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DOE Bioenergy Technologies Office (BETO)
2019 Project Peer Review

GCAM Bioenergy and Land Use Modeling

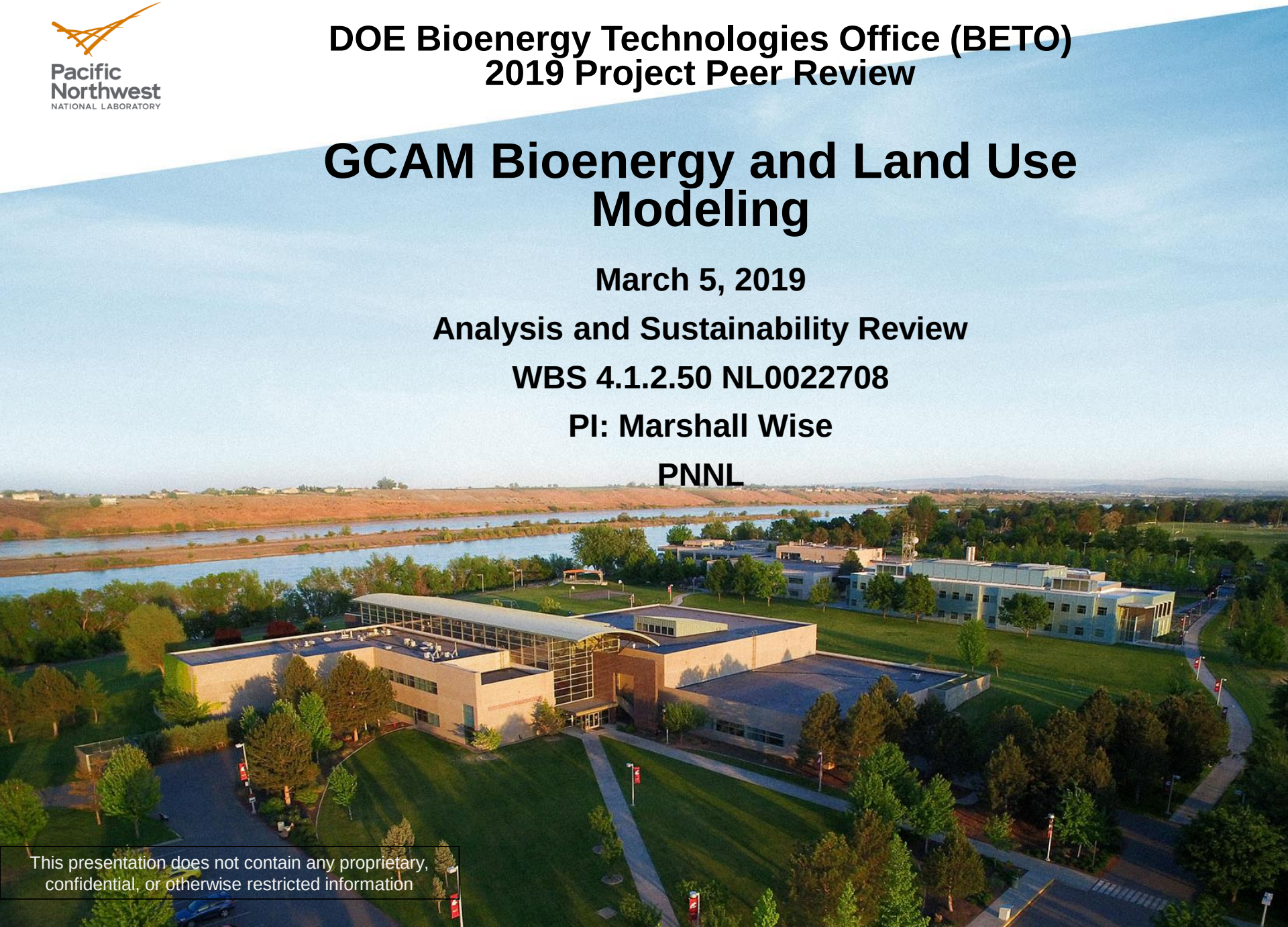
March 5, 2019

Analysis and Sustainability Review

WBS 4.1.2.50 NL0022708

PI: Marshall Wise

PNNL



Goal Statement:
Quantitative Analysis of Bioenergy in the Broader Context of Energy and Land Use

- **The Goal:** Provide quantitative, reproducible analysis of bioenergy demand and production in the integrated context of the multi-sector energy, agriculture, and land use systems.
  - Publishable analysis that furthers the understanding of the potential roles, scale, and impact of large-scale bioenergy production and use.

