DOE Bioenergy Technologies Office (BETO) 2017 Project Peer Review

GCAM Bioenergy and Land Use Modeling

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Analysis and Sustainability

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Goal Statement

▶ Goal: Assess the potential and impact of multi-sectoral bioenergy demand and production in the integrated context of US and global energy, agriculture, land use, and emissions using the GCAM model.

■ Global Change Assessment Model (GCAM) is a community integrated assessment model developed and maintained by PNNL.

■ Aligns with BETO Analysis and Sustainability MYPP goal: Develop and maintain analytical tools, models, methods, and datasets to advance the understanding of bioenergy and its related impacts.

▶ Outcome: Provide timely, relevant bioenergy analysis and publications while maintaining state-of-the-art modeling of bioenergy in GCAM.

■ Aligns with BETO Analysis and Sustainability MYPP goal: Ensure high-quality, consistent, reproducible, peer-reviewed analysis.

■ In parallel, ensure that bioenergy is considered comprehensively in GCAM analysis used in policy and technology studies as part of efforts for BETO, other DOE, EPA, energy firms, and the international user community.

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Quad Chart Overview

Timeline

► Project start date: Oct. 1, 2015
► Project end date: Sep. 30, 2018
► Percent complete: 50%

Budget

	Total Costs FY 12 –FY 14	FY 15 Costs	FY 16 Costs	Total Planned Funding (FY 17-Project End Date)
DOE Funded	$450K	$150K	$150K	$300K
Project Cost Share (Comp.)*	0	0	0	0

Barriers

► Barriers addressed
  ■ At-A. Comparable, Transparent, and Reproducible Analyses
  ■ At-B. Analytical tools and capabilities for system-level analysis
  ■ St-B. Consistent and Science-Based Message on Bioenergy Sustainability
 ■ St-F. Systems Approach to Bioenergy Sustainability

Partners

- PNNL Joint Global Change Research Institute (JGCRI)
- GCAM Modeling Team
- GCAM Core Model Committee
  - Formal management and peer review of model and data development before incorporation and release in core community model
- International User Community

► The BETO GCAM project is strongly leveraged by the current and the more than two decades of funding by DOE Office of Science, other DOE such as FE, NE, EPSA, and EERE, multiple offices in EPA, and several energy industry sponsors.

- GCAM/PNNL has long participated in international forums and studies such as the IPCC and the Stanford Energy Modeling Forum (EMF).
- Bioenergy is always a key component of our integrated analysis of energy and land use for all of our work for all sponsors.

► With BETO, we specify relevant bioenergy questions for which GCAM can be leveraged and developed to provide modeling and analysis. These are specified annually in the AOP and are updated as needed. Past efforts have included the following.

- Modeling production of bioenergy crops globally
- Integrated economic analysis of biofuels and biopower.
- Incorporation of water demands for bioenergy production.
- Recently, potential and impact of bioenergy for aviation and for freight.

