NREL
NATIONAL RENEWABLE ENERGY LABORATORY

DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

WBS 4.2.1.31 Integrated Life Cycle Sustainability Analysis

Analysis & Sustainability

March 5, 2019

Dr. Patrick Lamers

National Renewable Energy Laboratory

PR-6A20-73215

Goal Statement

- To develop a coherent **methodology** and consistent **model framework** to quantify the **net effects** of an expanding U.S. bioeconomy at national and regional levels.
- To **inform BETO's strategic decision making** by engaging in and synthesizing key **global multilateral activities** that develop, compare or apply metrics, methods, and tools to quantify the sustainability effects of specific bioeconomy products.

Outcomes

Integrated modeling framework

- Multi-criteria analyses quantifying the net economic and environmental effects of specific bioeconomy scenarios.

Multilateral engagement

- Greater understanding of key global bioeconomy activities to identify opportunities and challenges for the expansion of the U.S. bioeconomy.

Relevance

- Fills a BETO analysis gap identified by Peer review and addresses a related MYP milestone.
- Supports consensus on metrics, methods, and tools to quantify sustainability effects across agencies and country-level initiatives.
- Informs efforts of other federal agencies (EPA, USDA) and initiatives (Biomass R&D Board).
- Ensures U.S. work is presented by respective experts, considered, and used globally.

Quad Chart Overview

Timeline

- Start: FY14
- Merit review cycle: FY17-19
- 75% complete of review cycle
- Continuation/Ongoing

	Total Costs FY14-16	FY17 Costs	FY18 Costs	Total Planned Funding FY19
DOE Funded	$612k	$229k	$242k	$350k

Partners

EPA National Risk Management Research Laboratory (USEEIO developers)
USDA Offices of Chief Economist & Scientist
Biomass R&D Board
Lab partners: ORNL, INL, ANL; NREL colleagues
Eastern Research Group/Franklin Associates
Members of IEA Bioenergy (e.g., Tasks 39, 45)
Global Bio-Energy Partnership (GBEP)/FAO

MYP Goals & Barriers

MYP Milestone: "By 2019 complete a model framework to support multi-dimensional analysis on specific economic, environmental, and other benefits of an expanding bioeconomy".

- At-A. Analysis to Inform Strategic Direction
- At-B. Analytical Tools and Capabilities for System-Level Analysis
- At-E. Quantification of Economic, Environmental, and Other Benefits and Costs

Objectives

1) Develop a transparent and consistent model framework to assess the net effects of an expanding U.S. bioeconomy.
2) Inform BETO's strategic decision making by engaging in, evaluating, and synthesizing selected global, multilateral activities that develop, compare, or apply metrics, methods, and tools to quantify sustainability effects of specific bioeconomy products.

End of Project Goal

FY19: Reach an externally vetted methodology quantifying the net effects over time (based on a retrospective case) and apply it to other products of the current or near-term U.S. bioeconomy.

FY22 (vision): Create an open source, fully disaggregated, prospective model capable of computing the net environmental and economic effects of an expanding U.S. bioeconomy at a national and multi-regional level.

Project Overview

- Project evolved from international sustainability work by Dr. Helena Chum (NREL Senior Research Fellow Emeritus)
- Global engagement and 2017 Peer Review showed the need for an integrated sustainability analysis framework for BETO
- This project addresses this BETO A&S gap and related MYP A&S milestone by
  - Building a framework for national level analysis to inform BETO, other federal agencies, and initiatives (Biomass R&D Board),
  - Continuing the engagement in multilateral efforts on sustainability, and utilizing the framework for comparison and answering questions,
  - Focusing on framework and method development (domestic importance) but remaining engaged and stay on top of international discussions.

Management Approach

- All efforts are clearly defined in agreement with BETO in an Annual Operating Plan (AOP) including formal monitoring and respective written reporting (for annual milestones, Go/No-Go decision points, etc.). Additional communication and reporting to BETO:
  - Quarterly: Formal progress reports including financial and project updates.
  - Bi-Weekly: Project updates with Technical Monitor (Kristen Johnson).
  - Ad-hoc: Briefings (e.g., prior to international trips).

- NREL collaborates with EPA's National Risk Management Research Laboratory (developer of the public USEEIO version) and engages with other practitioners and developers of LCA and Input-Output modeling to validate the approach/method, prototype model, and results via workshops and white papers.

- NREL performs active outreach to and engagement of other national labs and federal agencies (e.g., USDA) regarding definitions, data, and scenarios.

- NREL participates in selected *bi-annual* international planned activity meetings or workshops (virtual and in person) to discuss metrics, methods, and tools quantifying sustainability effects of specific bioeconomy products; and contributes to related joint, multilateral studies, reports, and papers.

Technical Approach

Challenges

- Complexity: Economic and environmental outcomes affected by many factors
- Data intensity: large amount of data required to understand all processes associated with a large-scale bioeconomy
- Data heterogeneity/comparability: harmonization and creation of data-sets to initiate model for future runs
- Model results are not verifiable by measurement (at the level of aggregation): validation test case needed (corn ethanol)
- Determining suitable scenarios: relying on other models for predictions
- Multitude of stakeholders (domestic and global)

Critical Success Factors

- ✓ Stepwise (product level) build-out
- ✓ Data vetting (integrity and quality)
- ✓ External review in early stages to validate framework and data
- ✓ Reviewers are practitioners and/or developers of LCA and IO models
- ✓ Open source, transparent framework
- ✓ Following Federal LCA Commons standards: efficient data transfer and repeatability, model data provided for use with open source LCA software
- ✓ Consistent framework to calculate economic and environmental metrics
- ✓ Include all product, service, and final demand sectors: minimizing system boundary/cutoff error and placing the bioeconomy in the context of household and other consumption
- ✓ Consensus among key stakeholders

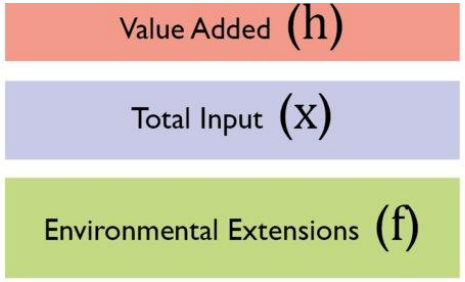
Technical Approach

Life cycle based environmentally-extended input-output model

U.S. Economy

Cake: total economy
Layers: sectors, industries

→ weight (oz) = transactions ($)



U.S. Bioeconomy

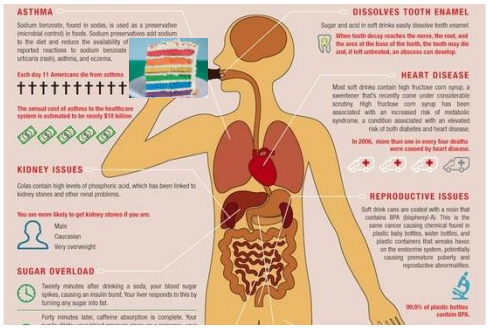
A slice *cuts* across industries

- *cutting = disaggregating* economic activities ($)
- careful disaggregation is important and data intense

Our approach:

- Achieve a higher confidence in results through external vetting & peer-review of data, method, and test case results
- Model build-out on a product by product basis

Net effects



Measured at point of *consumption:* Environmental effects related to economic activities ($-value) across the *life cycle*, i.e., from production (milk, butter, …) to consumption.

