United States Department of Agriculture

Large-Scale Carbon Management via Bioenergy with Carbon Capture and Storage (BECCS)

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Summit on Realizing the Circular Carbon Economy:
Charting a Course for Innovations in Agriculture and Energy

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The Findings and Conclusions in This Preliminary Presentation Have Not Been Formally Disseminated by the U.S. Department of Agriculture and Should Not Be Construed to Represent Any Agency Determination or Policy.

Overview

- An economic point of view*
  - Technical potential
  - Economic potential
  - Competitive potential
- Global analysis (Energy Modeling Forum study 33)
- U.S. analysis (Energy Modeling Forum study 32)
- Lessons learned and next steps in modeling

* These concepts are discussed further in McCarl and Sands, “Competitiveness of terrestrial greenhouse gas offsets: are they a bridge to the future?” *Climatic Change* (2007) 80: 109–126

Technical Potential

- A technical appraisal is one that looks at a strategy in isolation, generally without consideration of implementation cost
- Example: U.S. Department of Energy and U.S. Department of Agriculture. 2005. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* ("Billion-Ton Study")

Economic Potential

- A single-strategy economic appraisal is one that adds in the concept of implementation cost but also considers the fact that as one expands, the implementation gets placed in less suitable environments facing higher costs
- Example: U.S. Department of Energy. 2011. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*
- Limitations: The Billion-Ton Update states that “bioenergy markets currently do not exist for the resource potential identified”

