DOE Bioenergy Technologies Office (BETO)
2015 Project Peer Review

Pathways Toward Sustainable Bioenergy Feedstock Production in the Mississippi River Watershed

March 24, 2015
Analysis and Sustainability Review

Jason Hill
University of Minnesota

Goal Statement

- The overall goal of this project is to use an ecosystem service framework to evaluate the environmental impact of biomass production options and their placement on the landscape so as to guide the burgeoning bioenergy industry toward greater sustainability. We are providing actionable information on the life cycle environmental impacts of biomass production and use.

Quad Chart Overview

Timeline

- Project start date: 9/30/2010
- Project end date: 12/31/2015
- Percent complete: 85%

Budget

	Total Costs FY 10 – FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date
DOE Funded	$104k	$93k	$149k	$300k
Project Cost Share (Comp.)*	90k	$67k	$10k	$27k

Barriers

- Barriers addressed
  - St-C. Sustainability Data Across the Supply Chain
  - St-D. Implementing Indicators and Methodology for Evaluating and Improving Sustainability
  - St-E. Best Practices for Systems for Sustainable Bioenergy Production
  - Ft-A. Feedstock Availability and Cost
  - Ft-B. Sustainable Production

Partners

- All work is being conducted at the University of Minnesota.
- Ongoing collaborative work with ANL, NREL, and ORNL

1 - Project Overview

- Achieving multiple sustainability goals requires simultaneous consideration of multiple sustainability indicators.
- The modeling system employed in this project allows for comparison among multiple sustainability indicators using a common metric ($).
- Our life cycle approach assists in identifying potential roadblocks in the sustainable development of the bioeconomy.

2 – Approach (Technical)

- *We have sought to advance the quantification and valuation of ecosystem services, with particular focus on air quality.*
- *Our overall approach has been to integrate the life cycle approach with other modeling efforts (e.g., Agro-IBIS, InVEST, WRF-chem).*
- *Our critical success factors include:*
  - *Publication of results in high-impact journals*
  - *Communication of results through highly-visible media*
  - *Invitations for continued collaboration beyond the duration and scope of this project*

2 – Approach (Management)

- *Focus on providing actionable information to DOE, industry, policy makers, regulators, and the public*
- *Encourage flexibility to explore emerging opportunities for high-impact work and as they arise*
- *Leverage related projects within our research group*
- *Foster ongoing synergies with National Laboratories*
- *Use project as opportunity to train graduate students and postdocs for advancement in field.*
- *Establish research directions that can be sustained beyond the duration of this project.*

3 – Technical Accomplishments/ Progress/Results

Environmental Science & Technology

September 17, 2013
Volume 47
Number 18
pubs.acs.org/est

Achieving
U.S. Renewable Fuel Standards:
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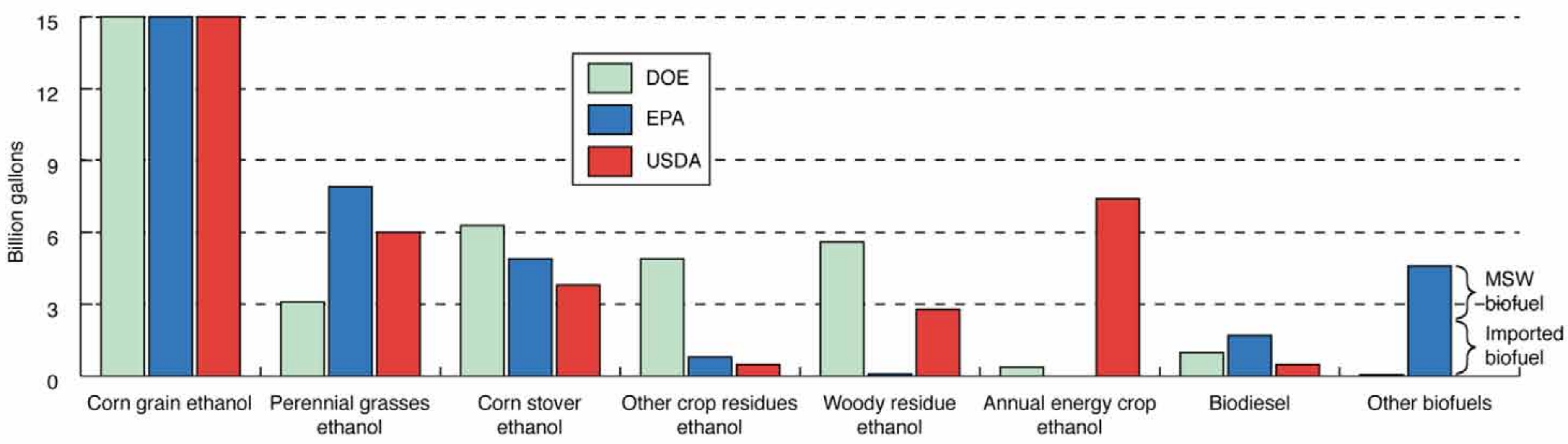
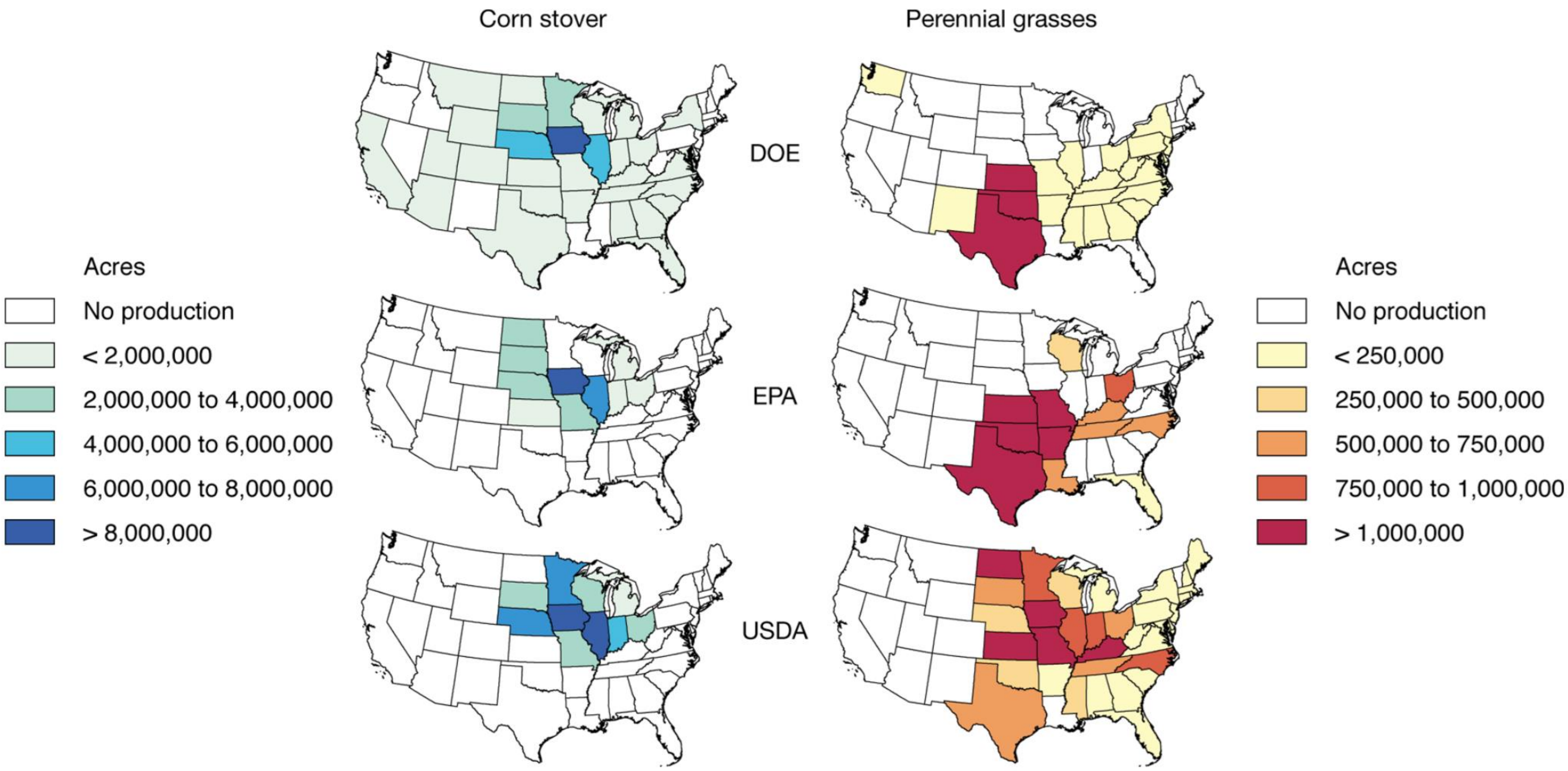
Keeler *et al.* (2013)