Metaphor:
α (oz) : economic activity ($)
→ β oz sugar (value-add, GDP)
→ γ cal (direct jobs)
→ δ m^3 H_2O (water use from production through consumption)

Same approach for all metrics (consistency)

No trade, only domestic

Images: https://parade.com/334610/parade/how-to-make-a-rainbow-layer-cake/
https://www.seriouseats.com/recipes/2011/09/rainbow-layer-cake-recipe.html
https://www.pinterest.com/pin/299630181428800129/

Technical Approach

Top Challenges

- The bioeconomy overlaps many economic sectors
  - Estimates are confounded by methodological differences, and
  - Different definitions of the bioeconomy (boundaries)
- First of a kind approach to quantify key metrics of the bioeconomy

Technical Approach

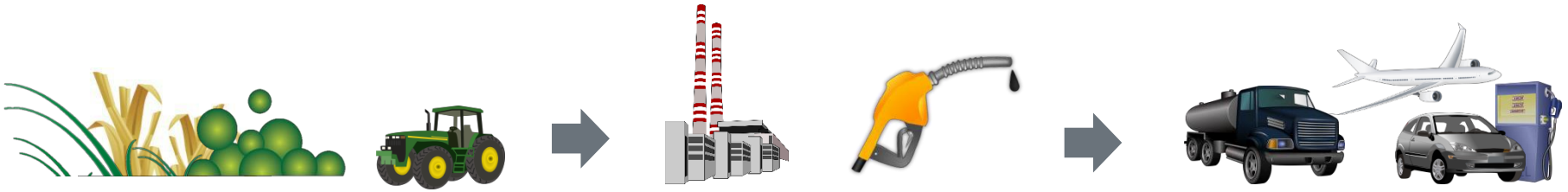
- Life cycle-based environmentally-extended economic input-output framework
  - Consistent (no cut-off points) & transparent (open source code)
- Link to existing federal efforts (model, data, evaluation) at USDA, EPA, BEA, BLS
  - Collaborate with developers of the U.S. Environmentally-Extended Input-Output (USEEIO)
- Structured input from practitioners and external reviews to validate model/method

FY18

- External feedback on proposed model
- Prototype model development
- Validation test case (retrospective)
- Go/No-Go Decision (Q4FY18)

FY19

- External review (test case) & (re)calibration
- Model expansion (three biofuels)
- Collaboration to develop reference case
- Net effect methodology white paper



Accomplishments

Establishment and Demonstration of the Analysis Framework

1. **Discussion and consensus** on the proposed modeling framework (workshop)
2. **Disaggregation** of the base model: national dataset creation
3. **Briefing** of DOE BETO management and federal agencies
4. **Validation test case** development: corn ethanol (retrospective)
   - Disaggregate sectors for biomass production and conversion
   - Perform national analysis
   - Add regional economic and environmental data
   - Perform regional analysis
5. **Go Decision** (September 2018)

Engage with other federal agencies beyond DOE (EPA, USDA, DOD, etc.)

Accomplishments

Workshop

Invite practitioners and developers of Life Cycle Analysis (LCA) and Input-Output (IO) Modeling across U.S.

Federal Agencies
National Labs
Universities
Industry

To identify & form a common understanding of

- models describing the U.S. economy and how to build off of them,
- a bioeconomy definition for the next modeling steps,
- the (sub)sectors that can/should be used in the framework,
- opportunities for collaboration and data sharing.

Accomplishments

Workshop

27 participants:

Federal Agencies
(DOE, USDA, DOD, BEA, EPA)

National Labs
(ANL, NREL, INL, ORNL)

Universities
(CSM, LTU, MSU, NCSU)

Industry
(Cotton Inc.)

Creating a Framework for Economic and Environmental Assessment of the U.S. Bioeconomy
February 27, 2018
National Renewable Energy Laboratory, Golden, CO

Agenda

Block	*Title/Topic*	*Speakers*
1	Welcome to NREL	Adam Bratis, NREL
	BETO's Role in Economic and Environmental Assessment of the Bioeconomy	Kristen Johnson, DOE
	The Need for a Framework for Economic and Environmental Assessment of the Bioeconomy	Helena Chum, NREL
	How We Plan to Create a Framework for Economic and Environmental Assessment of the Bioeconomy	Troy Hawkins, Franklin Associates
	Discussion – Block 1	
2	U.S. Environmentally-Extended Input Output Model and State-based Modeling	Wes Ingwersen, EPA NRMRL
	2017 U.S. Energy and Employment Report (USEER) – Overview and methodology.	Kirsten Verclas DOE/Office of Policy (overview) and David Keyser, NREL (methodology)
	Discussion – Block 2	
3	Invited comments	Chris Clark (EPA) Amy Landis (CMU)
4	The USDA Economic Impact Analysis of the U.S. Biobased Products Industry – Overview and methodology	Karen Zhang, USDA (overview) and Jesse Daystar, Cotton Inc. (methodology)
5	Bioeconomy Scenarios, Indicators, and Economic Analysis	Keith Kline, ORNL
	Bioeconomy AGE and the GREET Biofuels Program	Michael Wang, ANL
	The Jobs and Economic Development Impact (JEDI) of Biofuels	Yimin Zhang, NREL
	Discussion – Blocks 3-5 & closing	

Accomplishments

Expert workshop outcome: confirmation of suggested Integrated Analysis Framework

Data & Model Inputs

Federal data & models
- **EPA** U.S. Environmentally-Extended Input Output (**USEEIO**) model
- **BEA** Economic Input Output Tables
- EPA Inventories (TRI, NEI)
- BLS Employment
- Economic Census / BEA NIPA
- USDA Ag Census / Surveys
- EIA Energy Prod. / Consumption

Disaggregation & scenario details
- Biofuel TEAs (NREL, PNNL)
- Reference system, net effects (ORNL, NREL)
- Process-based LCA: GREET (ANL)
- Job economic analyses: JEDI (NREL)

Main Model

BioEconomy IO Model (BEIOM)

National USEEIO
Bioeconomy sectors
Regional detail

EPA Tool for the Reduction and Assessment of Chemical and Environmental Impacts (**TRACI**)

Datasets
- Python coded framework (open source)
- Excel output (illustration)

Output Metrics

- **Economic**
  - Employment (Jobs)
  - GDP (Value-added)
- **Air, water & soil**
  - GHG emissions
  - Air pollutants
  - Pesticides
  - Smog formation
  - Respiratory effects
  - Human toxicity
  - Eutrophication
  - Ecosystem toxicity
  - Acidification
  - Ozone depletion
- **Natural resource use**
  - Water
  - Land
  - Energy
  - Mineral