- PNNL performs most of the analysis in this project with its Global Change Assessment Model (GCAM): an internationally-used community model.
  - GCAM economically and physically integrates longer-term modeling of regional and global energy, agriculture, forestry, and land use systems.

- **Project Outcome:** Timely, relevant bioenergy analysis and publications while maintaining state-of-the-art modeling of bioenergy in GCAM.
  - 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.

GCAM Bioenergy and Land Use Quad Chart Overview

Timeline

- Initial project start: FY2010
- Merit review cycle: FY2019-FY2021
- Percent of review cycle complete: 15%

	Total Costs Pre FY17	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19 – 21)
DOE Funded	$1,150	$150K	$100K	$475K

Partners: None

Barriers addressed

- At-A. Analysis to Inform Strategic Direction
- At-B. Analytical Tools and Capabilities for System-Level Analysis
- At-E. Quantification of economic, environmental, and social benefits and costs

Objective

Provide quantitative analysis of the potential and impact of bioenergy demand and production in an integrated economic context.

End of Project Goal

Advance the understanding of the key issues surrounding the future of bioenergy, with a focus on biopower for this project phase, communicated by reports and published papers.

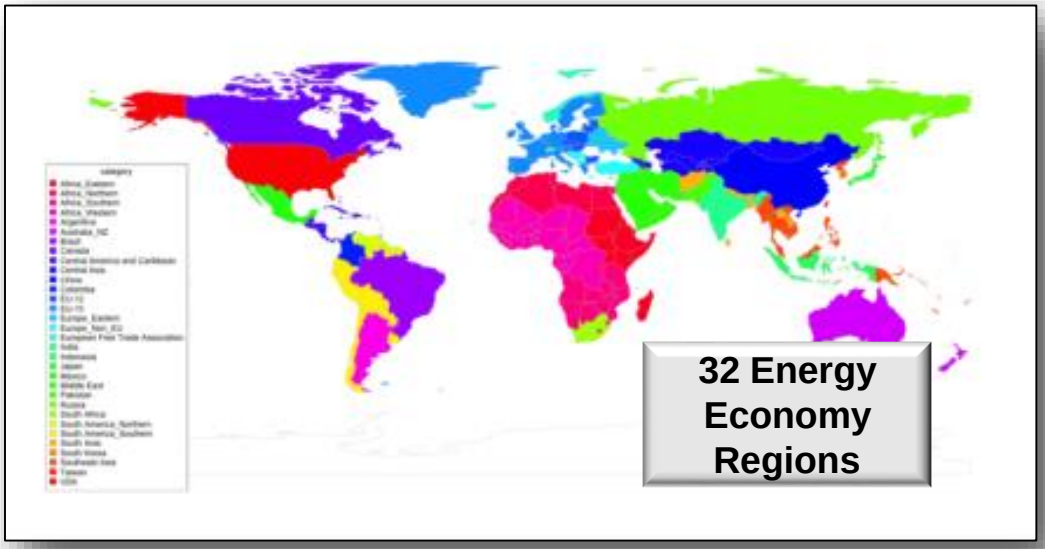
1 - Project Overview:
Modeling to address key bioenergy analysis and sustainability questions

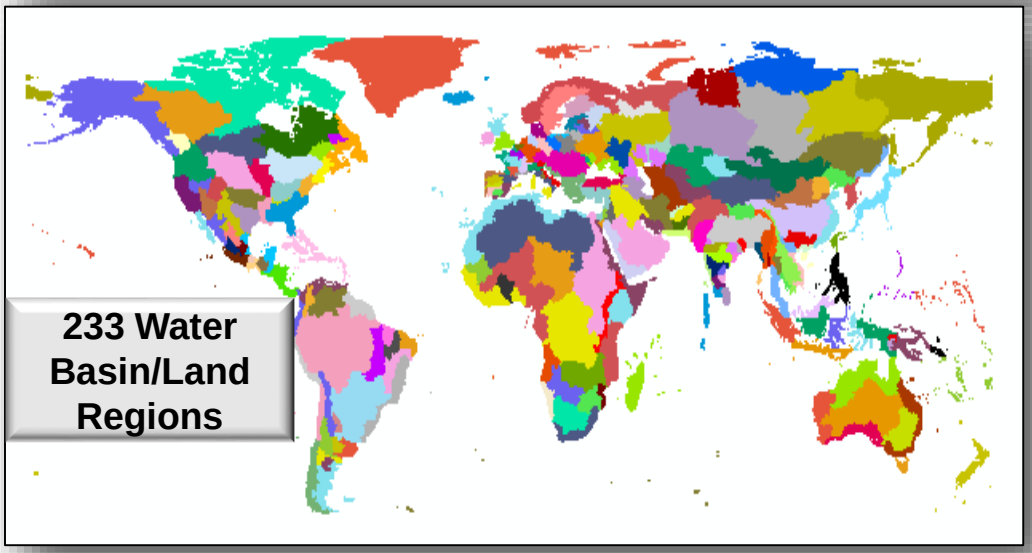
- The BETO GCAM project leverages several years of federal (DOE Science, FE, NE, EERE, as well as EPA) and industry-sponsored funding.
  - GCAM/PNNL has long participated in international forums and studies such as the IPCC and the Stanford Energy Modeling Forum (EMF).
  - Bioenergy is always a key component of our integrated analysis of energy and land use for all of our work for all sponsors.

