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GCAM Bioenergy and Land Use Modeling

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Data, Modeling, and Analysis

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U.S. DEPARTMENT OF ENERGY BATTELLE

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Project Overview: GCAM Modeling of Bioenergy in a Multisector Economic Context

- Overarching goal of the GCAM project is to provide analysis of bioenergy production and use as part of the larger context of domestic and global energy, land use, and carbon management.
  - Quantitative, reproducible analysis with technological detail and multisector economic feedbacks.
- Most of the analysis involves developing the representation of bioenergy production, conversion, and use in the PNNL Global Change Analysis Model (GCAM).

- Role within BETO: Provide complementary insights to more detailed BETO life cycle, techno-economic, technology, and systems tools by ***addressing questions about the long-term market scale, roles, and impacts of bioenergy***.

1 – Management

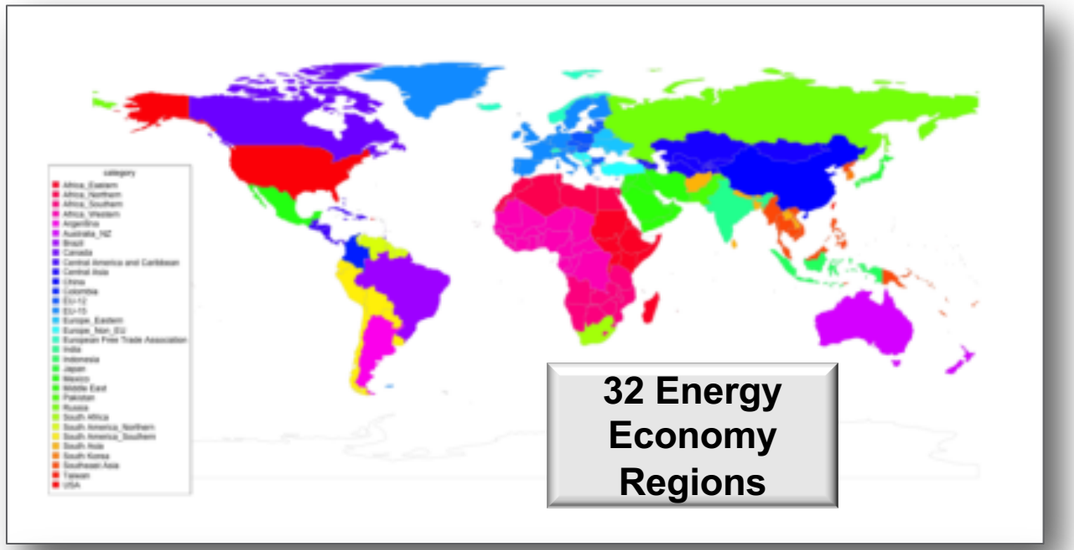
- Marshall Wise serves as PI/PM responsible for research and ensuring that the project is executed to the statement of work.
  - Post-docs and research associates assist the research, modeling, and writing.
- BETO project draws from and contributes to developments of the multi-client, multi-year GCAM program.
- The BETO GCAM project leverages several years of federal (DOE Science, FE, NE, EERE, as well as EPA) and industry-sponsored funding.
  - To mitigate risks from leveraging the GCAM program, BETO project plans must be done in close collaboration with the GCAM team to ensure goals are achievable.
  - To ensure quality, 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.
  - To distinguish the BETO project from parallel GCAM efforts, all tasks are clearly defined in agreement with BETO in annual proposals and statements of work with formal monitoring.

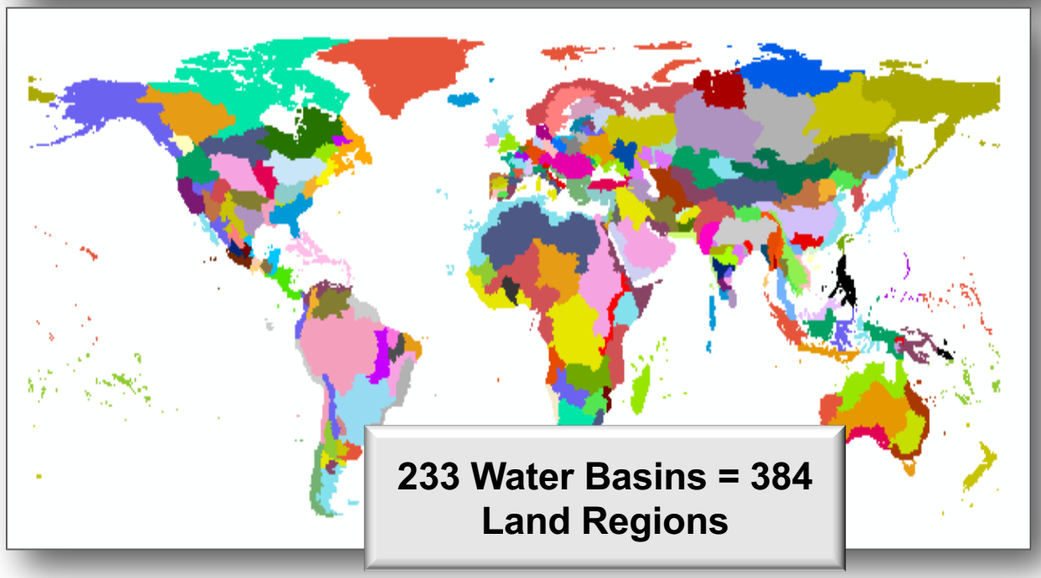
1 – Management – GCAM is a Community Model

- GCAM is an open source and open data community model.
- GCAM has an international user base and has been downloaded thousands of times.
- GCAM has been used extensively by PNNL and collaborators in several countries such as India, Canada, China, Spain, Pakistan, and Colombia.