NEI: National Emissions Inventory
NIPA: National Income and Product Account
TRI: Toxics Release Inventory
USEEIO: U.S. Environmentally-Extended Input-Output Model

Accomplishments

Validation test case: corn ethanol (retrospective)

- Important part of the current bioeconomy
- Large amount of public industry data (for disaggregating economic activities)
- Wealth of peer-reviewed literature (for results comparison and model calibration)

Scenarios/Results

1. National: Effects ***per MJ***
2. National: Effects *per MJ* ***over different years***
3. National: Effects in relation to the ***total*** U.S. economy
4. National: Differences between products on a MJ basis
5. *Regional*: Effects *per MJ* ***across regions***

Metrics/Parameters

CO2e: GHG emissions (kg CO2 eq)
H2O: Water consumption (m3 H2O)
Land: Land use (m2)
Smog: Smog formation potential (kg O3 eq)
EP: Eutrophication potential (kg N eq)
AP: Acidification potential (kg SO2 eq)
ETX: Ecotoxicity (CTUe)
NREU: Non renewable energy use (MJ)
FD: Final Demand (US$)

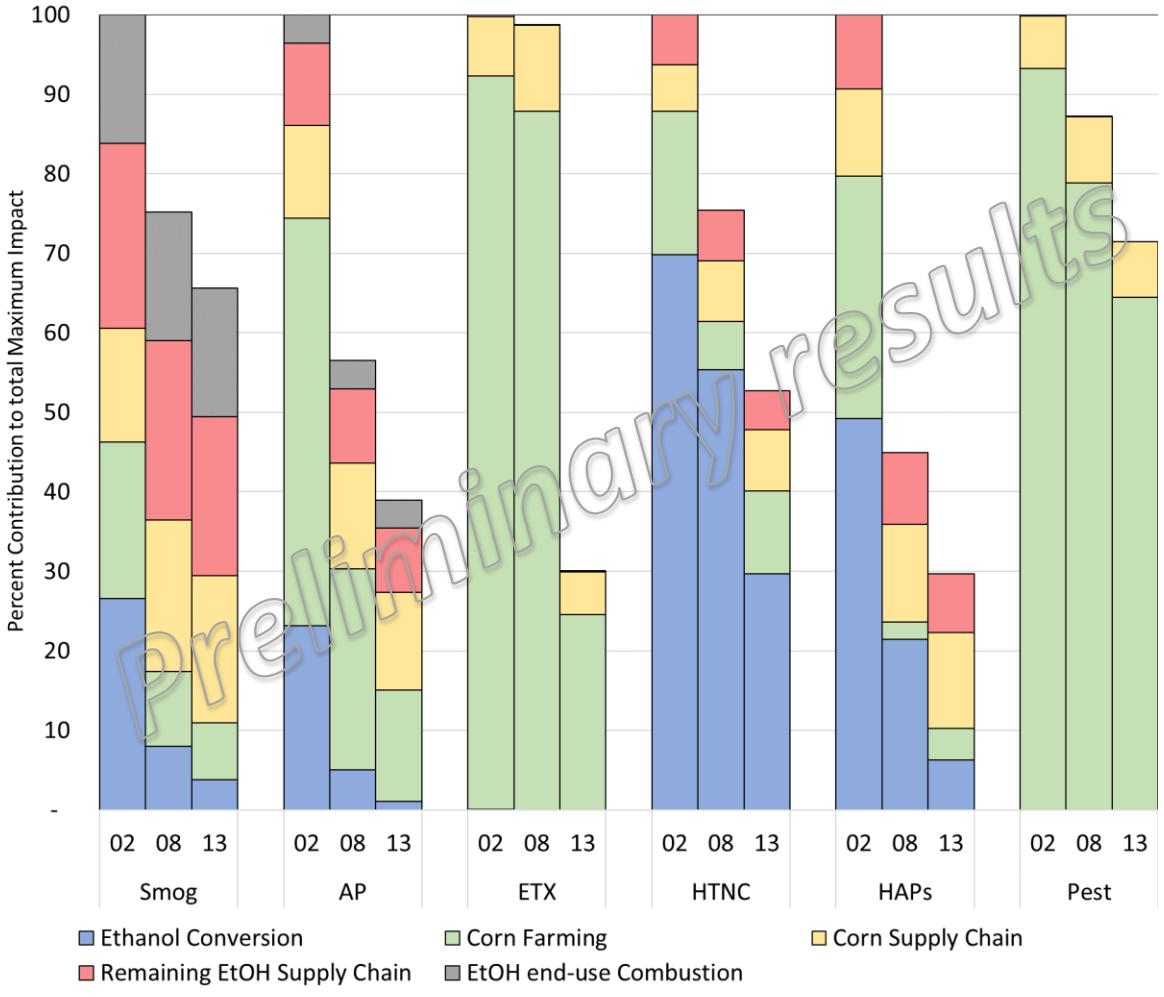
HTNC: Human toxicity, non-cancer potential (CTUh)
HTC: Human toxicity, cancer potential (CTUh)
RE: Respiratory effects (kg PM2.5 eq)
ODP: Ozone depleting potential (kg CFC-11 eq)
Minerals: Total mineral use (kg)
HAPs: Total release of hazardous air pollutants (kg)
Pest: Total release of pesticides (kg)
Jobs: Total direct jobs (persons)
Value-add: Gross Domestic Product (US$)

Accomplishments

National: Selected effects *per MJ* over *different years (2002, 2008, 2013)*

Time series evaluation within 2002 as the reference year (100%)

Demonstrates improvements across several impact categories



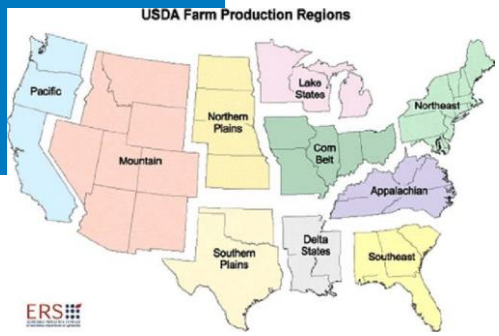
Significant improvements in emission reductions at the ethanol facilities have resulted in much lower *Smog* formation, acidification potential (*AP*), human toxicity non-cancer (*HTNC*), hazardous air pollutants (*HAPs*) over the periods investigated.

Impacts from pesticide use (*Pest*) for corn farming have decreased over time, and an even greater drop in ecotoxicity (*ET*), reflecting a shift towards less toxic pesticides.