- With BETO, we have opportunistically identified relevant bioenergy questions for which GCAM can be further developed and utilized.
  - E.g., what are competing and complementary roles of biofuels and biopower?
  - What would be the impact on agriculture and land use change of an expanded use of biofuels in multiple regions of the world?

- Since last Peer Review
  - Published paper on global potential and impact of bioenergy for aviation.
  - Recently, performed an integrated analysis of biofuels and electric vehicles to serve transportation energy demands in the US.

GCAM 5.1 model and regional resolution





- GCAM economically and physically links global Energy, Technology, Agriculture, Land-use, Emissions, Water, and Climate.
- Bioenergy Crops, Ag. and Forestry Residues, Wastes, and 1st-gen sources.
- Bioenergy to liquid, power, gas, and used directly in industry and buildings.
- New to GCAM 5.0+: 380 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 (Management):
Define specific BETO project goals and outcomes in coordination with GCAM Program developments

- Marshall Wise serves as PI/PM responsible for research and ensuring that the project is executed to the statement of work.
  - Because of GCAM leveraging, plans must be done in close collaboration with other non-BETO GCAM projects to ensure goals are achievable.
  - Post-docs and other staff assist the research, modeling, and writing.
- 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 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.
  - Quarterly Milestones are defined in the AOP with written reports or briefs delivered at the end of each quarter.
- For the Biopower analysis beginning 2019, participate in a multi-lab effort to coordinate GCAM analysis with other BETO projects.

2 – Approach (Technical):
Identify, define, and perform analysis for which GCAM is appropriate and complementary

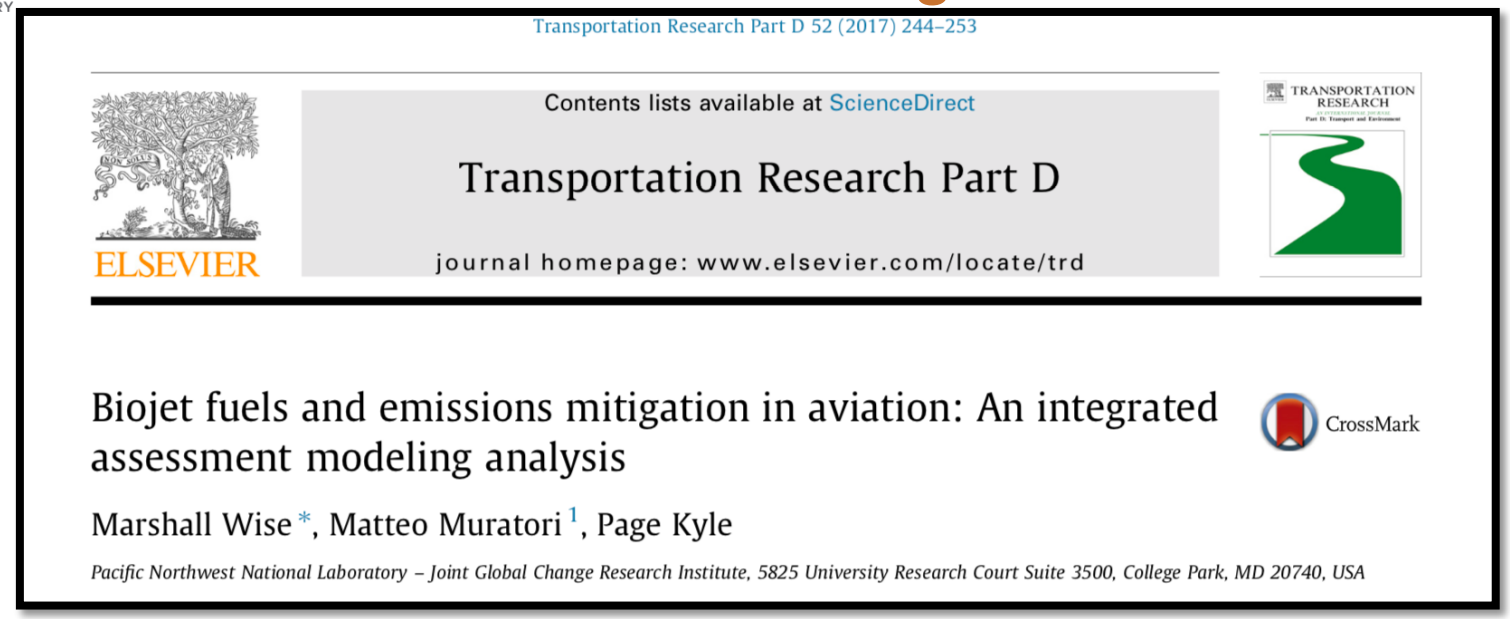
- Identify bioenergy analysis and sustainability questions for which GCAM can be developed to provide complementary insights to other BETO life cycle, technology, and systems tools and analyses.
  - Leverage the broader program of GCAM development.
  - Balance detail and complexity in representing bioenergy in large 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.
- Key measures of progress are published analyses relevant to Bioenergy and continued development of Bioenergy in GCAM.
  - Go/No-go milestone due March 31, 2020 – assess the continued economic viability of and interest in biopower as a potential renewable energy source for domestic energy needs over the next few decades.

