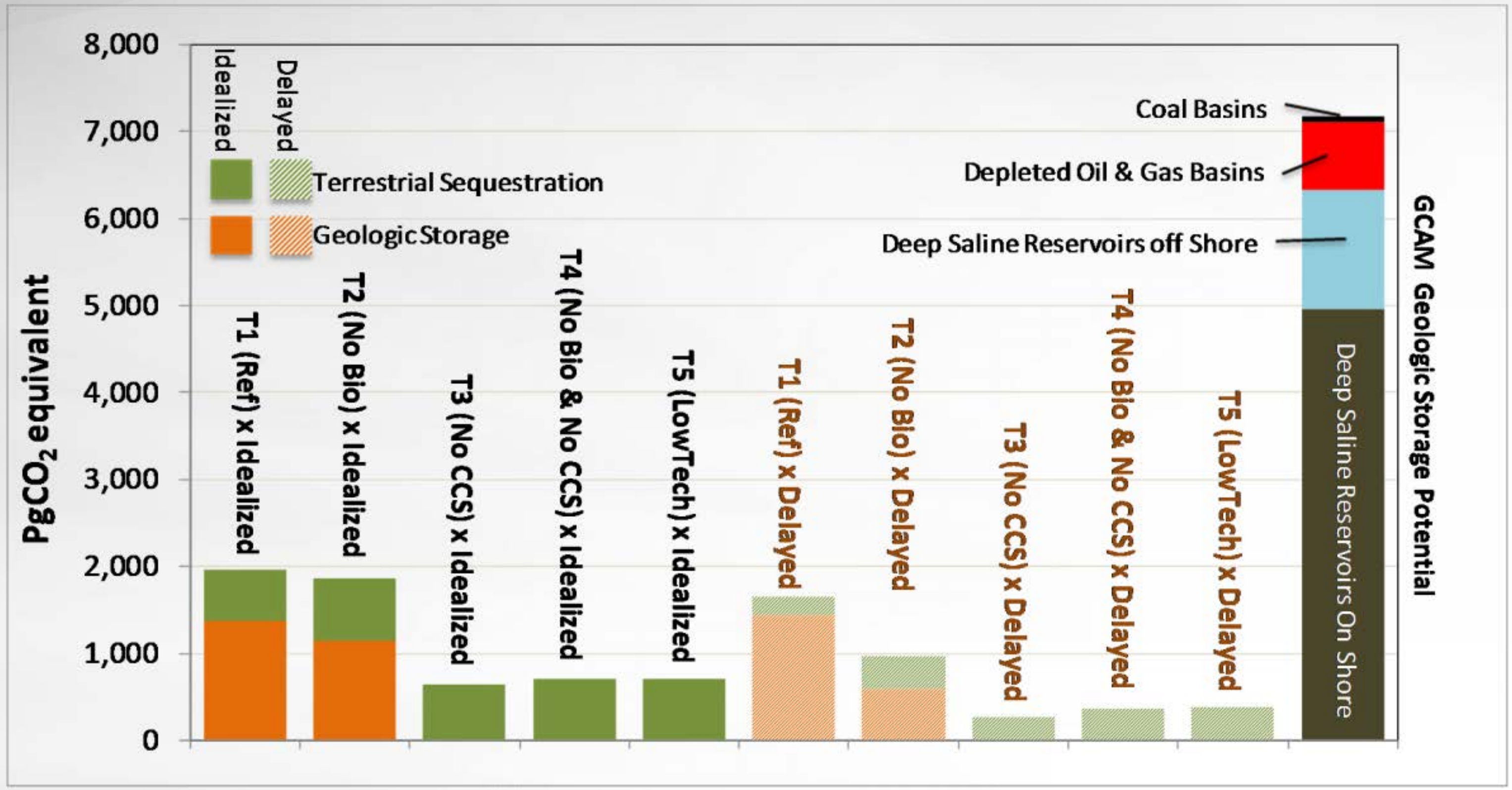


450 ppm Stabilization Scenario When Terrestrial Carbon is NOT Valued



Carbon Storage and Sequestration

- Idealized world: 1,156-1,376 $PgCO_2$ stored in geologic systems.
- Idealized world: 584 to 716 $PgCO_2$ stored in terrestrial systems.



- Delayed world: 602-1,448 $PgCO_2$ stored in geologic systems.
- Delayed world: 202 to 375 $PgCO_2$ stored in terrestrial systems.

Land use: Afforestation and Leakage

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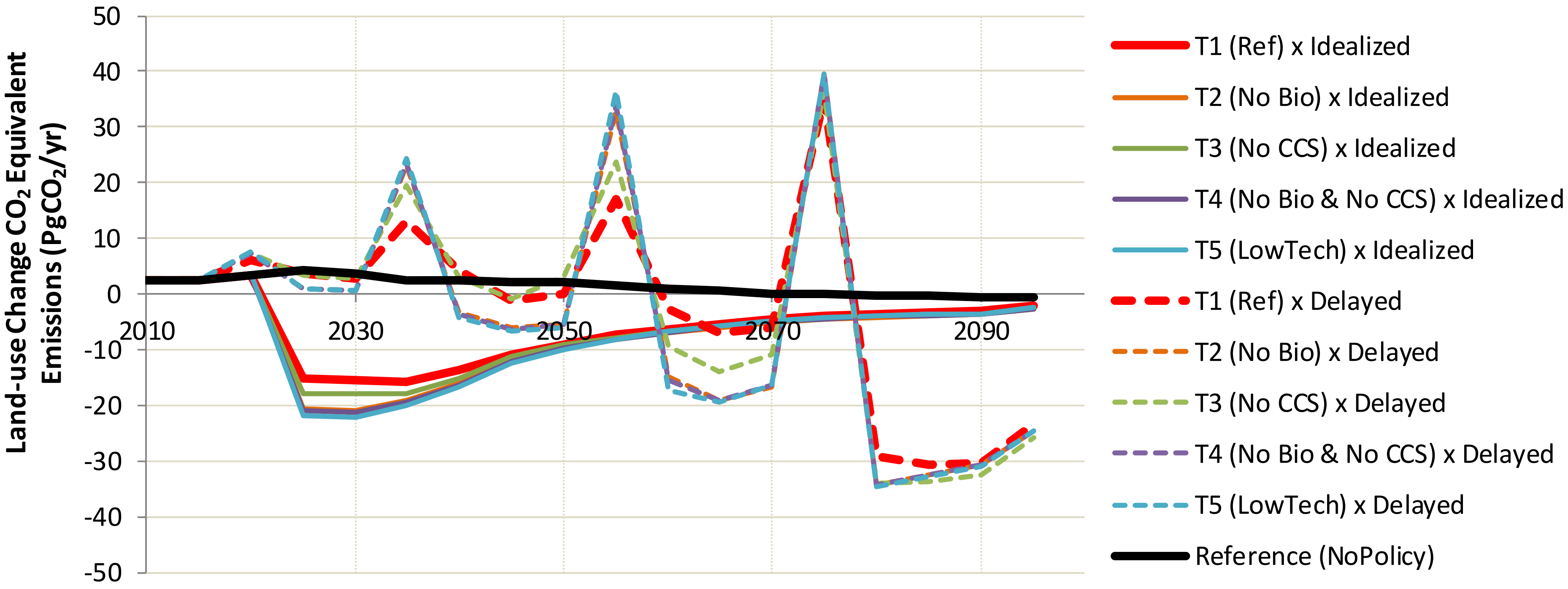
- Idealized world: CO_2 price instantly changes deforestation into afforestation.



- Delayed world: Each accession drives outsourcing of crop production and deforestation in non-participating regions.

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GCAM 3.0 AG-LAND-USE

Agriculture and Land-use in GCAM 3.0

- The GCAM land-use model is documented on line at:
  https://wiki.umd.edu/gcam/images/8/87/GCAM3AGTechDescript12_5_11.pdf

- The agriculture and land-use sector is part of the larger GCAM modeling system.
  - It is fully coupled
  - We do not run GCAM energy and land-use systems independently.