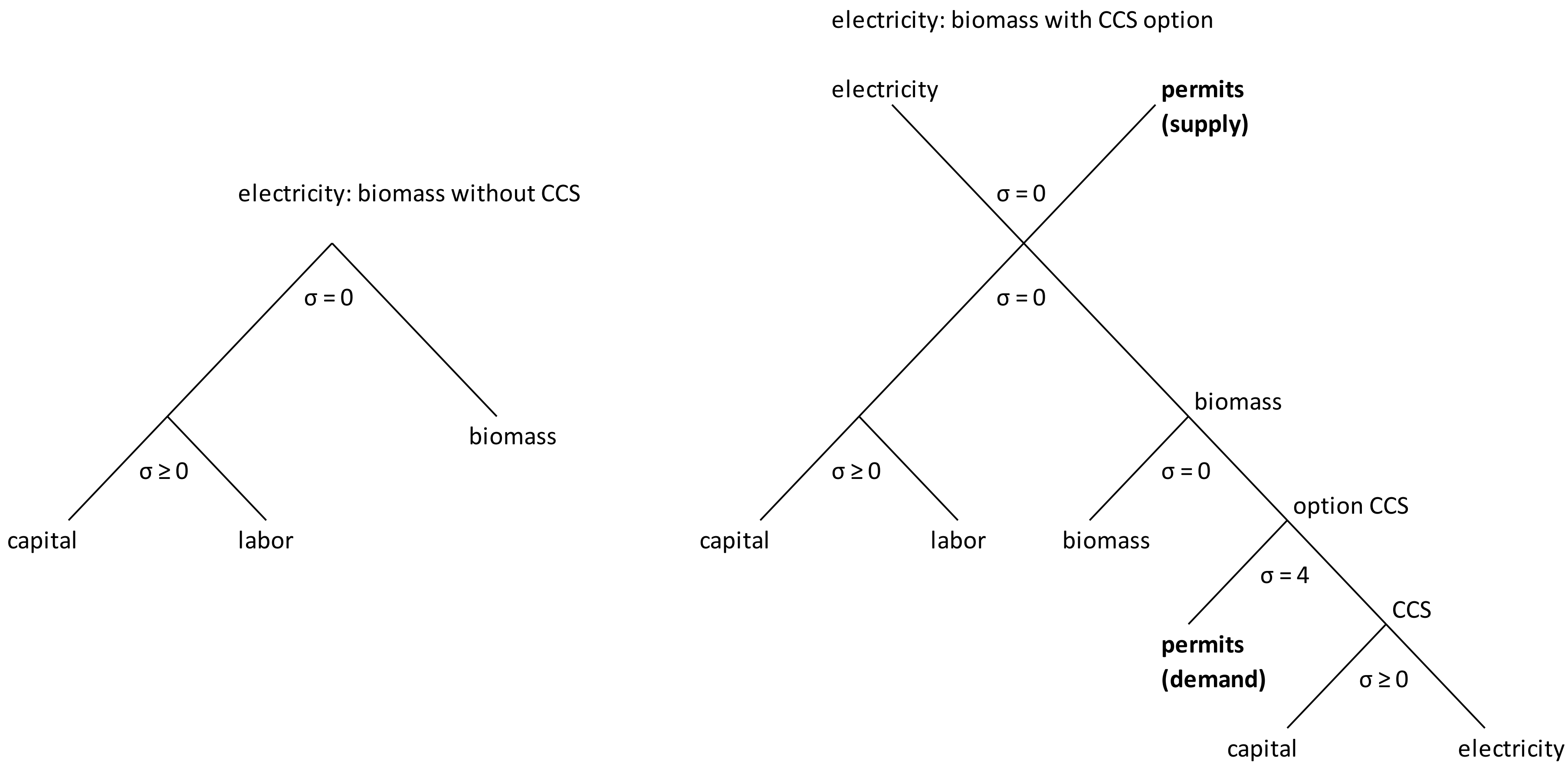
Competitive Potential

- Competitive potential considers multiple strategies simultaneously and examines how particular strategies fare in terms of the total mix of strategies
- Markets important for BECCS
  - Land use and competition for food
  - Electricity (market share for bio-electricity)