- 2019 PNNL GCAM annual meeting for sponsors, collaborators, and users with research updates and hands-on training had 150 attendees from 13 countries.
  - http://www.globalchange.umd.edu/annual-meetings/2019-gcam-community-modeling-meeting/

GCAM 5.3 (PNNL Global Change Analysis Model)





- Economically and physically links long-term (to year 2100) Energy, Agriculture, Land, Water, and Emissions.
- Bioenergy Crops, Ag. and Forestry Residues, Wastes, and 1st-gen sources.
- Bioenergy to liquid, power, gas, and used directly in industry and buildings.
- 384 land regions based on water basins and energy regions, endogenous modeling of irrigation and yield intensification for agriculture.
- **GCAM community model: Download and documentation at http://jgcri.github.io/gcam-doc/index.html**

2 – Approach: Identify and perform analysis for which GCAM is appropriate and complementary

- Address bioenergy sustainability questions and provide complementary insights to other BETO life cycle, technology, and systems models.
- Leverage the broader program of GCAM development.
- Coordinate studies with BETO teams and modeling efforts at other labs.
- Our project go/no go milestone was met March 2020 by demonstrating the continued relevance of our analysis of bioenergy through published papers and participation in bioenergy analysis with EPA and private industry, and the international research community.

2 – Approach: Balancing Completeness with Level of Detail in Model Development Plans

- Challenges/Risks: defining an appropriate complementary scope and level of detail to provide insights while avoiding unhelpful complexity.
- Goal: to include sufficient structural detail in representing bioenergy in GCAM to provide useful insights without duplicating work best done by others.
- There are risks in availability and usability of data, especially globally.
- In line with previous peer review comments – we brought the newly-developed GCAM-USA into BETO analysis, which represents energy systems at the 50-state level while operating in the global model.

2 – Approach: Complementary Modeling with BSM

- In FY20 – Began close collaboration with NREL Biomass Scenario Modeling (BSM) team to do model coordination exercises with GCAM
- Goal: take advantage of the complementary scopes and resolutions between a US sector-specific model with more logistical and infrastructural detail (BSM) and a global integrated model (GCAM).
- Align technical assumptions where there is overlap and commonality.
  - Biofuel technologies, crop yields, land areas.
- Run joint scenarios to explore results' similarities and differences.
  - Ethanol limits, carbon management, electrification, land availability, international trade.
- Plan for manuscript Q3 FY21.

2 – Approach: Coordinated GCAM - BSM Modeling

BSM Scope / Results

- Production of Bioenergy in US with Multiple Feedstocks, Pathways, and Incentive Options
- Biofuel Capacity Growth Dynamics
- Detailed Biofuel Conversion Technologies
- Bioenergy Logistics and Learning
- US Bio Feedstock, Agricultural Production, and Land Use
- Transportation Sector Fuel Demands

Biofuel Conversion Pathway TEAs
Technology Dynamics and Logistics
Technology Learning and Costs

Energy, Fuel, Crop, and Carbon Prices
US Crop Production/Demands/Yield
Multi-Sector Bioenergy Demands

GCAM Scope / Results

- US and Global, Multi-sector, Energy Production, Demands, and Prices
- International Energy Trade
- US and Global Agricultural Production, Demand, and Prices
- International Agricultural Trade
- Commercial and other Land Uses
- Carbon Emissions from Energy and Land Use

Parallel Results for United States

- Bioenergy Production by Feedstock
- Bioenergy Crop Land Use
- Transportation Biofuel Demands
- Production by Conversion Pathways

3 – Impact: Bioenergy in the Larger Context

- GCAM provides a unique contribution to bioenergy analysis through its comprehensive physical and economic coverage of global energy, land use and emissions combined with detailed representations of energy technologies.
- Ensures that bioenergy is considered comprehensively and at the state of the art in GCAM analysis for BETO, other DOE, EPA, energy firms, and the international user community.
- With BETO funding, we have published papers on biopower vs biofuel, the land use impact of biofuel standards globally, and the impact of biojet fuels.

- The GCAM project directly addresses goals in the BETO MYP.
  - Develop and maintain analytical tools, models, methods, and datasets to advance the understanding of bioenergy and its related impacts.
  - Convey the results of analytical activities to a wide audience.

3 – Impact: Conveying Results to a Wide Audience

- Bioenergy model and data developments are reflected in published GCAM analyses for all our sponsors and collaborators.