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.
  - 2014, published paper funded by BETO looking at potential impact of expanded global biofuels use on energy, agriculture, and emissions.
  - 2017, published paper on global potential and role of biojet fuels for aviation.

- Over the last few years, we have focused specific analyses for BETO on the bioenergy demand and use (though all GCAM analysis does include agriculture and land use).
  - Published paper on global impact of biojet fuels.
  - 2018 task, completed study and draft paper of an integrated analysis of biofuels and electric vehicles in US passenger and freight transportation.
  - 2019, began task on studying potential and impact of biopower in US.

3 – Technical Accomplishments:
Manuscript: Biojet Fuels could enable a significant reduction in fossil fuels for global aviation



Transportation Research Part D 52 (2017) 244–253

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Biojet fuels and emissions mitigation in aviation: An integrated assessment modeling analysis

Marshall Wise *, Matteo Muratori [1], Page Kyle

Pacific Northwest National Laboratory – Joint Global Change Research Institute, 5825 University Research Court Suite 3500, College Park, MD 20740, USA

- Aviation energy consumption and GHG emissions are a small fraction of global energy system (approx. 2% but growing), but highly dependent on liquid fossil fuels and thus with a high GHG-intensity.
  - Small total, but high intensity leaves sector vulnerable to GHG policies.
- Our analysis showed the potential and impact that biojet fuels could have on the ability of the aviation sector to reduce fossil fuel use and emissions.
  - Amount of bioenergy would not be large relative to other uses.
  - Quantified the impact on emissions from incremental LUC.

3 – Technical Accomplishments:
Performed integrated analysis of Biofuels and Electric Vehicles for transportation demand