- Externalities
  - What is the missing market?
- Example: Bauer *et al*. (2018) "Global energy sector emission reductions and bioenergy use: overview of the bioenergy demand phase of the EMF-33 model comparison," *Climatic Change* (in press)

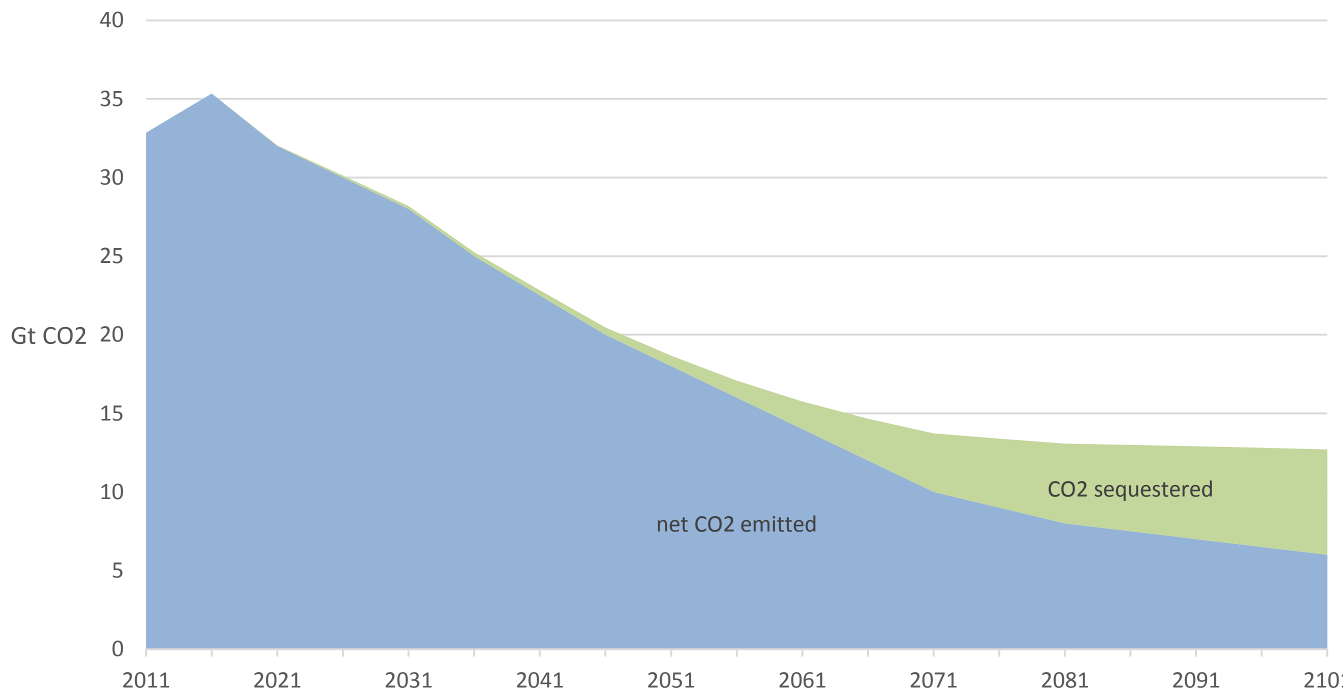
Energy Modeling Forum (EMF-33)