- Modeling capability and data are accessible to community model users and consumers of analysis in the industry, research and policy communities.

- GCAM also has a long record of participation in international forums with leading European, Asian and other regions' integrated assessment modeling teams such as the Intergovernmental Panel on Climate Change (IPCC) and the Stanford Energy Modeling Forum (EMF).

- Marshall Wise is on the steering committee of the recently-completed EMF-33 study on global bioenergy, and he is co-author on several papers arising from this study published in the journal *Climatic Change*.

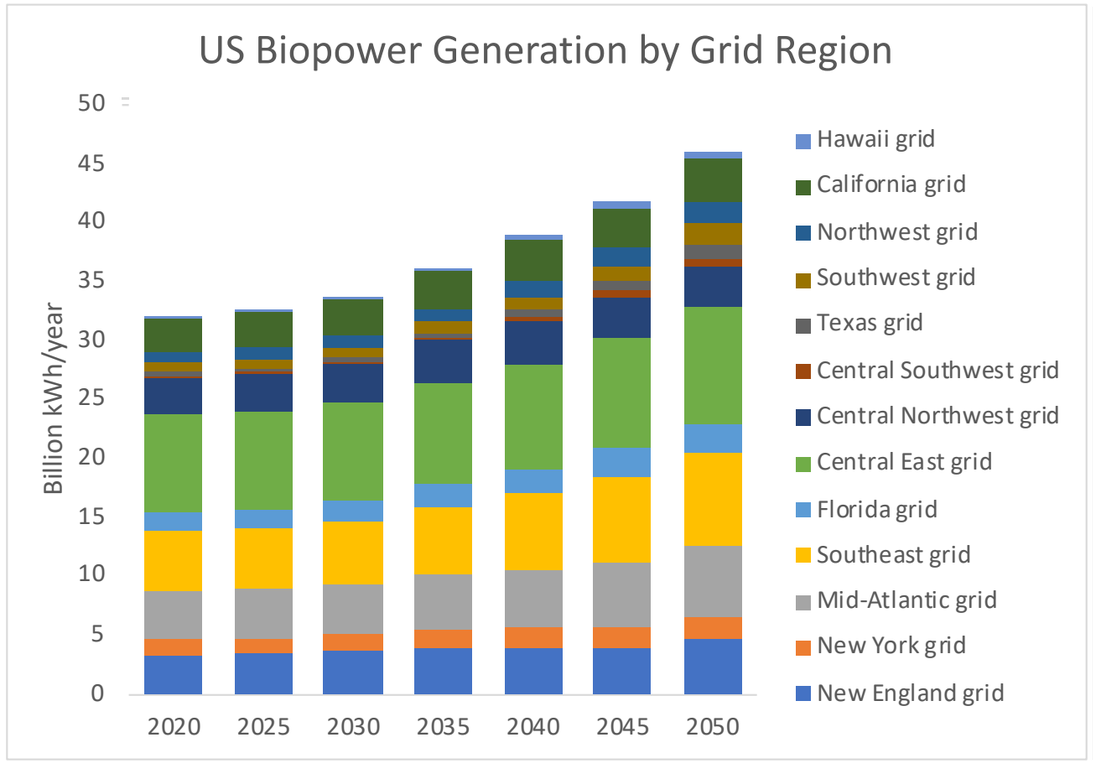
4 – Progress and Outcomes: Biopower and CCUS

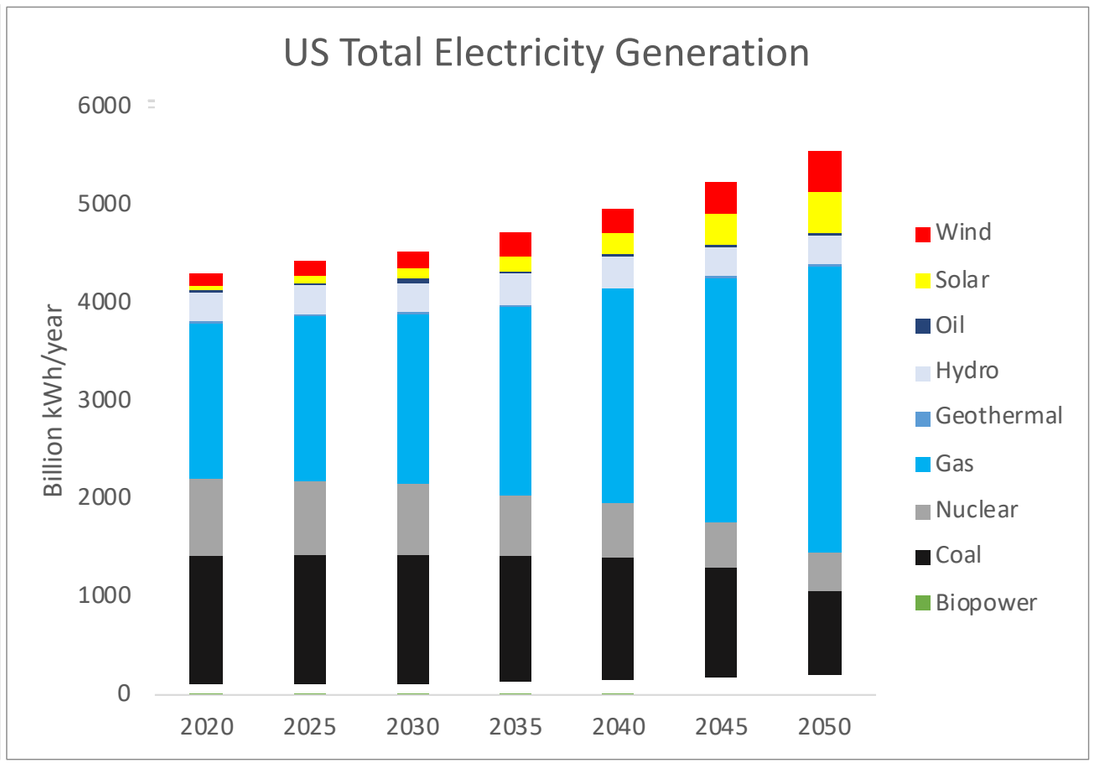
- FY 19-20 – Modeled potential future scale and impact of bioenergy for central power and for industrial steam in the US, including with CO_2 capture utilization and storage (CCUS), in the the context of competing energy sector demands.