← Years

← Parameters: see slide 14

Accomplishments

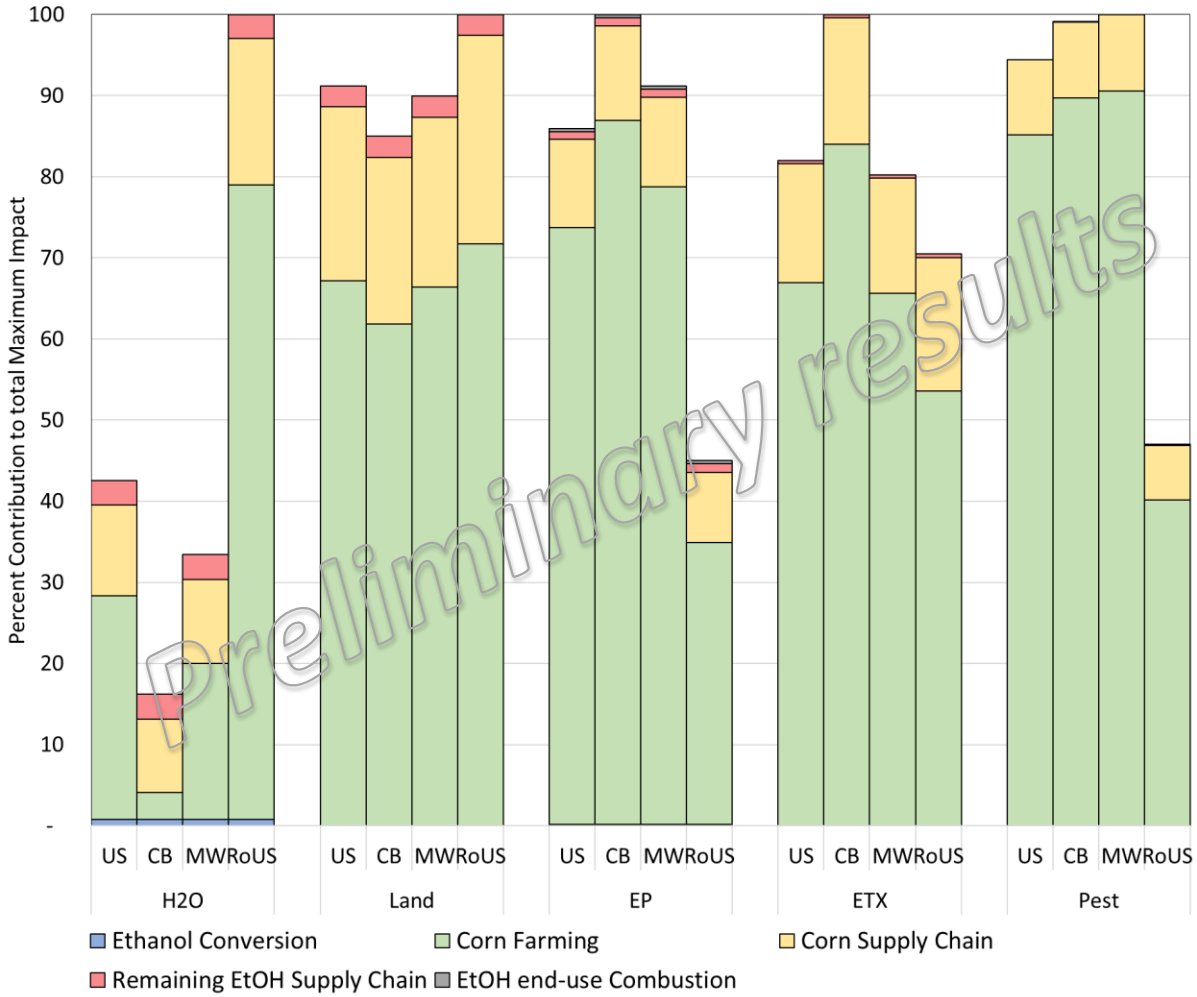


Regional*: Selected effects *per MJ across regions (2013)

National (US), Corn Belt (CB), Midwest (MW), Rest of US (RoUS)

Regional distribution of national supply chain effects

Effects not geospatially homogenous



Regional variation in fertilizer applications, nutrient runoff, water use, and pesticide applications result in noticeable differences in regional life cycle water consumption (*H2O*), eutrophication potential (*EP*), and ecotoxicity potential (*ETX*).

In particular, the Midwest and Corn Belt have lower than average rates of water use, but higher than average rates of fertilizer applications (and runoff) and pesticide applications.

← Regions

← Parameters: see slide 14

Accomplishments

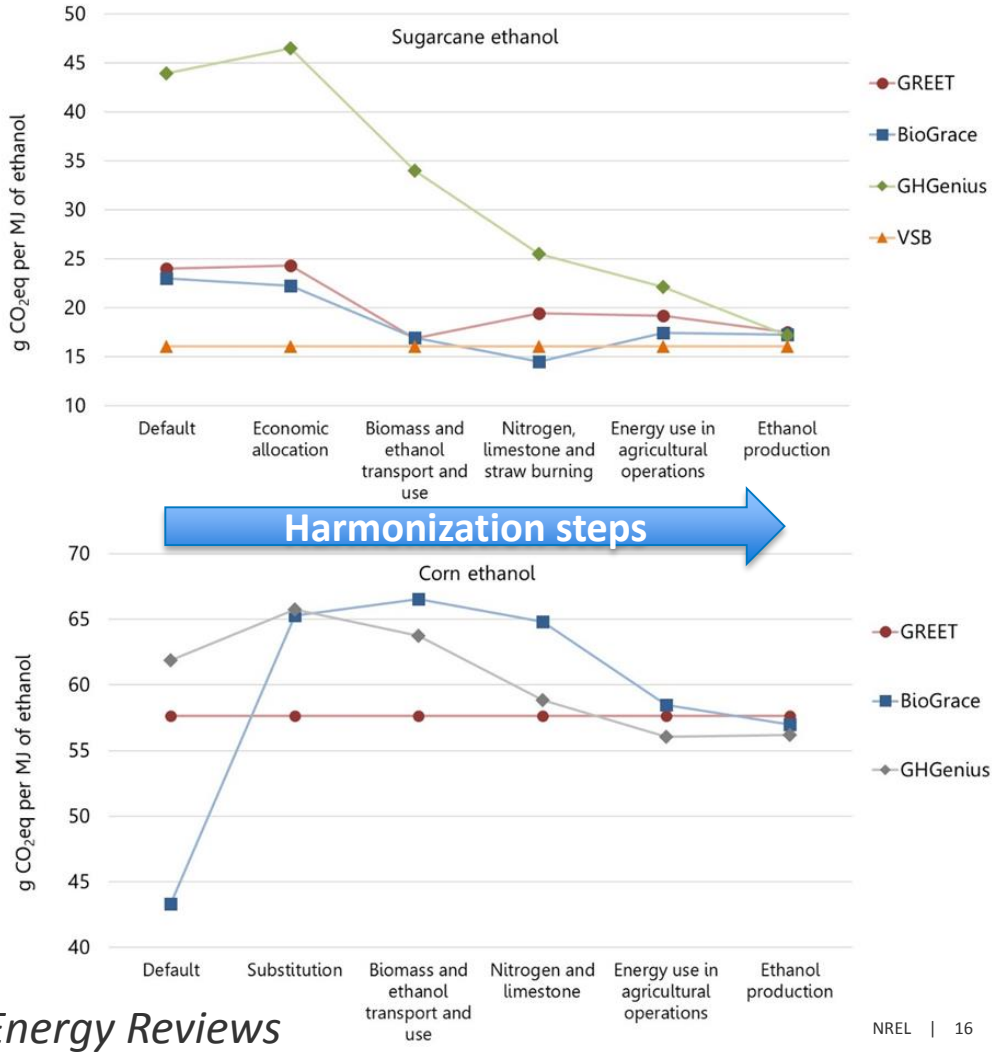
IEA Bioenergy

Multilateral studies on LCA metrics, tools, and analysis: comparisons and critical reviews

Studies show (mis-)alignment in methods and tools to assess sustainability effects

Conclude that further alignment/harmonization is required to deliver consistent results

- Example: Comparison of life-cycle emissions for ethanol pathways across LCA tools with regulatory relevance.
- Goal: evaluate the methodological and data alignment across the tools.
- Results: Heavy discrepancies across the tools resulting mainly from differences in default values, but also allocation.
- Following a harmonization of data and allocation methods, the tools eventually show similar results.
- Conclusion: Need for additional global harmonization and alignment of data and tools in LCA.