- Biomass supply
  - Global biomass supply targets in 2100 (100 EJ, 200 EJ, 300 EJ, 400 EJ)
  - Land use change (e.g., cropland used for bioenergy)
  - Supply curve for biomass
- Integration of global biomass supply and demand
  - 11 participating modeling teams: USA (2), Japan (4), Europe (5)
  - Constraints on cumulative CO_2 emissions (2011 through 2100) globally
    - High budget (1,600 $GtCO_2$)
    - Low budget (1,000 $GtCO_2$) represents 2.0 degree C ceiling
    - Very low budget (400 $GtCO_2$) represents 1.5 degree C ceiling
  - Allocation of biomass across energy technologies
    - Bio-electricity with and without CCS
    - Cellulosic liquid fuels

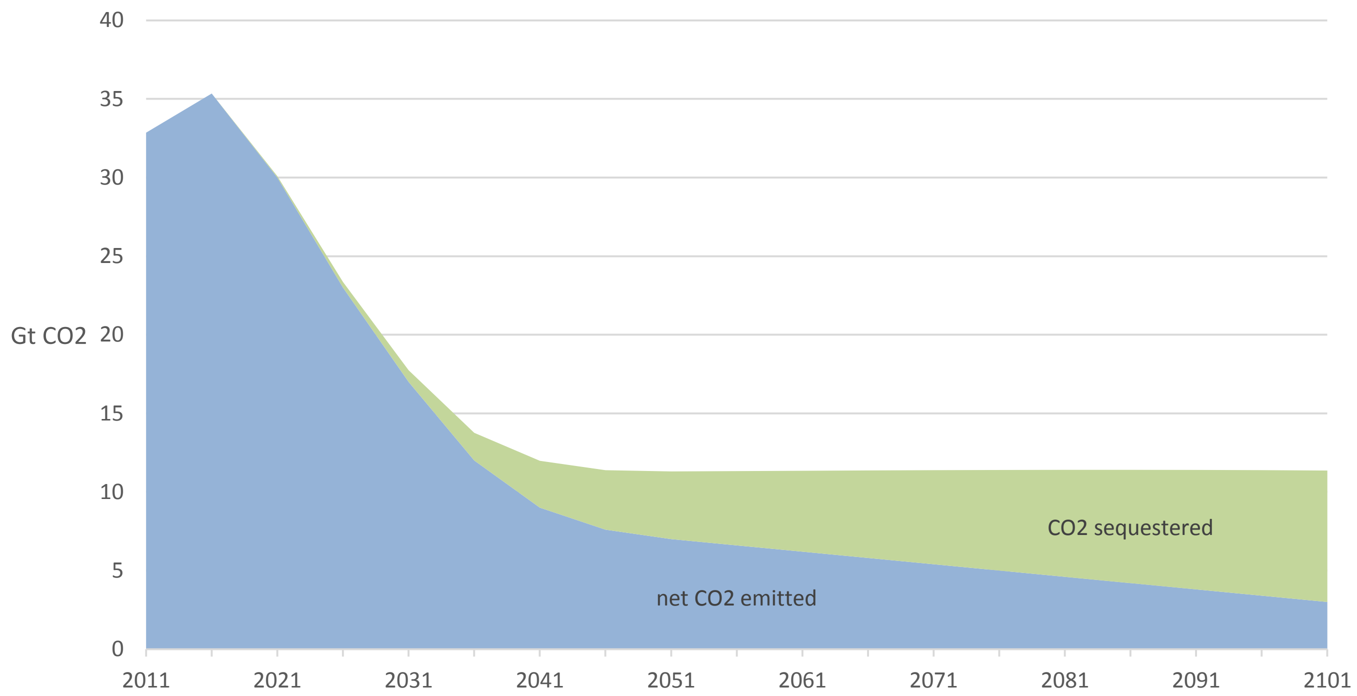
Modeling Bio-electricity



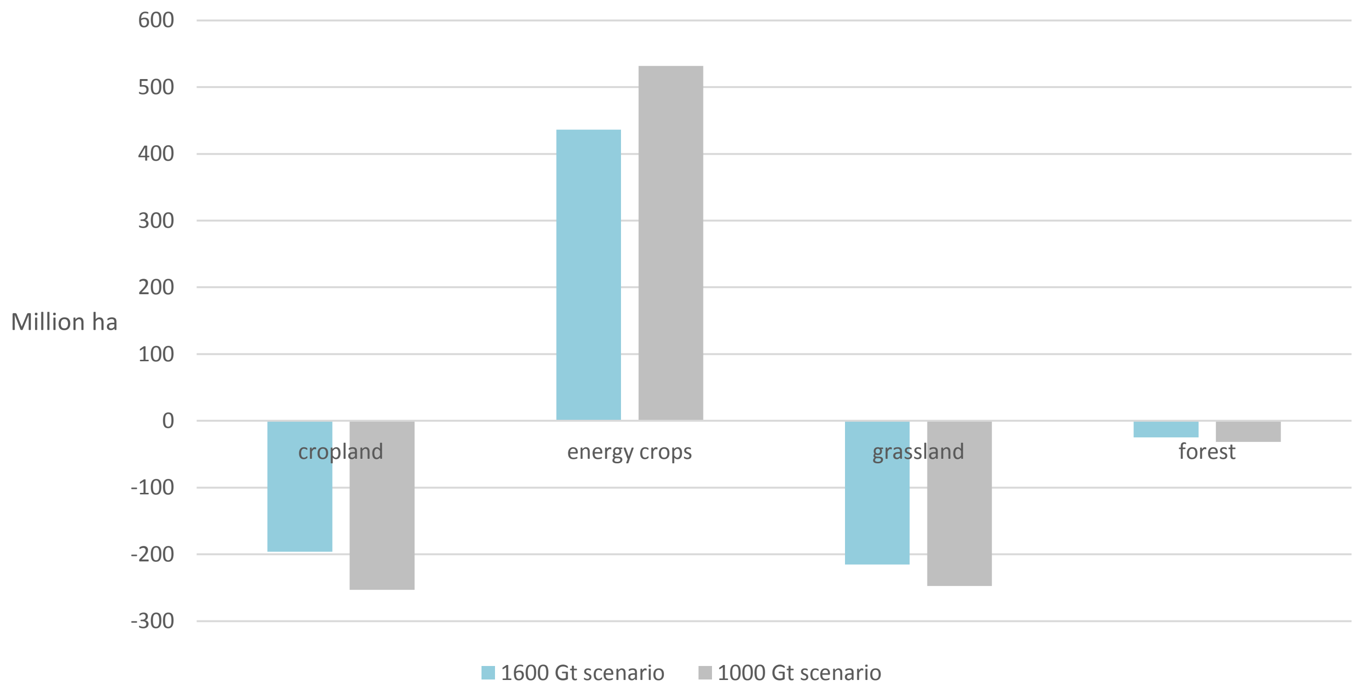
Cumulative global emissions target: 1,600 billion tons CO_2