- A complete description of the present version of GCAM takes a full day of presentations.
  - Annual community modeling meeting.
  - GCAM 3.0 can be downloaded from the JGCRI website
  - http://www.globalchange.umd.edu/models/gcam/download/

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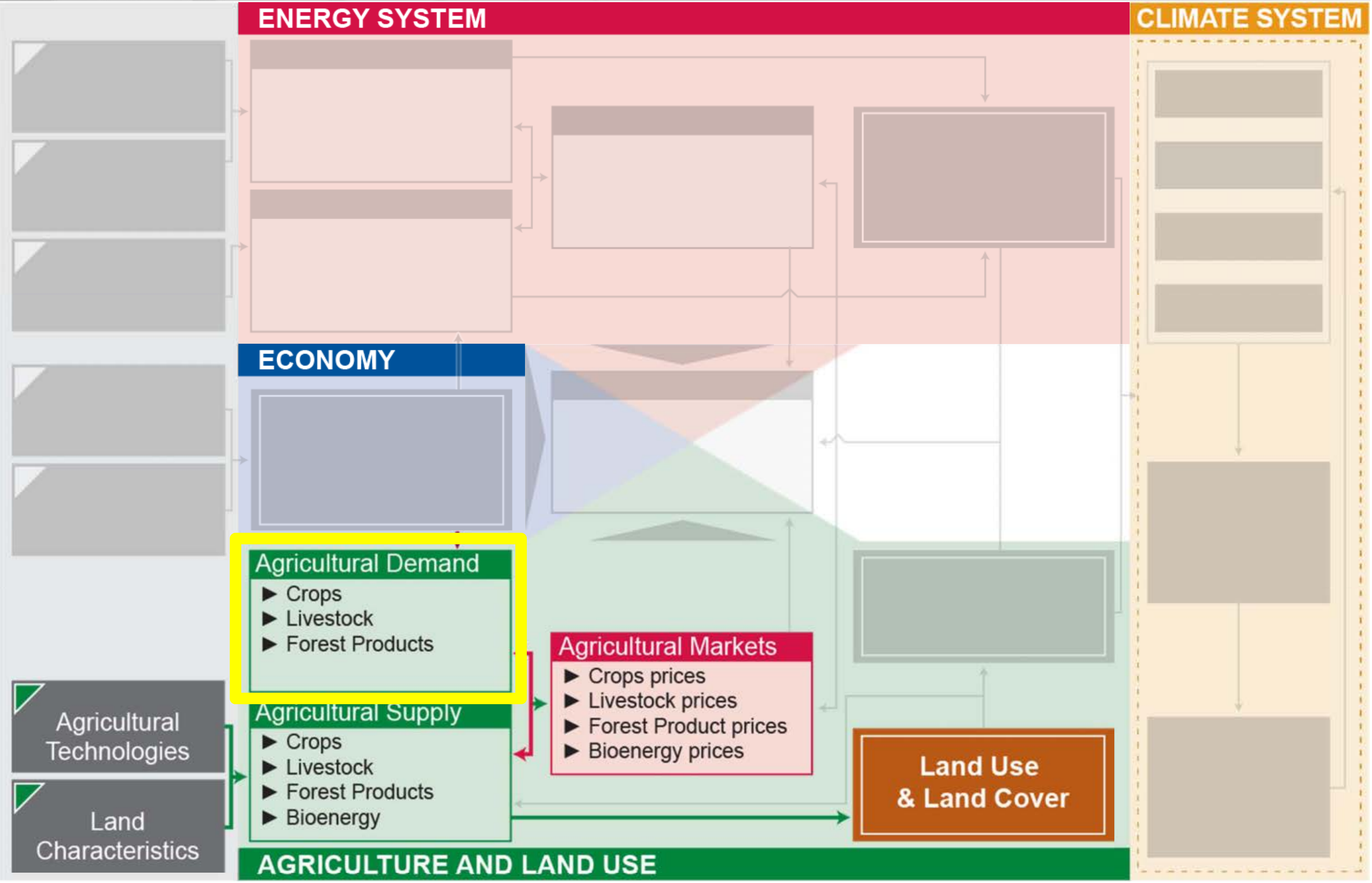

The Agricultural System: Demand

- GCAM currently models supply and demand for 12 crops, 6 animal categories, and bioenergy:
  - Crops: corn, rice, wheat, sugar, oil crops (e.g., soybeans), other grains (e.g., barley), fiber (e.g., cotton), fodder (e.g., hay, alfalfa), roots & tubers, fruits & vegetables
  - Animals: beef, dairy, pork, poultry, sheep/goat, other
  - Forest: roundwood
  - Bioenergy: switchgrass, miscanthus, jatropha, willow, eucalyptus, corn ethanol, sugar ethanol, biodiesel (from soybeans and other oil crops)
- We account for both food and non-food demand, including animal feed.
- Demand is modeled at the 14 region level.