Accepted in *Renewable and Sustainable Energy Reviews*

Accomplishments

IEA Bioenergy

Examples of scientific review and collaboration activities

Workshops and multilateral studies are a critical measure to facilitate scientific exchange

Project ensures U.S. viewpoints on metrics, methods, models are discussed appropriately

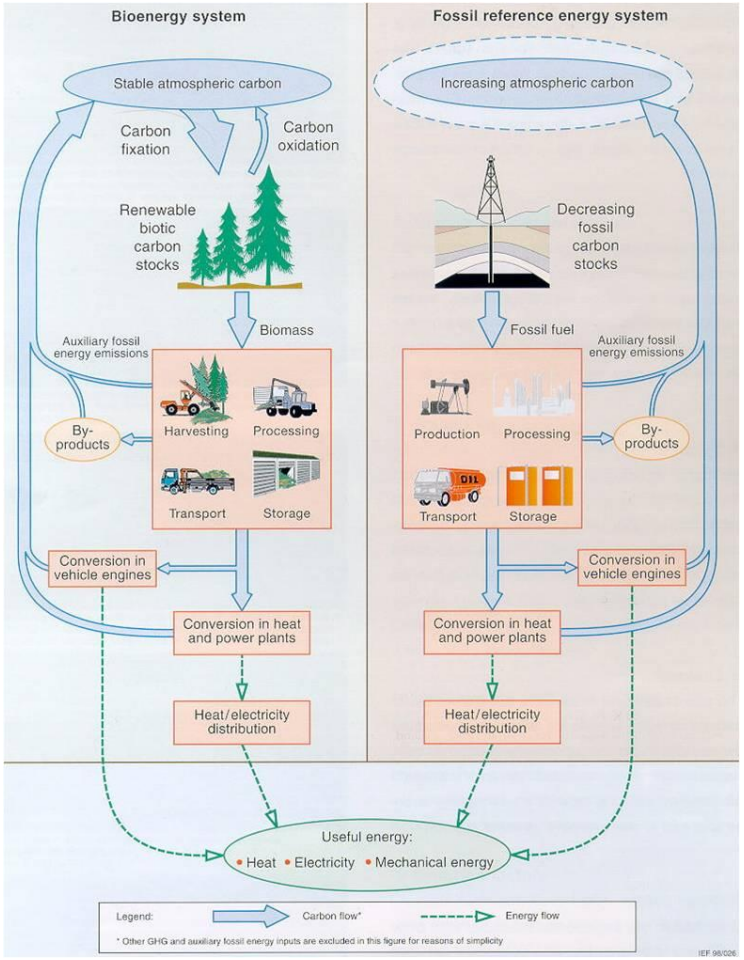
Also ensures U.S. bioproducts and biofuels are represented and modeled correctly, given the potential discrepancies across tools (LCA and other)

Workshops: accounting frameworks & protocols

- Accounting for biogenic carbon in LCA and related national and international frameworks to ensure U.S. forestry practices are appropriately modeled and respective products are not disadvantaged. http://task38.ieabioenergy.com/workshops/

Public Reports: metrics, methods, models

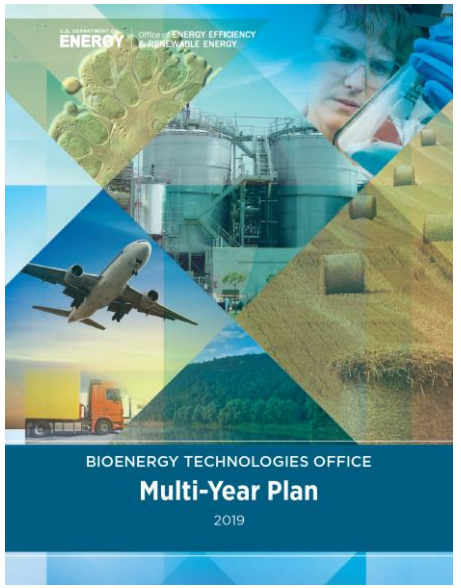
- Standard Methodology – Update:
  Capturing the latest, best available knowledge and state-of-the art methods for modeling the effects of biomass and bioenergy systems.
- Review of Integrated Assessment Model (IAM) assumptions with respect to bioenergy, e.g., land-use (change), yield improvements, etc.
  http://task38.ieabioenergy.com/iea-publications/



Relevance

- To develop a coherent **methodology** and consistent **model framework** to quantify the **net effects** of an expanding U.S. bioeconomy at national and regional levels.
- To **inform BETO's strategic decision making** by engaging in and synthesizing key **global multilateral activities** that develop, compare or apply metrics, methods, and tools to quantify the sustainability effects of specific bioeconomy products.

- Directly supports an A&S milestone of BETO's MYP: "By 2019 complete a model framework to support multi-dimensional analysis on specific economic, environmental, and other benefits of an expanding bioeconomy".
- Fills an analysis gap in BETO's sustainability efforts previously identified by 2015 & 2017 Peer Review and through international requests (e.g., GBEP)
- Important for BETO's Sustainability Strategy
  - Model and method to quantify net effects (bioeconomy)
  - Unique: economy wide picture
  - Integrated: economic and environmental effects
  - First of a kind for the bioeconomy



Relevance

- Supports *consensus* on metrics, common models, and quantification of the net effects of bioeconomy products across federal agencies and country-level initiatives:
  - Bioeconomy spans across sectors and U.S. agencies: integrated framework assessing net effects important to DOE and other federal agencies (EPA, USDA)
  - Present lack of NAICS codes for consistent quantification of the U.S. "bioeconomy"
  - Specific DOE motivation to address interagency needs including Biomass R&D Board
  - Ongoing discussions with USDA, EPA on method and model development with the potential to influence future NAICS code definitions

- Ensures U.S. definitions, metrics, methods, and tools for the integrated sustainability analysis of bioeconomy products are considered and appropriately discussed across selected global scientific and technology collaboration programs.

