

General Equilibrium Characterization of Bio-electricity with Carbon Dioxide Capture and Storage (CCS)

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*The views expressed are the authors and should not be attributed to the Economic Research Service or USDA

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Overview

- Motivation for modeling a negative-emissions technology
- Overview of current Energy Modeling Forum (EMF) study
- Brief history of Future Agricultural Resources Model (FARM)
- Model structure and data
 - CGE Framework
 - GTAP 7 Data and Aggregation
- Carbon Dioxide Capture and Storage (CCS)
- CCS with bio-electricity
- Sample results
 - Global reference and mitigation scenarios
 - U.S. electricity generation
 - No CCS
 - CCS with electricity generated from coal, natural gas, and biomass
- To Do List

Motivation

- Global greenhouse gas emission scenarios reported by the U.S. Climate Change Science Program provide examples of using global energy-economy models to describe possible energy transitions toward a low-carbon economy.
- Low-emission technologies, such as commercial biomass and carbon dioxide capture and storage, are prominent in the mitigation scenarios in this report.
- More recently, a set of Representative Concentration Pathways (RCPs) were constructed to support research intended for the 5th Assessment Report of the Intergovernmental Panel on Climate Change.
- The most stringent of the RCPs, limiting the increase in radiative forcing to 2.6 watts per square meter, **require a negative emissions technology such as bio-electricity combined with CCS.**
- The purpose of this presentation is to report on the application of bio-electricity and CCS within a new computable general equilibrium (CGE) model developed at the Economic Research Service of the U.S. Department of Agriculture.

EMF 24: Technology Strategies for Greenhouse Gas Reductions and Energy Security

- Participants
 - Global scenarios (17 modeling teams)
 - U.S. scenarios (12 modeling teams)
- EMF steering group specifies a large set of scenarios that vary by policy and availability of technologies
- Modeling teams choose whether to run a “policy focus” subset or “technology focus” subset of scenarios
- Technology scenarios vary efficiency or availability of key energy technologies
 - End-use energy efficiency
 - CO₂ Capture and Storage (CCS)
 - Nuclear energy
 - Wind and solar
 - Bio-energy potential

EMF-24 Global Scenarios

Technology Dimension									
	Default	Single technologies changed					Conventional renewable	vs.	Frozen technology
Energy Intensity	Ref	Low	Ref	Ref	Ref	Ref	Ref	Low	Frozen
CCS	On	On	Off	On	On	On	On	Off	Off
Nuclear energy	On	On	On	Off	On	On	On	Off	Frozen
Wind & Solar	Adv	Adv	Adv	Adv	Cons	Adv	Cons	Adv	Frozen
Bioenergy potential	High	High	High	High	High	Low	Low	High	Frozen
Policy Dimension									
Baseline	R2G1	R2G2		R2G3	R2G4	R2G5	R2G6	R2G7	R2G8
450 CO2e	R2G9	R2G10	R2G11	R2G12	R2G13	R2G14	R2G15	R2G16	
550 CO2e	R2G17	R2G18	R2G19	R2G20	R2G21	R2G22	R2G23	R2G24	R2G25
G8	R2G26							R2G27	
Muddling through	R2G28							R2G29	

Brief History of FARM

- Legacy FARM
 - The first version of the Future Agricultural Resources Model (FARM) was constructed in the early 1990s by Roy Darwin and others at the Economic Research Service
 - By partitioning land into land classes, this model provided a unique capability among CGE models to simulate land use on a global scale
 - Early versions of the FARM model were used to simulate the impact of a changed climate or biofuel policies on global land use, agricultural production, and international trade
- New FARM
 - Planning began in 2009 with model construction in 2010
 - Adds a time dimension for analysis of alternative climate policies
 - Tracks energy consumption and greenhouse gas emissions
 - Provides a balance between greenhouse gas mitigation opportunities in agriculture and energy