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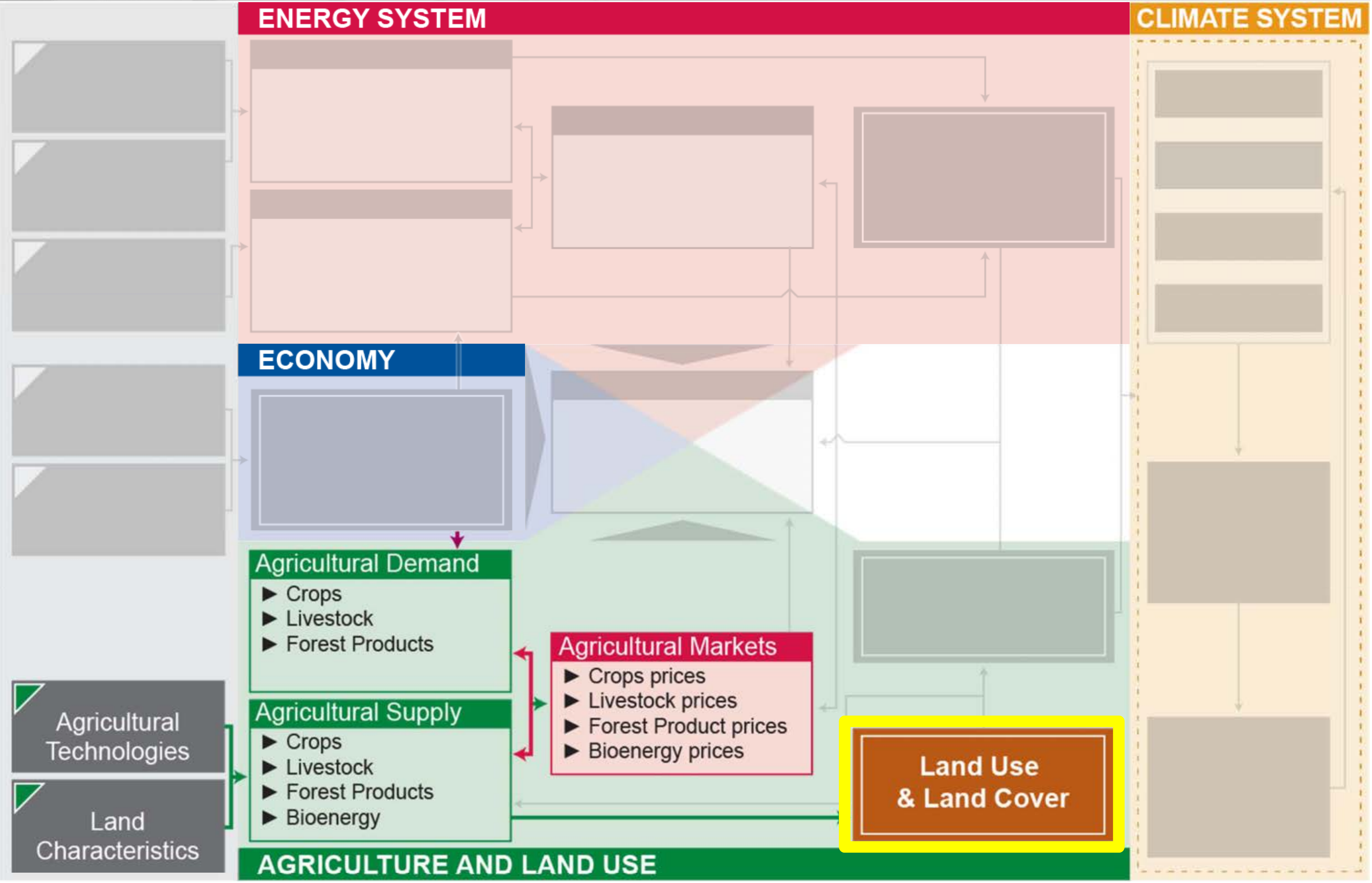
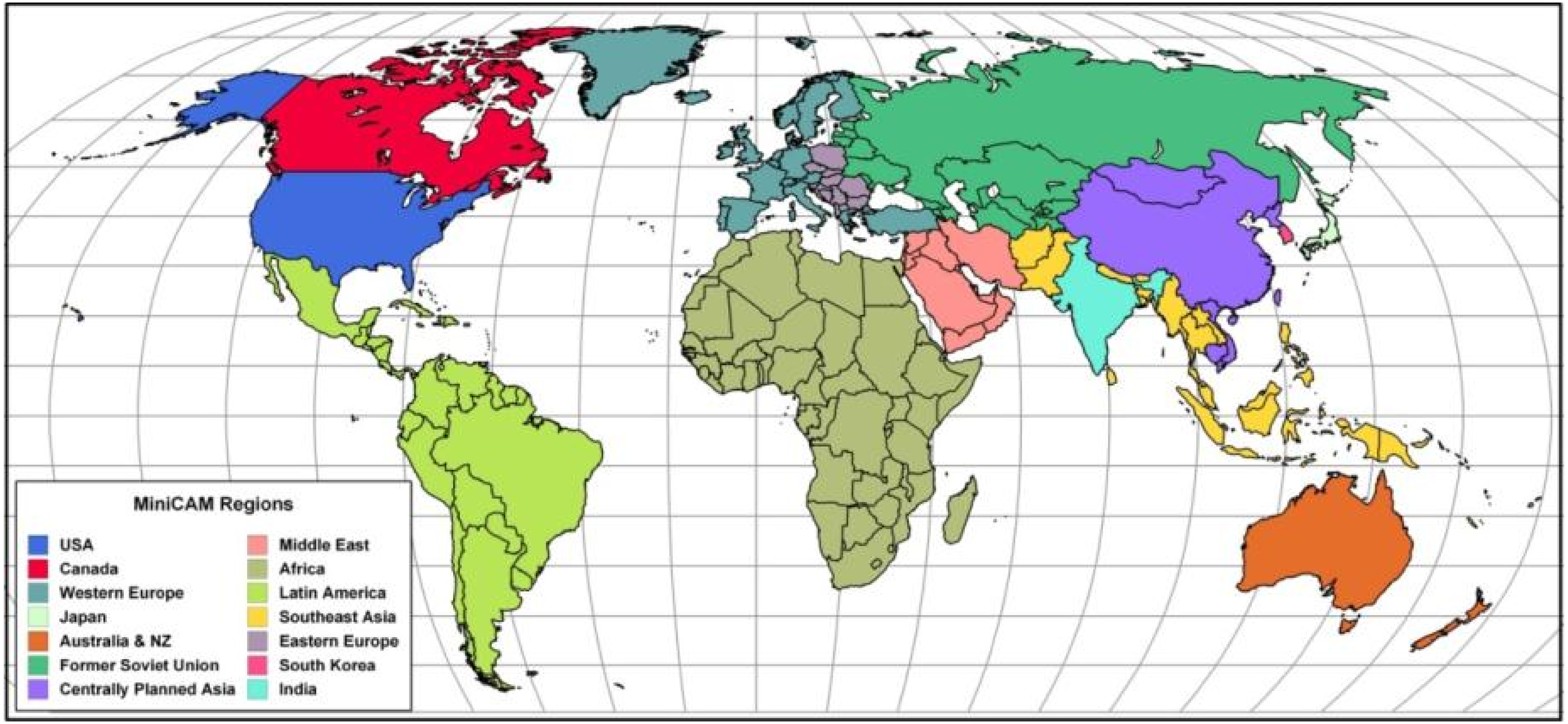
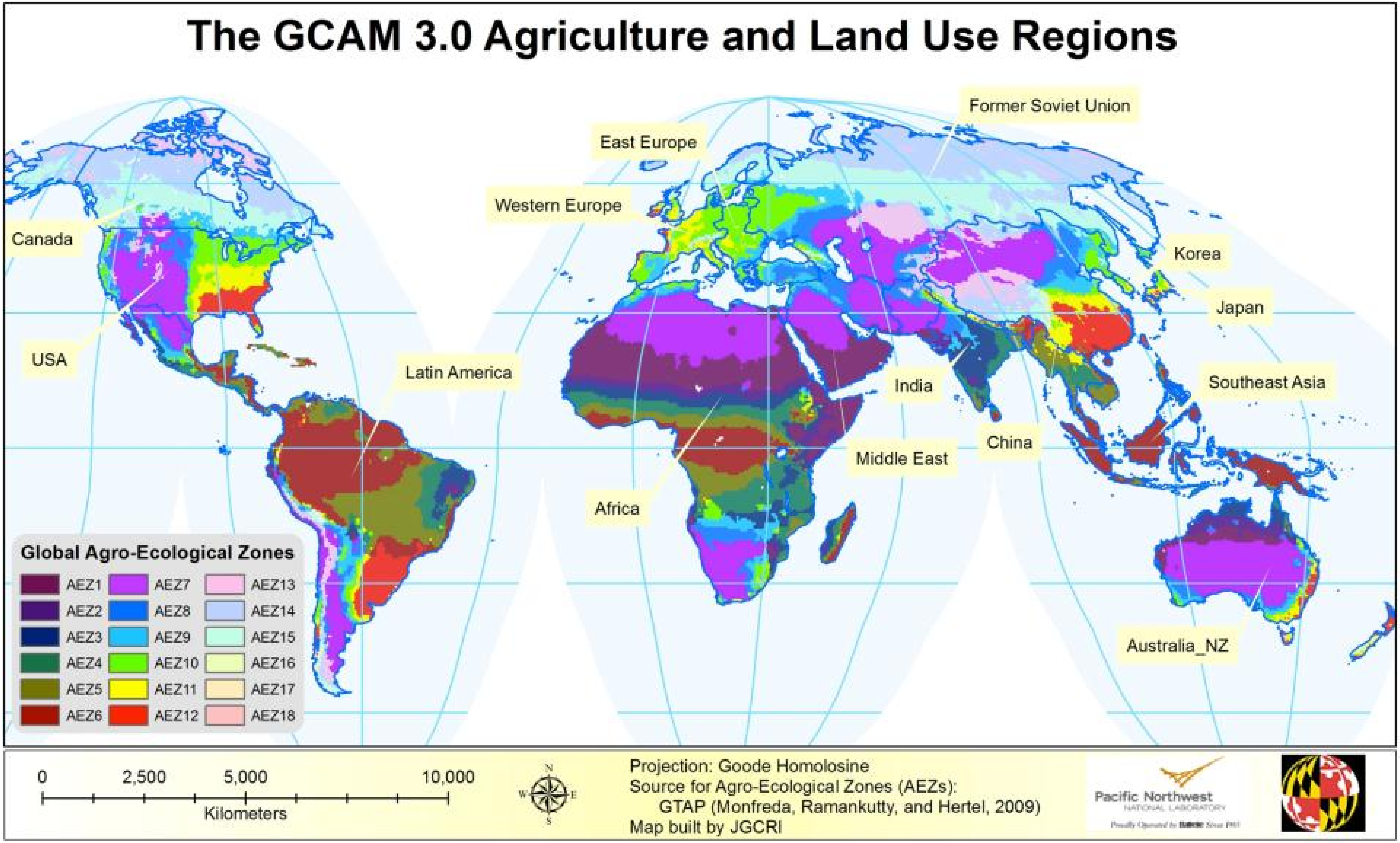