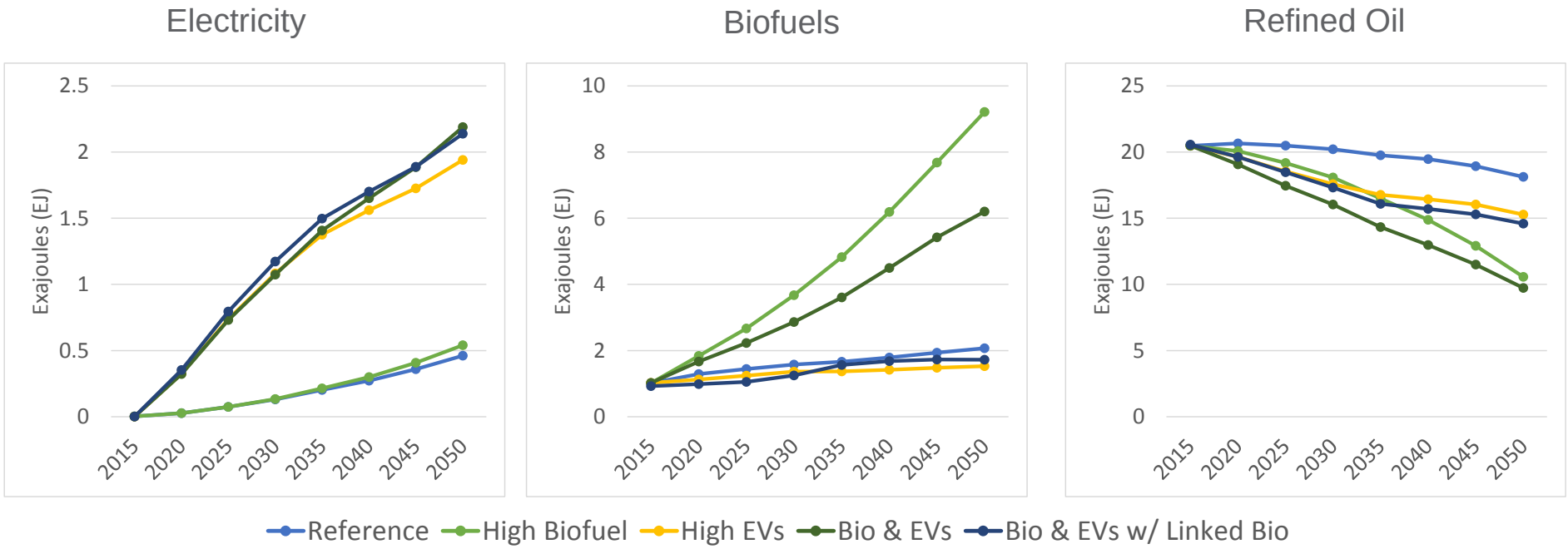
- FY 2018 Task Objective: Design and perform a quantitative multi-sector analysis of bioenergy and competing technologies for transportation in the U.S. to the Year 2050.
  - Bioenergy for liquid fuels, power, and gas for passenger and freight transportation.
  - Scenarios exploring biofuels targets, ethanol blend wall, bioliquids, electric passenger cars and electric freight trucks.
  - Consider synergistic and competing relationships across sectors.
  - Analysis of informative scenarios – not specific policies.

- Completed an analysis and draft paper using GCAM to look at vehicle competition and energy demand under different bioenergy targets and different assumptions about competition from electric vehicles.
  - Added a new scenario option in which electric vehicles can purchase “credits” used to incentivize biopower and use it to satisfy bioenergy targets.
  - In effect, biopower electricity is treated as a ”biofuel” for this scenario.

3 – Technical Accomplishments:

Increased penetration of Electric Vehicles would drive down demand for liquid fuels

Passenger and Freight Energy Consumption (EJ/yr)



- Exploratory Scenarios: Reference Case, High Biofuel (here, 50% of liquid fuels), High Electric Vehicles penetration, Link to BioPower (where biopower can contribute to the Biofuel target)
- Link to BioPower between the transportation and electric sector reduces biofuels while expanding electricity demand for transportation (with the increment served by biopower).
- Link to Biopower Scenarios are illustrative of a potential pathway where bioenergy remains an important domestic, renewable source of energy for transportation in a future where electric vehicle technology becomes more widespread.