CGE Framework

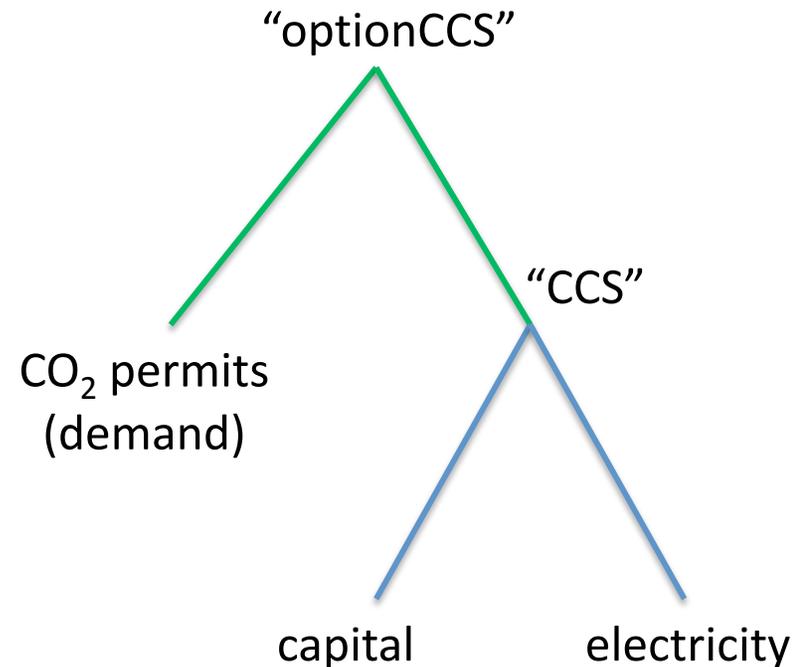
- New FARM uses Tom Rutherford's GTAP in GAMS code as a starting point
 - Comparative-static global CGE model
 - Armington trade between world regions
 - Constant-elasticity-of-substitution (CES) production and utility functions
 - Fully compatible with GTAP 7 social accounts
- Major extensions for new FARM
 - Conversion from comparative-static to dynamic-recursive framework with 10-year time steps
 - Conversion of consumer demand from CES to Linear Expenditure System (LES)
 - Production system allows joint products
 - Introduction of land classes for agricultural and forestry production
 - Introduction of electricity generating technologies

GTAP 7 Data and Aggregation

- Global Trade Analysis Project (GTAP) based at Purdue University provides social accounting matrix (SAM) for year 2004
 - GTAP coverage includes 113 world regions and 57 commodities
 - Data include bilateral trade for all commodities
 - GTAP version 8 will have a 2007 base year
- Aggregation for EMF-24
 - **15 world regions:** usa, japan, westEU, eastEU, othOECD90, russia, othREF, china, india, indonesia, othAsia, midEastNAf, subSahAf, brazil, othLatAmer
 - **25 GTAP production sectors:** 5 energy carriers (coal, oil, natural gas, refined petroleum, electricity); 11 agricultural sectors; forestry; 6 industries; transportation; services
 - **6 electricity generation technologies:** coal, gas/oil, nuclear, hydro, wind/solar, bio-electricity (using IEA data)
 - **New sectors:** biomass, optionCCS, household transportation, household energy services
- GTAP provides other types of data
 - Energy consumption in million tons of oil equivalent (mtoe)
 - Land rents for each region across 18 agro-ecological zones (AEZs) aggregated within each FARM region to 6 land classes
 - Production of forest products