3 – Technical Accomplishments/ Progress/Results (cont'd)



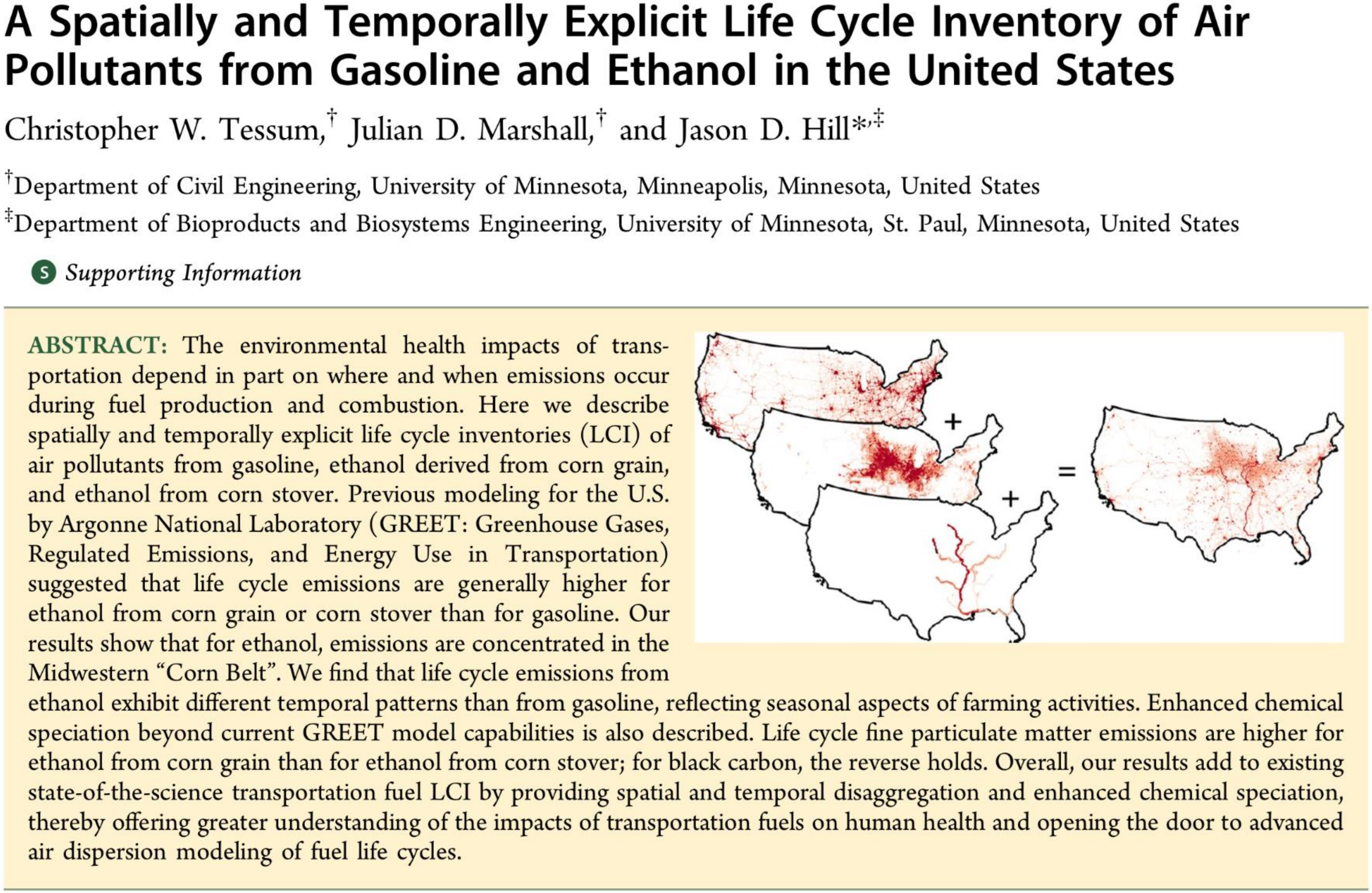
Keeler *et al.* (2013)