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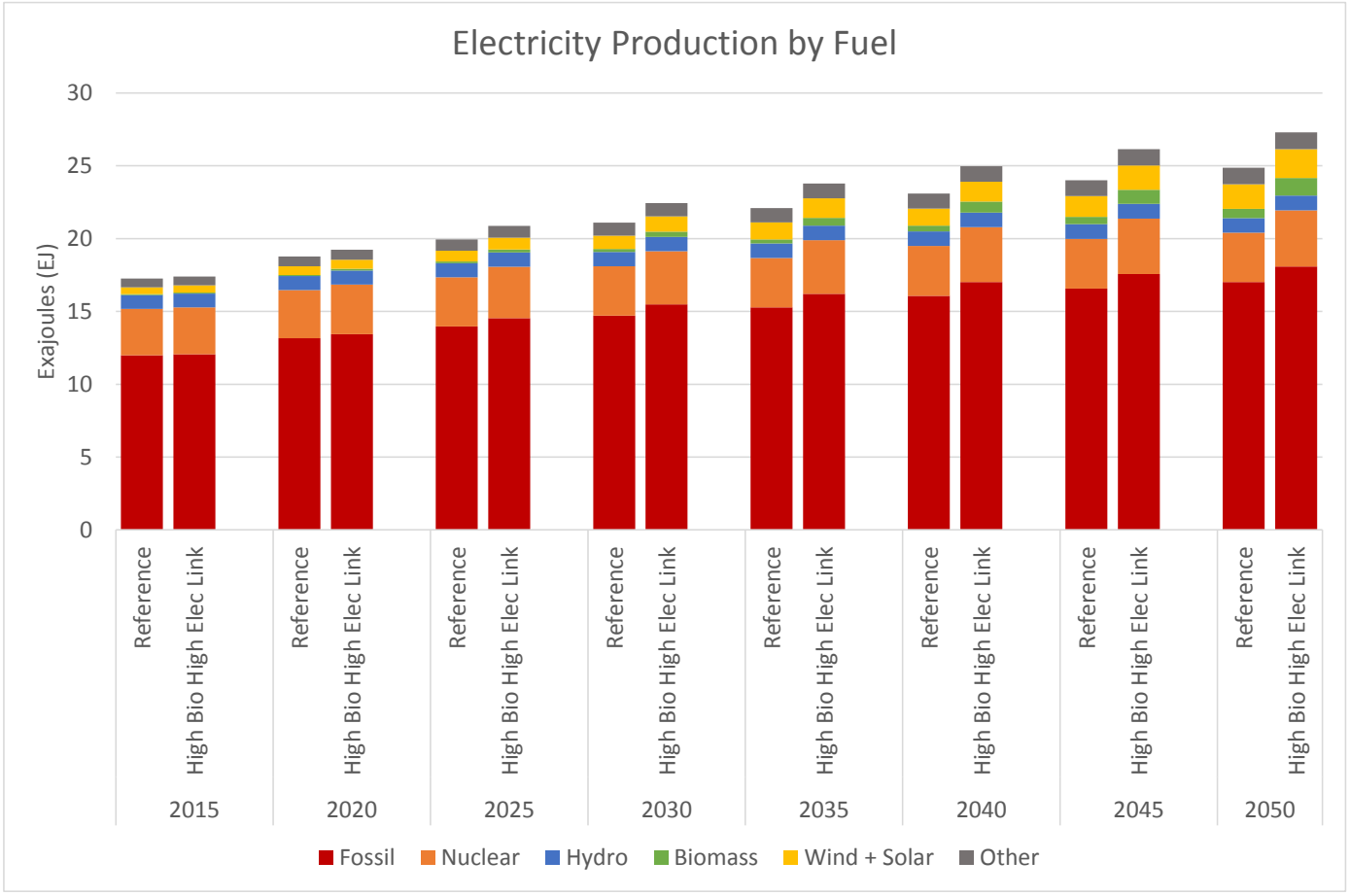
3 – Technical Accomplishments:
Linking Biopower to Biofuels targets is a path to use bioenergy for transportation.

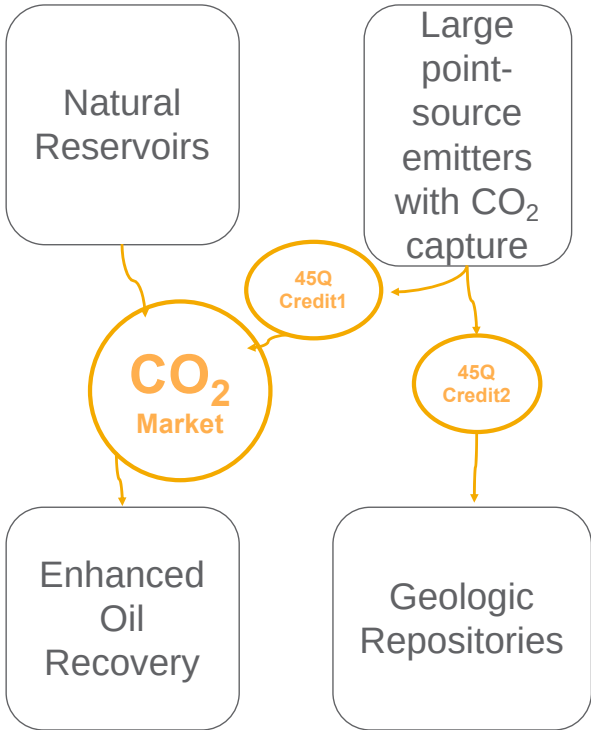
US Electricity Production for all Sectors



- For context, 2EJ is on the order of 20 billion gallons of liquid fuel.
- With Higher end-use efficiency of electric vehicles, 2 EJ of electricity serves a substantial portion of demand.
- But this amount of biopower is still relatively small in the context of total electricity generation.

3 – Technical Accomplishments:
FY2019: We have begun an analysis of Biopower and of Bioenergy with CCUS using GCAM-USA

- GCAM Modeling analysis of potential scale and impact of biopower.
  - New 50-state version of GCAM with state electricity sector detail.
  - Competition of biopower technologies in electricity and energy system.
  - Coordinating analysis with other labs, including NREL and ORNL.
- One case study: Bioenergy Carbon Capture, Utilization and Storage (CCUS) under section 45Q of 2018 Tax code that credits CCUS.