The Agricultural System: Basic Assumptions

- The world is divided into **151** regions

The Agricultural System: Regions



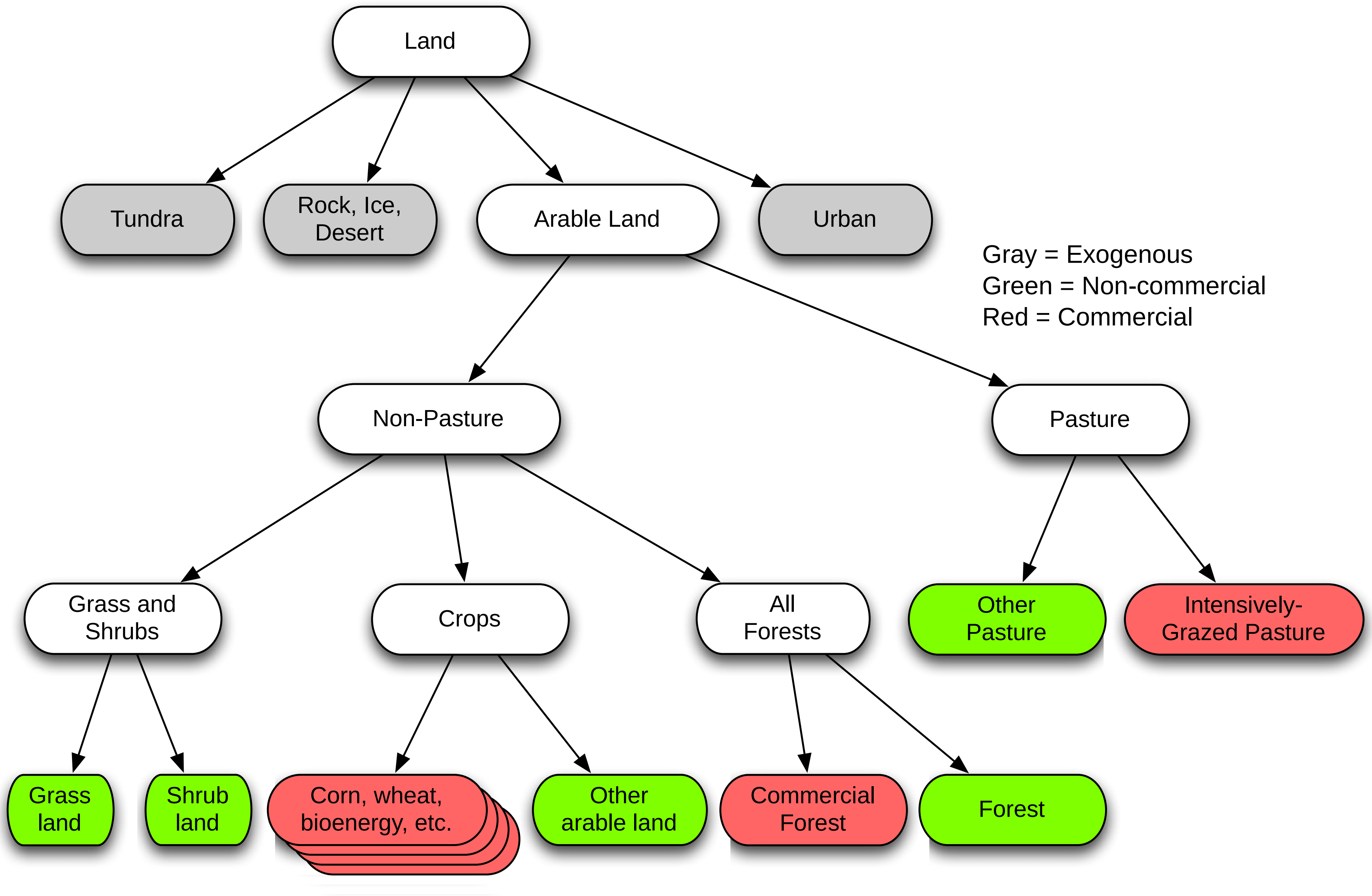


151 Different AgLU Supply Regions

The Agricultural System: Basic Assumptions

- The world is divided into **151** regions
- Farmers allocate land across a variety of uses in order to maximize profit
- There is a distribution of profits for each land type across each of the 151 regions
- The actual share of land allocated to a particular use is the probability in which that land type has the highest profit
- The variation in profit rates is due to variation in the cost of production
  - As the area devoted to a particular land use expands, cost increases
  - Yield is fixed within each region for each crop management practice

The Agricultural System: Nesting Structure



Gray = Exogenous
Green = Non-commercial
Red = Commercial

The Agricultural System: USA Wheat Yield

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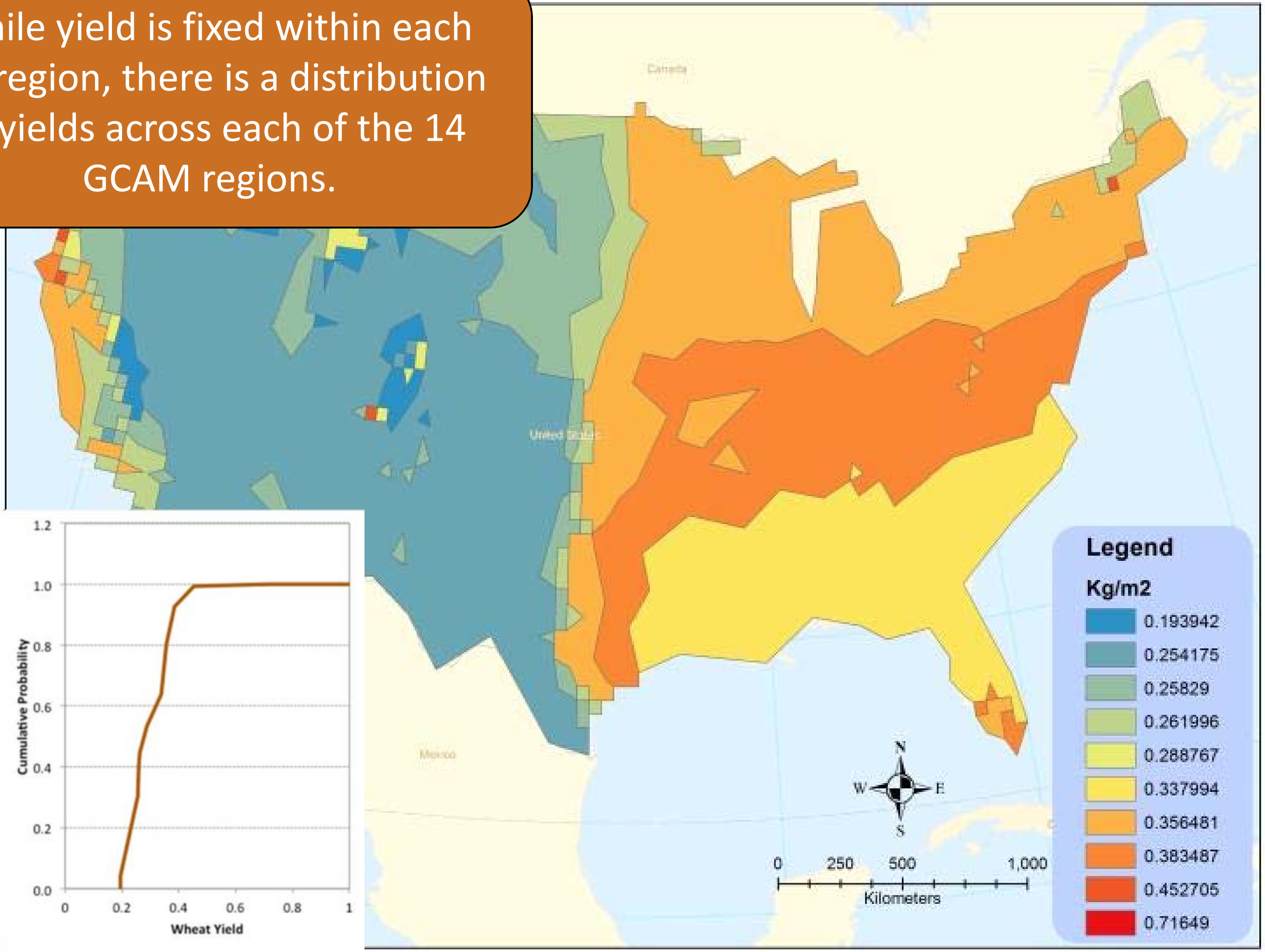
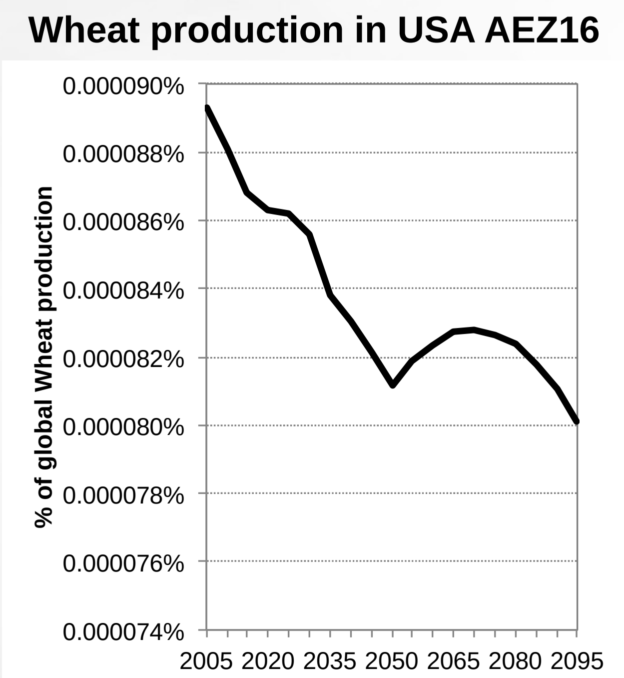
While yield is fixed within each subregion, there is a distribution of yields across each of the 14 GCAM regions.



The Agricultural System: Calibration

- During the AgLU calibration process, the model computes the average profit rate required to reproduce the base year land allocations. We assume that the difference between this profit and the observed profit (yield * (p – c)) is a cost to production that also applies in the future.
- Thus, if you have a region with a high crop yield, but low land allocation in the base year (e.g., Wheat in Alaska), the model assumes that there are some additional costs that must be considered when expanding its land area. As a result, that crop will continue to have a low share in the future in the absence of a technology or policy change..