Global Change Assessment Model 4.3

32 Energy Economy Regions

283 Land Regions
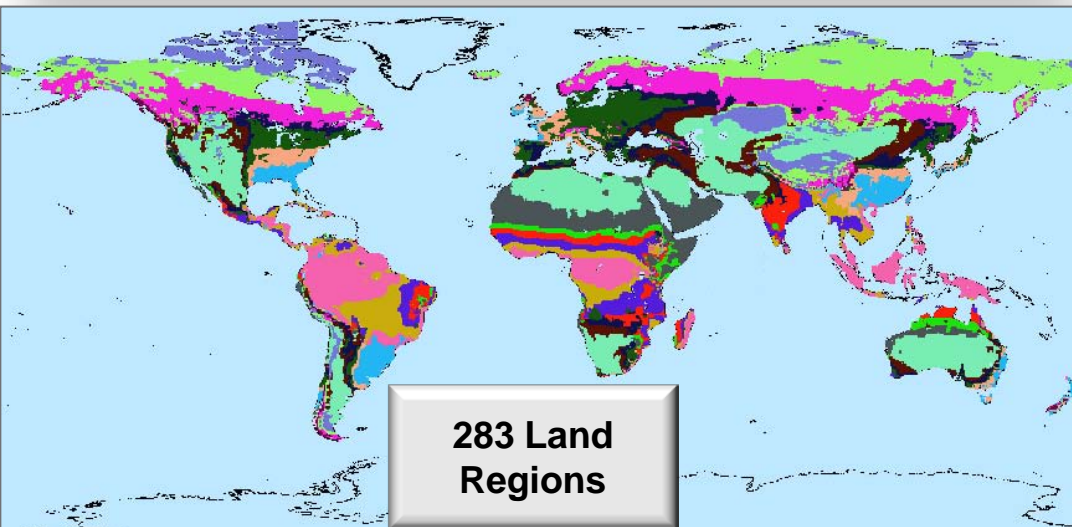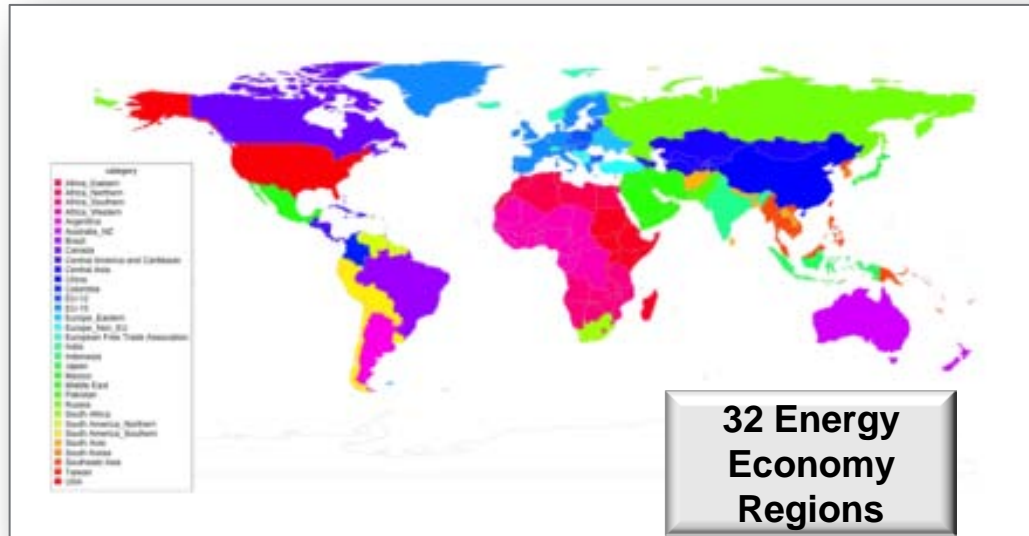
► GCAM is a community, long-term (2100) Integrated Assessment Model economically linking global Energy, Technology, Agriculture, Land-use, Emissions, and Climate.

► Bioenergy Crops, Ag. and Forestry Residues, Wastes, and 1st-gen sources.

► Bioenergy to liquid, power, gas, H2, and used directly in industry and buildings.

► **Download and documentation at http://jgcri.github.io/gcam -doc/index.html**

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2 – Approach (Management)

- ▶ Marshall Wise (PNNL) serves as PI and PM and is responsible for leading the research and analysis project and for ensuring that the project is executed to the statement of work and within budget.
  - ■ PNNL staff and post-doctoral researchers have collaborated on specific areas on this project when helpful and cost-effective.
  - ■ Because of GCAM leveraging, plans must be done in close collaboration with other non-BETO GCAM projects to ensure goals are achievable.

- ▶ All model and data development must be vetted and documented through a formal review process with PNNL GCAM Core Model Management Committee to become part of GCAM.

- ▶ All efforts are clearly defined in agreement with BETO in annual proposals and statements of work with formal monitoring.
  - ■ Quarterly Milestones are defined in the AOP with written reports or briefs delivered at the end of each quarter.
  - ■ Formal quarterly progress reports with financial updates and project progress updates are delivered to BETO.

▶ Identify bioenergy analysis and sustainability questions for which GCAM can be developed to provide complementary insights to other BETO life cycle, technology, and systems tools and analyses.