Cumulative global emissions target: 1,000 billion tons CO_2



Land Use Change in 2100 relative to Reference Scenario



Takeaways from EMF-33 Integration Phase

- Another good example of a Model Intercomparison Project (MIP) organized by the Stanford Energy Modeling Forum, including a wide variety of modeling strategies and “what-if” scenarios
- Wide variation of energy technologies across modeling teams (some use hydrogen as an energy carrier)
- Five models are partial equilibrium; six models are general equilibrium
- Scenarios
  - All 11 modeling teams ran the 1,600 Gt and 1,000 Gt scenarios
  - Six teams ran the 400 Gt scenarios (corresponding to a 1.5 degree C ceiling)
  - Still a challenge to reduce residual CO_2 emissions for many of the modeling teams
- Summary article accepted by *Climatic Change* in time for citation by IPCC Special Report on 1.5 degrees C

The EMF-32 Study on U.S. Carbon Tax Scenarios

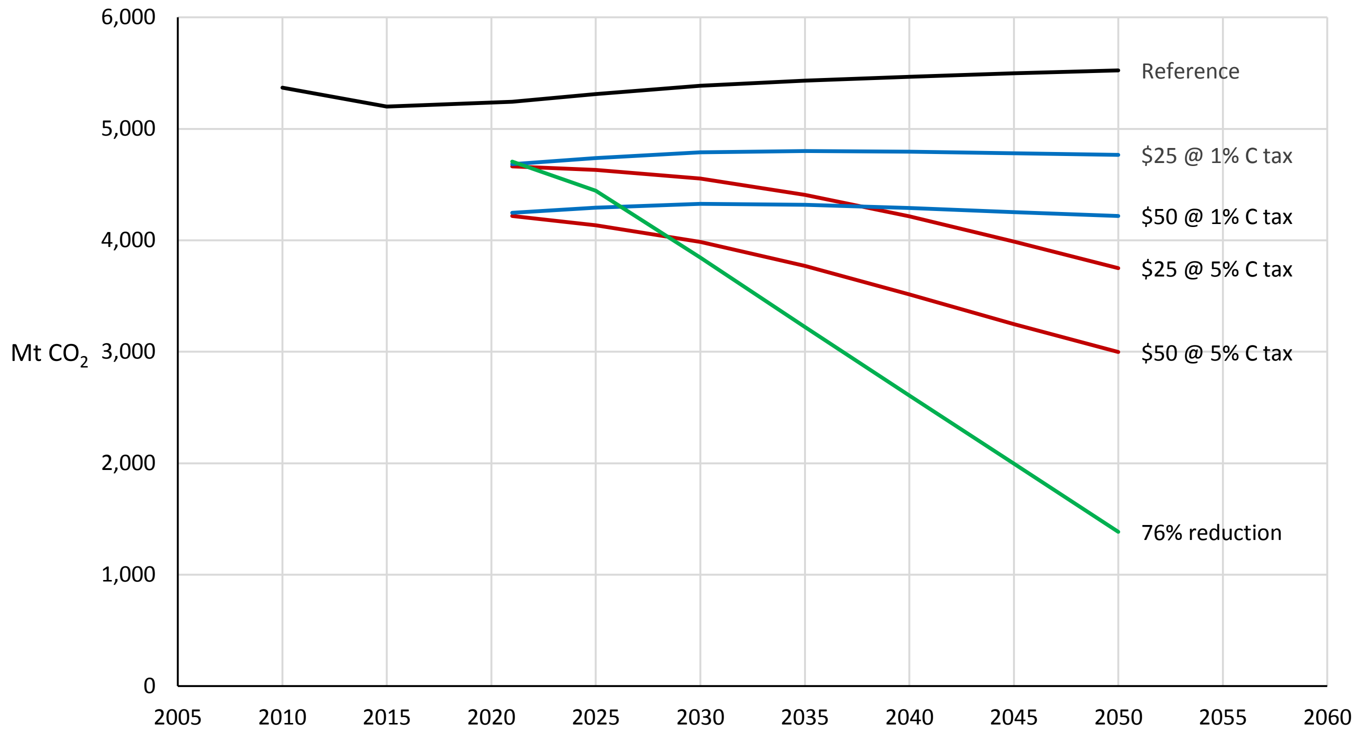
- This study is complete and all papers are open access in the February 2018 issue of *Climate Change Economics*
  - Overview papers (2)
  - Distributional outcomes (1)
  - Impacts on economic sectors (1)
  - Model-specific papers (10), one for each modeling team
- Policy questions
  - How would adoption of an economy-wide U.S. carbon tax affect carbon dioxide emissions and economic outcomes?
  - How would revenue recycling options affect consumer welfare?
- All participating models are computable-general-equilibrium (CGE) to handle welfare effects
- The Future Agricultural Resources Model (FARM) is the only model in this study that includes a negative emissions technology: bio-electricity with CO_2 capture and storage (BECCS)