Future work

Integrated analysis framework: method and model development

- **Vetting of method and results, potential recalibration (FY19)**
  - Finalize white paper of the corn ethanol test case (retrospective) with details on applied methodology and results (currently in draft form)
  - Peer-review of method and results through external experts (ongoing)
  - Recalibrate model and adjust methodology as needed

- **Continuous development of net effects methodology (FY19-20)**
  - Continue collaboration with ORNL and other experts to determine appropriate reference scenarios for net effects
  - Draft a white paper in FY19 and send for external peer-review in FY20

- **Continue staged model build-out**
  - FY19: near-commercial biofuel technologies, e.g., corn fiber ethanol, hydro-processed esters and fatty acids (HEFA), biochemical ethanol
  - FY20-22: BETO R&D pathways (e.g., syngas fermentation)

- **Add prospective analysis capability** (FY20-22)
  - Peer-review of reference scenarios and net effect methodology (FY20)
  - Continue engagement with USDA to determine suitable scenarios of an *expanding* U.S. bioeconomy (FY19-21)
  - Perform prospective scenarios with externally vetted net effect methodology (FY21-22)





Future work

Coordination, integration, consensus: federal and global efforts

- **Model & Methodology:**
  - Deliver framework to DOE BETO to achieve *MYP 2019 Milestone*
  - Continue method validation and model build-out to support *MYP 2025 Milestone:*
    - "By 2025, apply a suite of analytical methods to quantify a range of benefits associated with bioenergy and bioproduct production from biomass and waste streams and identify potential environmental, economic, or social implications that require new R&D solutions."
  - Continue *open source coding* for future *public release* (FY22)
  - Continue *collaboration with EPA* and its related work on regional effects applying the same base model (USEEIO) and coding language

- **National application and consensus:**
  - Continue *exchange with USDA* (and other interested agencies) on appropriate scenarios for an expanding U.S. bioeconomy, bioeconomy definition, and NAICS codes
  - Continue *dialogue with/input to interagency efforts* (e.g. Biomass R&D Board)

- **International application and consensus:**
  - Continue to position the framework as an *international standard*
  - Continue scientific review and advisory role for BETO in multilateral initiatives and collaborations (esp. IEA Bioenergy and GBEP) to create consensus on *metrics, methods and tools* (sustainability analysis of bioeconomy products)

Summary

Approach

- Provide BETO with a *coherent method* and *framework* based on lifecycle (LCA) and economic input-output (IO) analysis, *tested and vetted with stakeholders*, to quantify the *net effects of an expanding U.S. bioeconomy*.
- Inform BETO's decision making by *engaging in, evaluating, and synthesizing selected global activities* that develop, compare or apply metrics, methods, or tools to assess sustainability effects of bioeconomy products.

Accomplishments

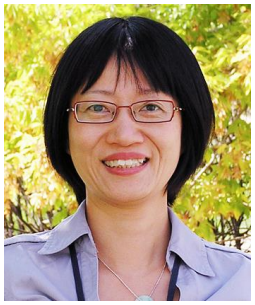
- Integrated modeling approach *confirmed by* practitioners and developers of LCA and IO models.
- Applied model to a *retrospective test case* (corn ethanol) providing multiple scenarios on national and regional level for a range of environmental and economic indicators (*Go Decision* FY18).
- Engaged multiple federal agencies (e.g., EPA, USDA) and informed interagency efforts (Biomass R&D Board).
- Several high level papers and international workshops discussing (LCA) metrics, methods, and tools.

Relevance

- Addresses a *gap in the BETO portfolio* (identified by Peer Review) and a related *BETO MYP milestone (FY19).*
- Develops a *first of a kind integrated* analysis capability, positioned to become an international standard.
- *Supports consensus* across federal agencies and country-level initiatives.

Future Work

- Vetting of test case method and results through *external peer-review*; model recalibration as needed.
- Continue *development of net effect methodology* via collaboration across national labs and federal agencies.
- *Staged model build-out* to include near-commercial and DOE R&D biofuel pathways.
- *Continuous engagement with federal agencies:* model, method development, scenarios, and definitions.


Thank You

www.nrel.gov

patrick.lamers@nrel.gov

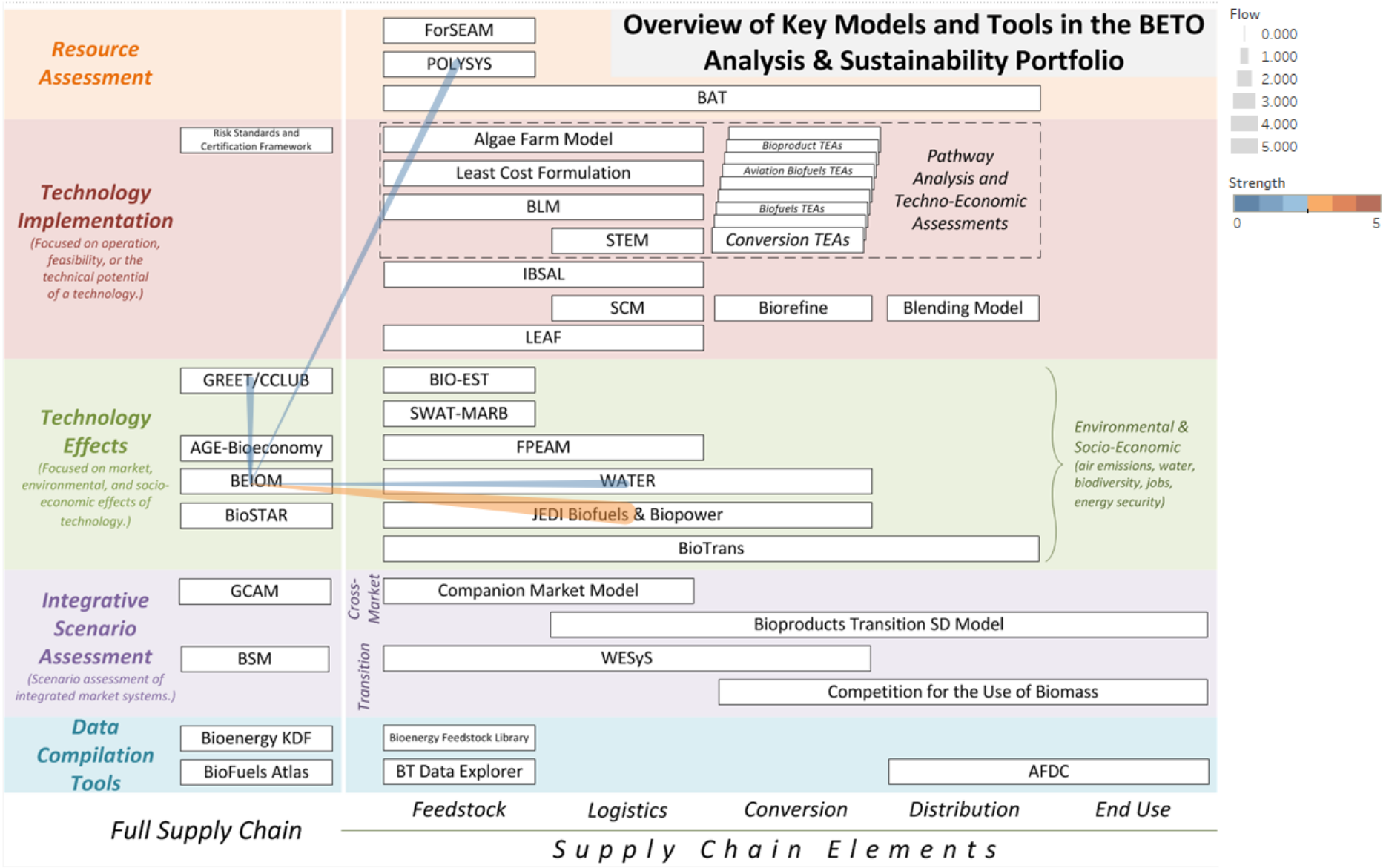
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Additional Slides