3 – Technical Accomplishments/ Progress/Results (cont'd)



Keeler *et al.* (2013)

3 – Technical Accomplishments/ Progress/Results (cont'd)



A Spatially and Temporally Explicit Life Cycle Inventory of Air Pollutants from Gasoline and Ethanol in the United States

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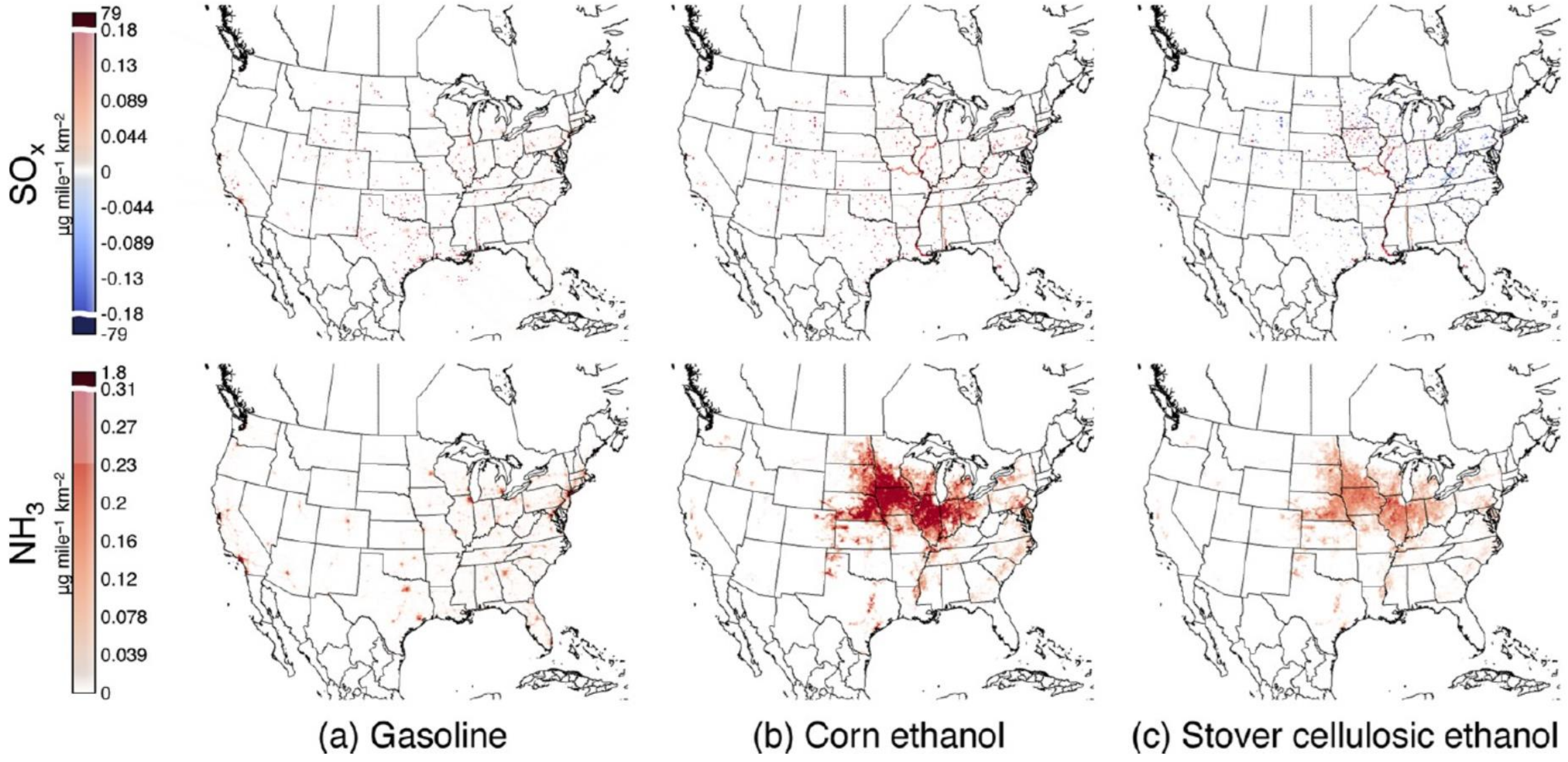
[‡]Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, Minnesota, United States

Supporting Information

ABSTRACT: The environmental health impacts of transportation depend in part on where and when emissions occur during fuel production and combustion. Here we describe spatially and temporally explicit life cycle inventories (LCI) of air pollutants from gasoline, ethanol derived from corn grain, and ethanol from corn stover. Previous modeling for the U.S. by Argonne National Laboratory (GREET: Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) suggested that life cycle emissions are generally higher for ethanol from corn grain or corn stover than for gasoline. Our results show that for ethanol, emissions are concentrated in the Midwestern "Corn Belt". We find that life cycle emissions from ethanol exhibit different temporal patterns than from gasoline, reflecting seasonal aspects of farming activities. Enhanced chemical speciation beyond current GREET model capabilities is also described. Life cycle fine particulate matter emissions are higher for ethanol from corn grain than for ethanol from corn stover; for black carbon, the reverse holds. Overall, our results add to existing state-of-the-science transportation fuel LCI by providing spatial and temporal disaggregation and enhanced chemical speciation, thereby offering greater understanding of the impacts of transportation fuels on human health and opening the door to advanced air dispersion modeling of fuel life cycles.