- We used the 50-state GCAM-USA in order to explore results in more spatial resolution.

- As part of Energy Modeling Forum (EMF) 34, we participated in a multi-group, multi-agency study of the potential impact of the US 45Q CCUS credits on electric power.
  - Under 45Q, tax credits are paid specifically for CO_2 capture, either for use in enhanced oil production or in deep underground storage.

4. Progress and Outcomes: Biopower & GCAM-USA





- We found that without additional incentives, bioenergy for power and steam is not likely to see large growth in the U.S. over the next several decades.
  - Although repowering of 2.6 GW of the Drax Station in the UK from coal to biomass burning does show that it is feasible at scale given economic and regulatory incentives.

4. Progress and Outcomes: Biopower and CCUS

- Economics of a strategy like 45Q that ***credits CO_2 captured*** rather than ***credits CO_2 abated*** does not favor biopower compared to coal and gas.

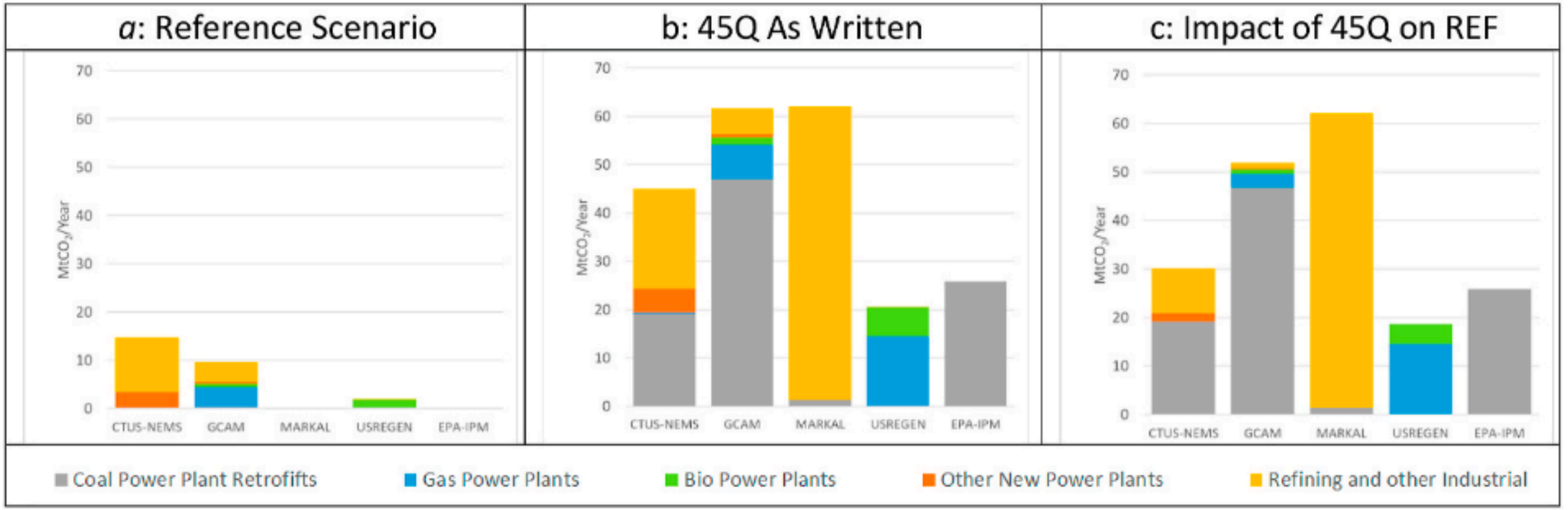


Fig. 4. CO_2 Capture stimulated by 45Q tax credits by type of facility in 2030.