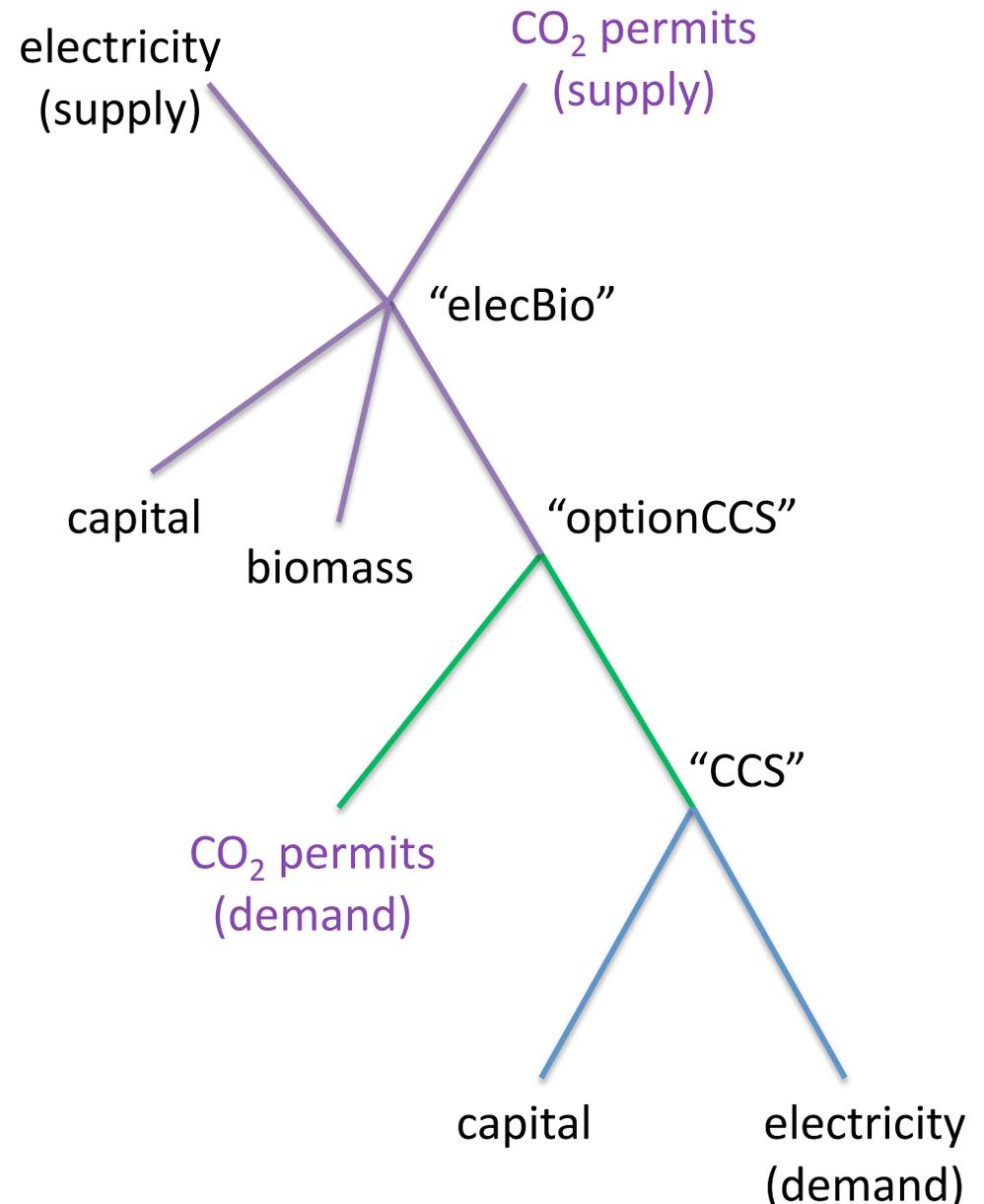
CO₂ Capture and Storage (CCS)

- CCS is a stand-alone production technology that can be used by any large point source of emissions
- Coal- and gas-fired electricity generation must purchase either CO₂ permits or CCS through a CES aggregator “optionCCS”
- “optionCCS” purchases CO₂ permits if the CO₂ price is less than cost per ton of CCS
- CO₂ price must be greater than zero as permits are an input to a CES function (benchmark CO₂ price is \$1 per ton)