Tessum *et al.* (2012)

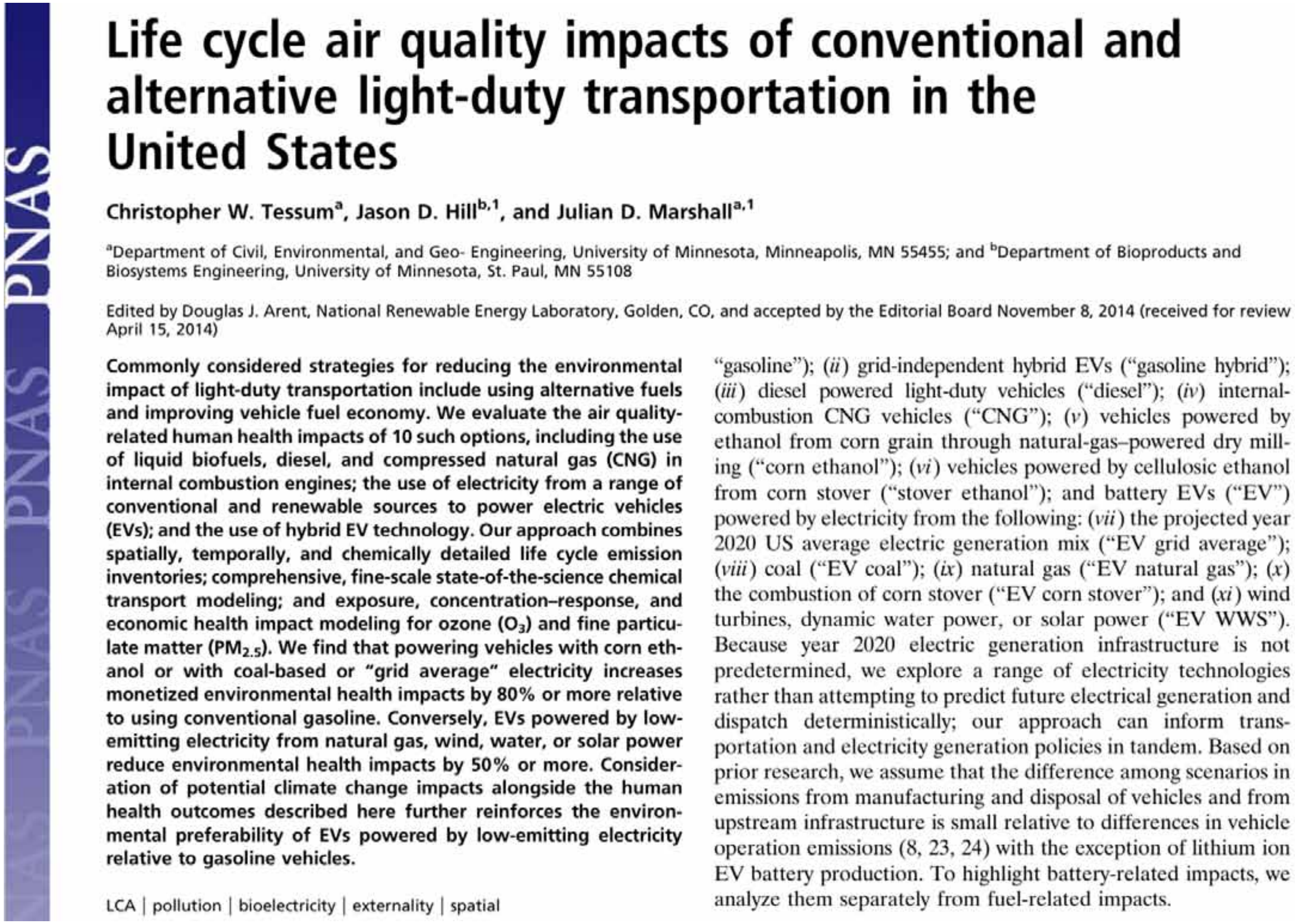
3 – Technical Accomplishments/ Progress/Results (cont'd)



(a) Gasoline (b) Corn ethanol (c) Stover cellulosic ethanol

Tessum *et al.* (2012)

3 – Technical Accomplishments/ Progress/Results (cont'd)



Life cycle air quality impacts of conventional and alternative light-duty transportation in the United States

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Edited by Douglas J. Arent, National Renewable Energy Laboratory, Golden, CO, and accepted by the Editorial Board November 8, 2014 (received for review April 15, 2014)