Edmonds, James, Nichols, C., Adamantiades, M., Bistline, J., Huster, J., Iyer, G., Johnson, N., Patel, P., Showalter, S., Victor, N., Waldhoff, S., Wise, M., and Wood, F. (2020) "Could congressionally mandated incentives lead to deployment of large-scale CO2 capture, facilities for enhanced oil recovery CO2 markets and geologic CO2 storage?" *Energy Policy Volume 146*, November 2020, 111775.

4 – Progress and Outcomes: Bioenergy, Soil Carbon, and Ecosystem Services

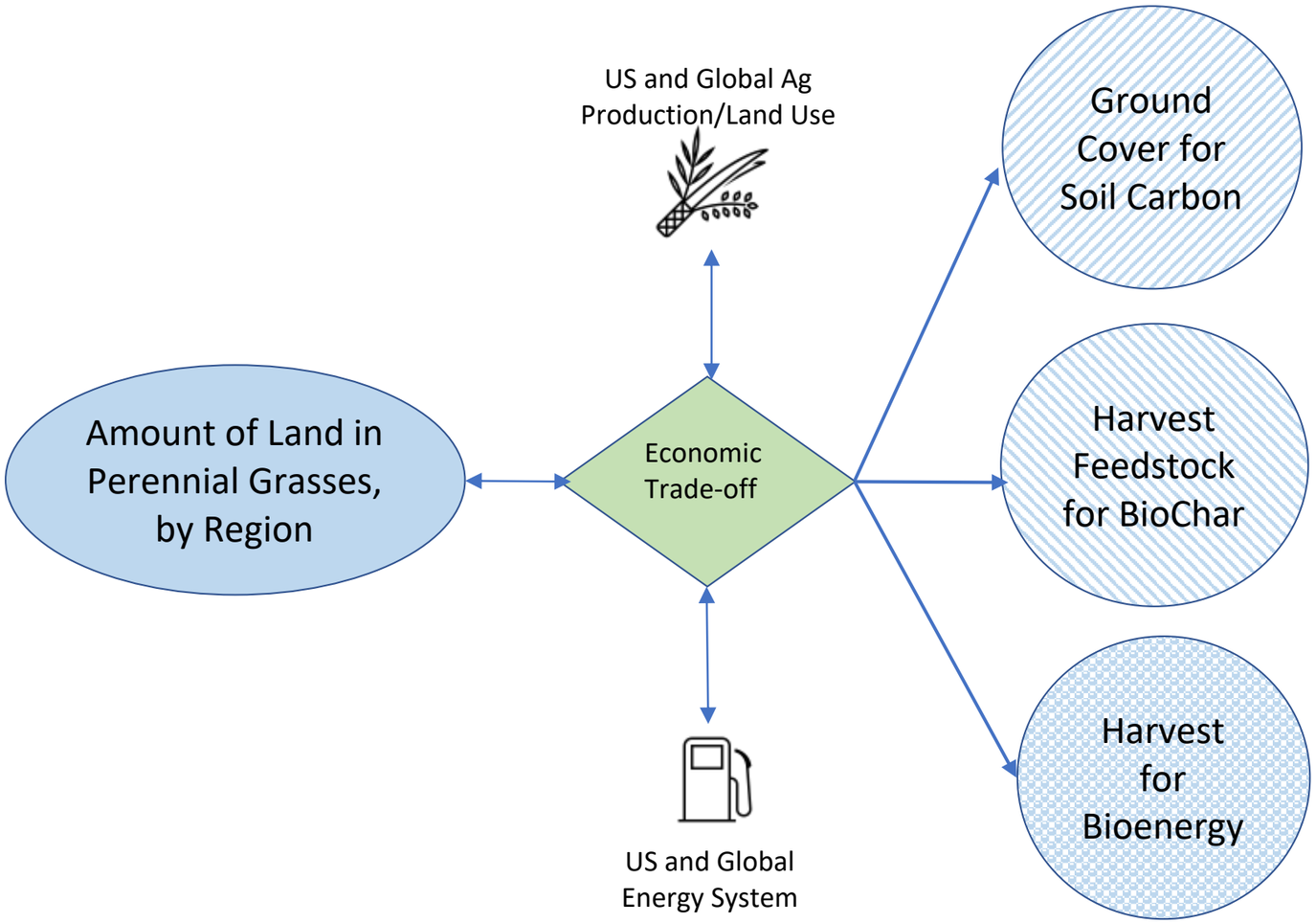
- FY21 - Developing methods to consider the economic value of ***Ecosystem Services*** associated with bioenergy production in large integrated models.

- We collaborate closely with crop and landscape management experts from ORNL, NREL, and INL in the BETO Sustainable Land Management Group.

- Effort underway to design and execute GCAM scenarios to assess the impact of including ecosystem services on bioenergy production and use.

- FY21 - Address questions concerning the carbon management trade-offs of using land for bioenergy production with perennial grass feedstocks.
  - Use GCAM to model responses under different future valuations of carbon.

