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Representation of the terrestrial system in Integrated Assessment Models

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March 27, 2014

Greenbelt, MD

PNNL-SA-101707

Outline

- Introduction to Integrated Assessment Models
- The Global Change Assessment Model (GCAM)
- Sample Analysis Using GCAM: The Role of Land in Mitigation Policy
- Synergistic Activities Between NASA & GCAM

INTRODUCTION TO INTEGRATED ASSESSMENT MODELS

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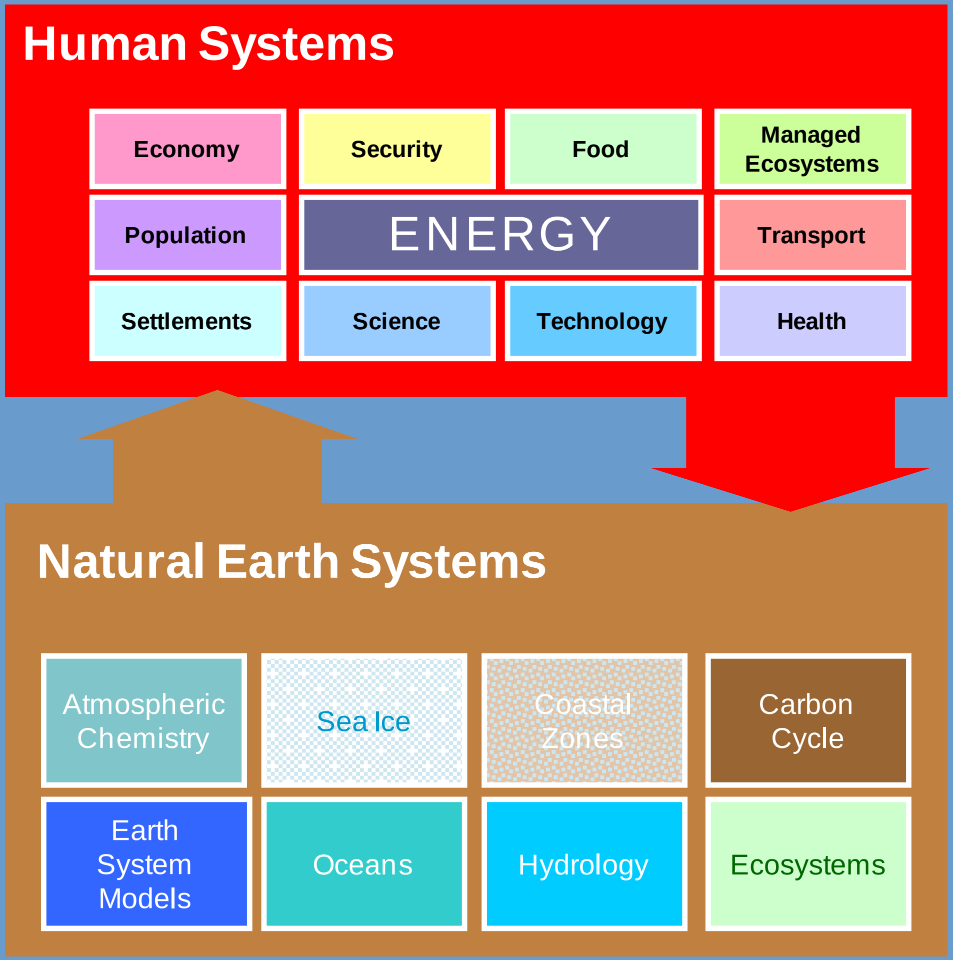
Integrated Assessment Models (IAMs)

IAMs integrate human and Earth systems:

- IAMs provide physical science researchers with information about human systems such as GHG emissions, land use and land cover.
- IAMs capture interactions between complex and highly nonlinear systems. IAMs provide insights that would be otherwise unavailable from disciplinary research.

IAMs provide important, science-based decision support tools.

- IAMs support national, international, regional, and private-sector decisions.



IAMs Are Strategic in Nature

- IAMs were designed to provide strategic insights.

- IAMs were never designed to model the very fine details, e.g.
  - Electrical grid operation
  - Daily oil market price paths.

- IAMs are analogous to climate models in that sense.
  - Climate models don’t forecast weather
  - They were designed to describe the determinants of 30-year moving averages of weather.

General Principles

- IAMs are:
  - Global in scope,
  - Include all anthropogenic sources of emissions,
  - Include some representation of the climate system.

- However, there is significant variation across models as to their:
  - Spatial resolution
  - Inclusion of gases and substances
  - Energy system detail
  - Representation of agriculture and land-use
  - Economic assumptions
  - Degree of foresight
  - Sophistication of the climate model component

Where IAMs fits in climate research…

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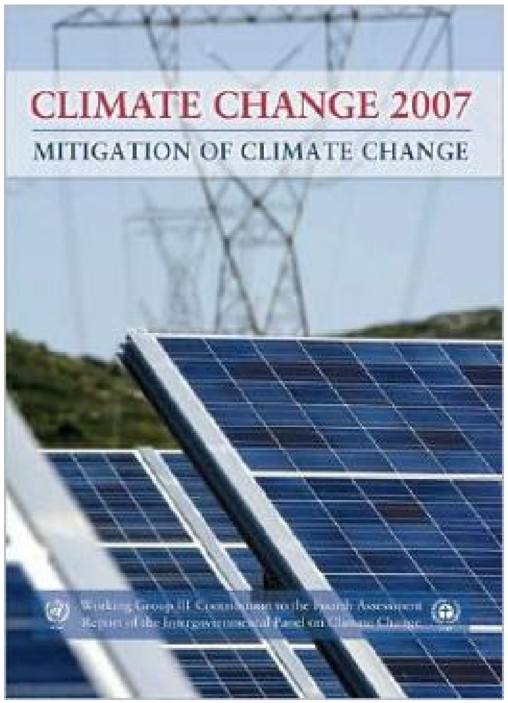
Integrated Assessment Models

IAMs



Human systems
Drivers of Climate Change

Physical Earth System Models

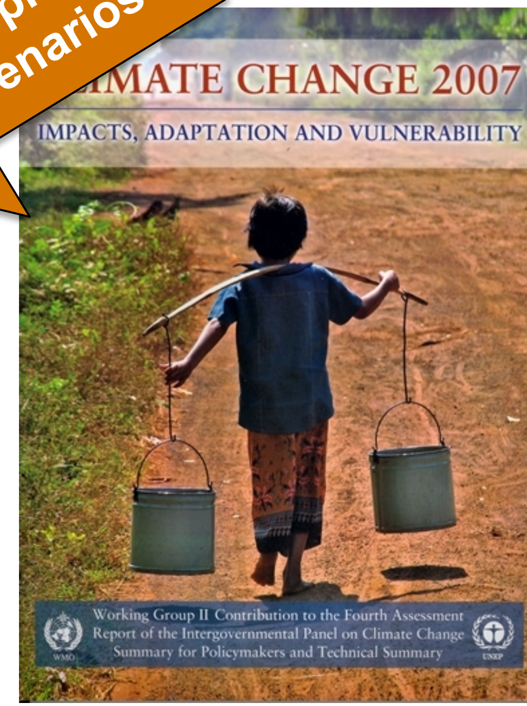
ESMs

Physical systems
Climate change

IAMs provide scenarios

Impacts, Adaptation,
d Vulnerability

IAV



Human systems
Impacts & adaptation

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THE GLOBAL CHANGE ASSESSMENT MODEL

The Global Change Assessment Model

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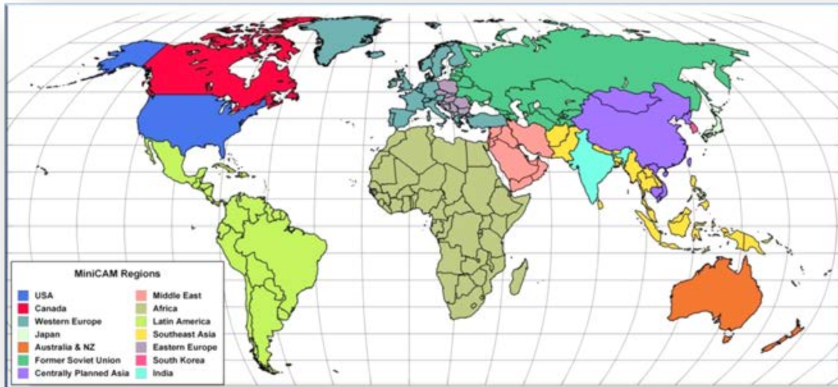
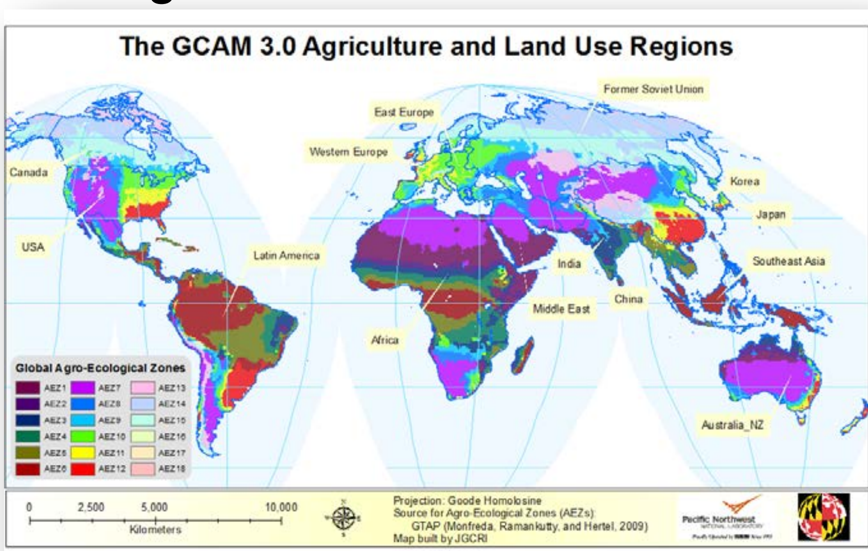
14 Region Energy/Economy Model



151 Agriculture and Land Use Model



- GCAM is a **global integrated assessment model**
- GCAM links **Economic**, **Energy**, **Land-use**, and **Climate** systems
- Typically used to examine the effect of technology and policy on the economy, energy system, agriculture and land-use, and climate
- Technology-rich model
- Emissions of 16 greenhouse gases and short-lived species: CO_2, CH_4, N_2O, halocarbons, carbonaceous aerosols, reactive gases, sulfur dioxide.
- Runs through **2100** in **5-year time-steps.**
- Documentation available at: **wiki.umd.edu/gcam**
- Model is open-source and can be downloaded at: **http://www.globalchange.umd.edu/models/gcam/download/**