4.2.1.31 Integrated Life Cycle Sustainability Analysis

Model linkages: input* from BETO models

*Note: no output to other BETO models at this point

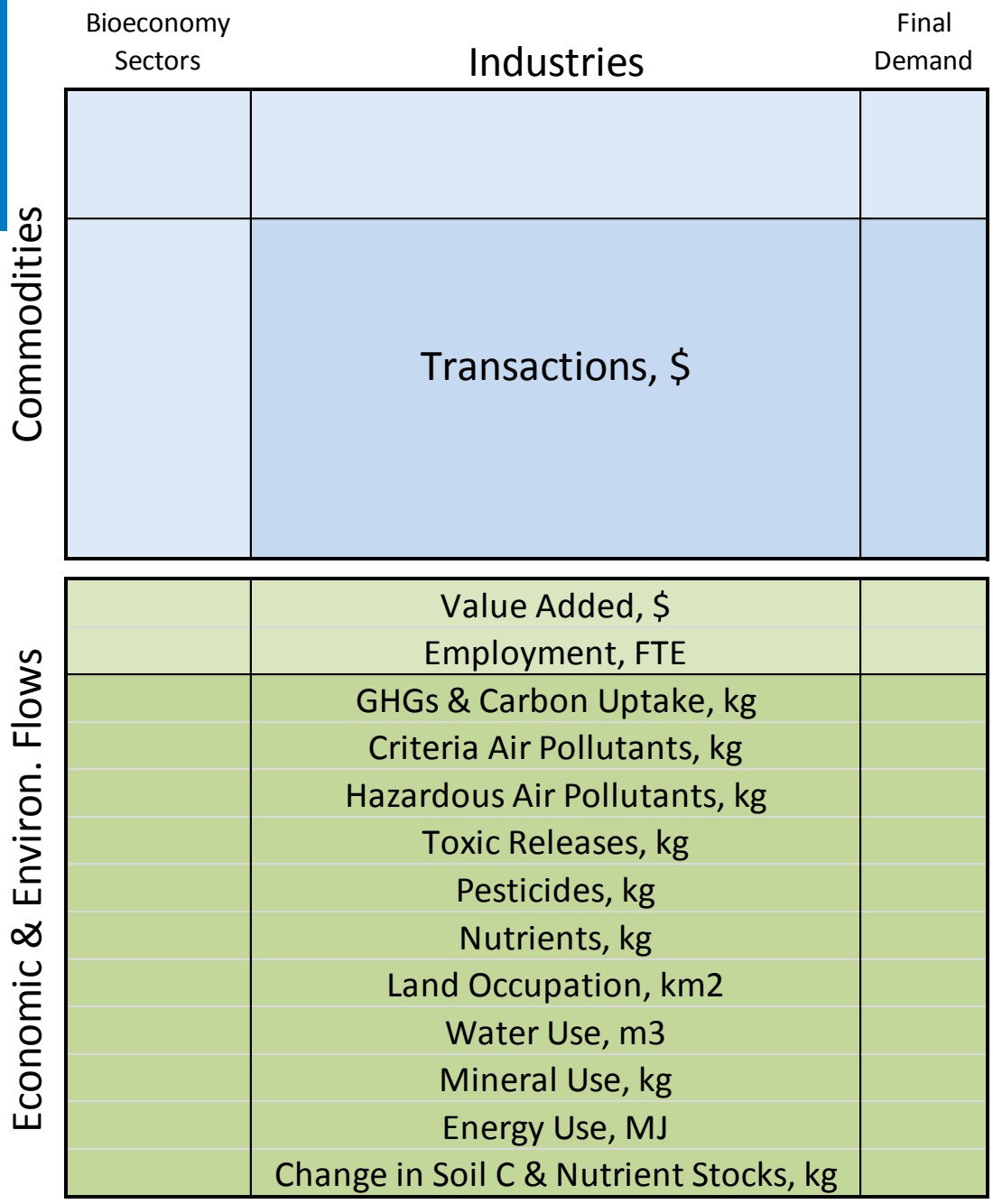


Data and Base Model

U.S. principal statistical collection agencies	
Bureau of Census (Census)	Bureau of Economic Analysis (BEA)
Bureau of Labor Statistics (BLS)	Bureau of Transportation Statistics (BTS)
Economic Research Service (ERS)	National Agricultural Statistics Service (NASS)
Energy Information Administration (EIA)	
Environmental Protection Agency (EPA): Environmental data and extension (USEEIO)	