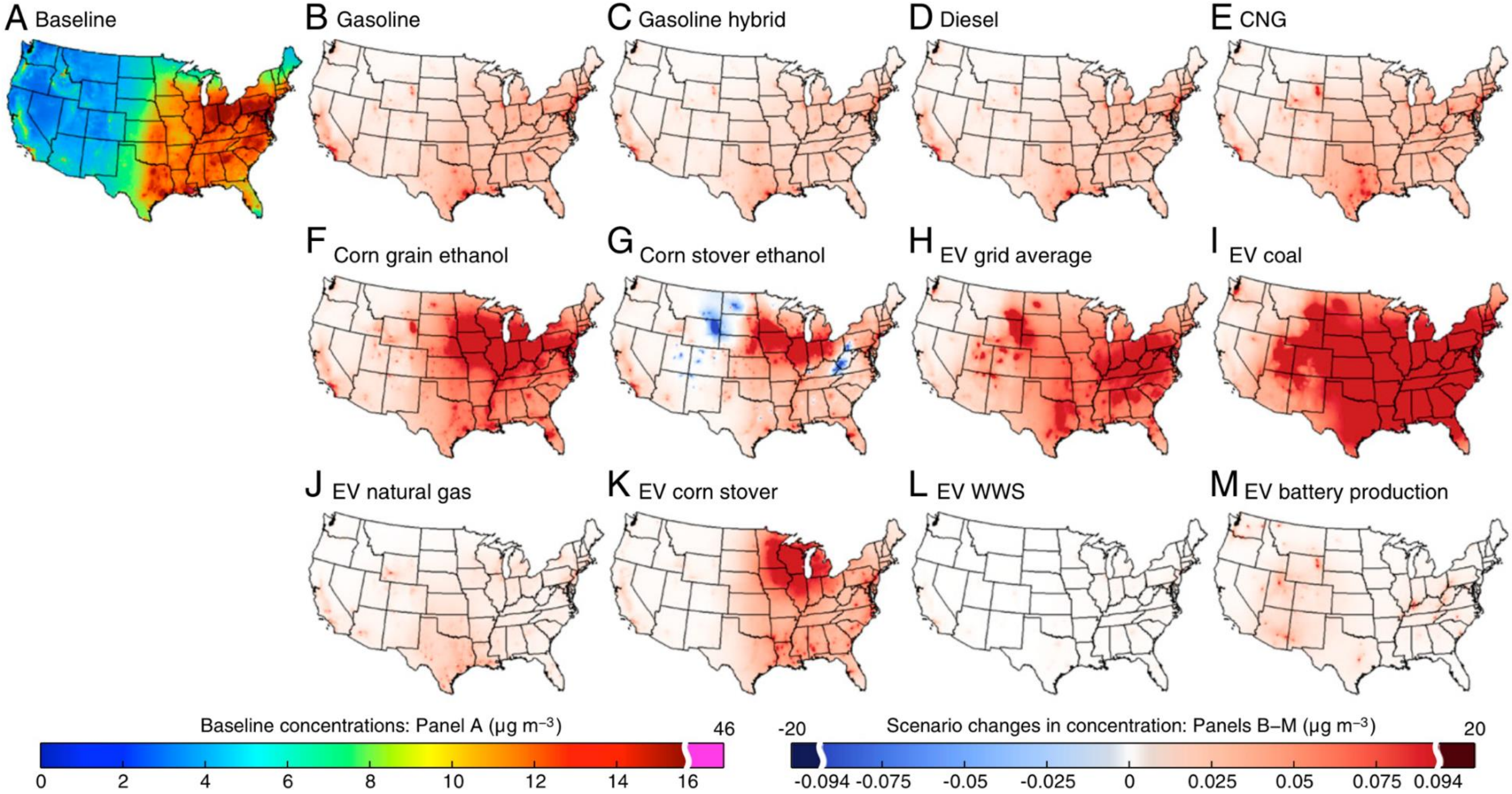
Commonly considered strategies for reducing the environmental impact of light-duty transportation include using alternative fuels and improving vehicle fuel economy. We evaluate the air quality-related human health impacts of 10 such options, including the use of liquid biofuels, diesel, and compressed natural gas (CNG) in internal combustion engines; the use of electricity from a range of conventional and renewable sources to power electric vehicles (EVs); and the use of hybrid EV technology. Our approach combines spatially, temporally, and chemically detailed life cycle emission inventories; comprehensive, fine-scale state-of-the-science chemical transport modeling; and exposure, concentration–response, and economic health impact modeling for ozone (O_3) and fine particulate matter ($PM_{2.5}$). We find that powering vehicles with corn ethanol or with coal-based or "grid average" electricity increases monetized environmental health impacts by 80% or more relative to using conventional gasoline. Conversely, EVs powered by low-emitting electricity from natural gas, wind, water, or solar power reduce environmental health impacts by 50% or more. Consideration of potential climate change impacts alongside the human health outcomes described here further reinforces the environmental preferability of EVs powered by low-emitting electricity relative to gasoline vehicles.

LCA | pollution | bioelectricity | externality | spatial

"gasoline"); (*ii*) grid-independent hybrid EVs ("gasoline hybrid"); (*iii*) diesel powered light-duty vehicles ("diesel"); (*iv*) internal-combustion CNG vehicles ("CNG"); (*v*) vehicles powered by ethanol from corn grain through natural-gas–powered dry milling ("corn ethanol"); (*vi*) vehicles powered by cellulosic ethanol from corn stover ("stover ethanol"); and battery EVs ("EV") powered by electricity from the following: (*vii*) the projected year 2020 US average electric generation mix ("EV grid average"); (*viii*) coal ("EV coal"); (*ix*) natural gas ("EV natural gas"); (*x*) the combustion of corn stover ("EV corn stover"); and (*xi*) wind turbines, dynamic water power, or solar power ("EV WWS"). Because year 2020 electric generation infrastructure is not predetermined, we explore a range of electricity technologies rather than attempting to predict future electrical generation and dispatch deterministically; our approach can inform transportation and electricity generation policies in tandem. Based on prior research, we assume that the difference among scenarios in emissions from manufacturing and disposal of vehicles and from upstream infrastructure is small relative to differences in vehicle operation emissions (8, 23, 24) with the exception of lithium ion EV battery production. To highlight battery-related impacts, we analyze them separately from fuel-related impacts.

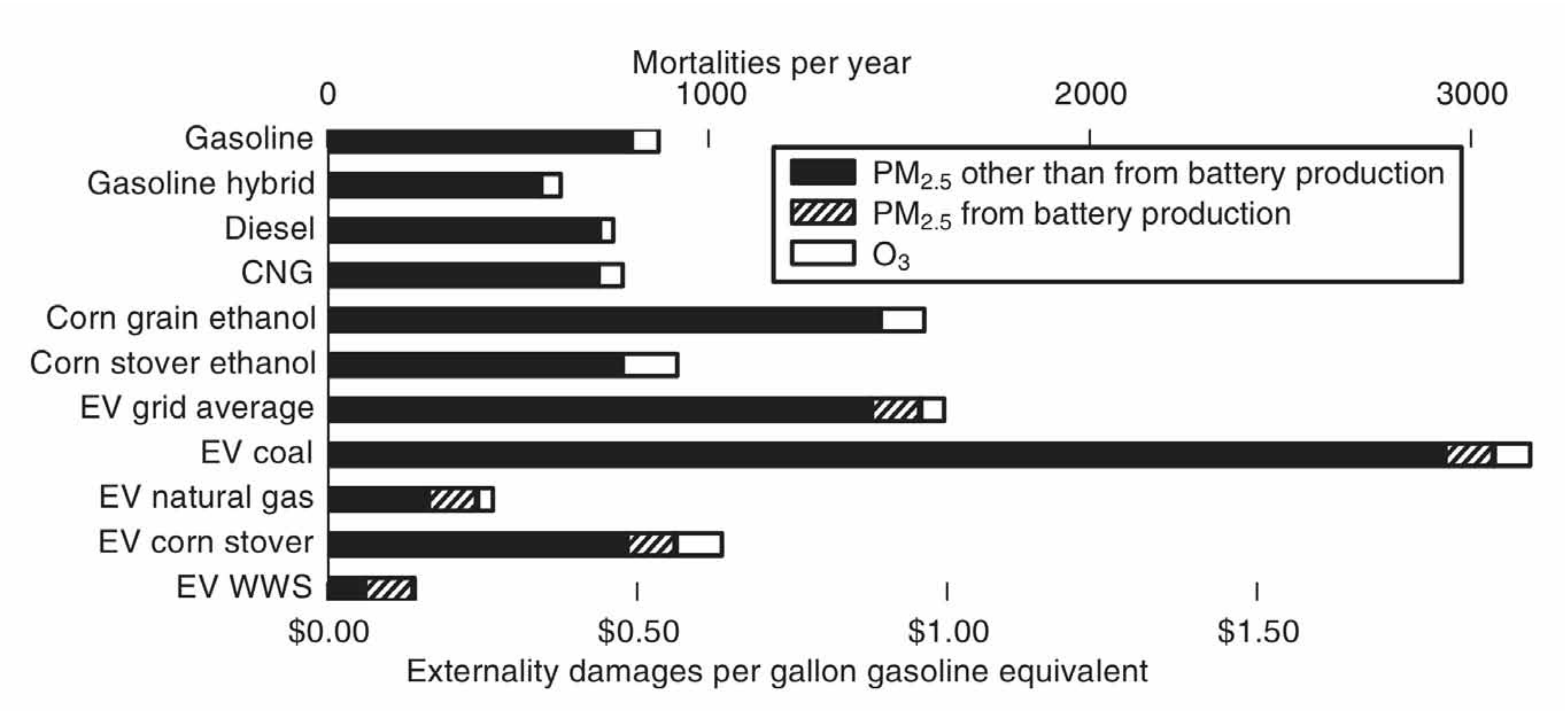
Tessum *et al.* (2014a)