The Global Change Assessment Model

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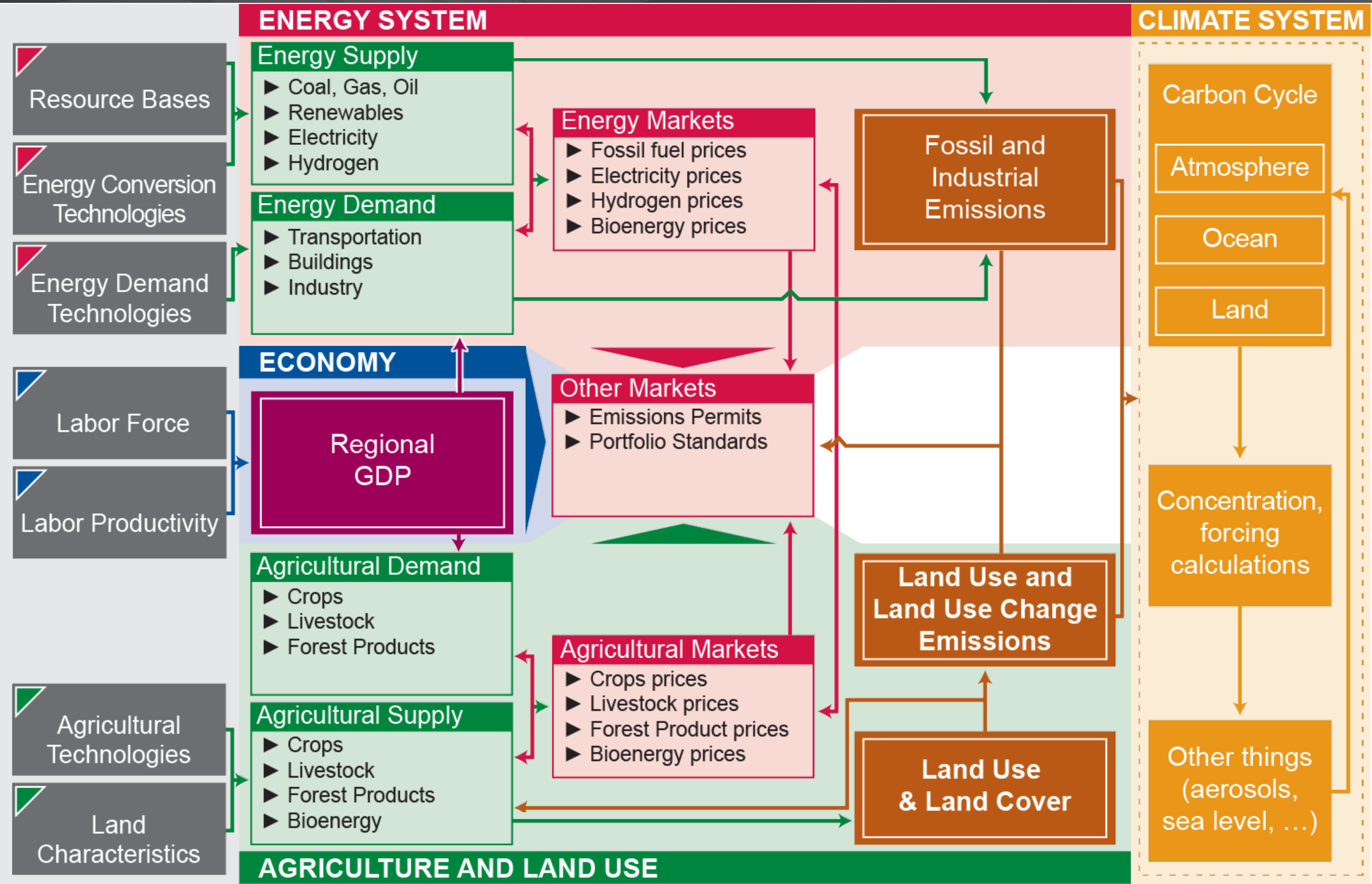
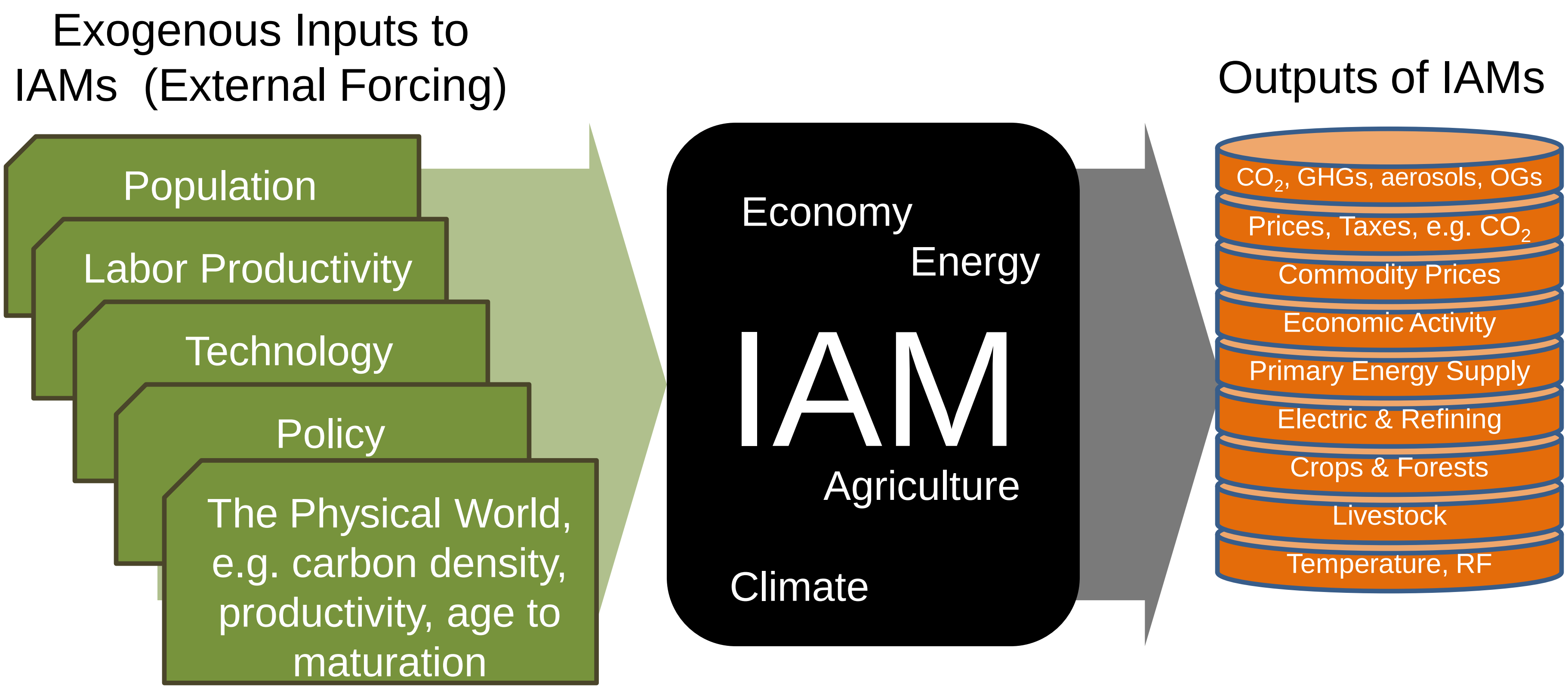


Inputs and Outputs in GCAM



Terrestrial Carbon Emissions in GCAM

- Methodology:
  - We use an accounting method to track CO_2 fluxes from the terrestrial system.
  - These fluxes are then passed into a climate model (MAGICC) to compute atmospheric concentrations of CO_2.

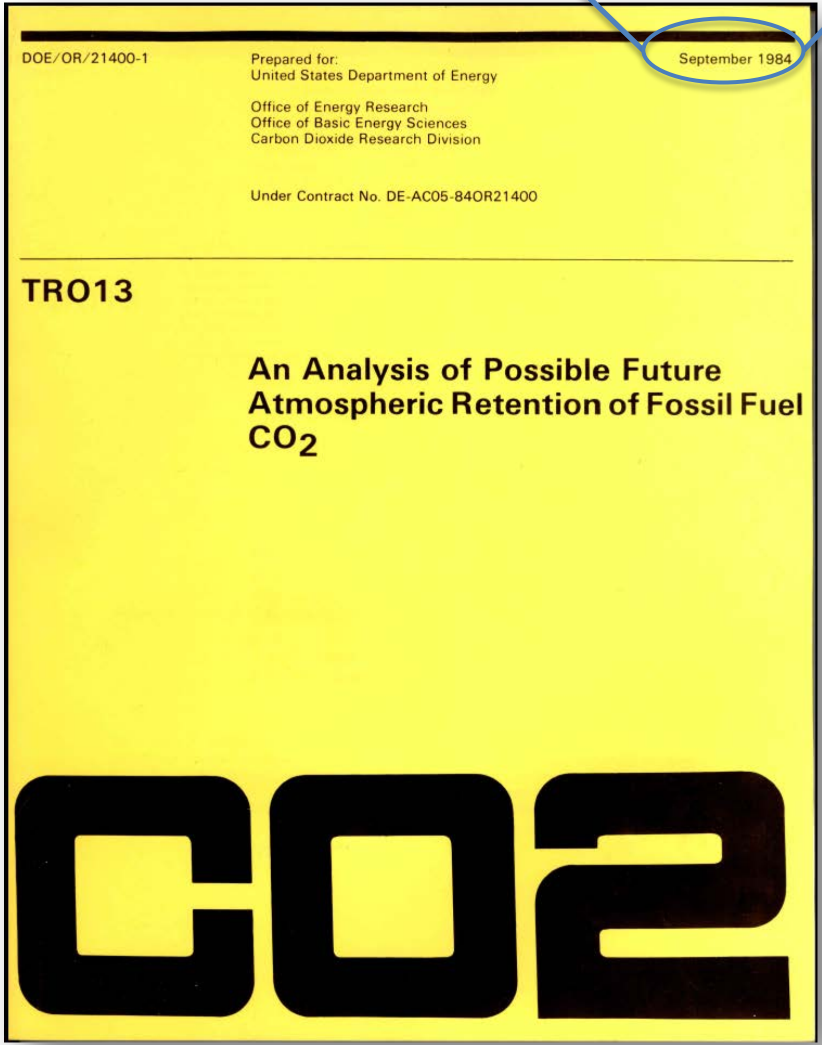
- Inputs:
  - Carbon densities (above & below ground): the amount of carbon per unit of land that would accumulate in an ecosystem if it grew until maturity.
  - Mature age: the length of time it takes an ecosystem to reach ~80% of its eventual carbon.
  - Soil time scale: the length of time it takes for soil to equilibrate after land conversion.

- Resolution:
  - Each of these parameters is read in for each of the land types in GCAM and for each of the 151 global regions.

IAMs have been engaged in carbon cycle science for a very long time

September 1984

- Original coupling was the ORNL carbon cycle and the Edmonds-Reilly energy-CO_2 model.
- Subsequent couplings were under taken between the climate modeling and emissions mitigation communities:
  - SA90 (IPCC AR1)
  - IS92 (IPCC AR2)
  - SRES (Special Report on Emissions Scenarios; IPCC AR3, AR4)
  - RCPs (Representative Concentration Pathways; AR5)



DOE/OR/21400-1

Prepared for:
United States Department of Energy

Office of Energy Research
Office of Basic Energy Sciences
Carbon Dioxide Research Division

Under Contract No. DE-AC05-84OR21400

September 1984

TRO13

An Analysis of Possible Future Atmospheric Retention of Fossil Fuel CO_2

CO_2

Emissions Scenarios

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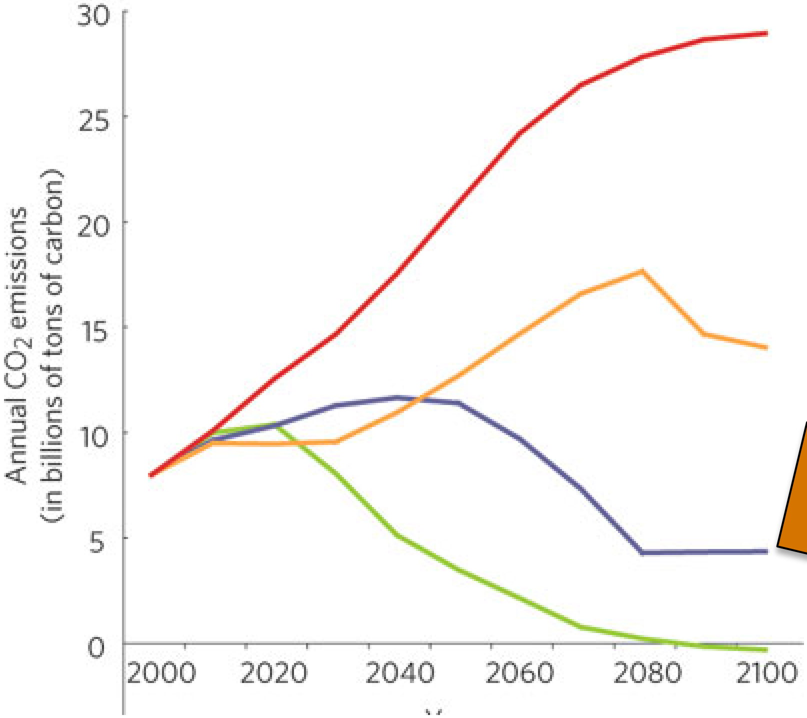
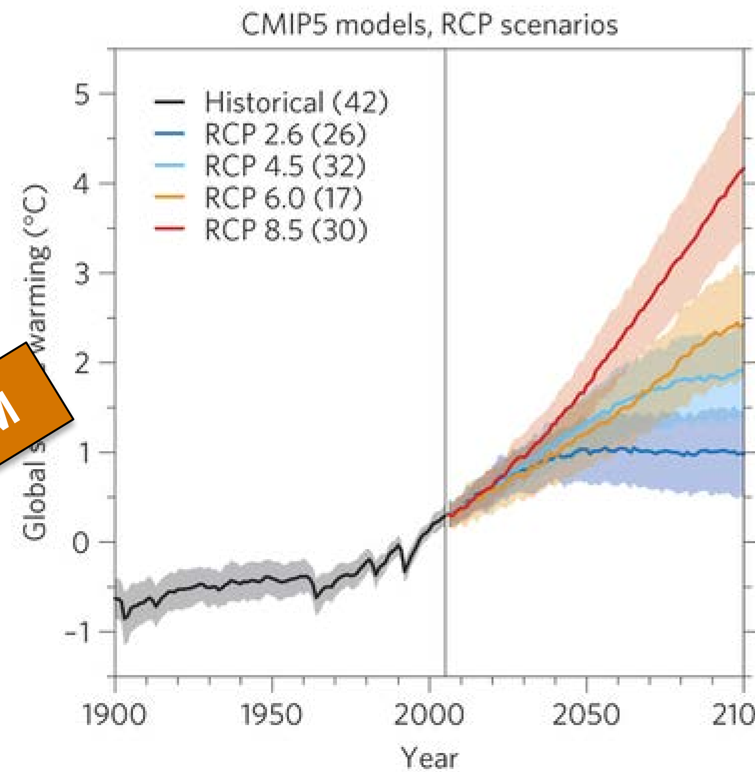
Emissions → Atmosphere → Climate