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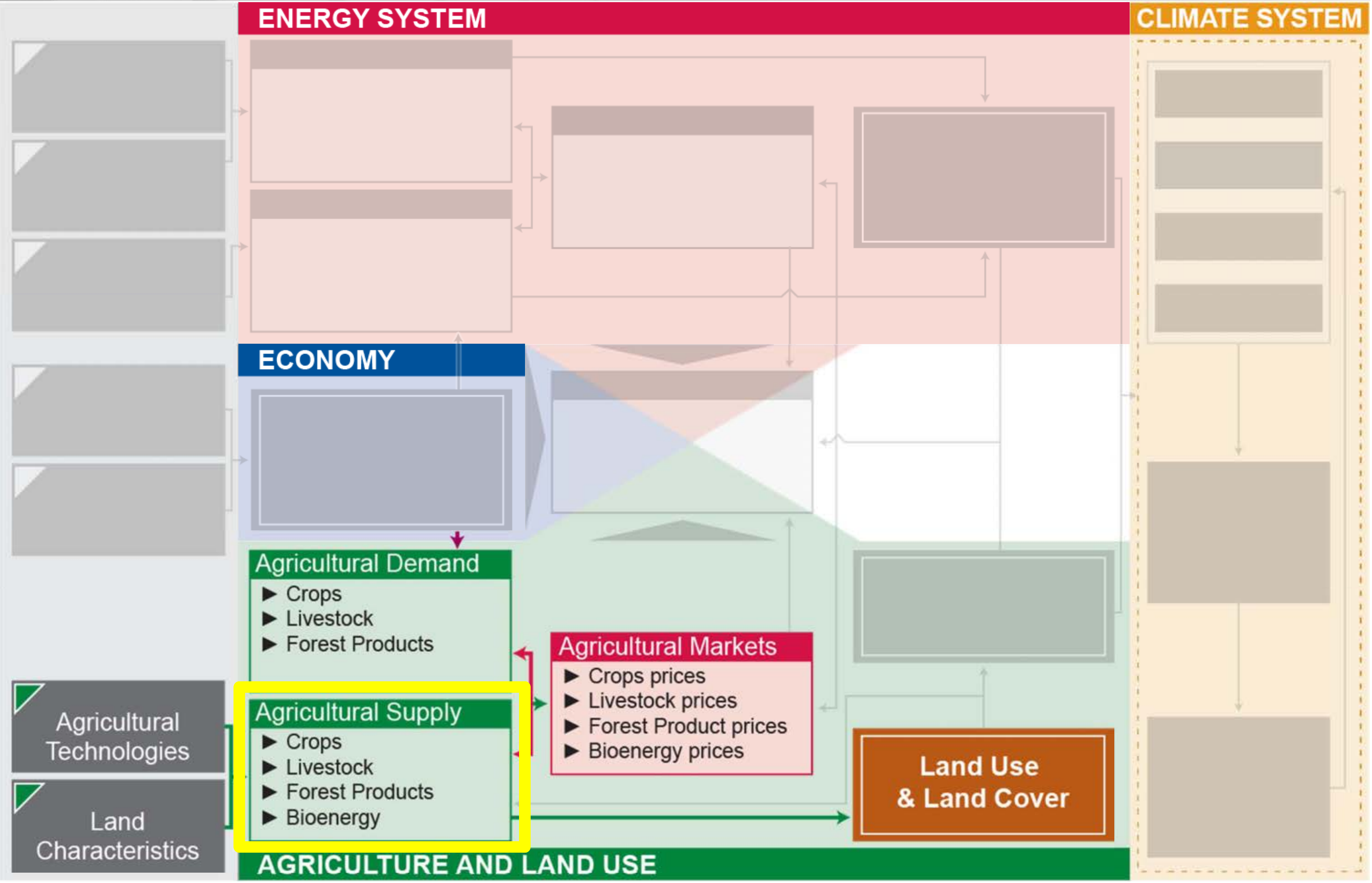
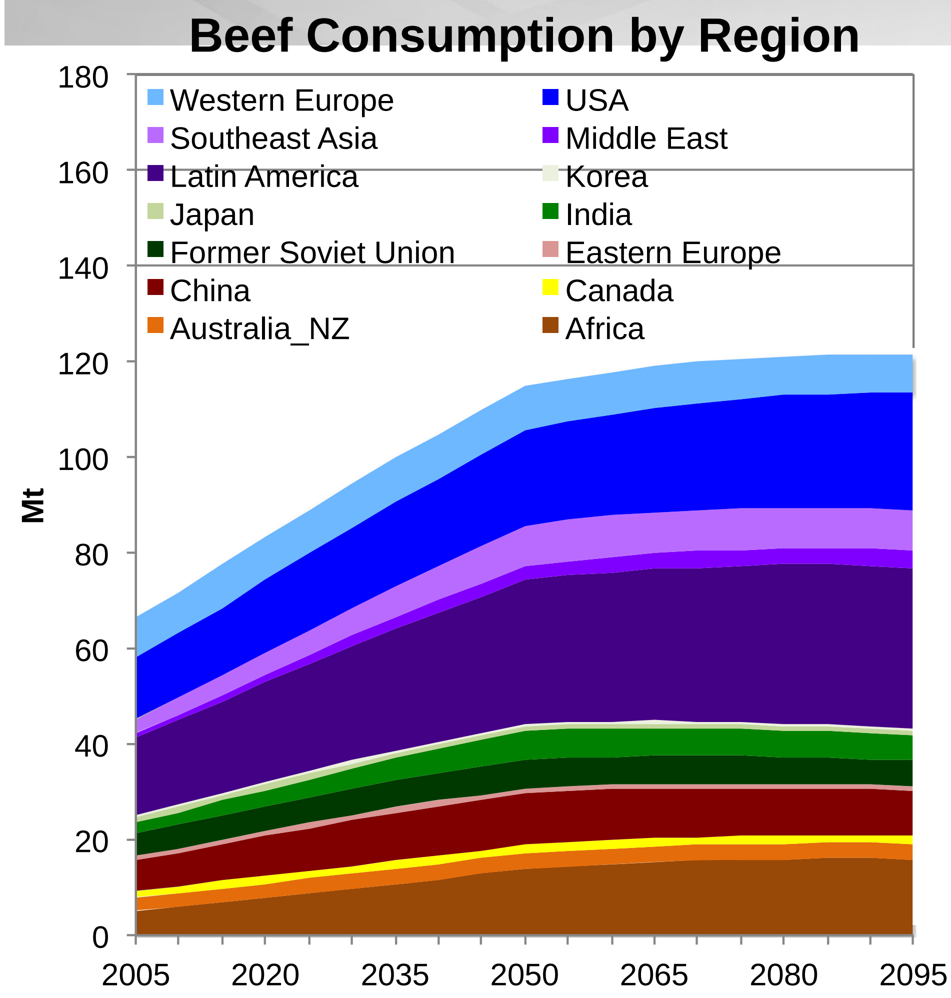
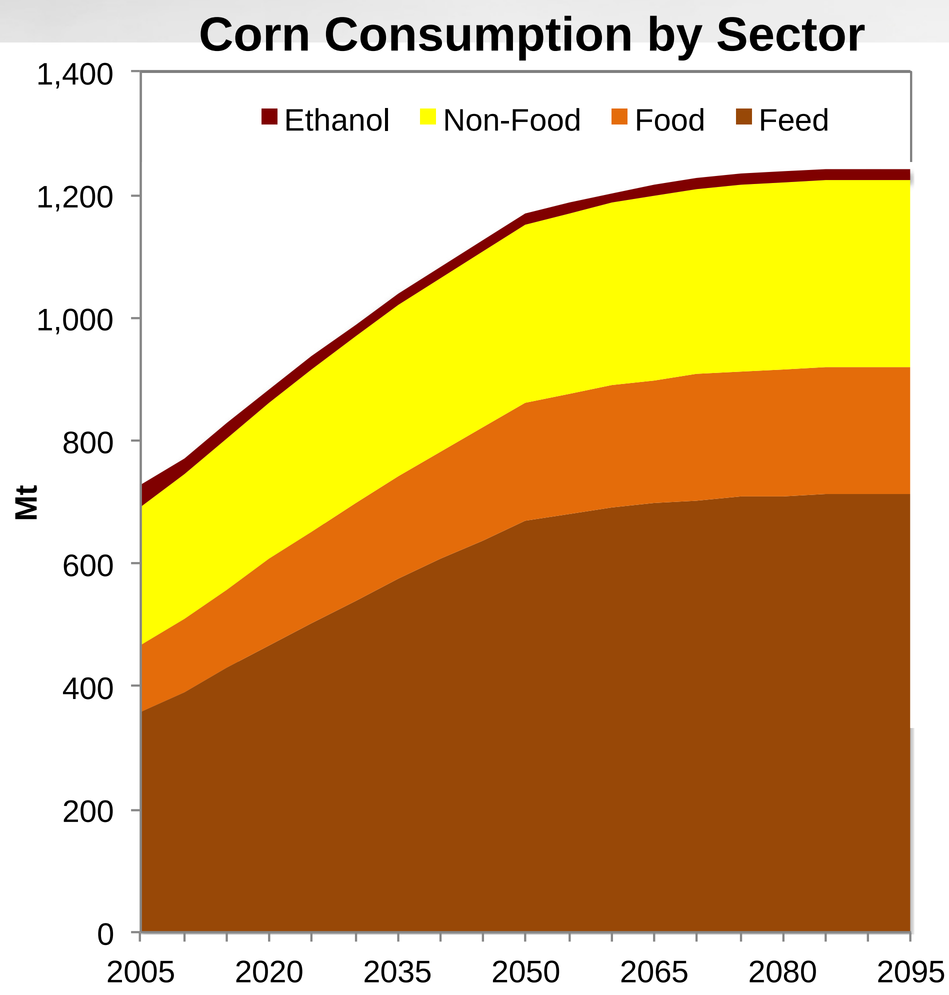


The Agricultural System: Supply

- Yield is exogenously calculated.
  - Base year derived from GTAP/FAO production and land area.
  - Yields increase over time based on exogenously specified technical change.
- Land area is endogenously calculated.
  - Each land types share of area in its region is the probability its profit is the highest in that region.
- Supply = land * yield