3 – Technical Accomplishments/ Progress/Results (cont'd)



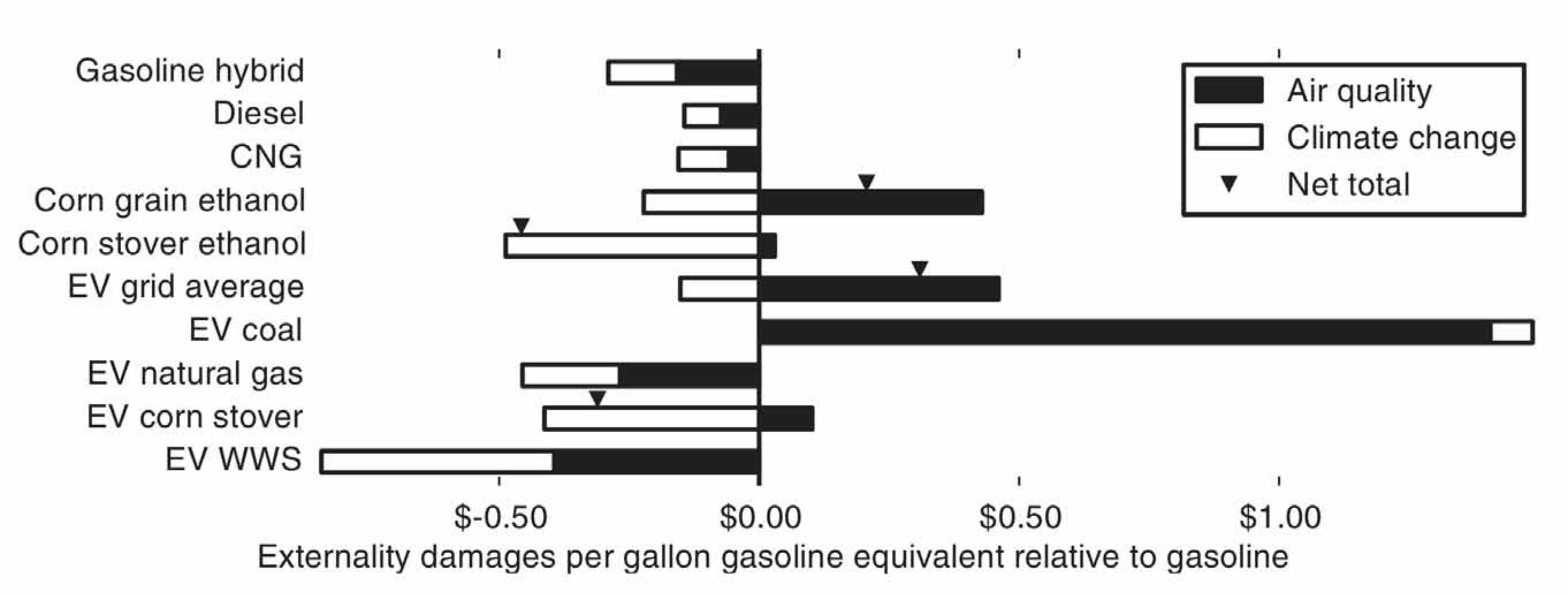
Tessum *et al.* (2014a)

3 – Technical Accomplishments/ Progress/Results (cont'd)



Tessum *et al.* (2014a)

3 – Technical Accomplishments/ Progress/Results (cont'd)



Tessum *et al.* (2014a)

3 – Technical Accomplishments/ Progress/Results (cont'd)

Geosci. Model Dev. Discuss., 7, 8433–8476, 2014
www.geosci-model-dev-discuss.net/7/8433/2014/
doi:10.5194/gmdd-7-8433-2014

Geoscientific
Model Development
Discussions
Open Access

Twelve-month, 12 km resolution North American WRF-Chem v3.4 air quality simulation: performance evaluation

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Tessum *et al.* (2014b)

3 – Technical Accomplishments/ Progress/Results (cont’d)