4 – Relevance:
GCAM provides scope complementary to other BETO analyses

- 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.
  - MYP Goal: Develop and maintain analytical tools, models, methods, and datasets to advance the understanding of bioenergy and its related impacts.
- Bioenergy-related model developments are key in published GCAM studies, analysis activities performed for government and industry, and in international research collaborations.
  - GCAM BETO PI is on Steering Committee of Stanford Energy Modeling Forum (EMF) 33, an international group focused on studying the potential scale and impacts of future global bioenergy production and use.
  - MYP Goal: convey the results of analytical activities to a wide audience.

4 – Relevance:
GCAM is a widely-used, prominent, community model.

- Model developments are incorporated into the GCAM community model and made accessible to users and consumers in industry, research and the policy community.
  - GCAM is open source and distributed as a community model.
  - MYP goal: Ensure high-quality, consistent, reproducible, peer-reviewed analysis.
- GCAM modeling, analysis, and tutorials are presented at PNNL's annual GCAM meeting in College Park, MD.
  - GCAM community model: Download and documentation at http://jgcri.github.io/gcam-doc/index.html.
  - GCAM Annual Meeting: http://www.globalchange.umd.edu/annual-meetings/2018_gcam_community_modeling_meeting/

5 – Future Work:
Improve integrated biopower modeling capability with multi-lab analysis to address key issues.

- Provide integrated economic modeling as part of the multi-lab, biopower initiative including ORNL, ANL, and NREL.
- Based on BETO TEA, LCA, and resource studies, improve GCAM model in areas relevant for biopower analysis.
  - Biopower electric generating technologies.
  - Regional feedstock resources including wastes, ag and forestry residues.
- Provide modeling analysis of economic scenarios and their impact on future biopower penetration.
  - Consideration of biopower in state-level renewable targets.
  - Sensitivity analysis of future technology changes in biopower along with competing and with complementary technologies and systems.

5 – Future Work:
Model the energy system impacts of Bioenergy and CCUS to store carbon and to produce energy.

- Perform integrated modeling analyses on the technologies, potential, and impacts of bioenergy and CCUS.
  - Consider potential impact of policies like 45Q on bioenergy.
- Use GCAM to provide integrate modeling analysis of future technology systems that recycle or re-use carbon emissions to make fuels.
  - Consider broad categories of technologies such as those explored in the DOE Study, *Rewiring the Carbon Economy* study from 2018. https://www.energy.gov/sites/prod/files/2018/02/f48/engineered_carbon%20_reduction_summary_report.pdf
  - Collaborate on technology data with BETO NREL project on carbon management.
- Continue to disseminate modeling capability through the GCAM community model program and findings and insights through published papers.

Summary

Overview	Provide quantitative, integrated analysis of bioenergy sources and technologies in a global modeling framework.
Approach	Define key bioenergy analysis and sustainability questions to guide analysis and model development efforts.
Accomplishments	Several published papers and analyses of integrated analysis of bioenergy as well as improved community modeling.
Relevance	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.
Future work	Future work – Integrated analysis of the potential, scale, and impact of biopower in the U.S. to 2050.

Acknowledgements

- We would like to thank the BETO Technology Manager Alicia Lindauer for continued technical and financial support for this effort.

- The PI thanks the technical team at PNNL who have contributed directly to this project in the last two years, including but not limited to the following:
  - Matteo Muratori (now at NREL)
  - Christopher Roney
  - Jonathan Huster

- The PI also acknowledges the valuable BETO program management support at PNNL including Asanga Padmaperuma, Corinne Drennan, and Michele Jensen.

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Additional Slides

- Responses to Previous Reviewers' Comments
- Review of Go/No-Go Decision from 2016
- Publications, Patents, Presentations, Awards, and Commercialization
- GCAM Model Structure Schematic
- GCAM Inputs

Responses to Previous Reviewers' Comments

- Review comment that the GCAM model and results should be available on the BETO KDF.
  - Response: Links to the GCAM model download and the Github site of documentation have been added to the KDF.
  - Links to Bioenergy relevant papers are also on the KDF.
- Review comment that we should clarify and ensure that this modeling is placed in the most useful context with other BETO models and analyses.
  - We have participated in the BETO modeling workshops to help understand and communicate the best role for GCAM as a complement to the more focused LCA and TEA analysis as well as the pure economic modeling such as GTAP.