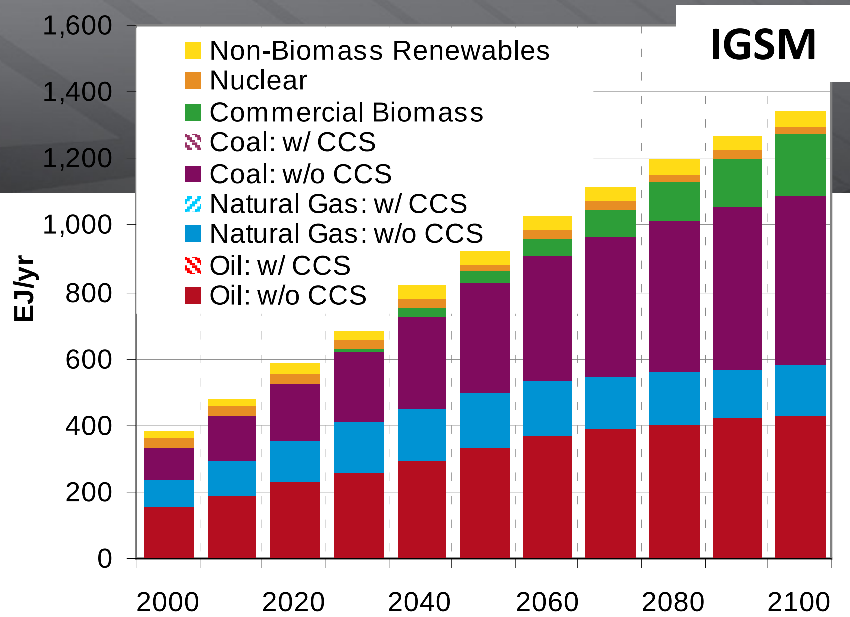


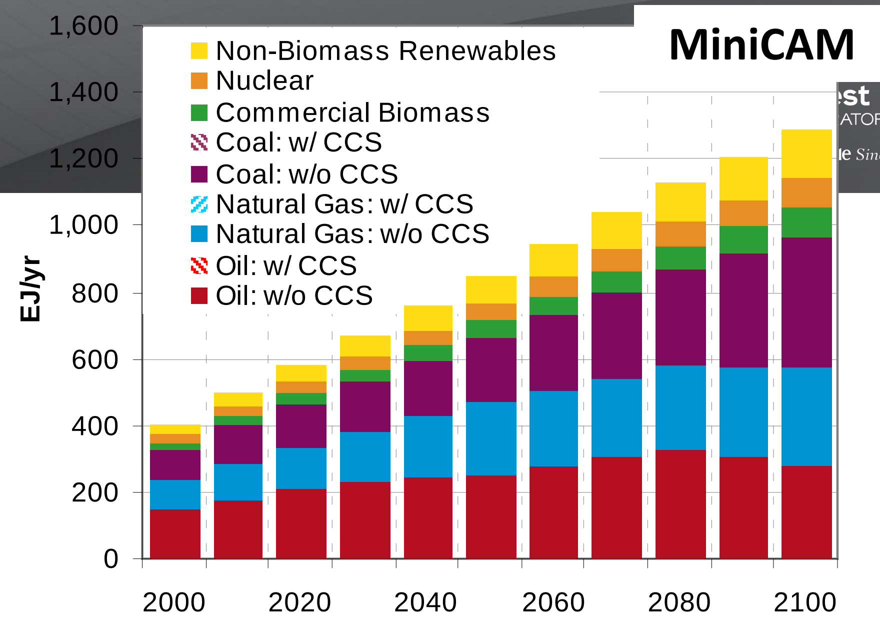


GHG Emissions and Concentrations from IAMs

- Greenhouse gases: CO_2, CH_4, N_2O, CFCs, HFC's, PFC's, SF_6
- Emissions of chemically active gases: CO, NO_x, NH_3, VOCs
- Derived GHG's: tropospheric O_3
- Emissions of aerosols: SO_2, Black Carbon (BC), Organic Carbon (OC)
- Land use and land cover

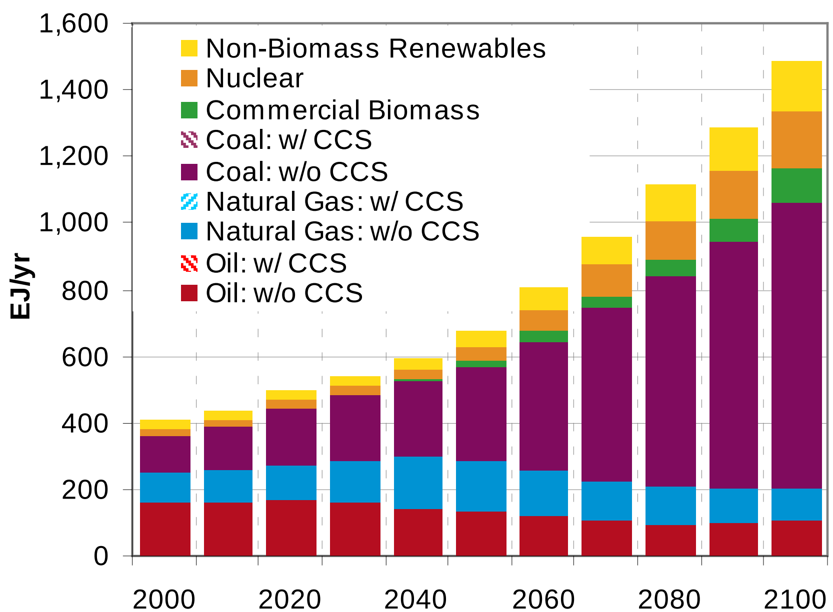
Source: Knutti, R. and J. Sedláček (2012), Robustness and uncertainties in the new CMIP5 climate model projections, *Nature Climate Change*, doi:10.1038/nclimate1716





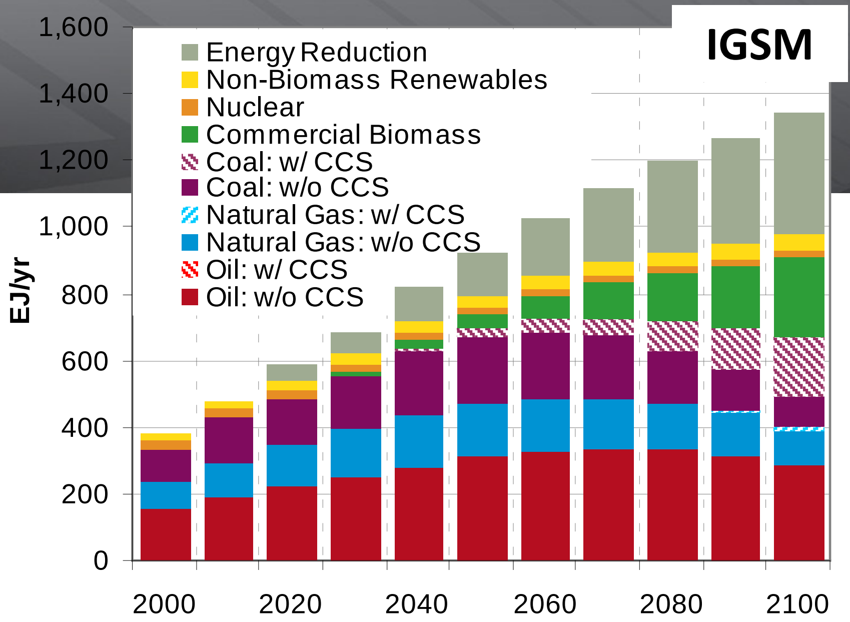
Primary Energy from the CCSP Scenarios

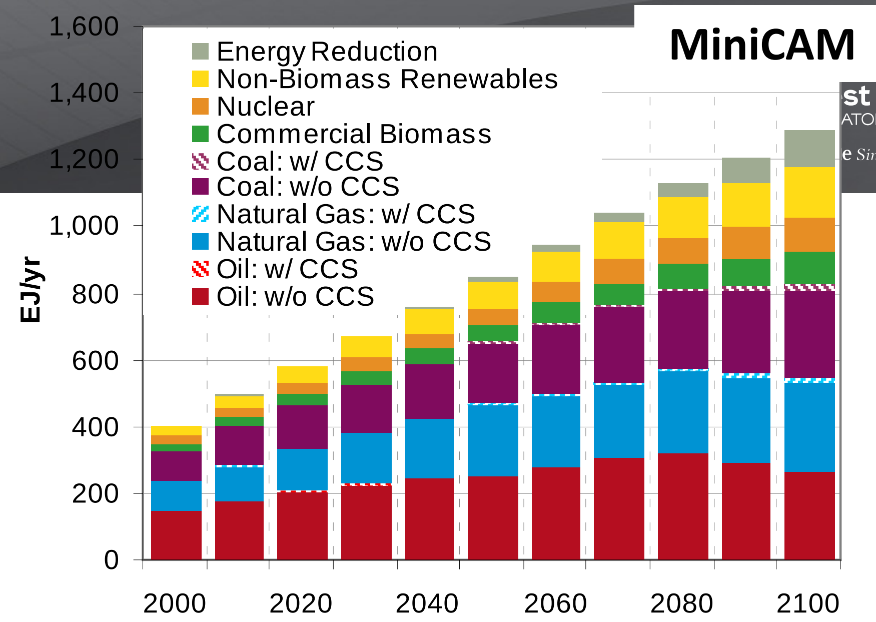
(Reference Scenario)

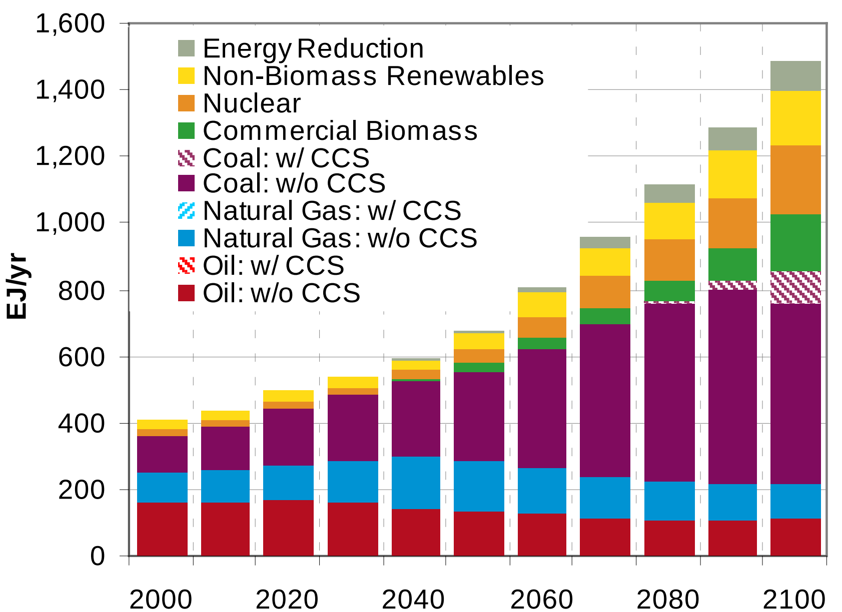


MERGE

From ***CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations***







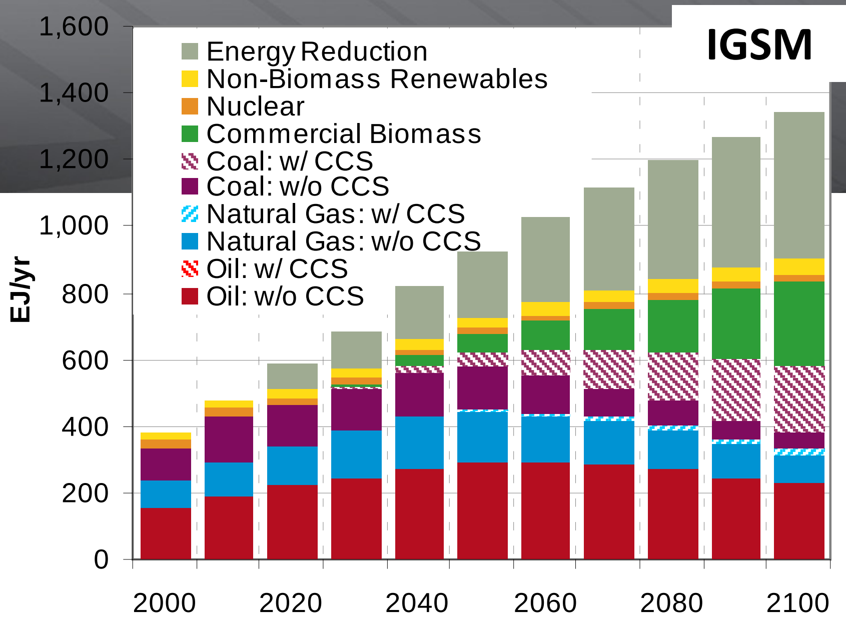
Primary Energy from the CCSP Scenarios

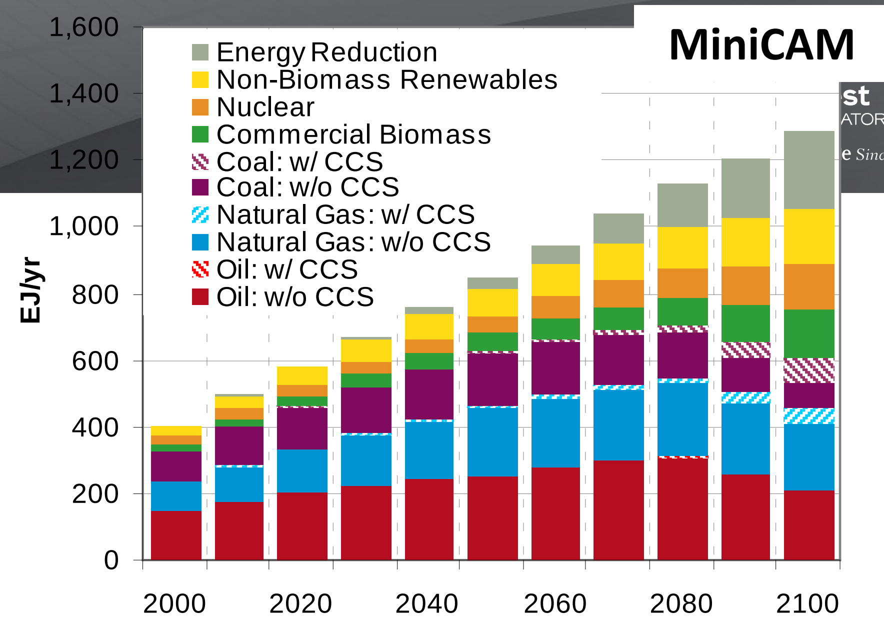
(≈ 750 ppmv CO_2)