Selected EMF-32 Scenarios

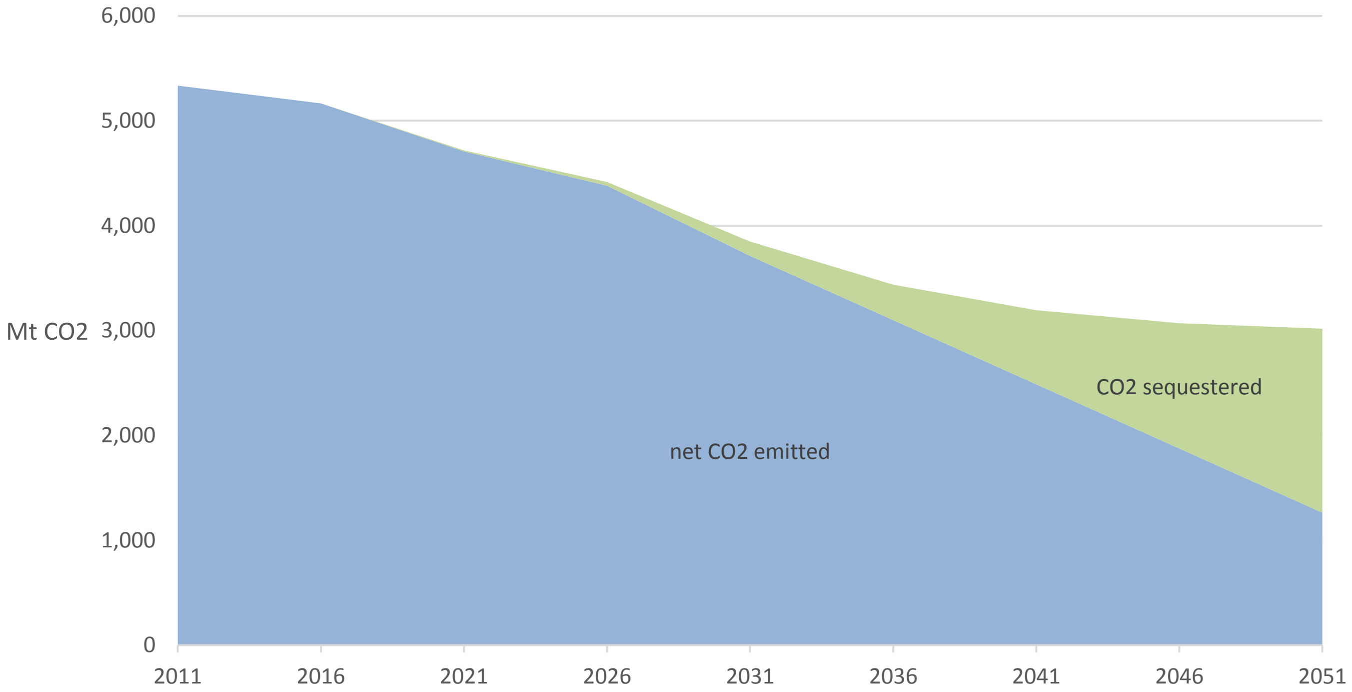
	Scenario description	Carbon tax recycling options
Reference	CO_2 emissions from fossil fuels from 2010 through 2050 without climate policy	
$25 @ 5% C tax	Carbon tax of $25 / t$CO_2$ beginning in 2020, increasing at 5 percent per year	Lump sum, labor, capital
$50 @ 5% C tax	Carbon tax of $50 / t$CO_2$ beginning in 2020, increasing at 5 percent per year	Lump sum, labor, capital
$25 @ 1% C tax	Carbon tax of $25 / t$CO_2$ beginning in 2020, increasing at 1 percent per year	Lump sum, labor, capital
$50 @ 1% C tax	Carbon tax of $50 / t$CO_2$ beginning in 2020, increasing at 1 percent per year	Lump sum, labor, capital
76% reduction (no BECCS)	CO_2 emissions reduced 76 percent from 2005 levels by 2050; CCS is available for fossil fuels but not for bio-electricity	Lump sum
76% reduction with BECCS	CO_2 emissions reduced 76 percent from 2005 levels by 2050; CCS is available for all electricity generation technologies, including bio-electricity	Lump sum