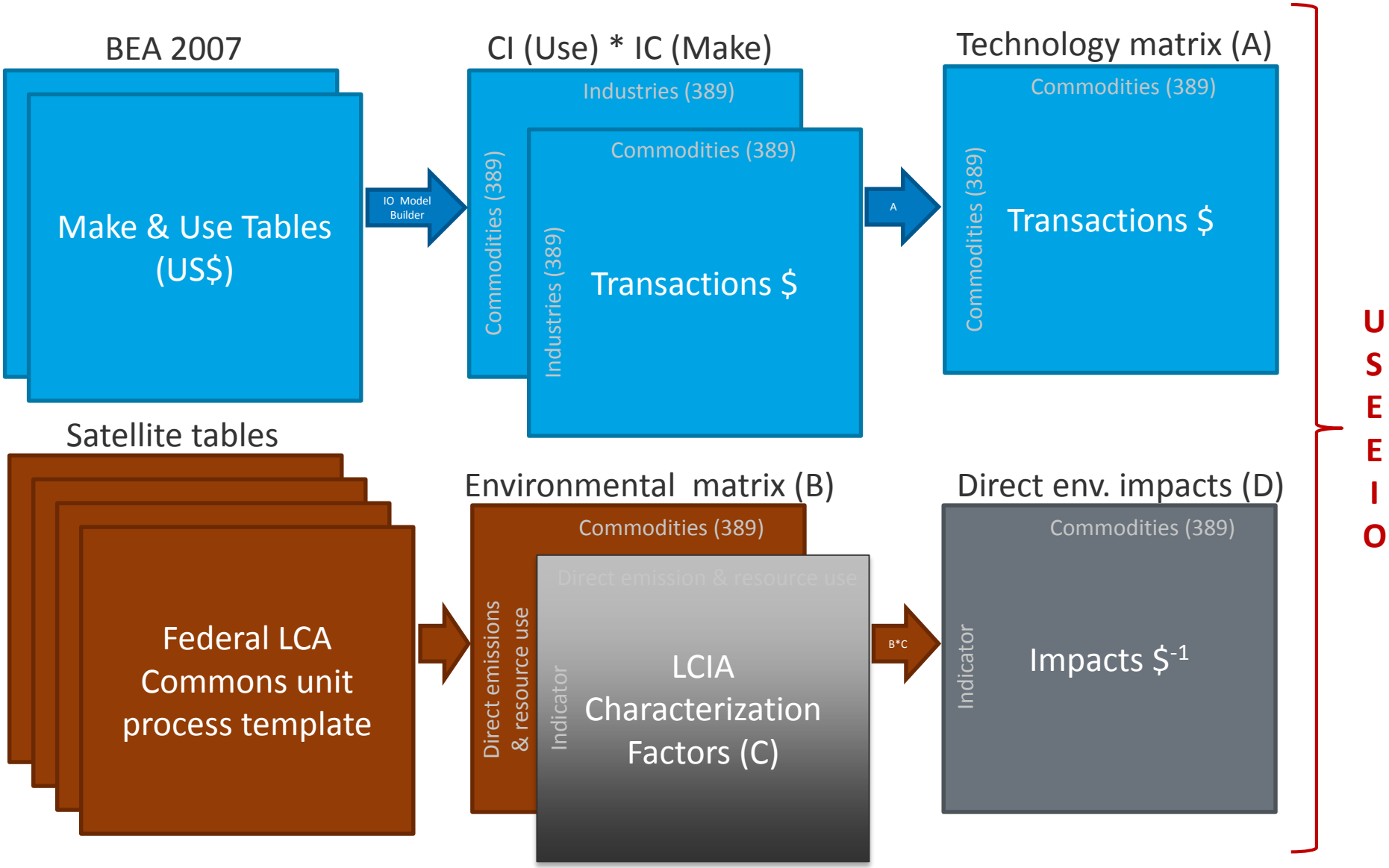
Base Model: USEEIO

- Sector level detail
  (U.S. production & services)
- 389 industry sectors
  (BEA 2007)
- Environmental flows:
  Tracked following Federal LCA Standards, including all relevant flows based on EPA NEI, TRI, and other publicly available data
- Impacts: All TRACI 2.1 impact categories plus land, water, energy, and mineral use



NEI: National Emissions Inventory | TRI: Toxics Release Inventory

Methodology



Reviewers' Comments 2017

- Value from this project comes from its ability to analyze and synthesize key global bioenergy and bioeconomy activities and thereby, identify opportunities and challenges for the expansion of the U.S. bioeconomy and sustainability.
- I applaud the efforts around harmonization of models and assumptions to ensure a more apples-to-apples approach.
- The project appears to play an analytical support role to a variety of […] processes.
- The accomplishments in terms of contributions to high-impact reports and processes […] are among the most impressive in the BETO portfolio.
- Participation in international fora is key to ensure alignment of standards at the global level to reduce trade barriers as well as ensure BETO's portfolio of research and expertise has a two-way channel of communications regarding leading science and best practices.
- Specific achievements […] are […] nebulous.
- The top challenge to maximize strategic value is to identify the most critical issues of alignment/ misalignment emerging from the international discussions and to ensure strong channels of communications to and from BETO's broader portfolio of initiatives.
- This project provides technical expertise and participation in international processes on bioenergy sustainability assessment and is one of the most strategic initiatives in BETO's portfolio.

Response to Reviewers' Comments 2017

- The reviewers summarized very well the difficulty of assessing the broad fields.
- For GHG emissions, looking at fossil energy use and other metrics, there are accessible tools to allow for harmonization of LCA efforts to directly attribute inputs and outputs within the analysis boundaries. Going outside these boundaries to understand emissions over time, space, economic sectors (consequential analyses), and policy implications, methodologies have not reached convergent results and research continues. For the environmental and social indicators, the level of agreement is not the same with significant differences between the US and European countries. Tools for some components are addressed by the program. *Our future work will test multiple approaches and show alignment/misalignment in methodologies used.*
- The harmonization analysis shows that it is important for the actual data for LCAs to come from the country where the resources are used to make the products and fuels.
- The US has multiple data sources and methodologies to evaluate the bioeconomy. We will follow EPA's environmentally extended methodology on an economic input and output basis (developed by EPA and collaborators).
- The data need to be obtained and this is a very strong aspect of BETO through ORNL, ANL, INL, and collaborators' projects, including the USDA, and is already embedded into the efforts of the current IEA Bioenergy Intertask.

Publications & Presentations

Lamers, P., Chum, H. (2017). “Tools for the GHG assessment of biofuels”. Understanding Climate Change Effects of Forest Biomass and Bioenergy Systems. ADEME Workshop. Angers, France, November 7.

Prisley, S., C. Gaudreault, P. Lamers, W. Stewart, R. Miner, M. Junginger, E. Oneil, R. Malmsheimer and T. Volk (2018). "Comment on Sterman, et al. (2018) “Does replacing coal with wood lower CO2 emissions? Dynamic lifecycle analysis of wood bioenergy”." *Environmental Research Letters.*

Pereira, L.G., Cavalett, O., Bonomi, A. Zhang, Y., Warner, E., Chum, H. (accepted). Comparison of biofuel life-cycle GHG emissions assessment tools: the case studies of ethanol produced from sugarcane, corn, and wheat. *Renewable and Sustainable Energy Reviews*.

Contributions to various studies, presentations and workshop material:
http://task38.ieabioenergy.com/iea-publications/
http://task38.ieabioenergy.com/workshops/

Abbreviations & Acronyms

A&S: Analysis & Sustainability
ANL: Argonne National Laboratory
AFDC: Alternative Fuels Data Center
BEA: Bureau of Economic Analysis
BEIOM: Bioeconomy Environmentally extended Input-Output Model
BETO: (DOE) Bioenergy Technologies Office
BLS: Bureau of Labor Statistics
CSM: Colorado School of Mines
DOD: U.S. Department of Defense
DOE: U.S. Department of Energy
EIA: Energy Information Administration
EPA: U.S. Environmental Protection Agency
FAO: Food and Agriculture Organization of the United Nations
GBEP: Global Bio-Energy Partnership
INL: Idaho National Laboratory
IO: Input-Output
LCA: Life Cycle Analysis
LTU: Louisiana Technical University
MJ: Mega Joule
MSU: Michigan State University
MYP: Multi-Year Plan (DOE BETO)
NAICS: North American Industry Classification System
NCSU: North Carolina State University
NIPA: National Income and Product Account
NEI: National Emissions Inventory
NRMRL: National Risk Management Research Laboratory (EPA)
ORNL: Oak Ridge National Laboratory
R&D: Research & Development
TRI: Toxics Release Inventory
USDA: U.S. Department of Agriculture; OCE: Office of the Chief Economist; OSE: Office of the Chief Scientist
USEEIO: U.S. Environmentally-Extended Input-Output Model