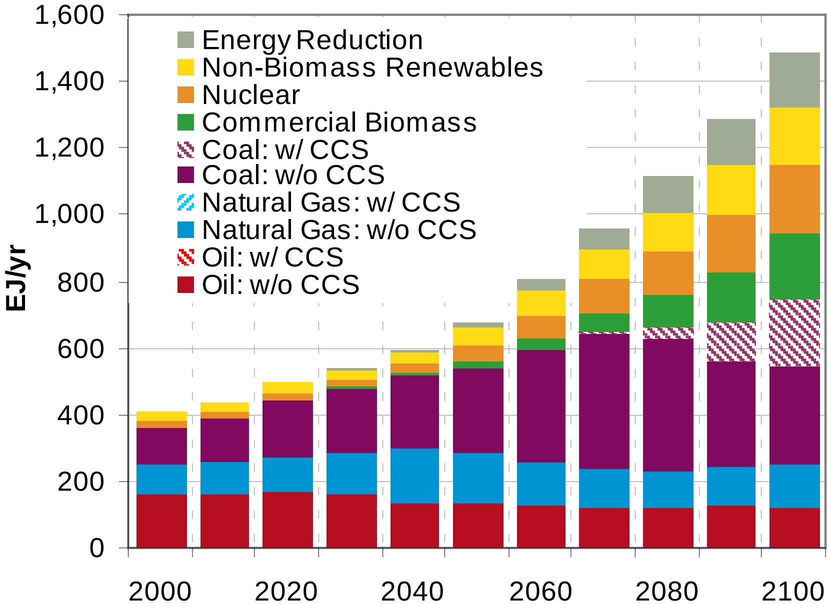
More like 850 CO_2-e

MERGE

From ***CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations***







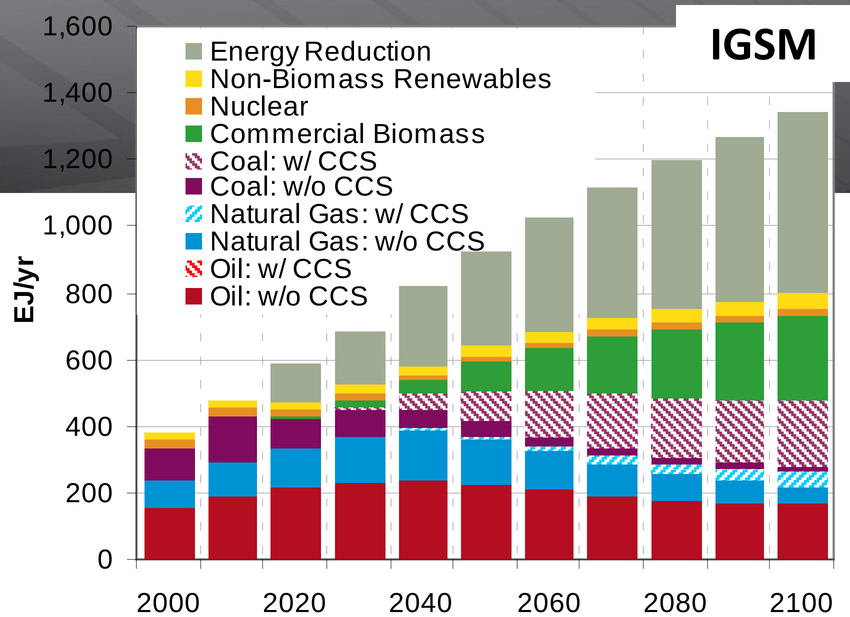
MERGE

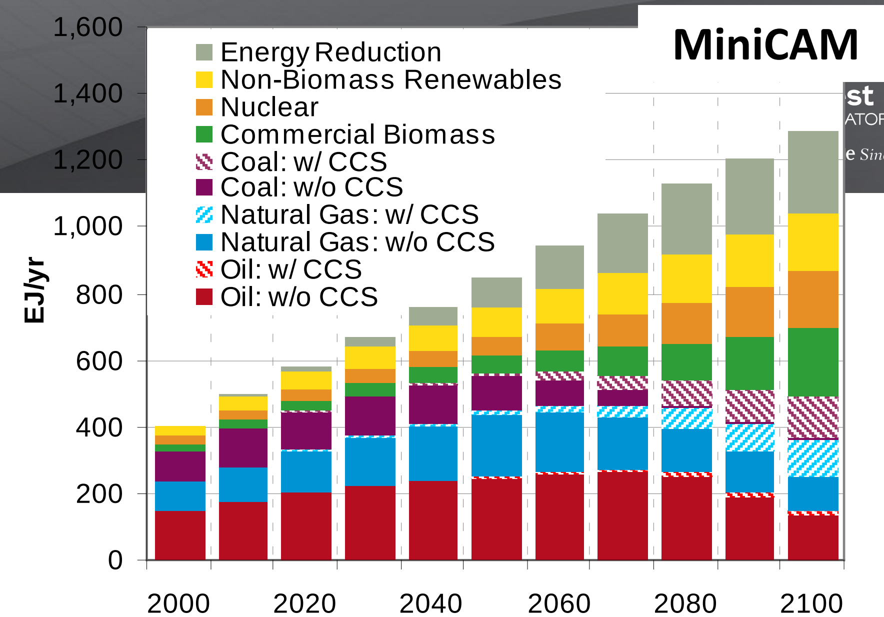
Primary Energy from the CCSP Scenarios

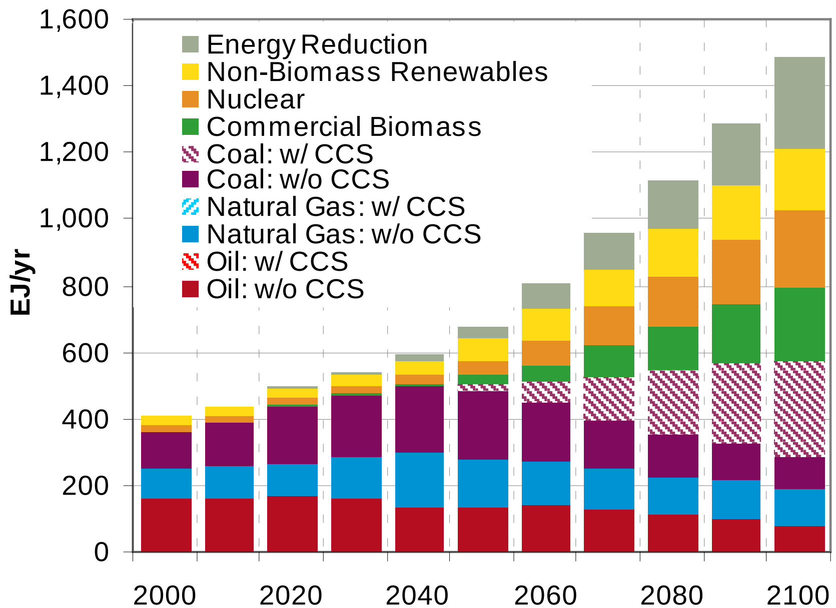
(≈ 650 ppmv CO_2)

More like 750 CO_2-e

From ***CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations***







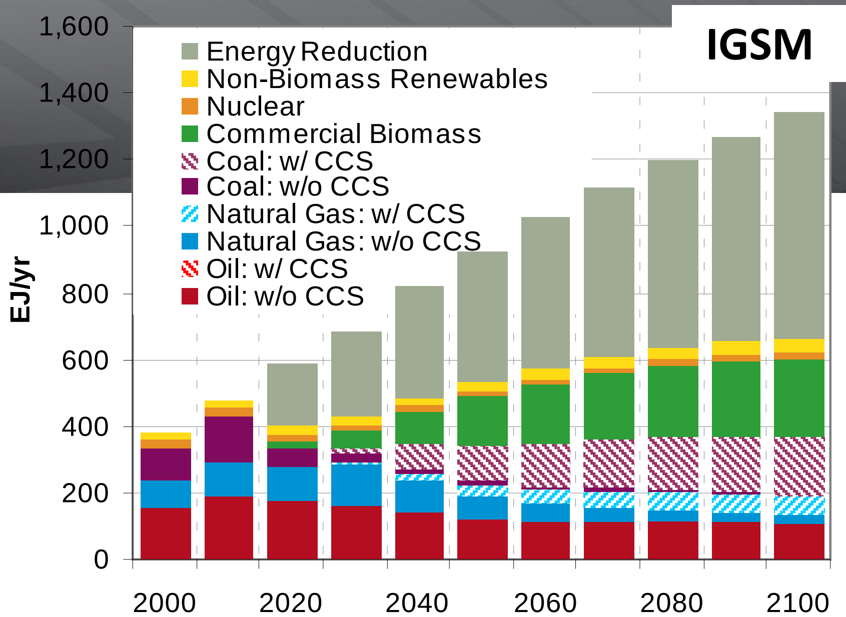
MERGE

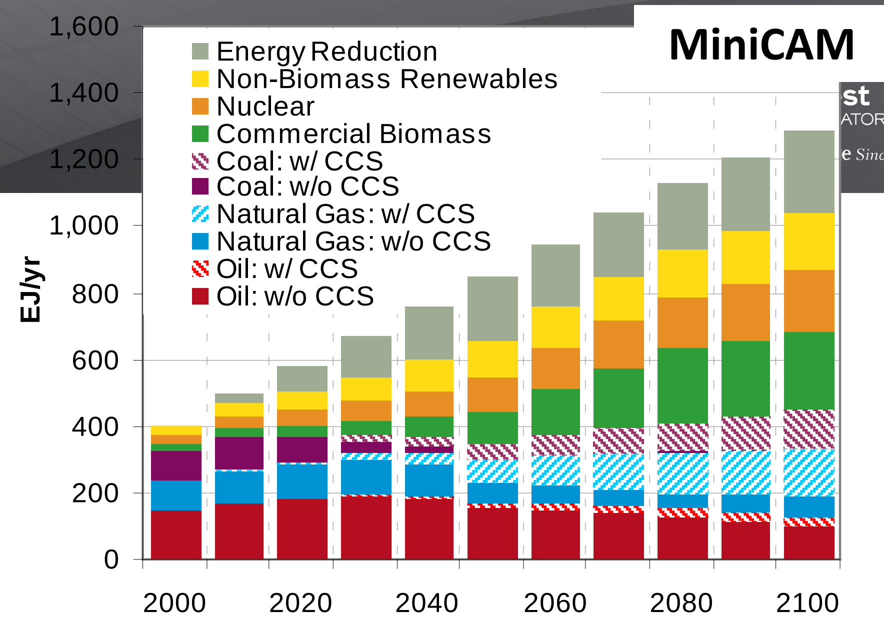
Primary Energy from the CCSP Scenarios

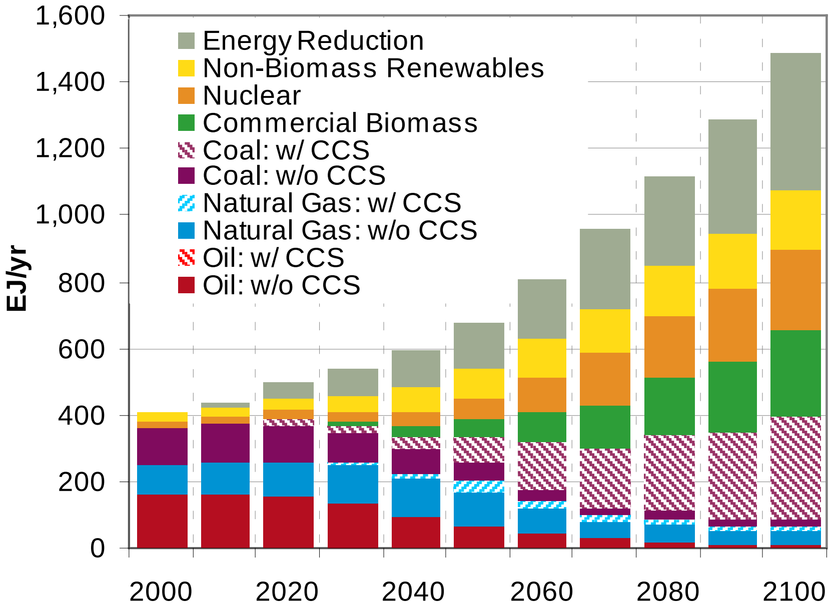
(≈ 550 ppmv CO_2)

More like 650 CO_2-e

From ***CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations***







MERGE

Primary Energy from the CCSP Scenarios

(≈ 450 ppmv CO_2)