4 – Progress and Outcomes: Bioenergy, Soil Carbon, and Ecosystem Services in GCAM



- Under different assumptions of carbon value – use GCAM to project amount of land in perennial grass and mix of uses for energy and land.
- GCAM will consider the economics of carbon in the context of energy and agriculture markets, regionally and globally.

FY21- Goal is to assess the hypothesis that valuing soil carbon will affect the relative economics and scale of bioenergy production.

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Summary: GCAM Bioenergy and Land Use

Management	Develop bioenergy modeling and data in PNNL's GCAM community model and use it to provide quantitative, analysis of bioenergy systems.
Approach	Define key bioenergy questions to guide analysis and model development efforts in collaboration with related BETO modeling efforts.
Impact	Provides a long-term economic, multi-sector, and international context for bioenergy considering energy, agriculture, and emissions. Complements other tools and supports research in several areas of the BETO multi-year program plan.
Progress and Outcomes	Analysis and published papers in diverse areas of bioenergy production, conversion, demand and carbon management. Updated bioenergy representation in GCAM community modeling.
Future Proposals	Study of bioproducts outside the energy system and carbon impacts in conjunction with NREL BSM. Expand GCAM bioenergy ecosystem services to include water impacts.

Quad Chart Overview

Timeline

- Project start date Oct 1, 2018
- Project end date Sept 30, 2021

	FY20	Active Project
DOE Funding	(10/01/2019 – 9/30/2020) **$175K**	(10/01/2018 – 9/30/2021) **$500K**

Project Partners

- NREL Biomass Scenario Modeling Team

Barriers Addressed

At-A (Analysis to Inform Strategic Direction)
At-B (Analytical Tools and Capabilities for System-Level Analysis

Project Goal

Perform quantitative, reproducible analysis of bioenergy demand and production in the integrated context of the multi-sector energy, agriculture, and land use systems in the United States and globally.

End of Project Milestone

Complete analysis of modeling physical and economic impacts of soil carbon ecosystem services from bioenergy in the GCAM model. Assess the hypothesis that the quantification and monetization of soil carbon ecosystem services from bioenergy production will change its relative economics and level of utilization in the US.