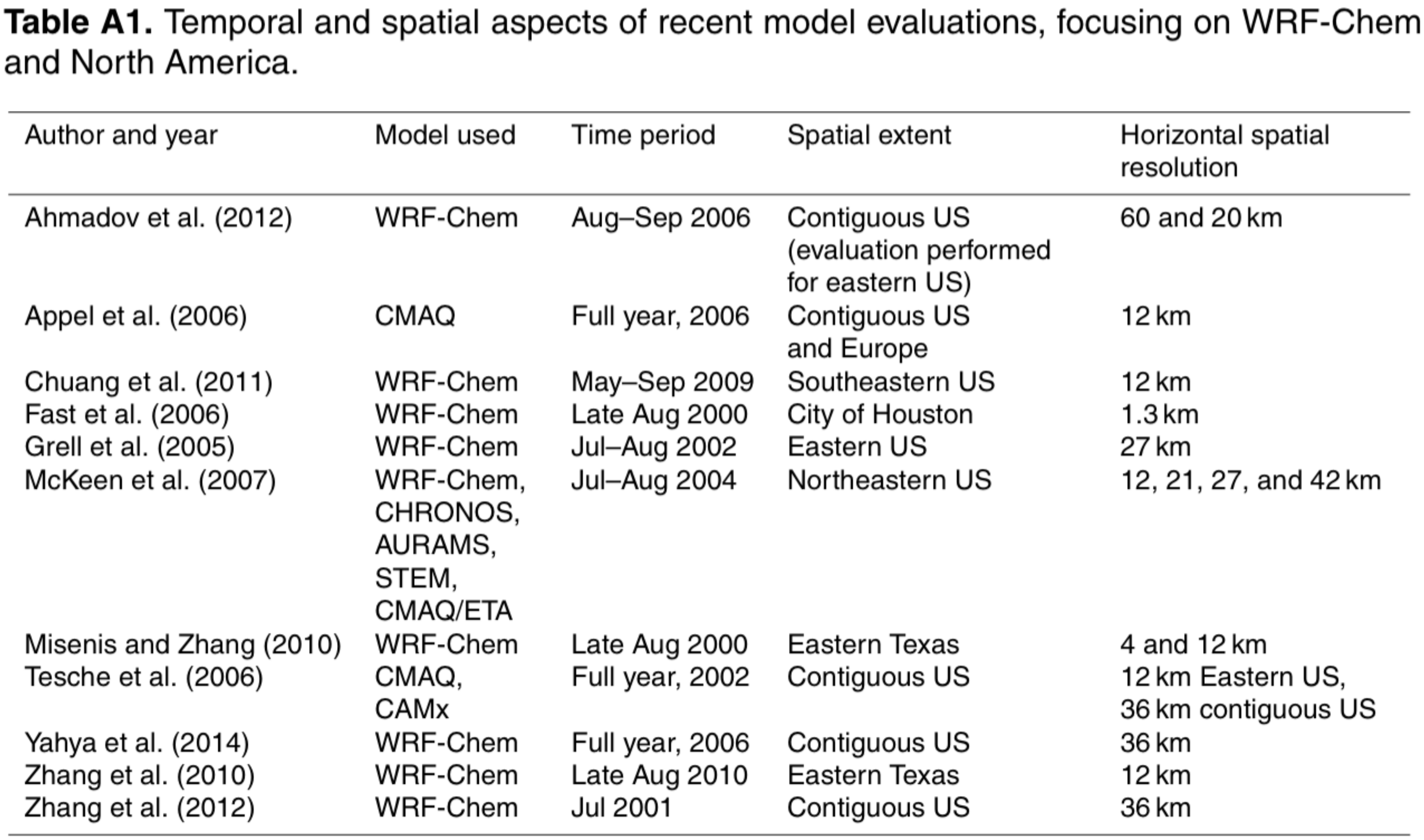


Table A1. Temporal and spatial aspects of recent model evaluations, focusing on WRF-Chem and North America.

Author and year	Model used	Time period	Spatial extent	Horizontal spatial resolution
Ahmadov et al. (2012)	WRF-Chem	Aug–Sep 2006	Contiguous US (evaluation performed for eastern US)	60 and 20 km
Appel et al. (2006)	CMAQ	Full year, 2006	Contiguous US and Europe	12 km
Chuang et al. (2011)	WRF-Chem	May–Sep 2009	Southeastern US	12 km
Fast et al. (2006)	WRF-Chem	Late Aug 2000	City of Houston	1.3 km
Grell et al. (2005)	WRF-Chem	Jul–Aug 2002	Eastern US	27 km
McKeen et al. (2007)	WRF-Chem, CHRONOS, AURAMS, STEM, CMAQ/ETA	Jul–Aug 2004	Northeastern US	12, 21, 27, and 42 km
Misenis and Zhang (2010)	WRF-Chem	Late Aug 2000	Eastern Texas	4 and 12 km
Tesche et al. (2006)	CMAQ, CAMx	Full year, 2002	Contiguous US	12 km Eastern US, 36 km contiguous US
Yahya et al. (2014)	WRF-Chem	Full year, 2006	Contiguous US	36 km
Zhang et al. (2010)	WRF-Chem	Late Aug 2010	Eastern Texas	12 km
Zhang et al. (2012)	WRF-Chem	Jul 2001	Contiguous US	36 km

Tessum *et al.* (2014b)

3 – Technical Accomplishments/ Progress/Results (cont'd)