More like 550 CO_2-e

From ***CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations***

Stabilizing the concentration of CO_2 in the atmosphere means fundamental change

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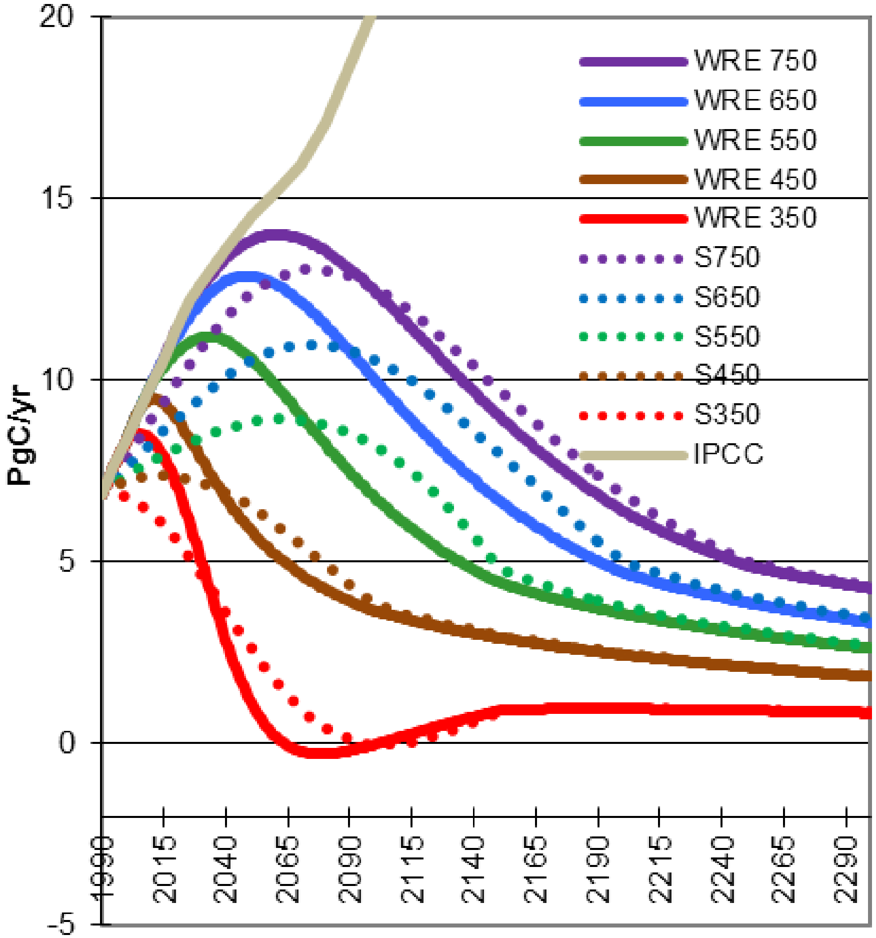
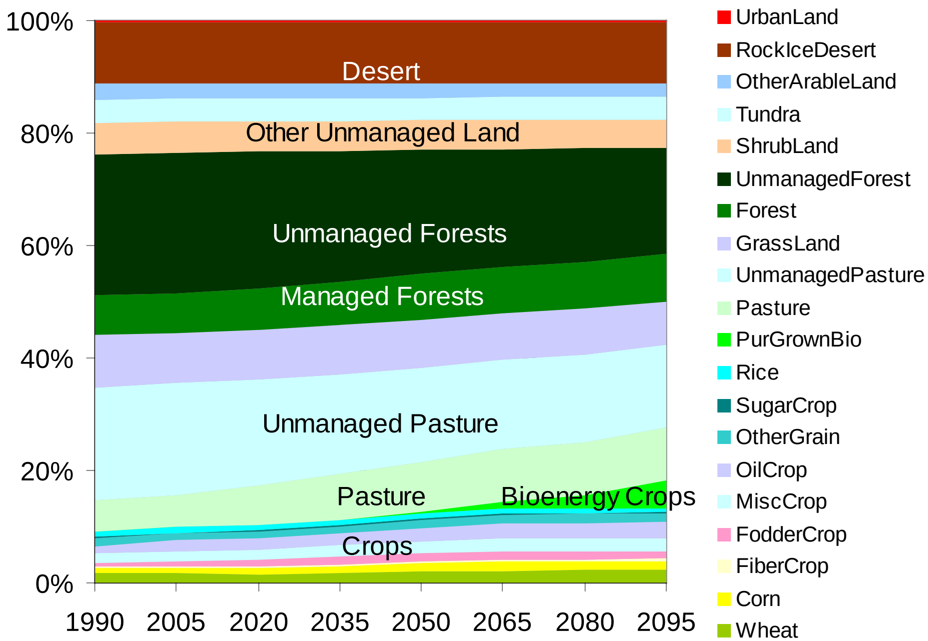
- Integrated assessment models combine models of human and biophysical Earth systems to estimate emissions pathways consistent with stabilization of CO_2 concentrations.

- The particulars of the carbon cycle matter greatly.



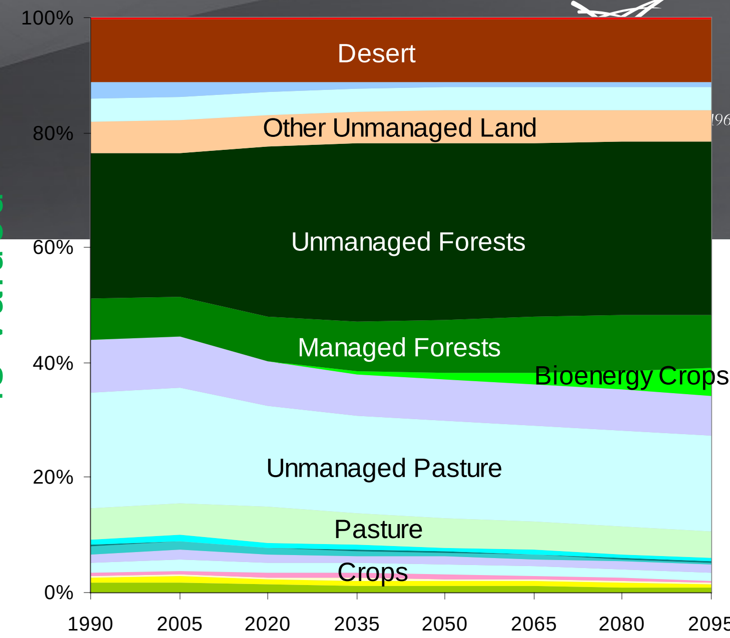
Source: Wigley, T.M.L., R. Richels and J. A. Edmonds. 1996. "Economic and Environmental Choices in the Stabilization of Atmospheric CO2 Concentrations," Nature. 379(6562):240-243.

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

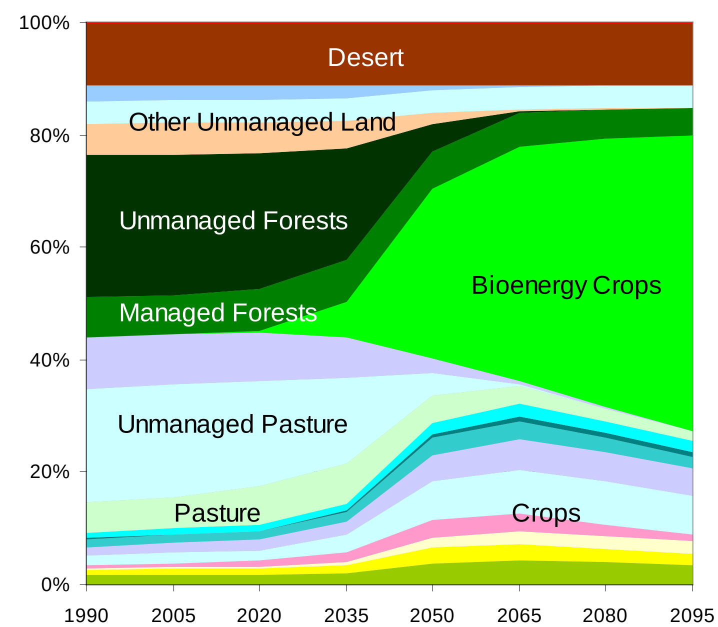


Reference Scenario

450 ppm Stabilization Scenario When ALL Carbon is Valued



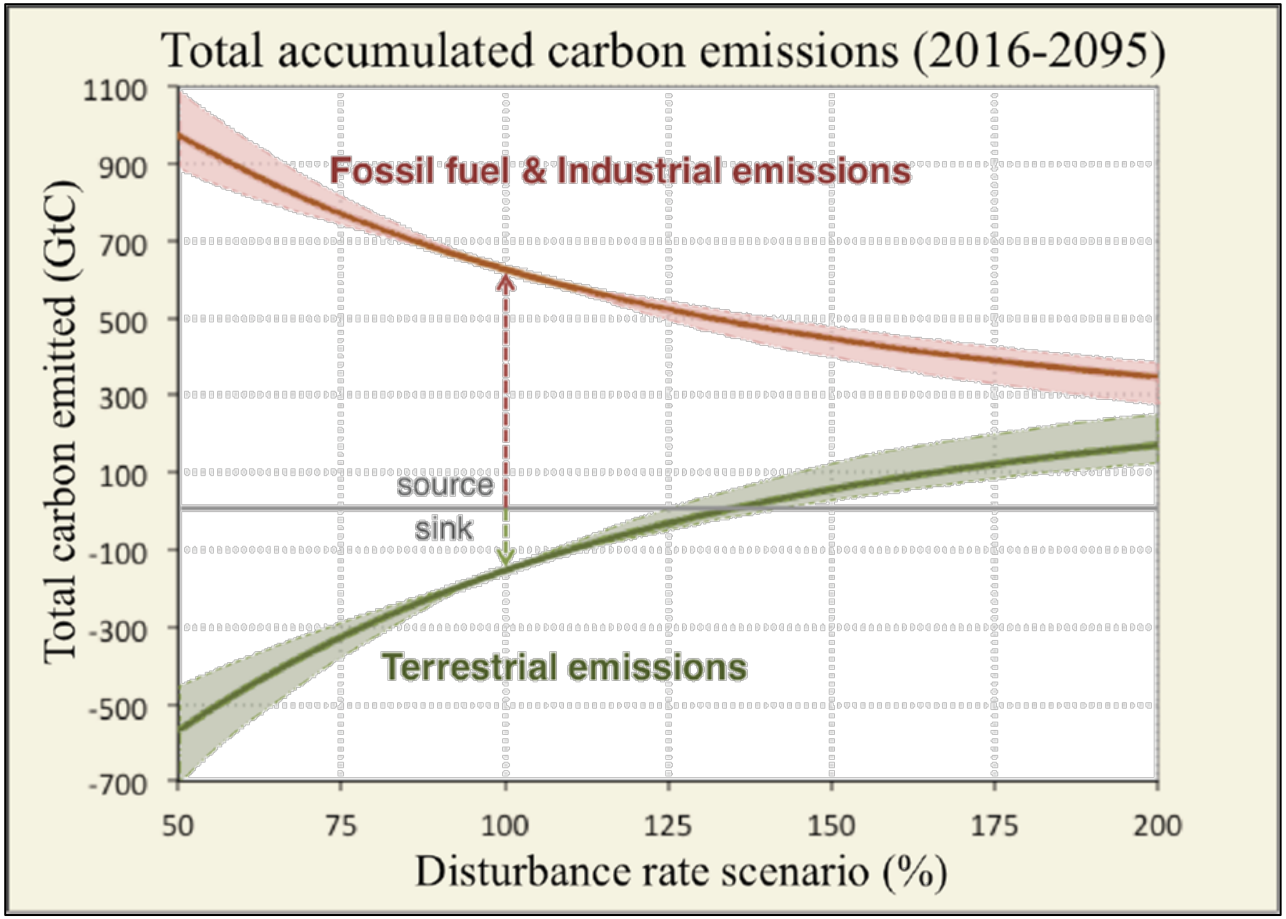
450 ppm Stabilization Scenario When Terrestrial Carbon is NOT Valued



Wise et al. (2009) "Implications of Limiting CO2 Concentrations for Land Use and Energy." *Science* 324(5931):1183-1186 .

Forest Disturbance

- Sensitivity study of potential future forest disturbance rates in GCAM illustrates the importance of representing ecosystem processes when considering mitigation policy



Le Page et al, 2013

SAMPLE ANALYSIS USING GCAM: THE ROLE OF LAND IN MITIGATION POLICY

Mitigation Policies

- Mitigation efforts have the potential to affect the land surface through the use of **bioenergy** and **afforestation** as a means of reducing emissions.
  - Both of these options compete for land with food and other uses.
- However, the extent to which these mitigation options are deployed depends on the amount of mitigation required and the policy context.
- Varying the policy context will affect:
  - The deployment of bioenergy
  - The extent of afforestation
  - Terrestrial carbon fluxes
  - The area available for food production
  - The price of food

Land Policy Scenarios

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Name	Climate Policy	Bioenergy	Land Policy	Protected Areas
Reference	None	No Constraints	None	None
No Land Policy	$\leq 3.7\ W/m^2$	No Constraints	None	None
Afforestation	$\leq 3.7\ W/m^2$	No Constraints	Full Carbon Tax	None
No Land Clearing	$\leq 3.7\ W/m^2$	No Constraints	None	99% of all natural ecosystems
No Deforestation	$\leq 3.7\ W/m^2$	No Constraints	None	99% of forests
Bio Emiss Tax	$\leq 3.7\ W/m^2$	Taxed	None	None

Source: Calvin K et al. (In press) Trade-offs of different land and bioenergy policies on the path to achieving climate targets. *Climatic Change.* DOI: 10.1007/s10584-013-0897-y

Land policy can significantly alter future land use and land cover.