Funding Mechanism

BETO Lab Call 2018

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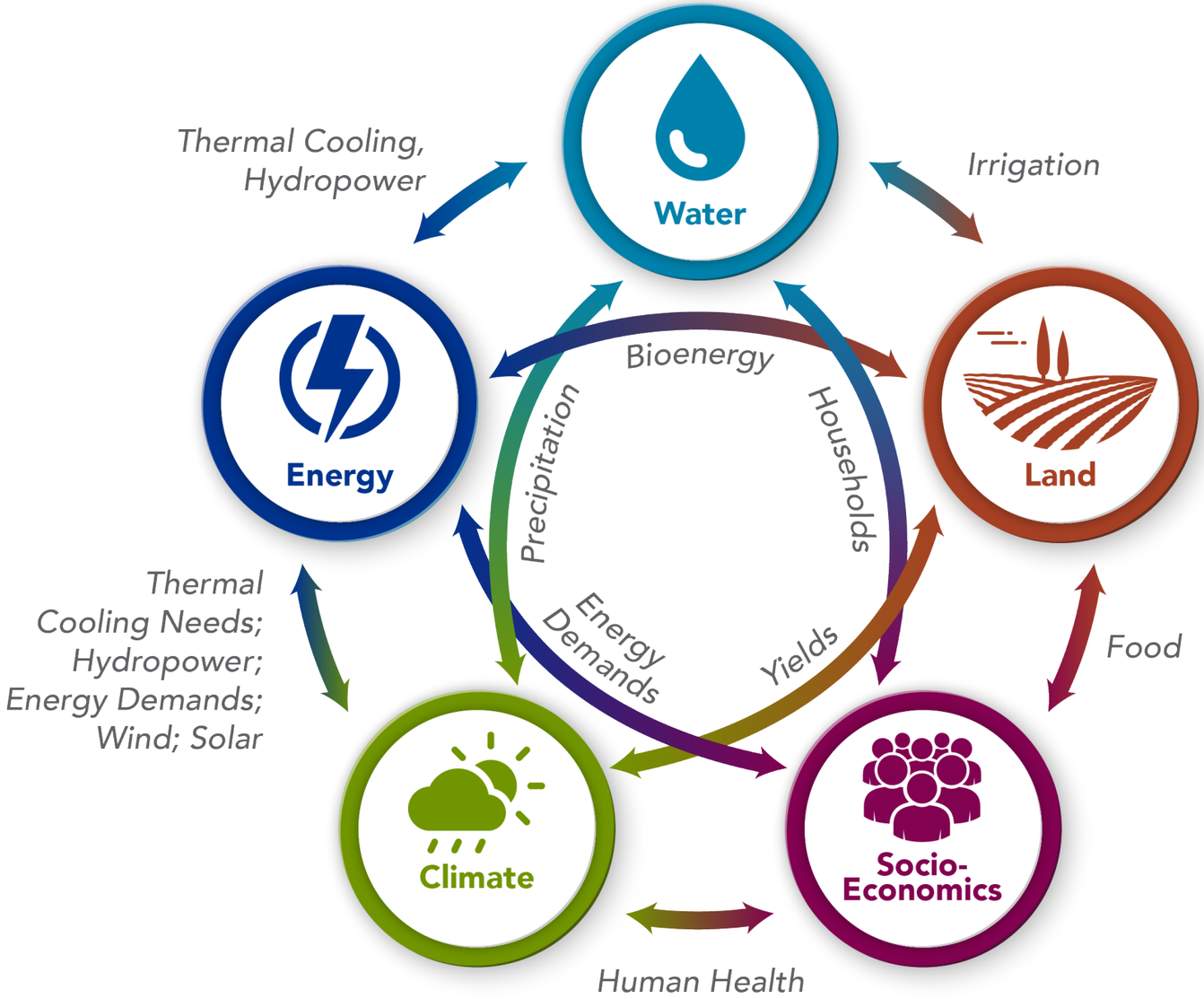
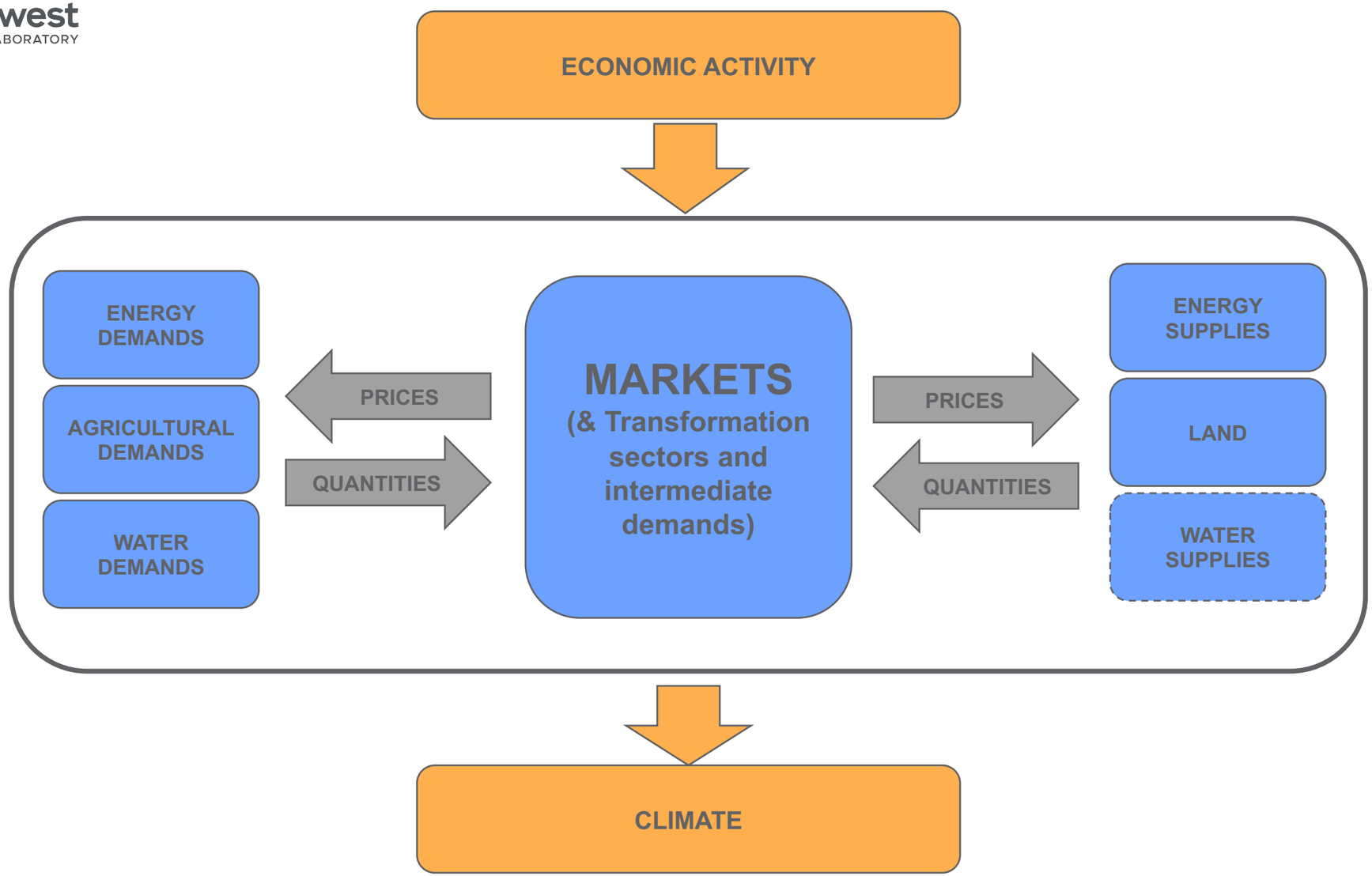
Additional Slides