The 76% reduction scenarios are labeled as 80% reduction scenarios in the EMF-32 protocol, with an 80% reduction in net greenhouse gas emissions. Some of the required reductions are offset by a land and forestry sink, so that CO_2 emissions need only be reduced by 76% relative to 2005.

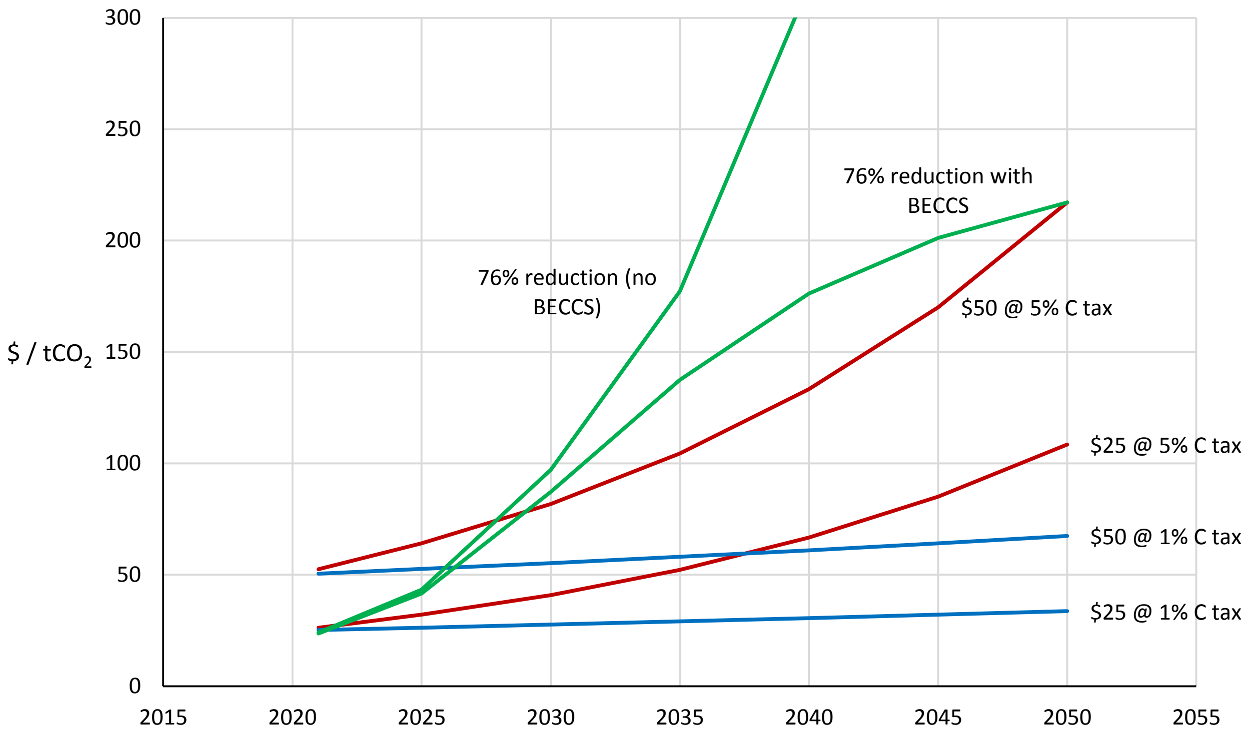
EMF-32 U.S. Emission Targets



U.S. CO_2 emissions target: 76 percent below 2005 emissions by 2050

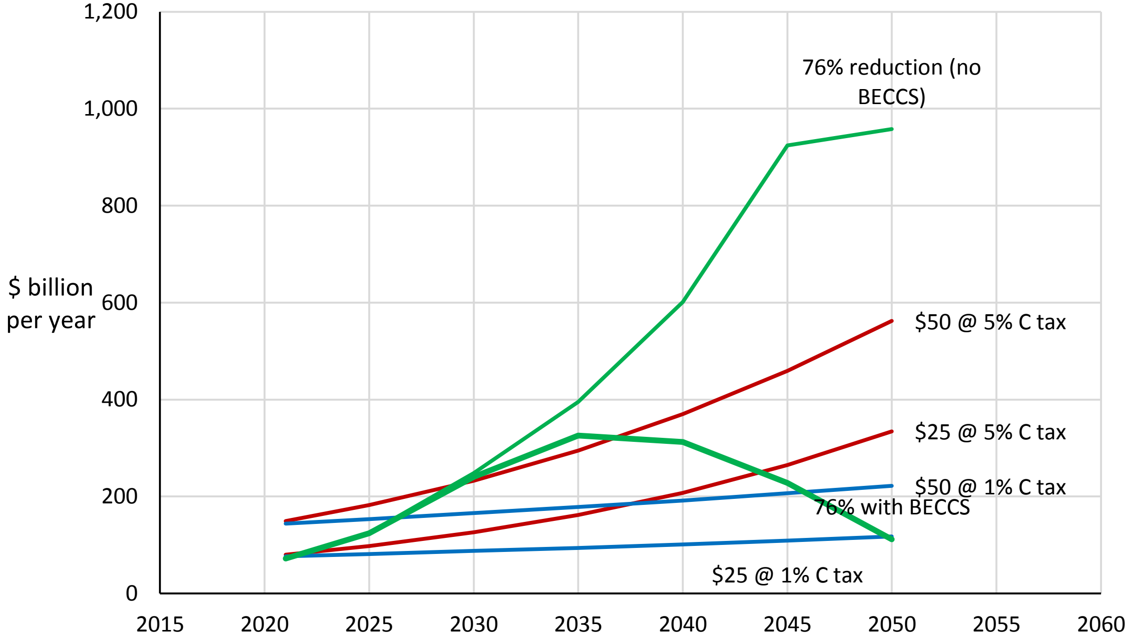


U.S. CO_2 Prices across EMF-32 Scenarios



Cost of meeting stringent emission target is reduced with BECCS

Carbon Tax Revenue: impact of bio-electricity with carbon capture and storage (BECCS)



Revenue declines with BECCS
due to carbon sequestration subsidy

Next Steps in Modeling

- Realism of reference scenario
  - UN population projections have increased since EMF-33 study began
  - Consider alternative reference scenarios based on Shared Socio-economic Pathways (SSPs)
- Agricultural productivity
  - Land competition between energy crops and food crops for a growing population
  - Increasing demand for animal products with rising per-capita incomes
- Realism of electricity generation
  - Highly stylized in most global models
  - Improve representation of bio-electricity relative to wind and solar
  - Introduce electricity storage over day-types and seasons
  - Integration of electricity generation model (of reduced complexity) into global economics