■ Leverage the broader program of GCAM development while identifying clearly-delineated, specific analysis areas for BETO.

■ Maintain a balance between detail and complexity in representing bioenergy technologies and systems within this larger model.

■ Capture the key elements and system interactions (rather than duplicate detail best suited to a more specifically focused model).

▶ Incorporate these model developments into published GCAM analyses and make them accessible to community model users and consumers in the industry, research and policy communities.

3 – Technical Accomplishments/ Progress/Results

▶ We have consistently published papers on bioenergy and its key role in the integrated assessment of global energy and agriculture.

- GCAM used in the integrated modeling of bioenergy and land use in the administration's MidCentury Strategy for reducing long-term GHG emissions, with bioenergy resources coordinated with the DOE Billion Ton Study.
- In FY 14, published paper funded by BETO looking at potential impact of expanded global biofuels use on energy, agriculture, and emissions.
- Currently In peer review, paper on global potential and role of biojet fuels.

▶ Since last peer review, we focused analysis for BETO back to the energy sector.

- Analyzed potential scale and context for biofuels for aviation to reduce reliance on fossil fuels and reductions in GHG emissions.
- Analyzed potential role and scale and for biofuels to provide energy for a growing demand for on-road freight transportation.

▶ Go/No-Go milestone met Dec. 31, 2016: Demonstrate success and relevance with at least three prominent analysis efforts or published papers where bioenergy analysis with GCAM was central.

▶ Modeling Global Bioenergy Potential: Food Crop Yields are Key

■ While the yields of bioenergy crops are important, the potentials for yield increases in food crops globally, along with the ease of global crop trade, have significant impacts on the competition of land for bioenergy production and its impact on food prices, emissions, and water.

▶ Integrated, Global Modeling of Bioenergy Production and Impacts

■ Measuring the impact of bioenergy on land use change and emissions is strongly dependent on assumptions about global agriculture and forestry land use policy (whether from explicit restrictions or implicit assumptions).

▶ Integrated Analysis of the Multi-Sector Potential of Bioenergy

■ For example, in scenarios or applications where electrification may be limited or costly, such as with heavy duty freight, biofuels are a competitive economic choice or reducing fossil fuel use.

■ But when electrification is viable, biopower remains an option for reducing fossil fuel use. And if carbon emissions mitigation is a goal, biopower with carbon capture and storage (CCS) becomes even more competitive.

3 – Modeling and Analysis of Biofuels for Aviation

▶ Paper in review by Wise, Matteo Muratori (now at NREL) and Page Kyle (PNNL) using GCAM to explore potential and impact of biofuels.

▶ Case for biofuels in aviation: Aviation energy consumption and GHG emissions are a small fraction relative to the global energy system (e.g, 2% of GHG emissions).

▶ However, aviation sector is highly dependent on liquid fuels (predominantly fossil), and demand in this sector is expected to grow as incomes increase around the world.

▶ Regardless of the small relative contribution or regulatory environment, industry groups are interested in reducing fossil fuel dependence and GHG impact of aviation.
  - Develop options ahead of any regulations.
  - Perception issue of jet travel as a high carbon footprint luxury.