GCAM explores the interactions between multiple systems



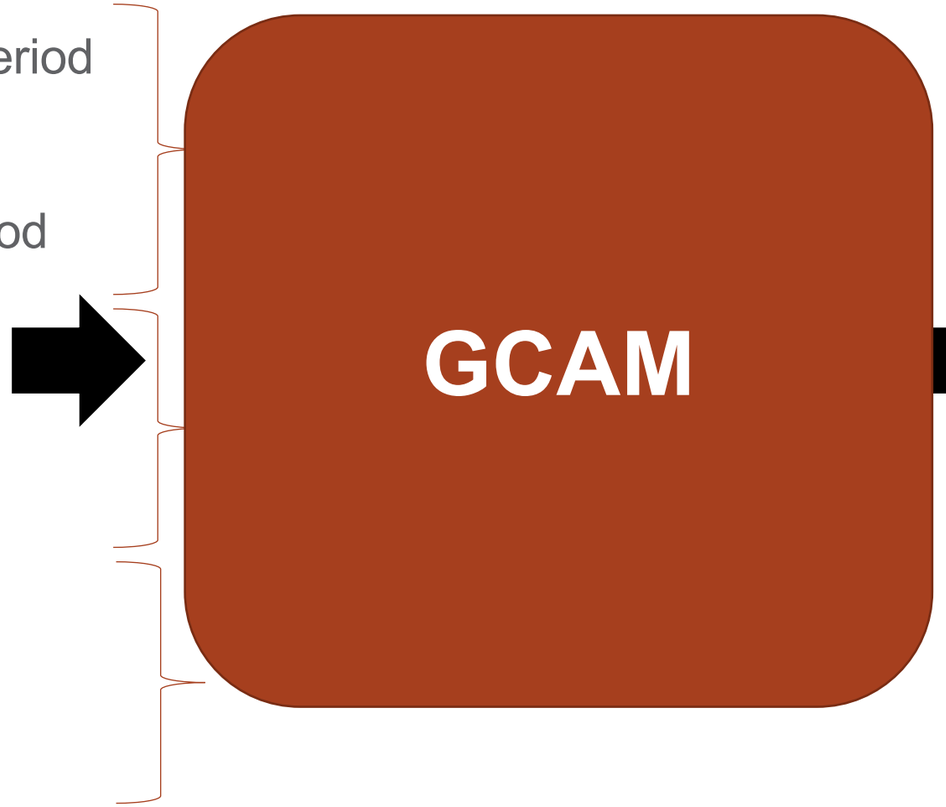
GCAM Operates by Solving for Market Equilibria



GCAM Land Modeling: Inputs and Outputs

Inputs

- Harvested area in historic period
- Land cover in historic period
- Production in historic period
- Consumption in historic period
- Cost of production
- Fertilizer application rates
- Water coefficients
- Carbon density, mature age
- Emissions factors
- Income elasticity of demand
- Price elasticity of demand
- Technical change
- Logit parameters
- FAO bilateral trade matrix



Outputs

- Production
- Consumption
- Land use, land cover
- Yield
- Price
- Fertilizer use
- Water withdrawals
- Water consumption
- Land use change emissions
- Other land emissions

Responses to Previous Reviewers' Comments

- We are directly addressing the review comment about not being well-integrated with other BETO modeling efforts.
  - We are actively collaborating with the NREL BSM team exploring complementary analysis.
  - We are also collaborating with a Multi-lab BETO Sustainable Land Management Group in exploring ecosystem services.
- One review comment was that the explanation was complicated to follow and it was hard to see the significance.
  - We have attempted to streamline and clarify the project explanation for this peer review.

Select GCAM and Bioenergy-Related Papers

- Rose, Steven K, Nico Bauer, Alexander Popp, John Weyant, Shinichiro Fujimori, Petr Havlik, Marshall Wise, Detlef P van Vuuren (2020). “An overview of the Energy Modeling Forum 33rd study: assessing large-scale global bioenergy deployment for managing climate change.” *Climatic Change*, https://doi.org/10.1007/s10584-020-02945-6.
- Bauer, Nico, Steven K. Rose, Shinichiro Fujimori, Detlef P. van Vuuren, John Weyant, Marshall Wise, Yiyun Cui, Vassilis Daioglou, Matthew J. Gidden, Etsushi Kato, Alban Kitous, Florian Leblanc, Ronald Sands, Fuminori Sano, Jessica Strefler, Junichi Tsutsui, Ruben Bibas, Oliver Fricko, Tomoko Hasegawa, David Klein, Atsushi Kurosawa, Silvana Mima, and Matteo Muratori (2018). “Global energy sector emission reductions and bioenergy use: overview of the bioenergy demand phase of the EMF-33 model comparison.”, *Climatic Change*. July 2018. https://link.springer.com/article/10.1007/s10584-018-2226-y
- Wise, M., M. Muratori, P. Kyle (2017). “Biojet Fuels and Emissions Mitigation in Aviation: an Integrated Assessment Modeling Analysis.” *Transportation Research Part D: Transport and Environment*, 52, pp 244-253. May 2017. http://dx.doi.org/10.1016/j.trd.2017.03.006
- 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.

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Thank you