The Agricultural System: Results





The Agricultural System: Results

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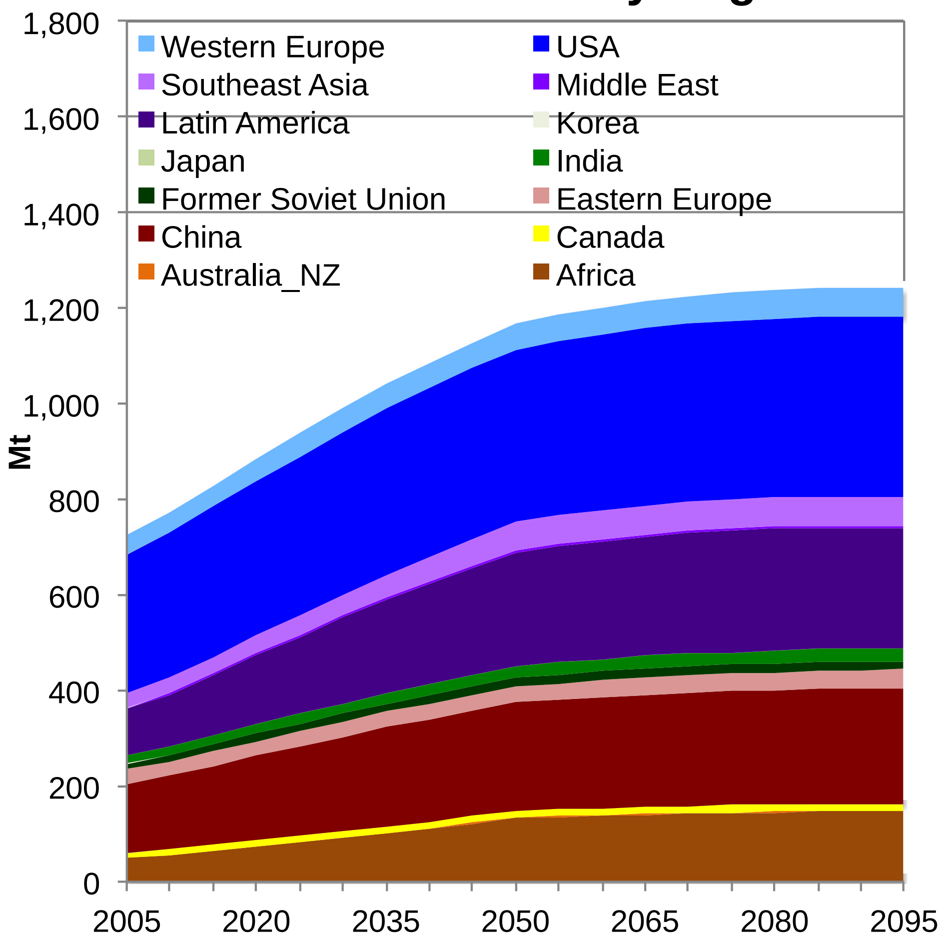
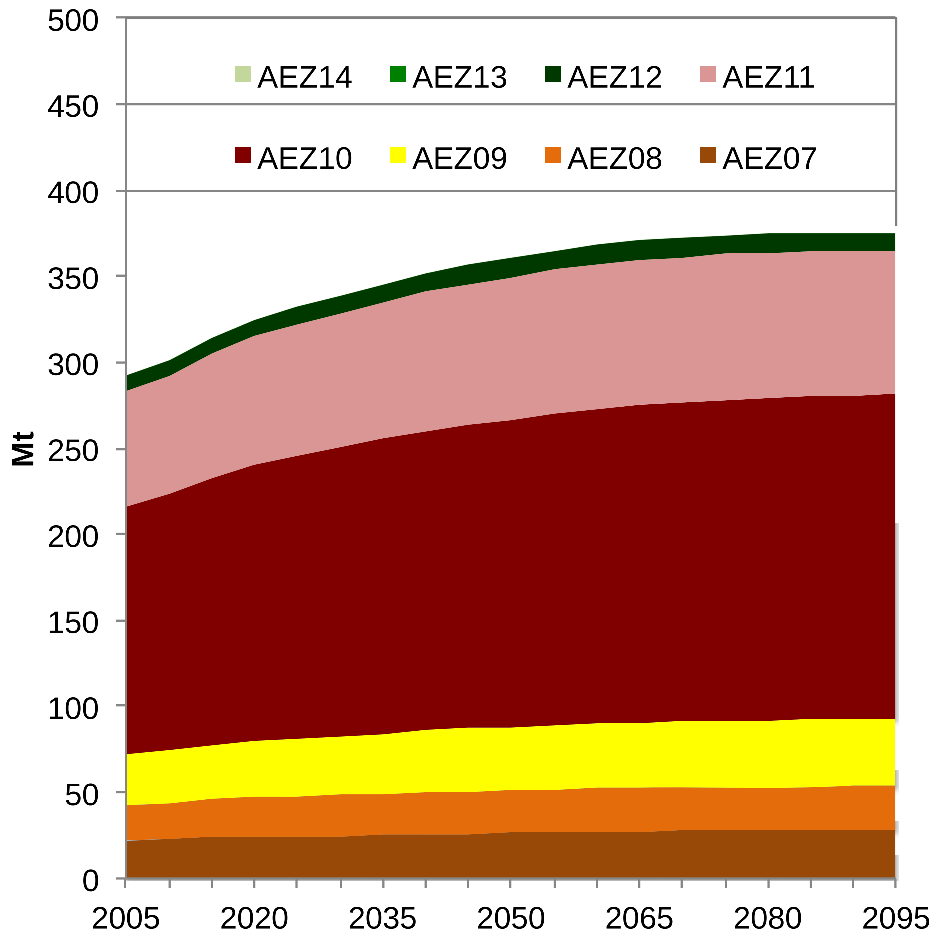
Corn Production by Region



Corn Production in the USA



The Agricultural System: Results

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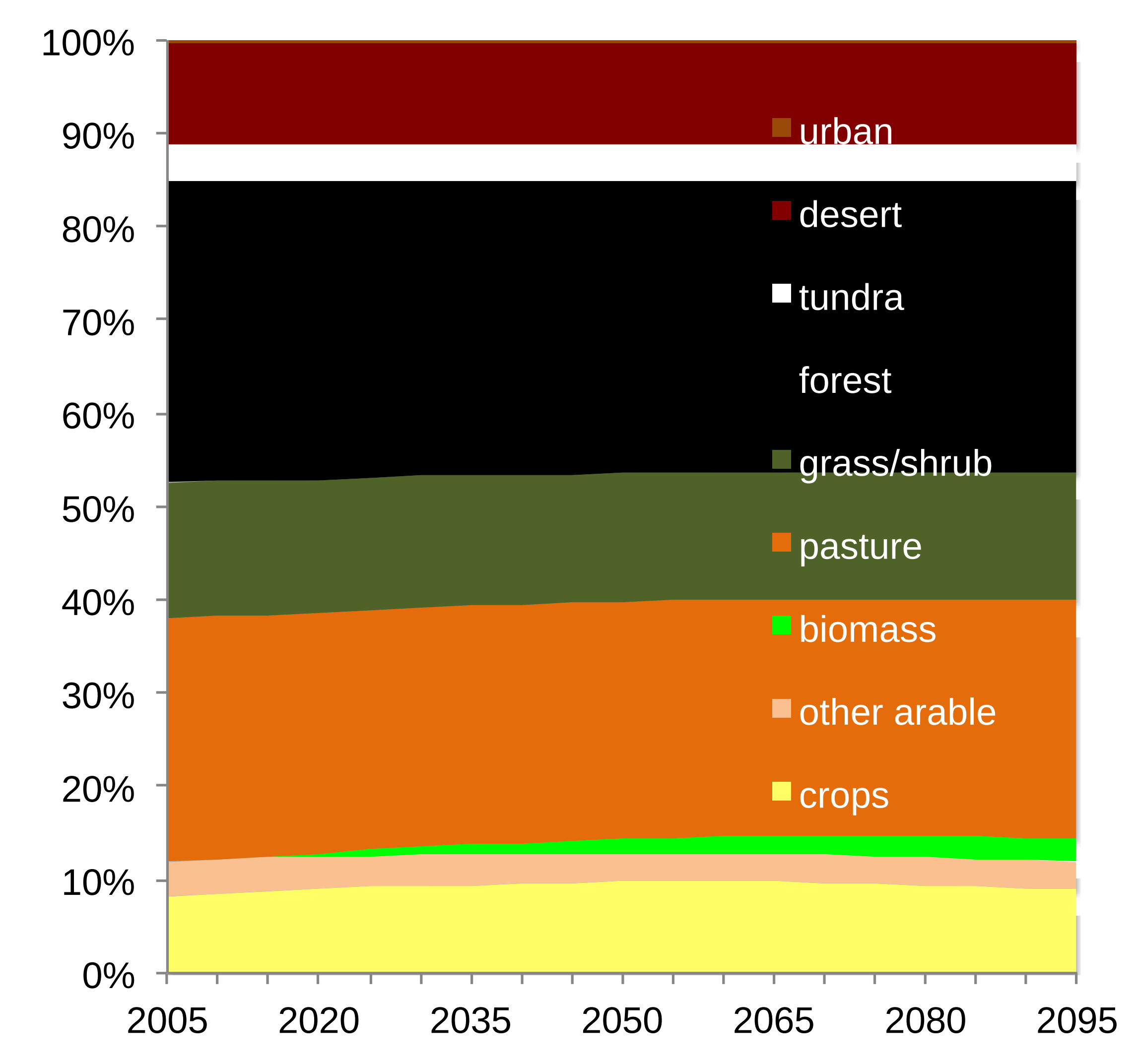
Global Land Allocation