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Based on GCAM assumptions of growing population and income, aviation demand grows globally by over a factor of three to 2050.
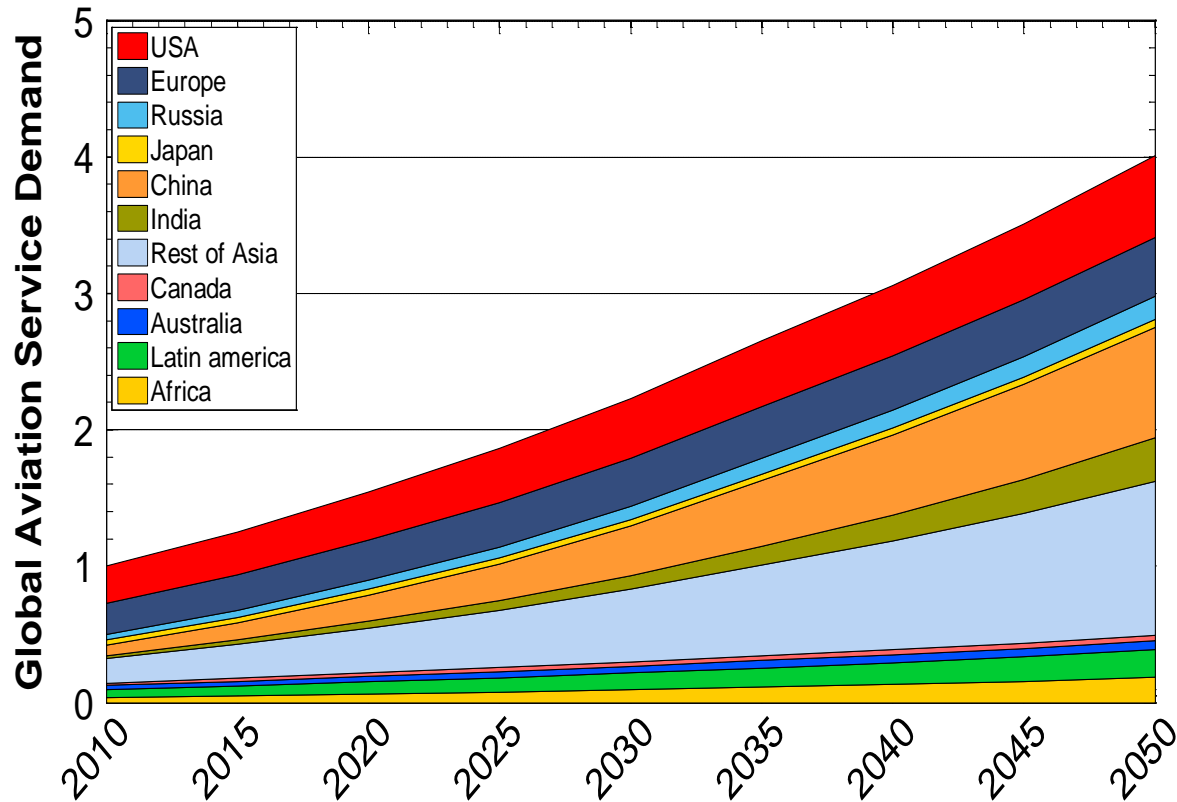
Figure: Index of Global Aviation passenger-km growth.

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For this study, several representative bio jet fuel pathways were parameterized in GCAM, along with links to respective feedstock supplies from the energy and ag/forestry sectors.