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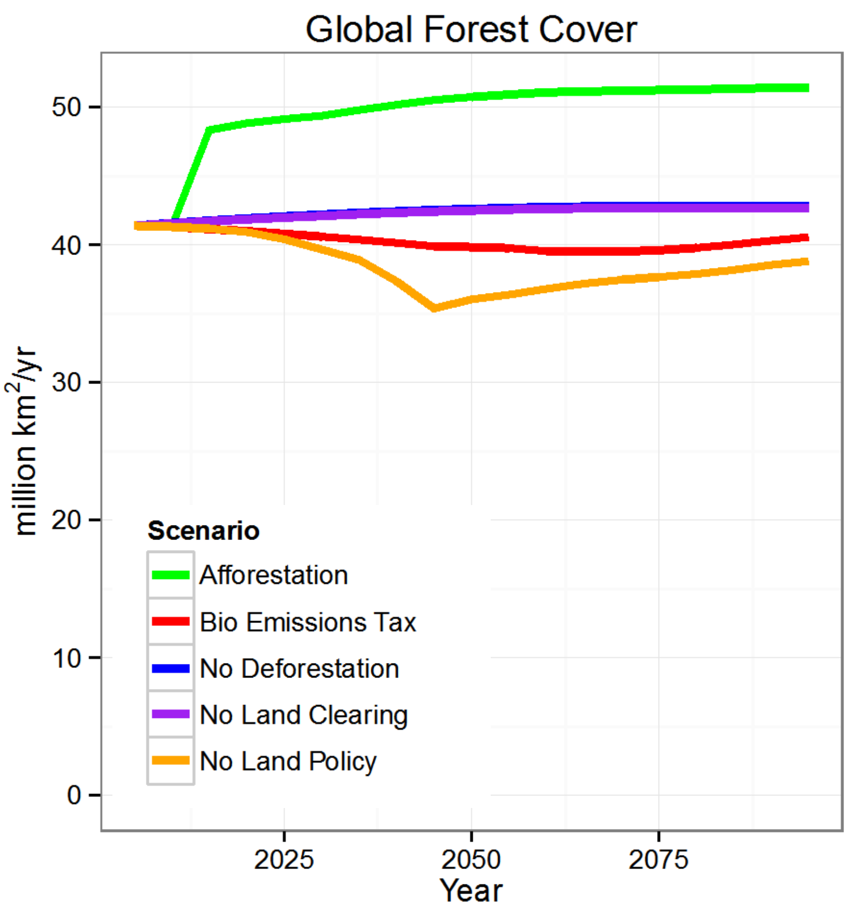
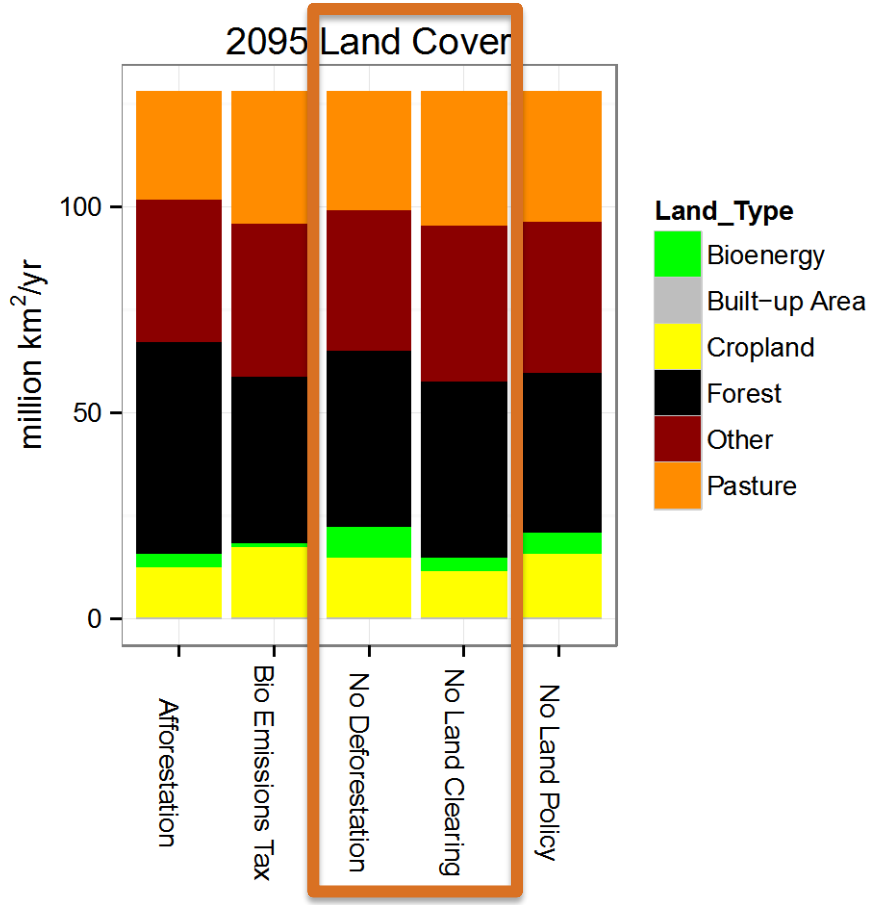
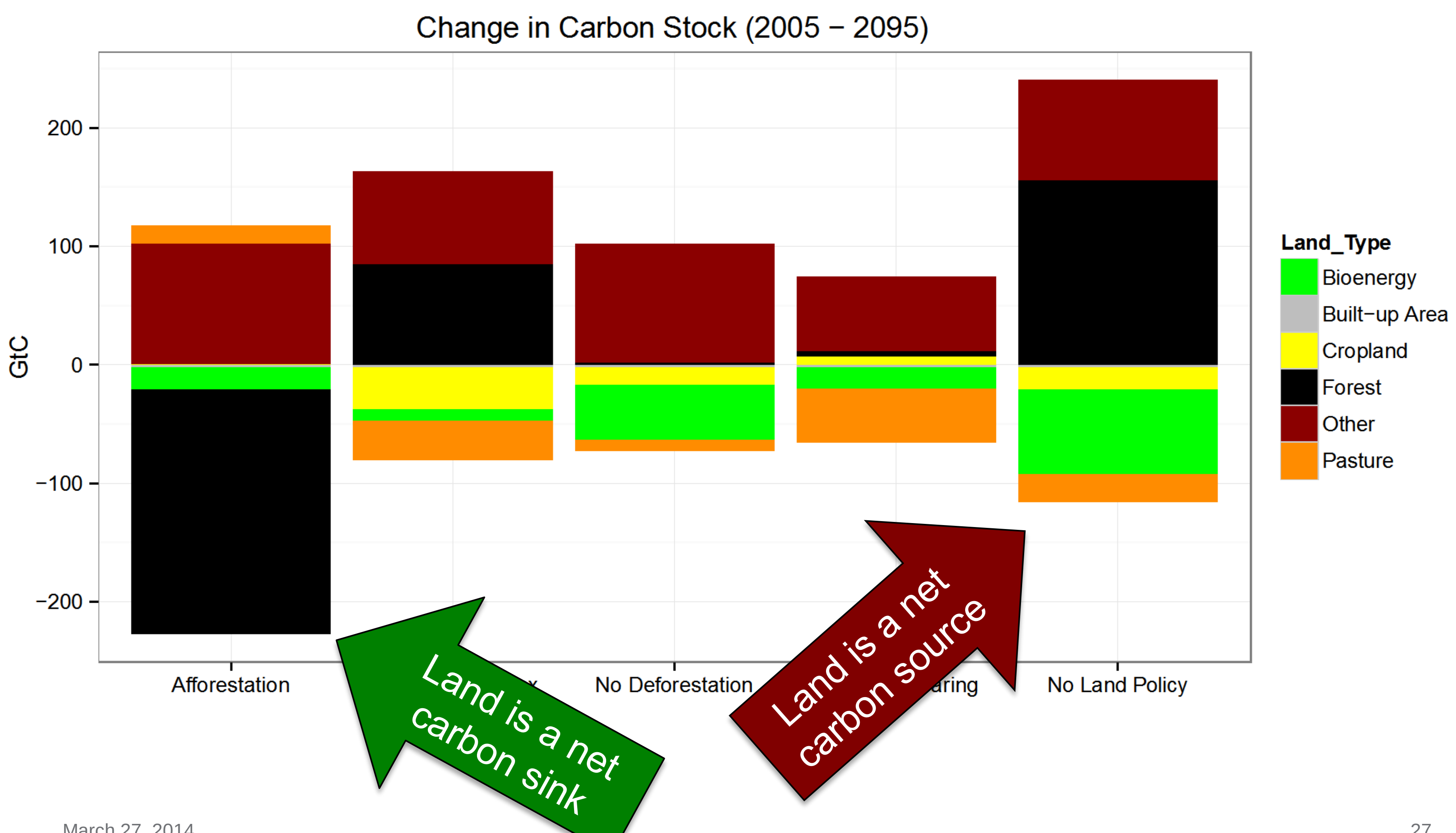




Note: All scenarios stabilize at 3.7 W/m^2

And, changes in land cover have implications for terrestrial carbon stocks.



Note: All scenarios stabilize at 3.7 W/m^2

These policies have only a small effect on total CO_2 emissions…

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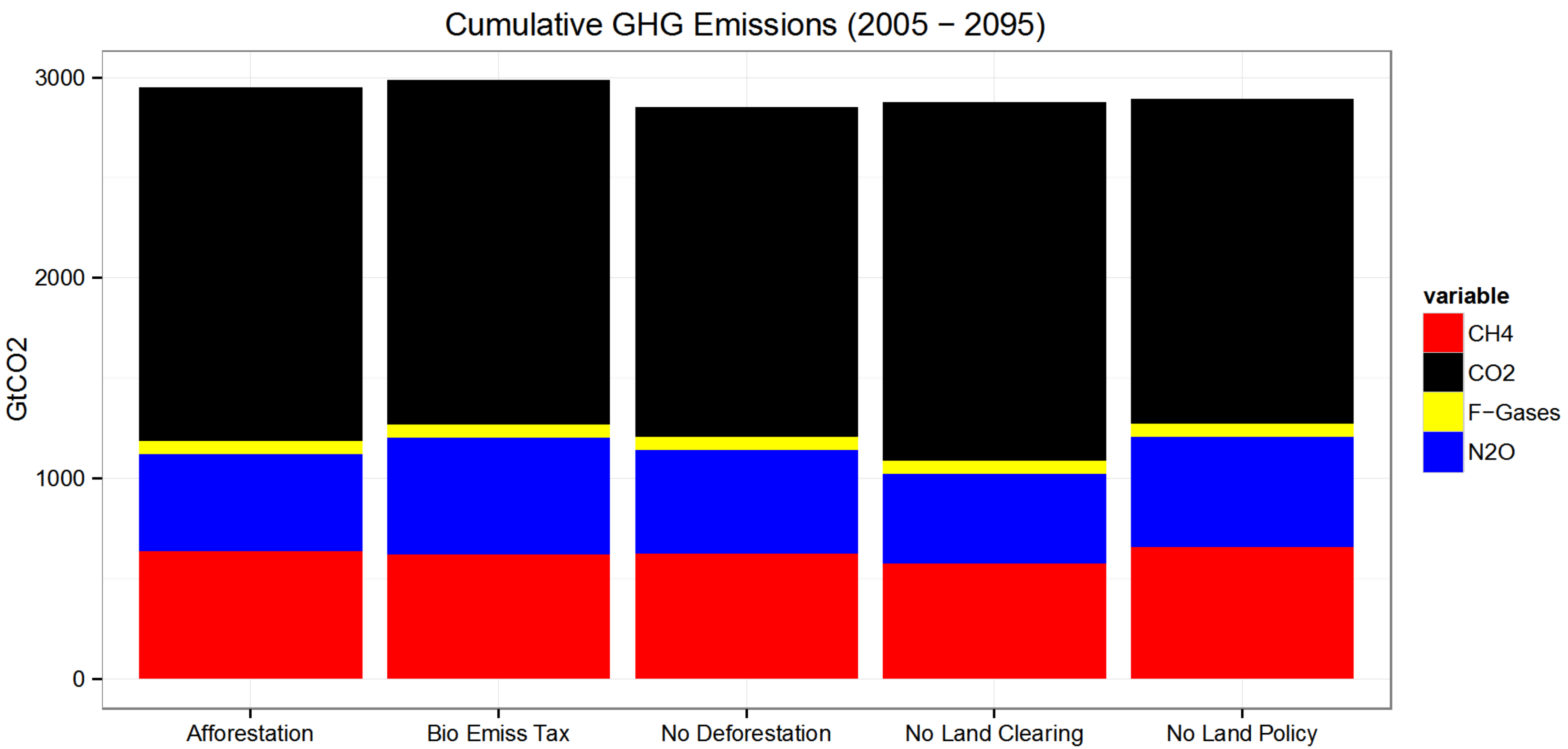
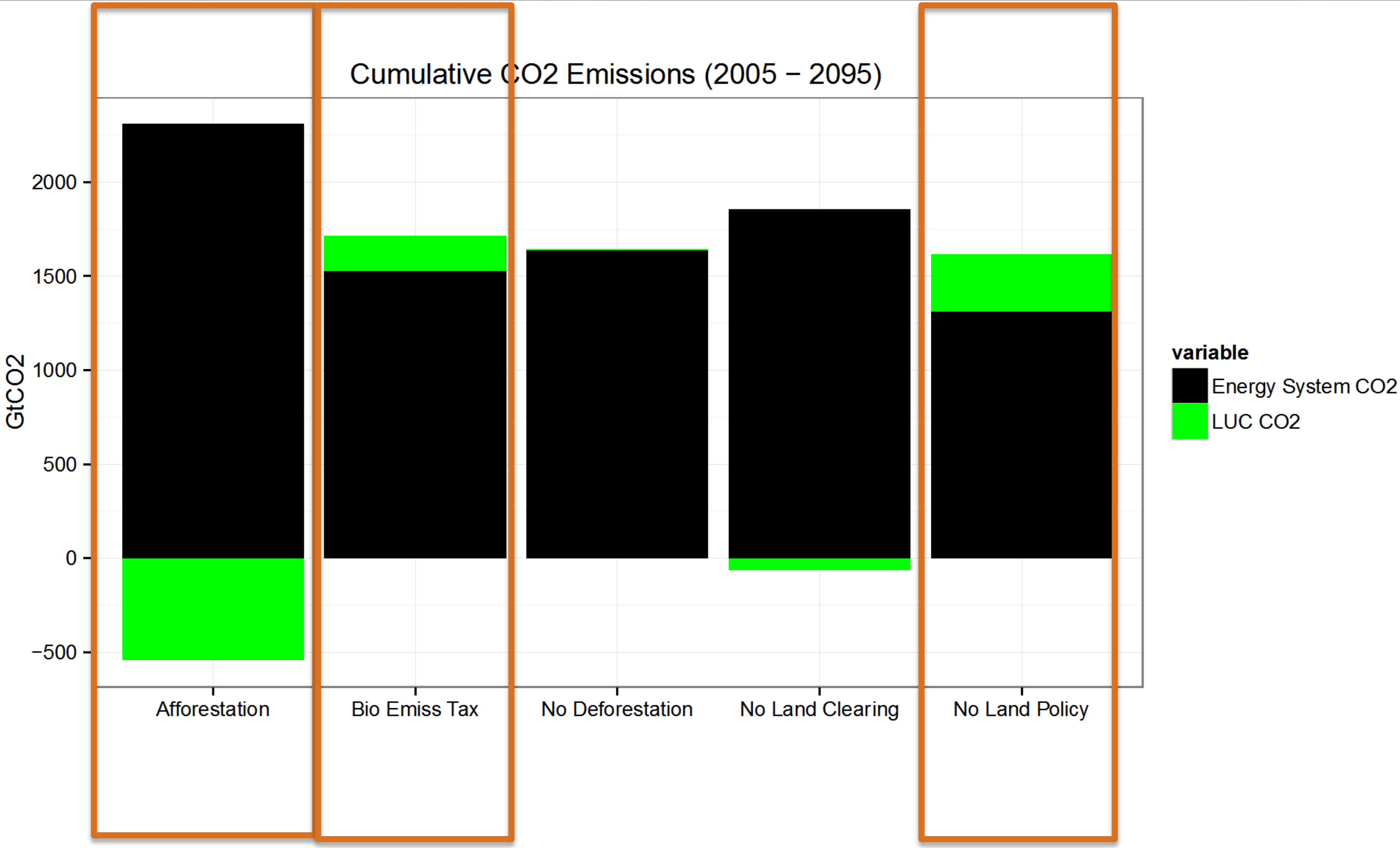