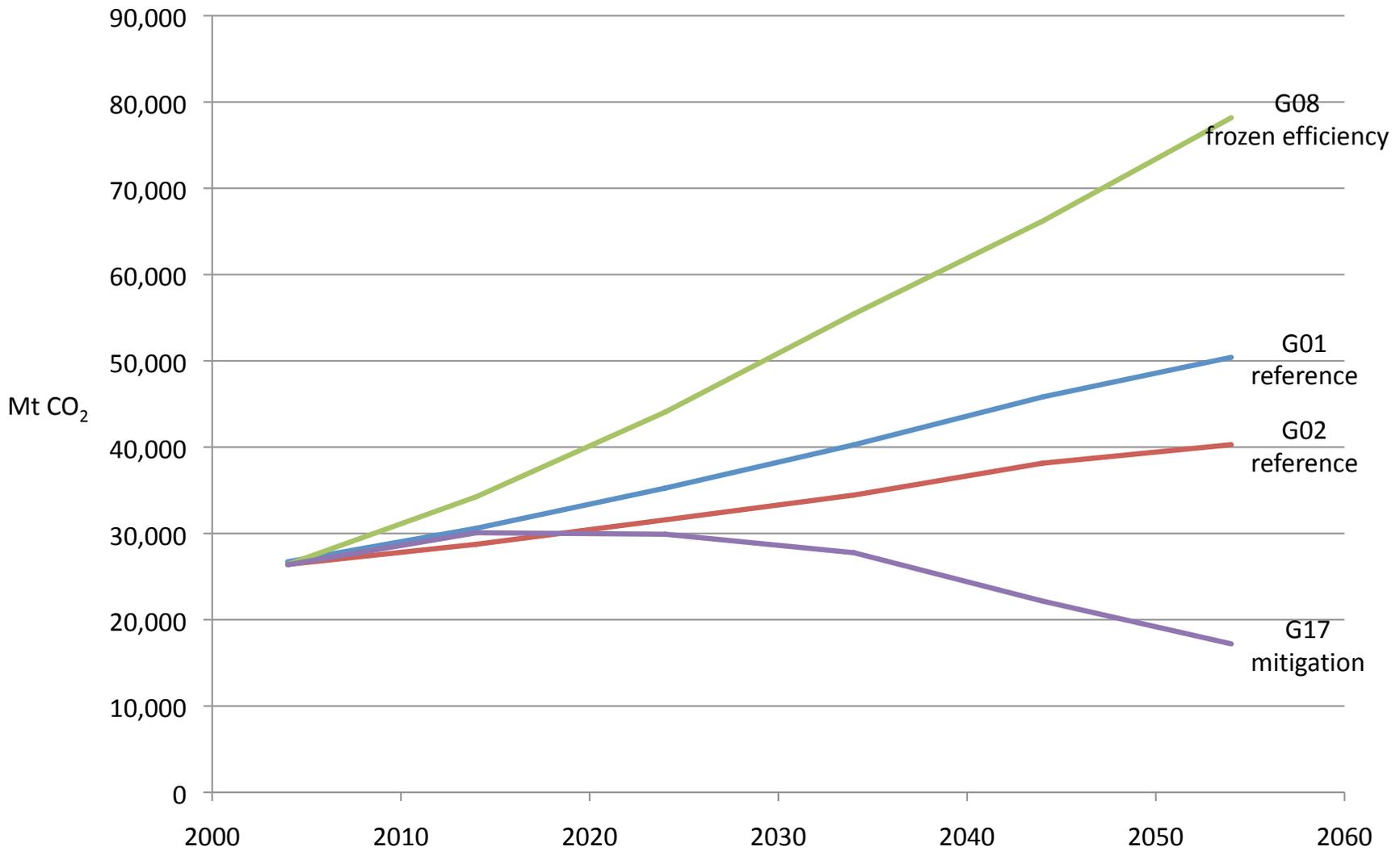


Bio-electricity with CCS

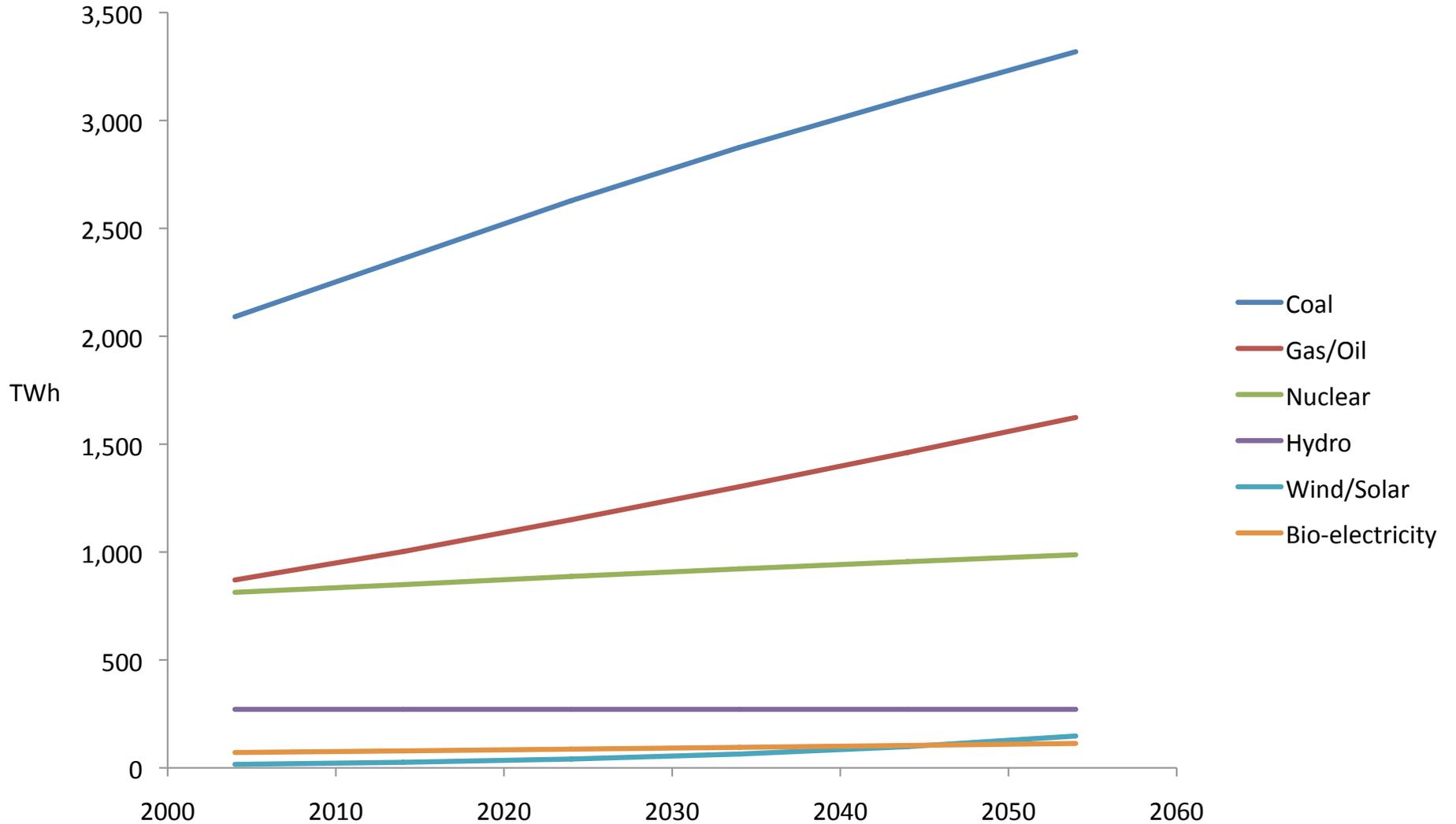
- “elecBio” generates electricity by combusting biomass for a steam turbine
- CO₂ from biomass combustion can be captured and stored if CO₂ price is high enough
- “elecBio” provides two joint products: electricity and CO₂ permits
- At low CO₂ prices, supply of permits equals demand for permits and there is no net sequestration
- At CO₂ prices high enough to drive CCS, supply of permits is greater than demand for permits
- Negative net emissions are possible if quantity of CO₂ sequestered is greater than emissions from related energy demands, such as energy needed to operate capture and storage process