COMPETING TECHNOLOGIES

- Petroleum-based
- FT biofuels
- HEFA
- Ethanol-to-jet

JET FUEL

AIR TRANSPORT DEMANDS

Domestic Aviation

International Aviation
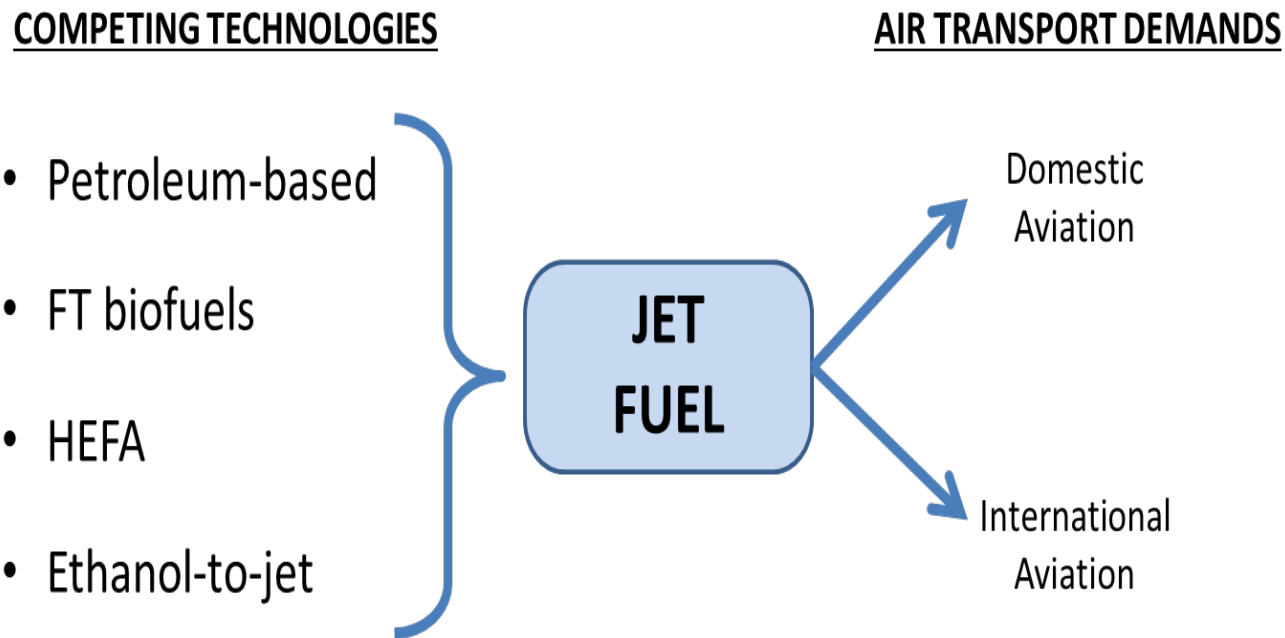
Figure: GCAM Jet fuel production pathways modeled for this paper.

3 – Modeling and Analysis of Biofuels for Aviation

Reference Biojet: biofuels sufficiently competitive to gain some market share.

Without Biojet: aviation response to GHG mitigation target is limited.

With Biojet: aviation response to GHG mitigation target includes expansion of biofuels, some with Carbon Capture and Storage (CCS).

Figure: GCAM Global Jet fuel demand under a Reference vs a global all energy sector Mitigation policy (GHG 50% below 2010 by 2050)

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- ► Provides a long-term economic, multi-sector, policy, and international context for bioenergy considering energy, agriculture, and emissions.

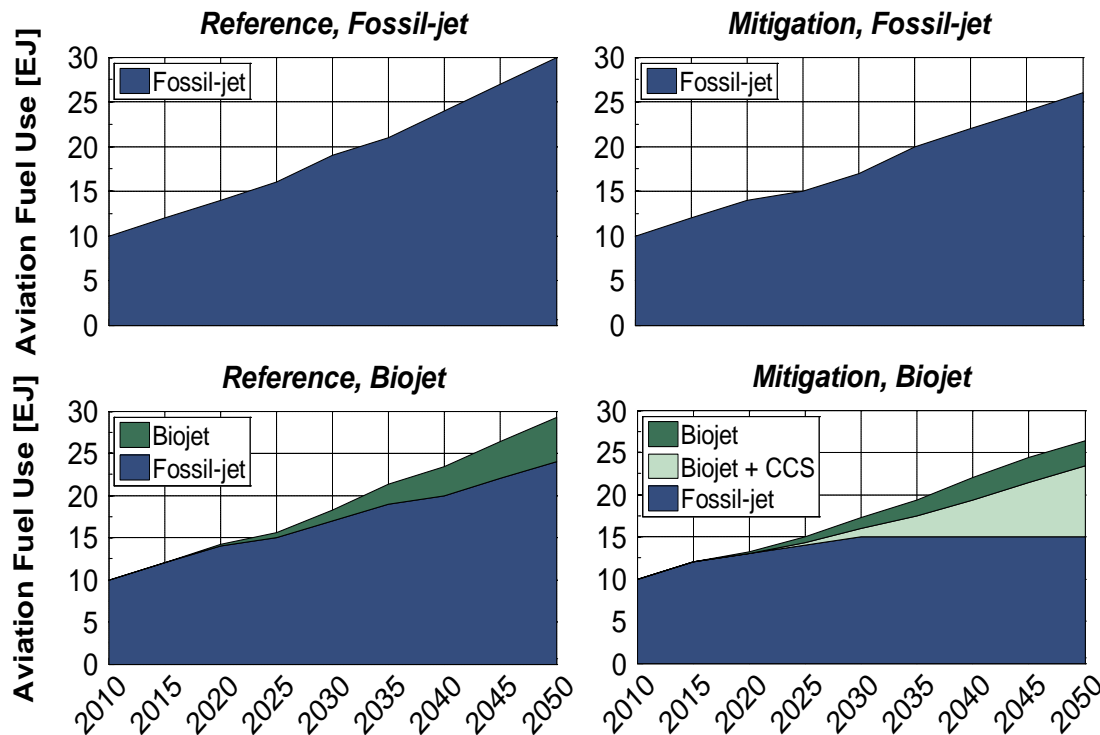 - ■ Complements LCA, techno-economic, and systems analyses by providing potential bioenergy scale and dynamics of drivers outside their scope.
  - ■ GCAM is also a consumer of insights and parameters from these more sector-and technology-focused modeling efforts.