Note: Policy Cases Stabilize at 3.7 W/m^2

…but a large effect on the balance between energy & land CO_2 emissions



Note: Policy Cases Stabilize at 3.7 W/m^2

Land policy also affects other aspects of the energy, agriculture, economy, and climate systems.

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- Afforestation lessens the mitigation pressure on the energy system, resulting in lower energy prices. But, afforestation competes with food for land, resulting in high food prices.

Land policy also affects other aspects of the energy, agriculture, economy, and climate systems.

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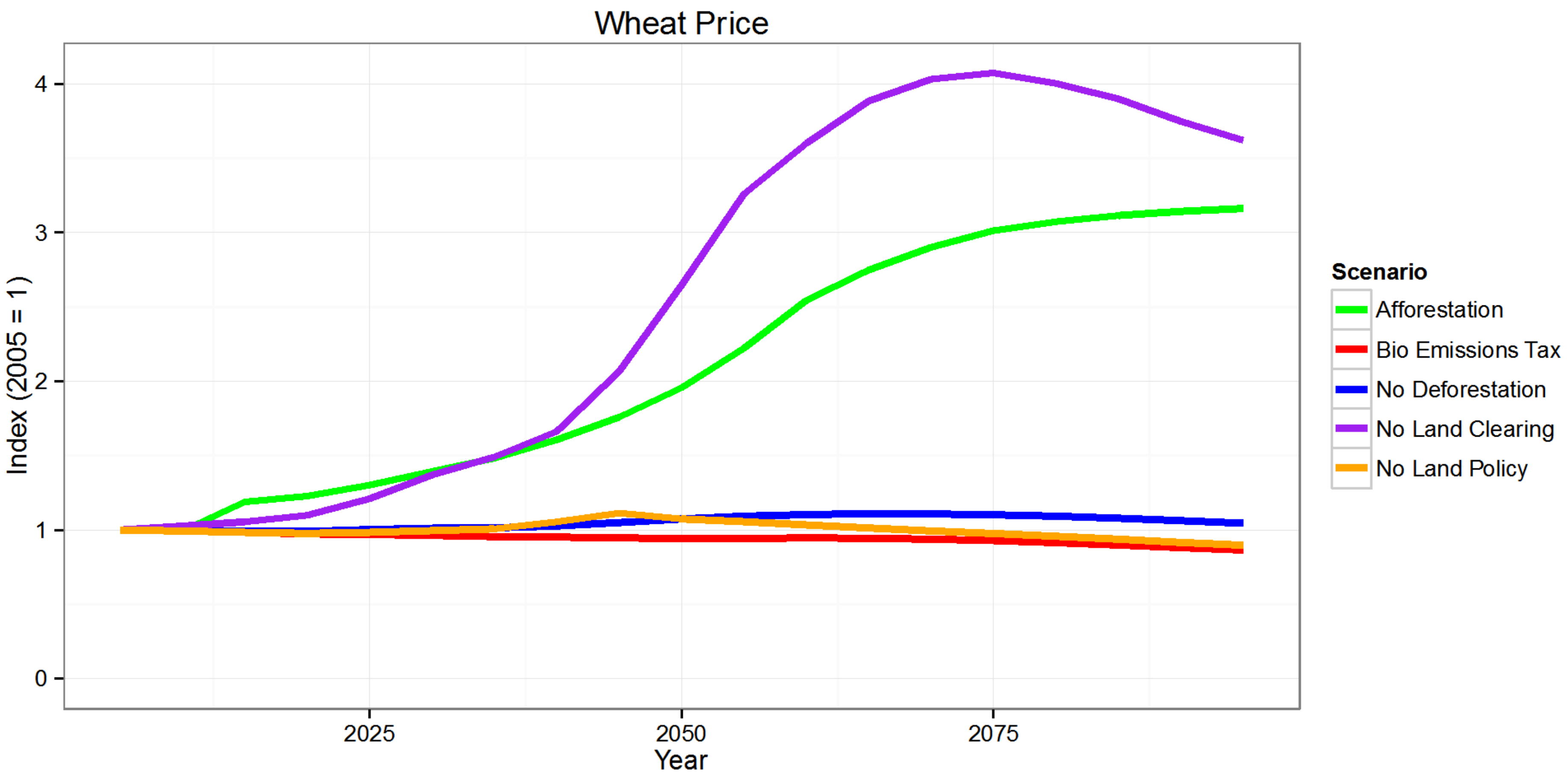

Note: All scenarios stabilize at 3.7 W/m^2

Land policy also affects other aspects of the energy, agriculture, economy, and climate systems.

- Afforestation lessens the mitigation pressure on the energy system, resulting in lower energy prices. But, afforestation competes with food for land, resulting in high food prices.

- No Land Policy allows for expansion of crop land, resulting in low food prices. But, the energy system must compensate for deforestation emissions resulting in high mitigation costs.

Land policy also affects other aspects of the energy, agriculture, economy, and climate systems.

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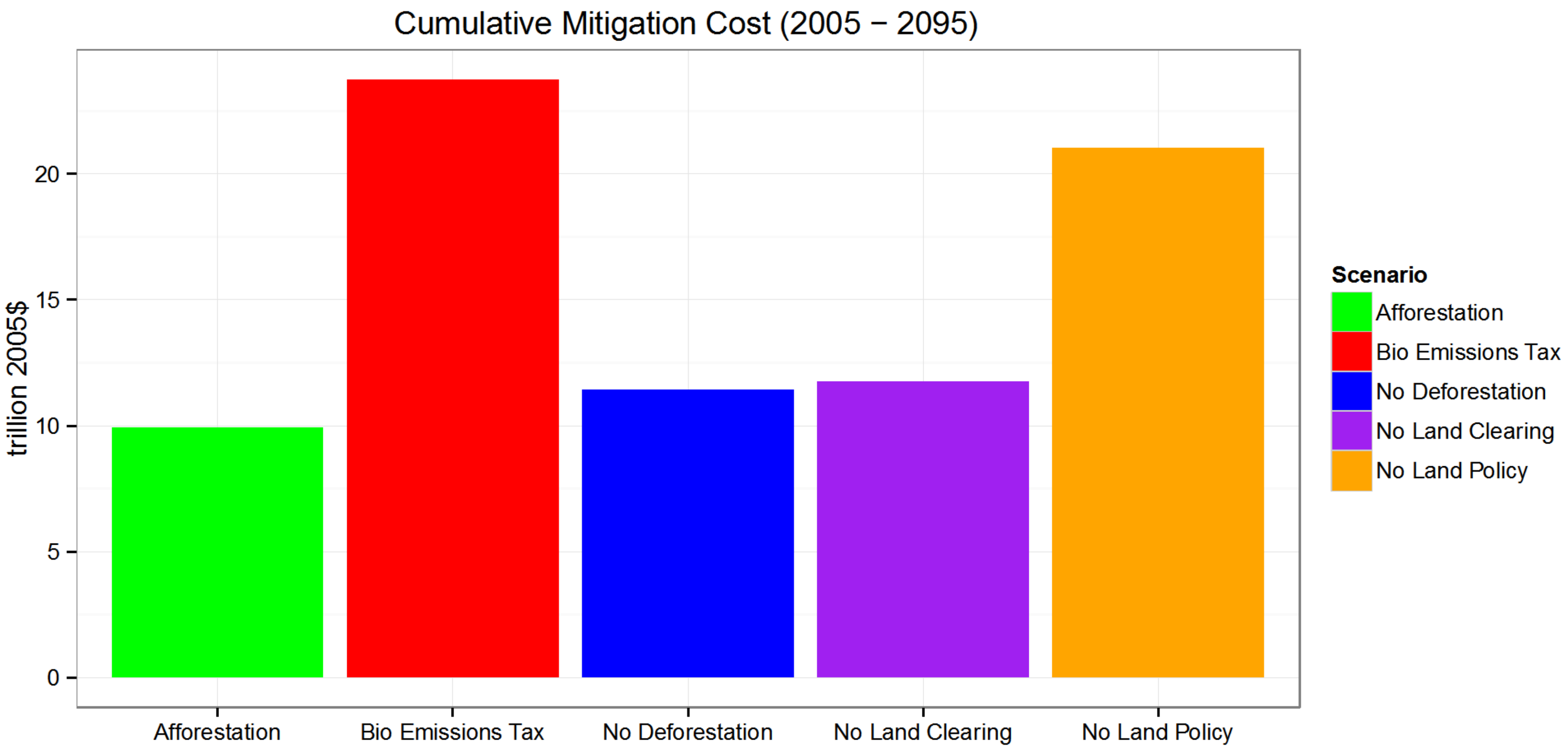