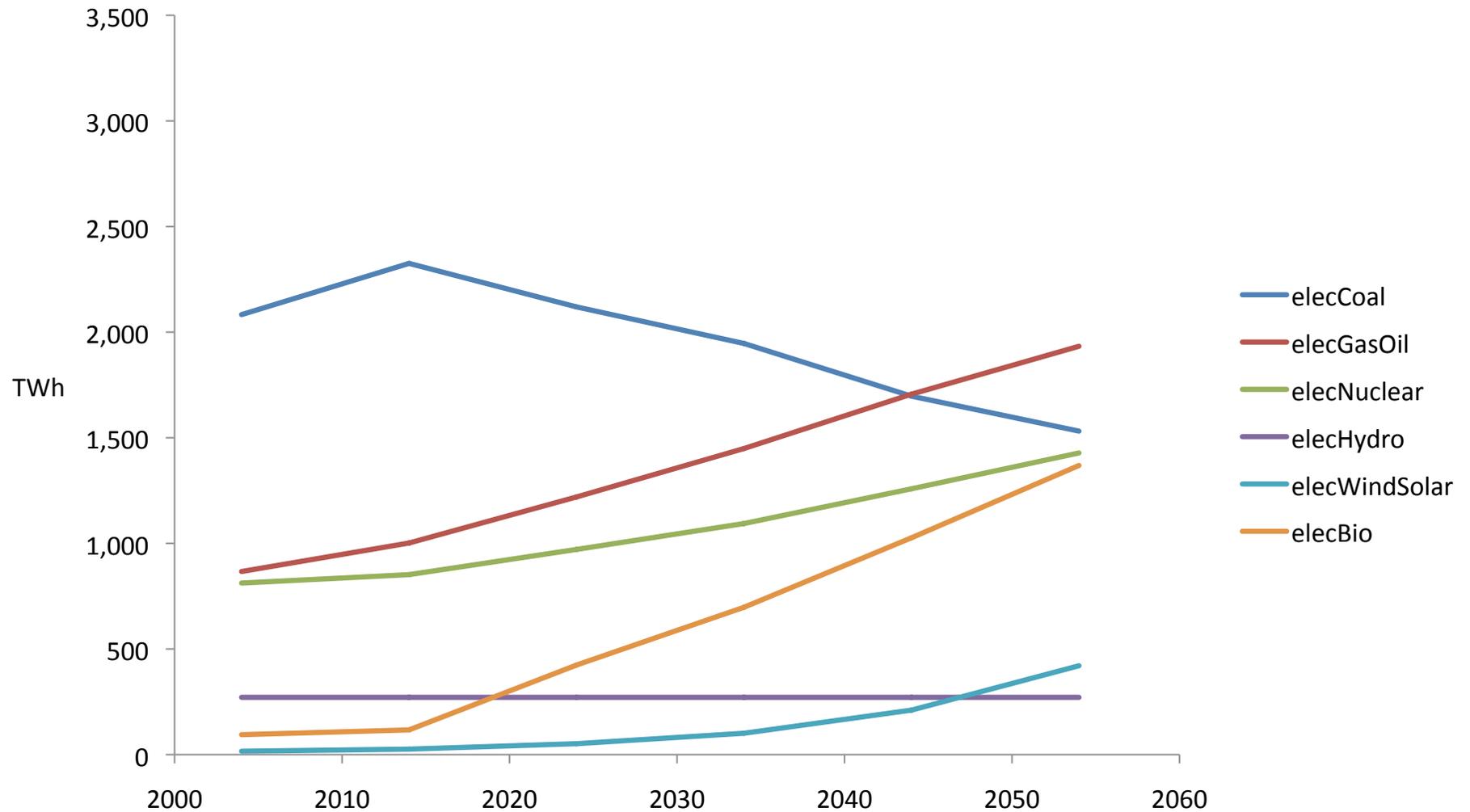
Global CO₂ Emission Scenarios



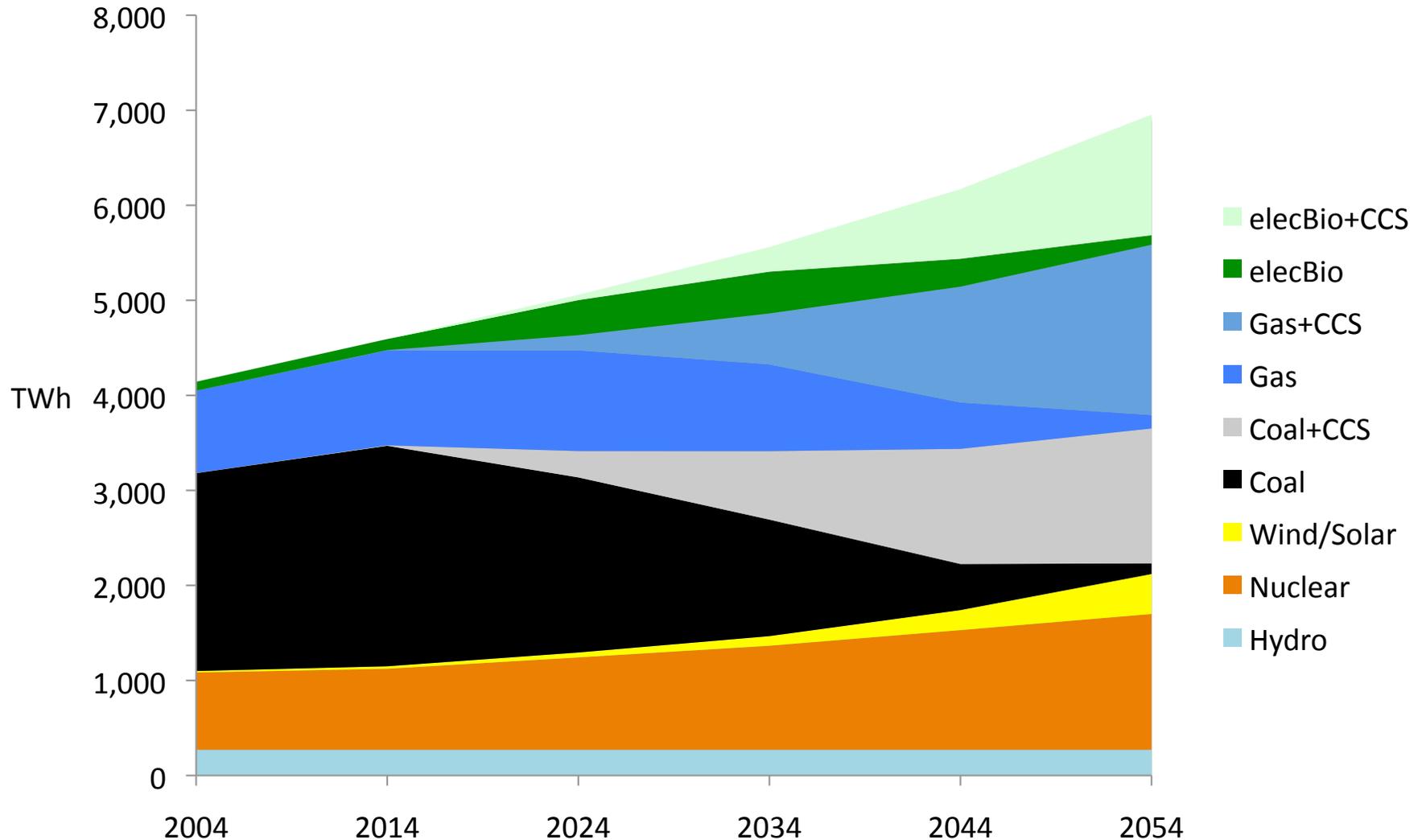
US Electricity Generation (G01 reference)