- ► Supports MYPP Barrier St-B by providing industry and policymakers with science-based, objective, quantitative analyses of sustainability issues including emissions, food prices, and water demand.

- ► GCAM is open source and distributed as a community model.
  - ■ MYPP Barrier At-A: Comparable, Transparent, and Reproducible Analyses.

- ► Supports MYPP goals by conveying the results of analytical activities to a wide audience: including our industry partners, DOE Office of Science, EPA, the Administration, other researchers, and the public.

5 – Future Work

- ▶ FY 17 Scope: Analyze integrated, multi-sector potential, scale, and impact of bioenergy.
  - ■ Consider jointly bioenergy for power, gas, and for liquid fuels for passenger and freight transportation.
  - ■ Explore impact of other non-fossil energy options in each sector on bioenergy.
  - ■ Consider complementary relationships of bioenergy across sectors.

- ▶ Milestones include defining with BETO key framing questions, parameterization of bioenergy technologies and pathways, generation of scenarios, and writing final paper.

- ▶ FY 18 Project: Bioenergy and carbon capture utilization and storage.
  - ■ Aligning with a key sub-strategy in BETO 2016 Strategic Plan.

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1. Overview - Integrated analysis of bioenergy sources and technologies in a global modeling framework.

2. Approach – Define key bioenergy analysis and sustainability questions to guide analysis and model development efforts.

3. Technical Accomplishments/Progress/Results - Published papers of integrated analysis of bioenergy.

4. Relevance – Complements other tools and supports research in several areas of the BETO multi-year program plan.

5. Future work –Analysis of integrated, multi-sector potential, scale, and impact of bioenergy.

▶ Since 2015, paper (in review) of new study on the potential scale and impact of biojet fuels for a growing US and global demand for aviation.

Additional Slides

Responses to Previous Reviewers' Comments

▶ The project has jumped around in focus from year to year.

- ■ This is a fair criticism. The goal each year has been to be opportunistic in defining specific bioenergy questions that are relevant to BETO and the bioenergy industry that can be addressed with GCAM. The scope of possibilities is quite large as bioenergy involves so many broad areas covering energy, land, agriculture, and water. In general, we believe that we have advanced the over-all understanding of these issues.

- ■ As part of the BETO merit review process, projects are now planned in 3-year phases. For the last couple of years, we developed different sectors with an eye towards this year's multisector integrated bioenergy analysis.

▶ A second concern: GCAM is unusually comprehensive in scope – but it can be so complex that they are "black boxes" difficult to master beyond the small group who have climbed a steep learning curve.

- ■ Using the model is not easy. But, we have now had about 5 years of success through community distribution and annual meetings. Outside researchers have had success in developing and using GCAM for their own research. Some studies, like the paper by Gao Ji et al (2016) were done through collaboration but others such as Walsh et al (2016) were done independently (citations on next slides).