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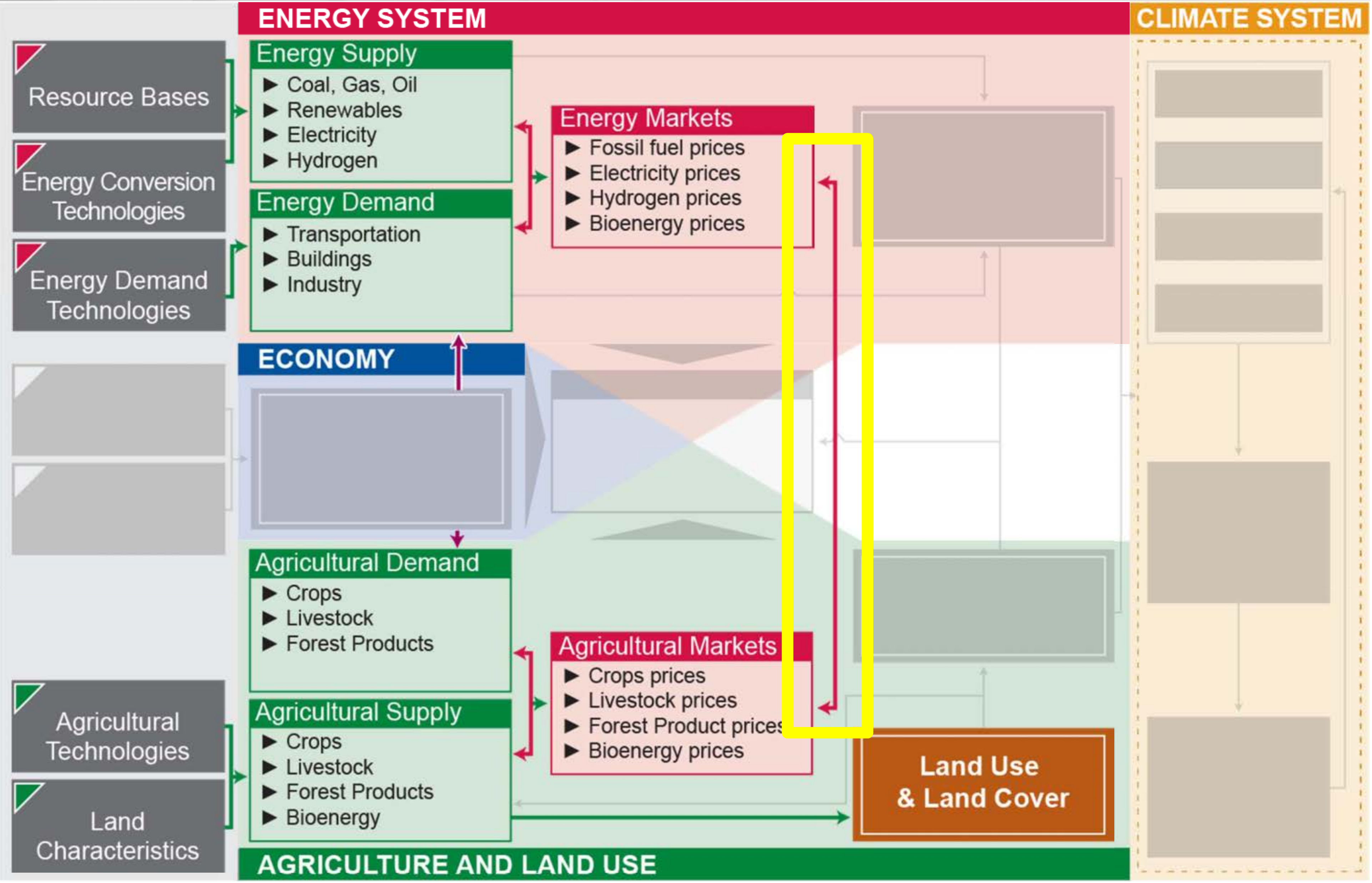

The Agricultural System: Linking the Energy & Agricultural Sectors

- While we can explain the energy and agricultural systems separately, these two systems cannot be separated in practice. Choices made in one sector affect outcomes in another sector.

- This is true both in the real world and in GCAM. You cannot run the different components of the model separately.

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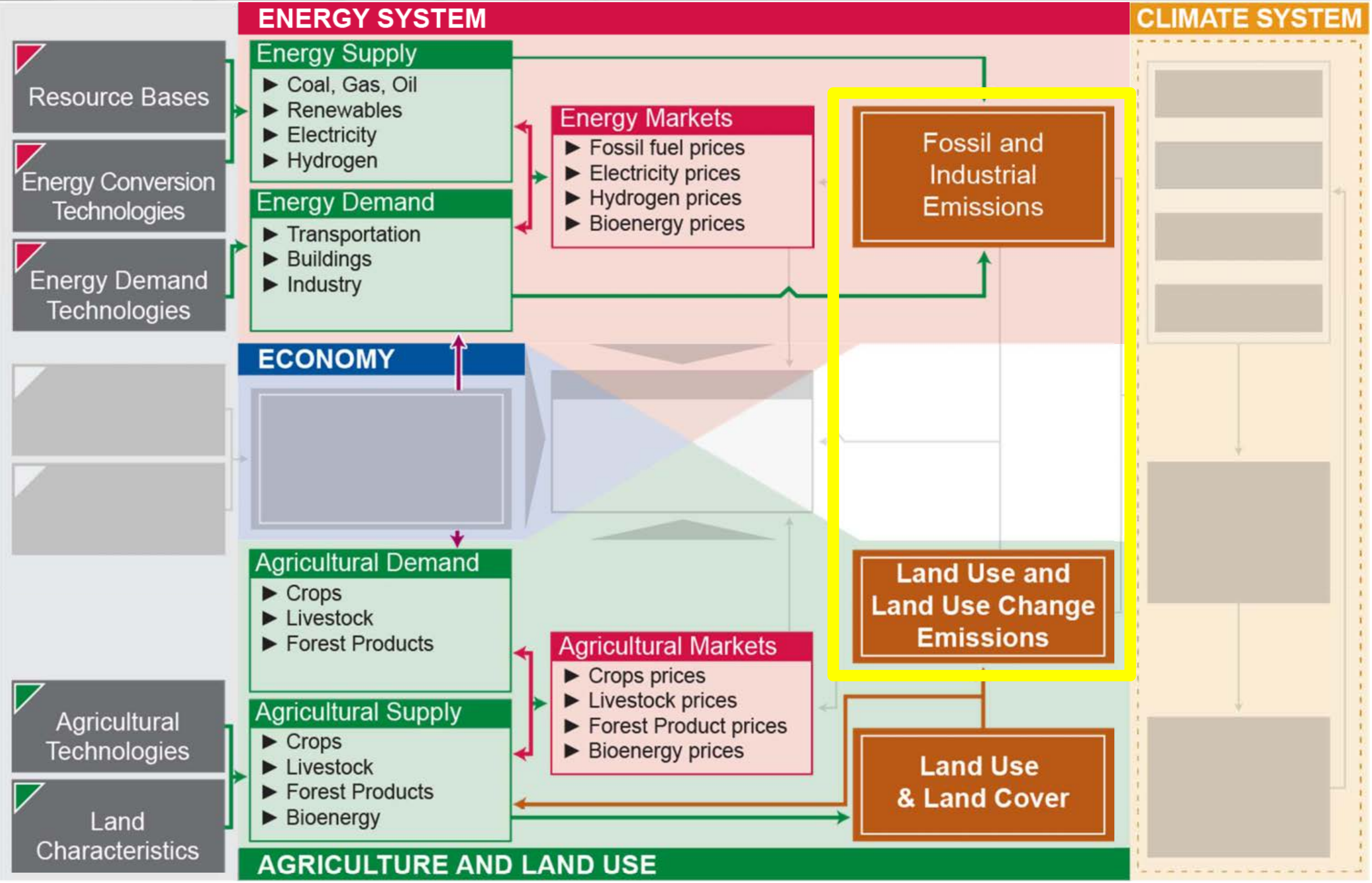

Bioenergy is produced in the Ag-Land-Use Sector but Consumed in the Energy Sector