US Electricity Generation (G17 mitigation, with CCS)



US Electricity Generation (G17 mitigation, with CCS)



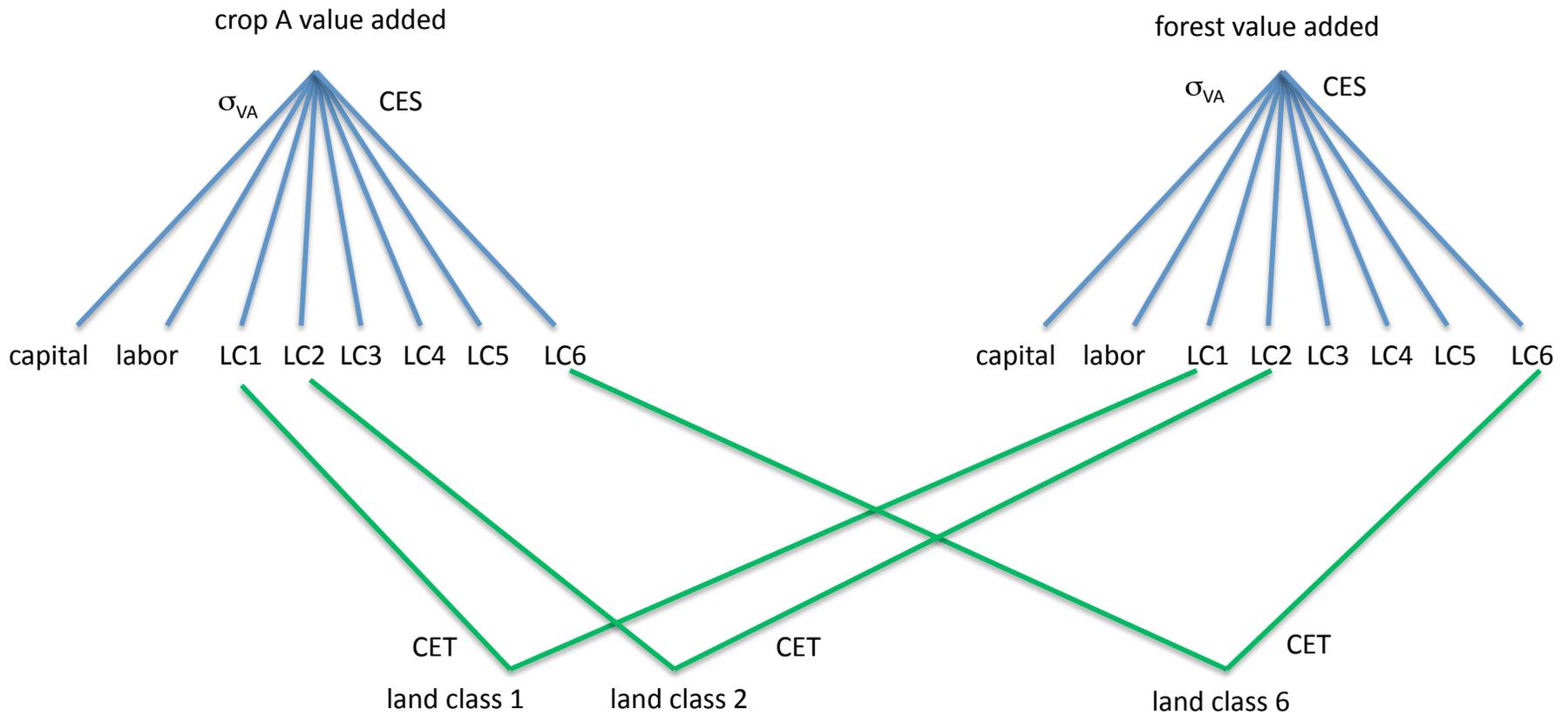
To Do List

- Electricity generation
 - Bio-electricity with CCS
 - Expand nesting structure (to separate generating cost from retail price)
 - Improve data on technology cost
- Non-CO₂ greenhouse gases
 - N₂O from fertilizer
 - N₂O from livestock
 - CH₄ from livestock
 - CH₄ from rice production
- Other biofuel pathways
 - Corn-ethanol
 - Sugar-ethanol
 - Liquid fuels from cellulosic biomass
- Land competition
 - Forest dynamics
 - Carbon emissions from land use change