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Go/No Go Milestone Summary

Name	Description	Criteria	Due Date
Ensure that GCAM modeling and analysis of bioenergy remains relevant to BETO and the broader community	Assess success of the BETO project in supporting a comprehensive analysis of bioenergy as a key component in GCAM activities for the policy and scientific communities while addressing BETO questions and goals.	At least three prominent activities, analysis efforts, or publications using GCAM where the role of bioenergy is a key component.	12/31/2016

► Walsh, MJ, LG Van Doren, DL Sills, I Archibald, CM Beal, XG Lei, ME Huntley, Z Johnson and CH Greene (2016). "Algal food and fuel coproduction can mitigate greenhouse gas emissions while improving land and water-use efficiency." *Environmental Research Letters, Volume 11, Number 11.* October, 2016.

  ■ Not a PNNL paper but shows success of GCAM community model.

► Calvin, K., M. Wise, P. Luckow, P. Kyle, L. Clarke and J. Edmonds (2016). "Implications of uncertain future fossil energy resources on bioenergy use and terrestrial carbon emissions." *Climatic Change* 136(1): 57-68.

► Muratori, M., K. Calvin, M. Wise, P. Kyle and J. Edmonds (2016). "Global economic consequences of deploying bioenergy with carbon capture and storage (BECCS)." *Environmental Research Letters* 11(9): 095004.

► J. Gao, A. Zhang, S.K. Lam, X. Zhang, A. Thomson, E. Lin, K. Jiang, L. Clarke, L. Edmonds, G.P. Kyle, S. Yu , Y. Zhou, and S. Zhou (2016). "An integrated assessment of the potential of agricultural and forestry residues for energy production in China." *GCB Bioenergy (2016) 8*, pp. 880–893.

► GCAM used in Administration's MidCentury Strategy for reducing GHG emissions, and in Stanford Energy Modeling Forum 33 on Bioenergy.

Publications, Patents, Presentations, Awards, and Commercialization

► Wise, M.A., J.J. Dooley, P. Luckow, K. Calvin, and P. Kyle. 2014. Agriculture, land use, energy and carbon emission impacts of global biofuel mandates to mid-century. *Applied Energy*. doi: 10.1016/j.apenergy.2013.08.042.

► Edmonds, James, Patrick Luckow, Katherine Calvin, Marshall Wise, Jim Dooley, Page Kyle, Son H. Kim, Pralit Patel, Leon Clarke. 2013. "Can radiative forcing be limited to 2.6 Wm−2 without negative emissions from bioenergy and CO_2 capture and storage?" *Climatic Change*. Special Issue on "Carbon Dioxide Removal from the Atmosphere: Complementary Insights from Science and Modeling". doi:10.1007/s10584-012-0678-z.

► Luckow, Patrick, Marshall Wise, James Dooley, Son Kim. 2010. "Large Scale Utilization of Biomass Energy and Carbon Dioxide Capture and Storage in the Transport and Electricity Sectors under Stringent CO_2 Concentration Limit Scenarios." *The International Journal of Greenhouse Gas Control.* 4 (2010) pp 865-877.

GCAM Model Structure Schematic

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ENERGY SYSTEM

Resource Bases

Energy Conversion Technologies

Energy Demand Technologies

Energy Supply
- ► Coal, Gas, Oil
- ► Renewables
- ► Electricity
- ► Hydrogen

Energy Demand
- ► Transportation
- ► Buildings
- ► Industry

Energy Markets
- ► Fossil fuel prices
- ► Electricity prices
- ► Hydrogen prices
- ► Bioenergy prices

Fossil and Industrial Emissions

ECONOMY

Labor Force

Labor Productivity

Regional GDP

Other Markets
- ► Emissions Permits
- ► Portfolio Standards

CLIMATE SYSTEM

Carbon Cycle

Atmosphere

Ocean

Land

Concentration, forcing calculations

Other things (aerosols, sea level, …)

AGRICULTURE AND LAND USE

Agricultural Technologies

Land Characteristics

Agricultural Demand
- ► Crops
- ► Livestock
- ► Forest Products

Agricultural Supply
- ► Crops
- ► Livestock
- ► Forest Products
- ► Bioenergy

Agricultural Markets
- ► Crops prices
- ► Livestock prices
- ► Forest Product prices
- ► Bioenergy prices

Land Use and Land Use Change Emissions

Land Use & Land Cover