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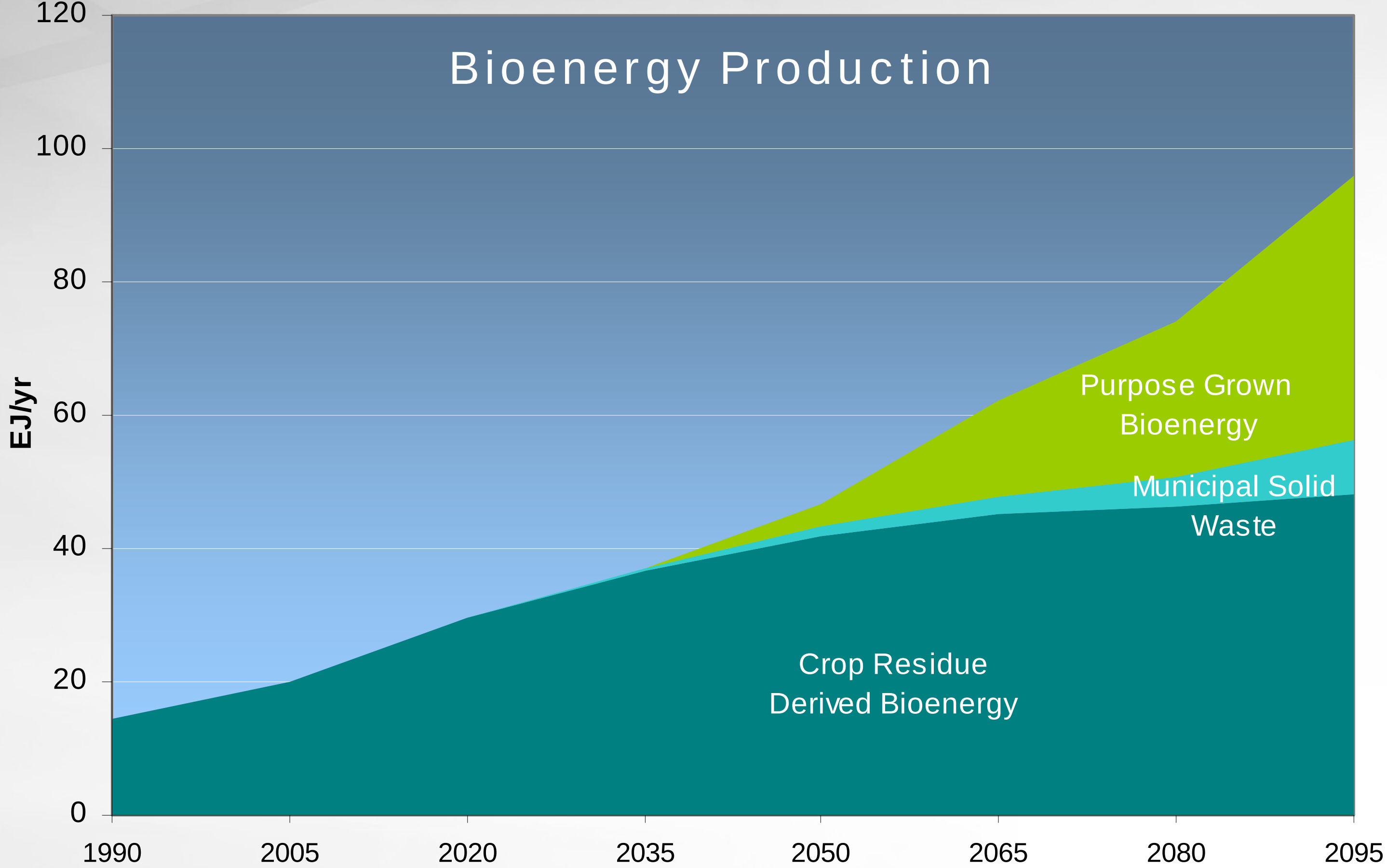

Emissions: General Structure

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- GCAM tracks emissions for several gases and species
  - CO_2, CH_4, N_2O, CF_4, C_2F_6, SF_6, HFC125, HFC134, HFC245fa, SO_2, BC, OC, CO, VOCs, NOx, NH_3
  - We calculate CO_2 from fossil fuel & industrial uses, as well as from land-use change
- Each gas is associated with a specific activity and changes throughout the coming century if:
  - The activity level changes
    - Increasing the activity increases emissions
  - Pollution controls increase
    - As incomes rise, we assume that regions will reduce pollutant emissions
  - A carbon price is applied
    - We use MAC curves to reduce the emissions of GHGs as the carbon price rises
- Emissions are produced at a region level.

Emissions: Vegetation CO_2 Emissions

- First, we determine the total change in carbon stock for each land type and region.
  - Δ C Stock = [Land Area (t)]*[C density (t)] - [Land Area (t-1)]*[C density (t-1)]

- Then, we allocate that change across time.
  - If change in land area decreases the carbon stock (e.g., deforestation), then all carbon is released into the atmosphere instantaneously.

  - If the change in land area increases the carbon stock (e.g., afforestation), then carbon accumulates slowly over time, depending on an exogenously specified mature age.
    - The mature age varies by land type and region.

Emissions: Forest Carbon Uptake

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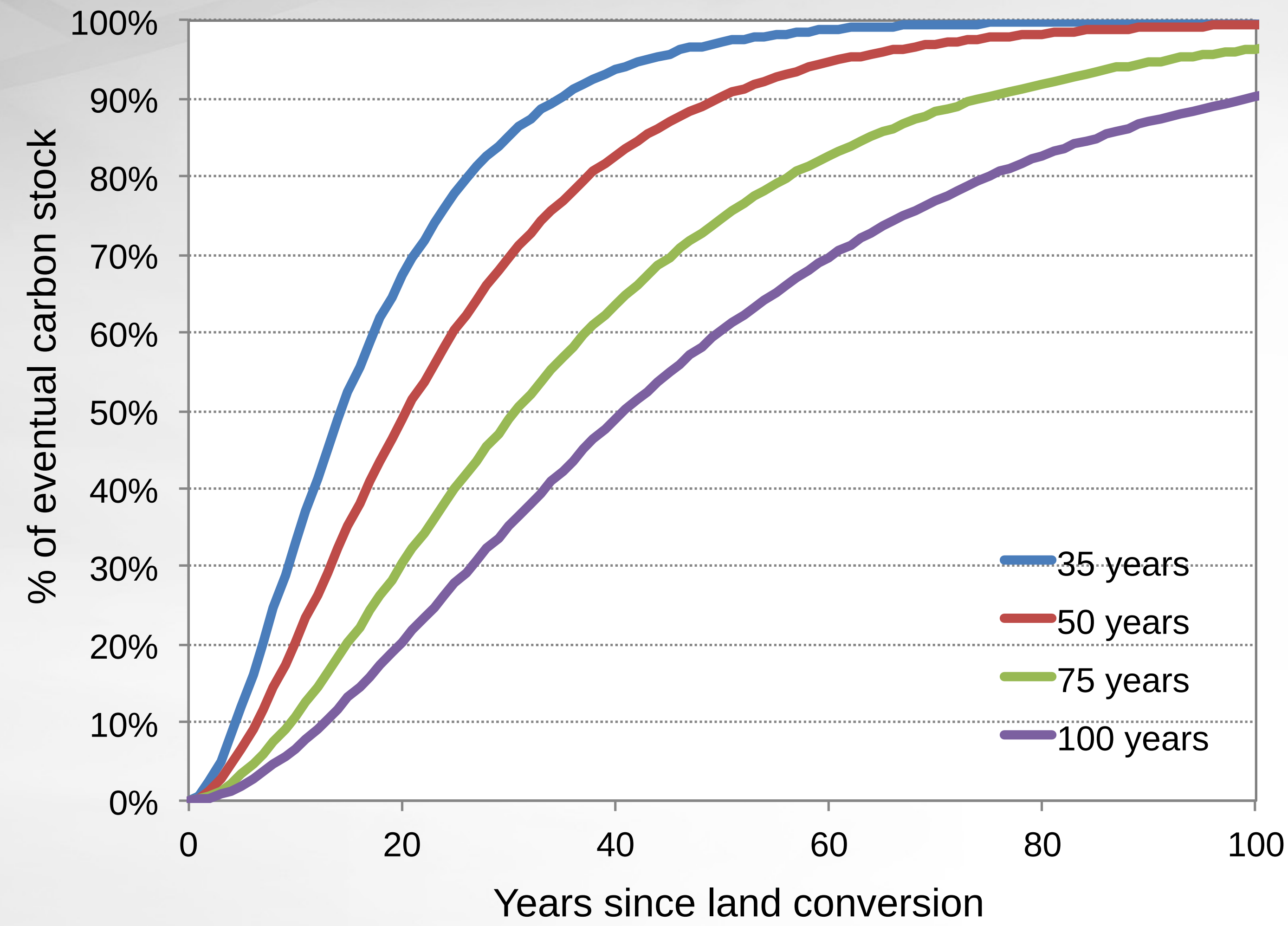

Emissions: Soil CO_2 Emissions

- First, we determine the total change in carbon stock for each land type and region.
  - Δ C Stock = [Land Area (t)]*[C density (t)] - [Land Area (t-1)]*[C density (t-1)]
- Then, we allocate that change across time.
  - Whether carbon stock increases or decreases, we assume that the change is allocated evenly over a read in number of years.
  - The number of years varies by region, but not by land type.
  - In general, colder regions have longer soil carbon time scales.

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QUESTIONS-DISCUSSION