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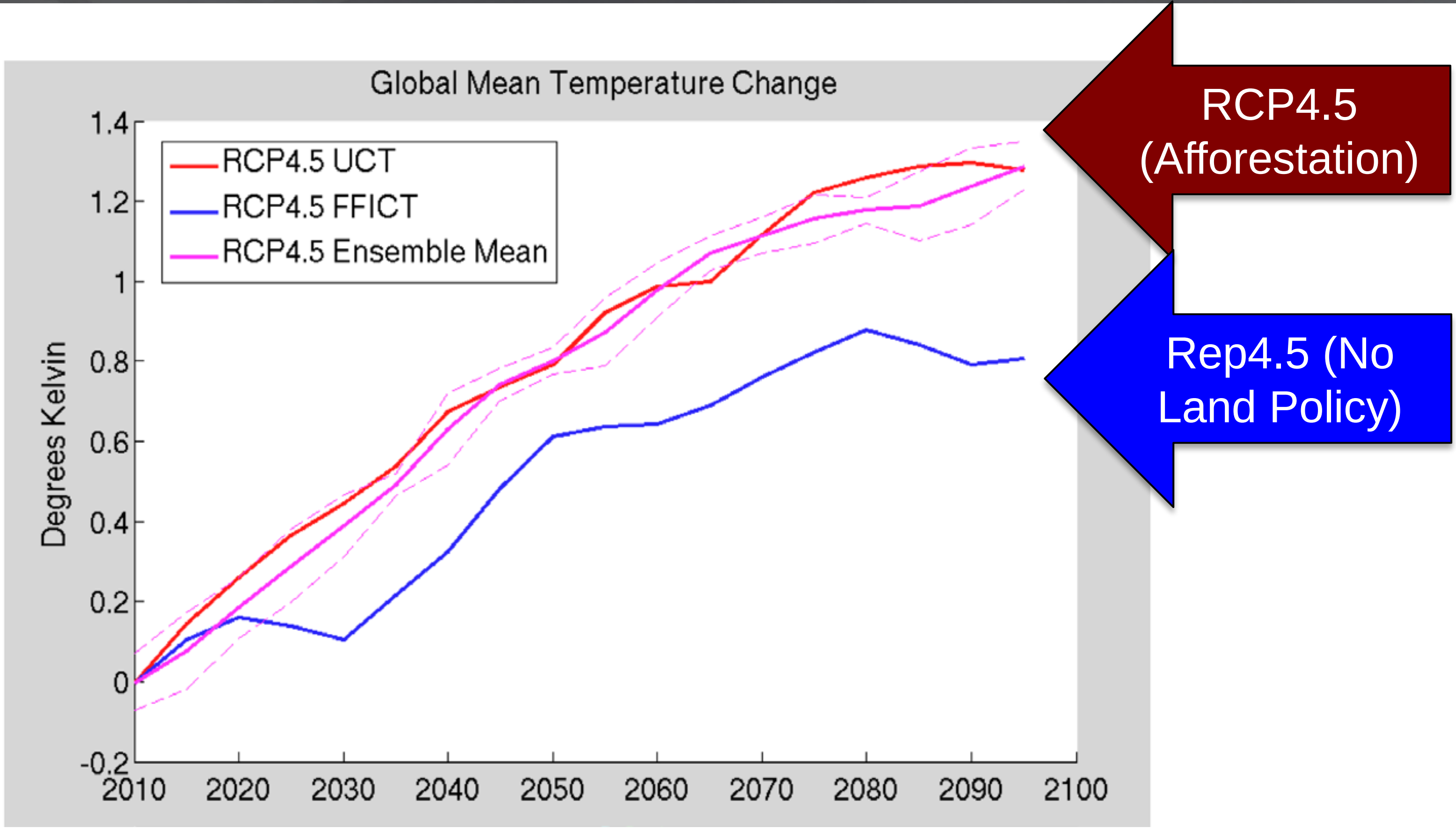
- No Land Policy allows for expansion of crop land, resulting in low food prices. But, the energy system must compensate for deforestation emissions resulting in high mitigation costs.

- And, these scenarios have implications for albedo and temperature rise.

Quantifying the effect of land cover on temperature: Results using GCAM & CESM



*Comparison between **Rep 4.5** and **RCP 4.5***
Rep 4.5** is shown to be cooler, with rapid transition under **Rep 4.5

Source: Jones A et al. (2013) Greenhouse gas policy influences climate via direct effects of land-use change. Journal of Climate 26:3657-3670.

Quantifying the effect of land cover on temperature: Results using GCAM & CESM

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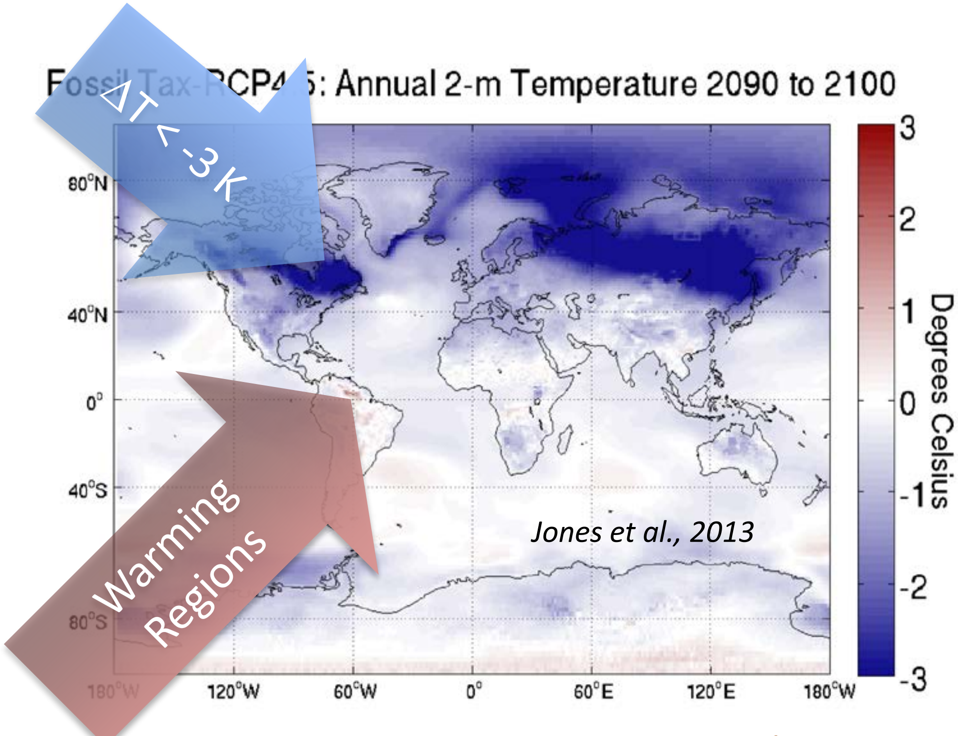
- **Regional & Local** changes are much larger than the global changes.
  - Cooling in high latitudes
  - Warming in other regions.



Comparison between ***Rep 4.5*** *and RCP 4.5 (difference RCP 4.5 less* ***Rep 4.5*** *).* ***Rep 4.5*** *is shown to be cooler, but with significant regional differences and some regions warmer under* ***Rep 4.5***

SYNERGISTIC ACTIVITIES BETWEEN NASA & GCAM

GCAM output is in AEZ format prior to downscaling

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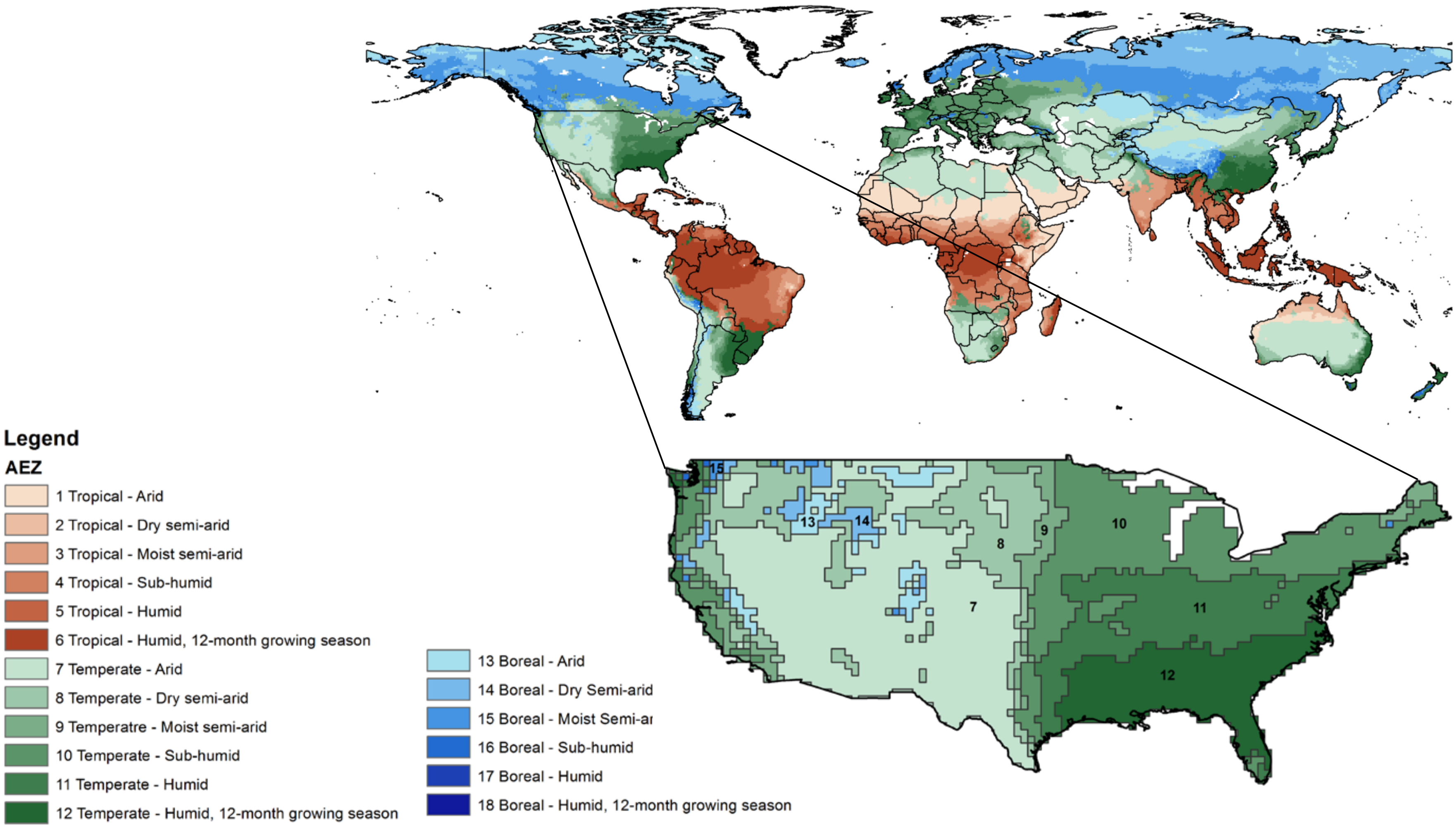

Mitigation Pathway 2.6

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2010 | 2090 | Expansion or Contraction

Crop

Grass

Shrub

Forest

Potential links between GCAM and CMS

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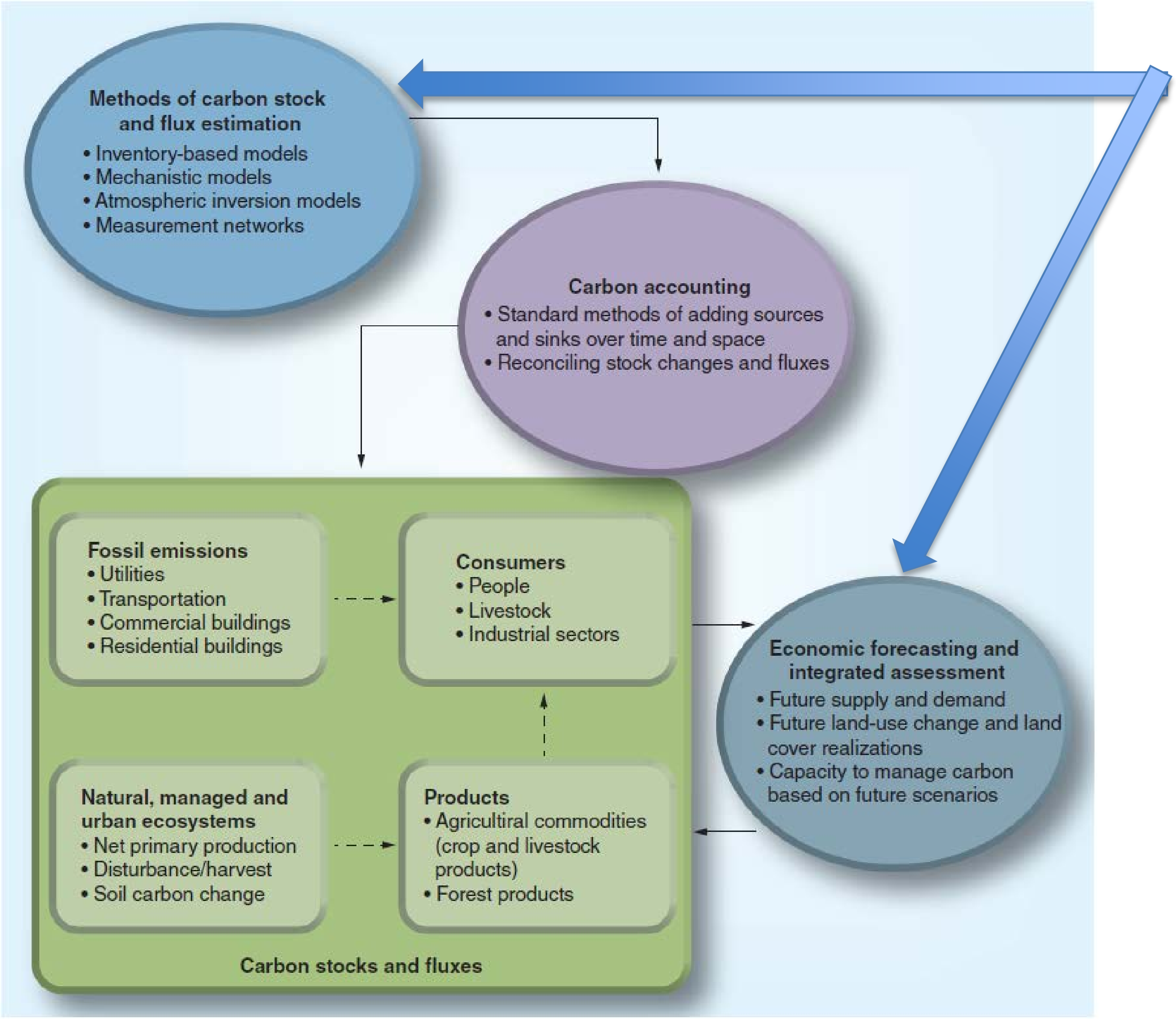

- Existing CMS estimates might be linked to GCAM via "bottom-up" inventory-based carbon stock/flux estimates
- Spatial resolution between the two can be made consistent using current downscaling methods

West et al. 2013. Carbon Management 4: 413-422.

DISCUSSION

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