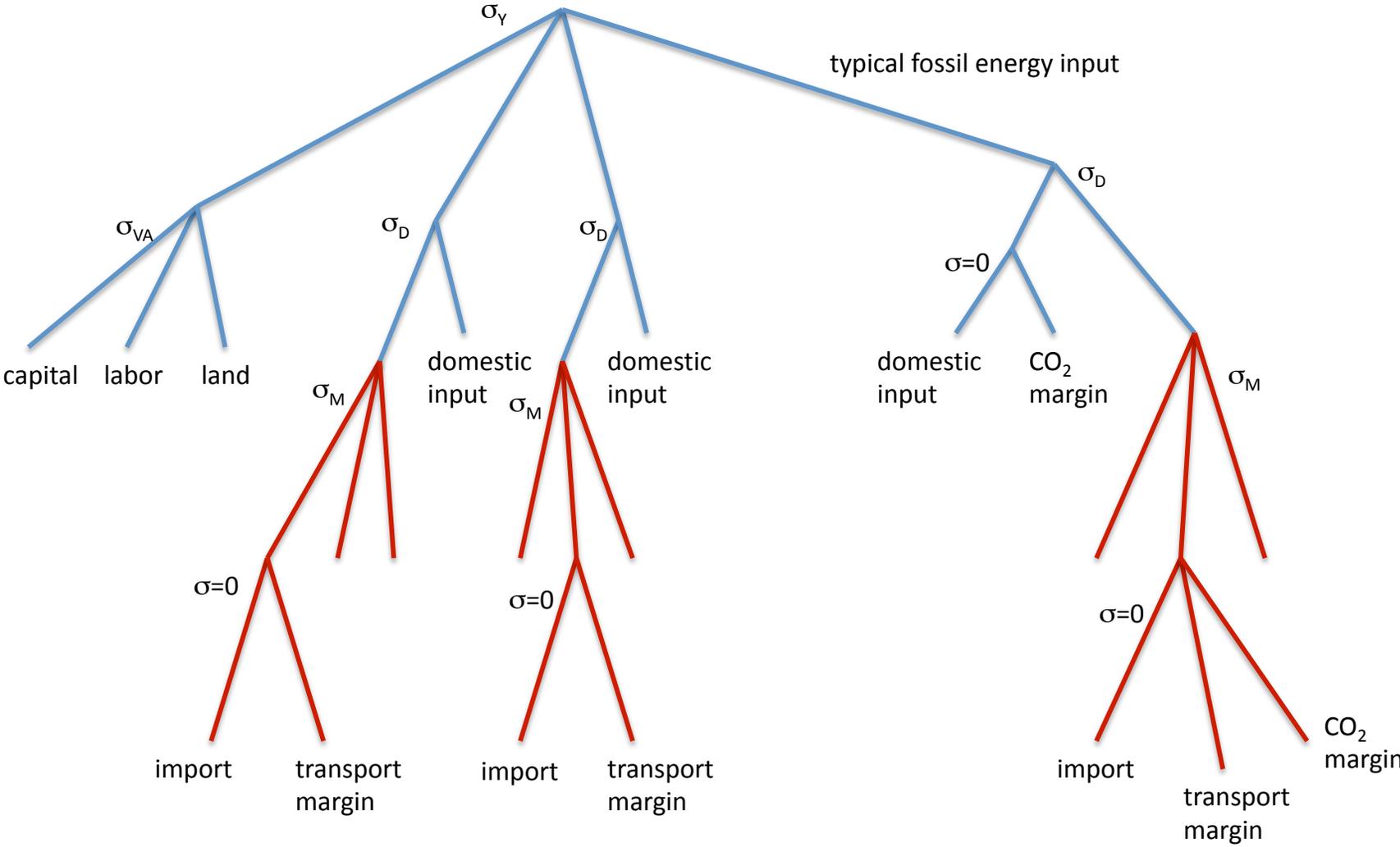
New FARM

EXTRA SLIDES

Land Competition



Nested CES Production



Model Classification

	U.S. only		Global coverage	
	Partial eq.	General eq.	Partial eq.	General eq.
Comparative static	REAP			Legacy FARM, GTAP
Comparative steady-state	<i>REAP (with forestry)</i>			
Dynamic recursive				New FARM
Dynamic with limited foresight			GCAM (with forward market for forest products)	<i>New FARM (with dynamic forestry)</i>
Dynamic optimization	FASOM		Global Timber Model	