Review of Go/No-Go Decision from 2016

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.

Review of Go/No-Go Decision from 2016 (2)

- 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

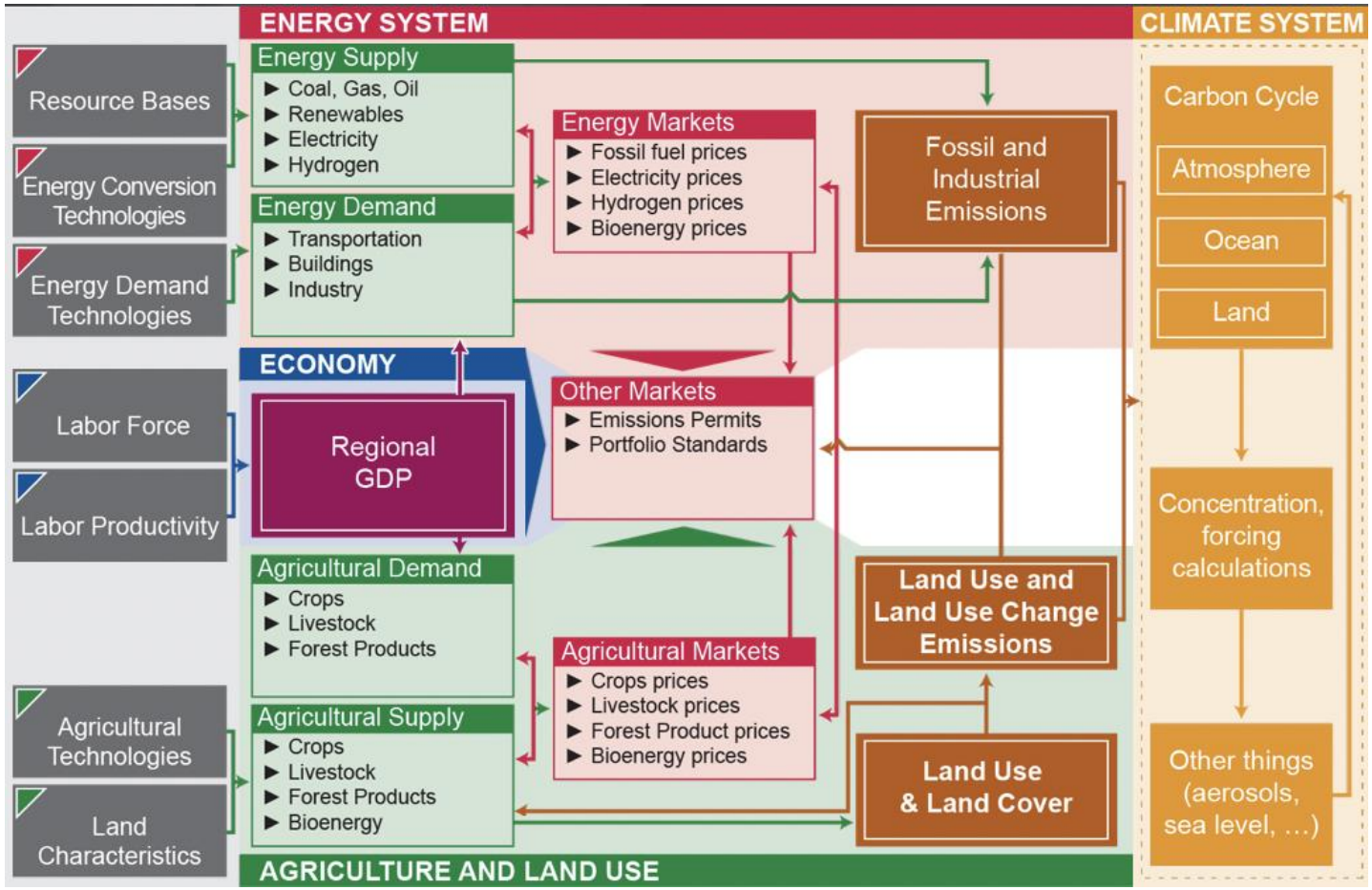
Bioenergy Papers since last Peer Review

- 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
- Bauer, Nico, Steven K. Rose, Shinichiro Fujimori, Detlef P. van Vuuren, John Weyant, Marshall Wise, 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*. July 2018. https://link.springer.com/article/10.1007/s10584-018-2226-y

Other Recent Bioenergy Papers

- 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.
- 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.

GCAM Model Structure Schematic



GCAM - Inputs

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