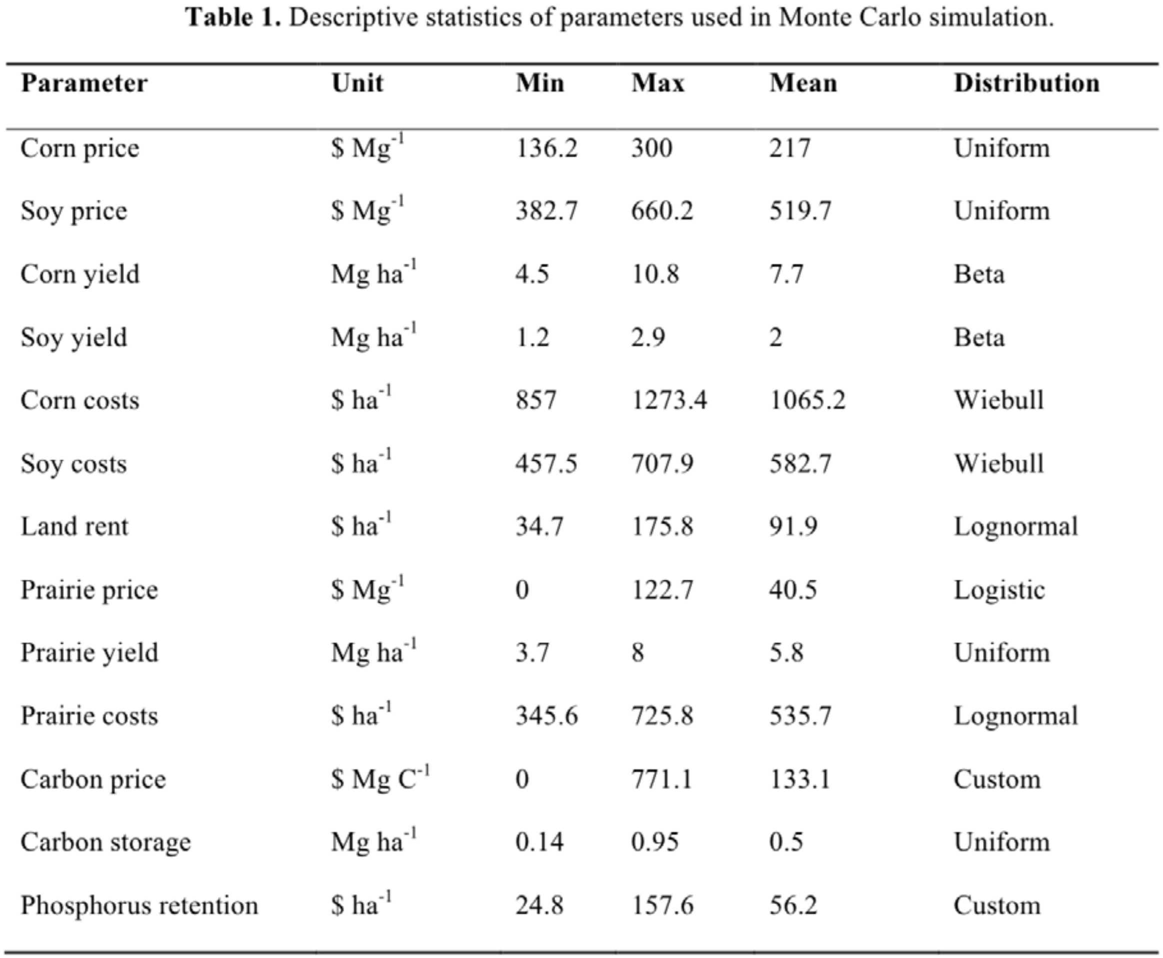
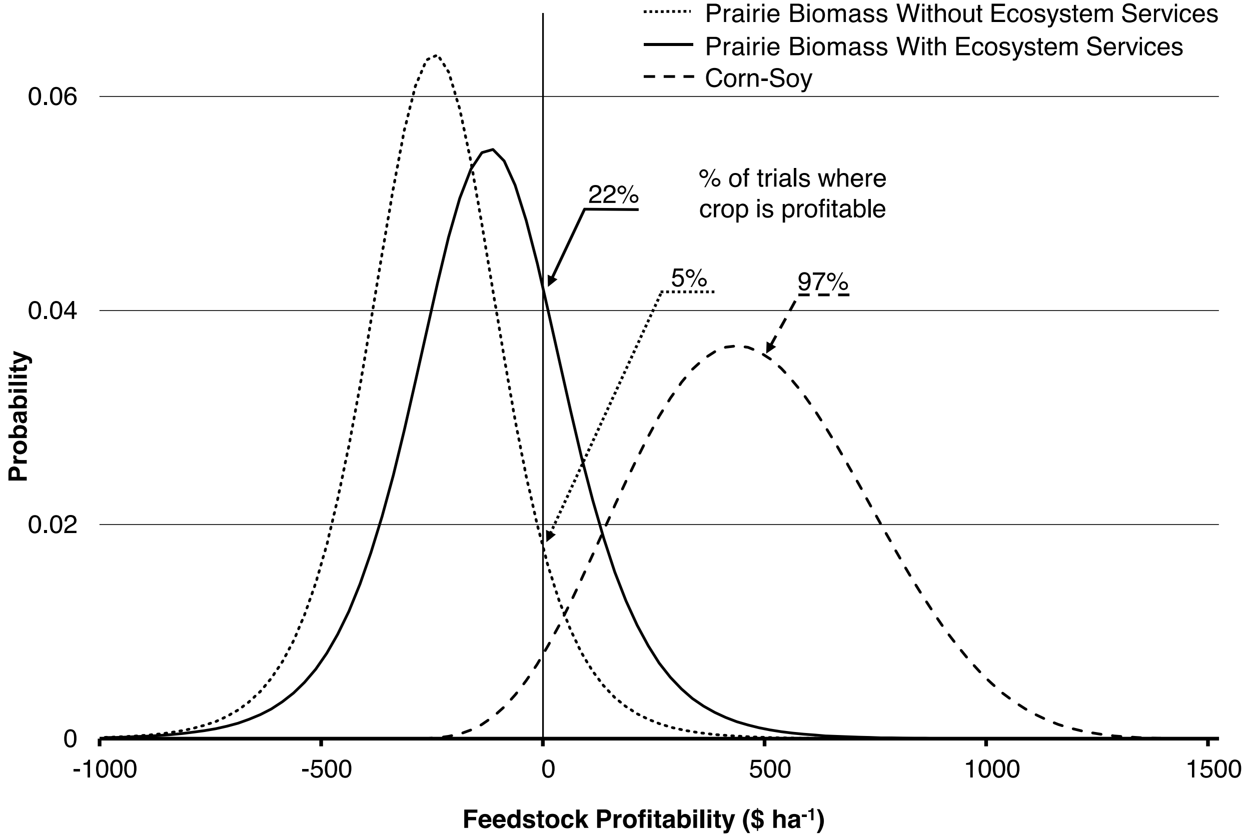


Table 1. Descriptive statistics of parameters used in Monte Carlo simulation.

Parameter	Unit	Min	Max	Mean	Distribution
Corn price	$ Mg^{-1}	136.2	300	217	Uniform
Soy price	$ Mg^{-1}	382.7	660.2	519.7	Uniform
Corn yield	Mg ha^{-1}	4.5	10.8	7.7	Beta
Soy yield	Mg ha^{-1}	1.2	2.9	2	Beta
Corn costs	$ ha^{-1}	857	1273.4	1065.2	Wiebull
Soy costs	$ ha^{-1}	457.5	707.9	582.7	Wiebull
Land rent	$ ha^{-1}	34.7	175.8	91.9	Lognormal
Prairie price	$ Mg^{-1}	0	122.7	40.5	Logistic
Prairie yield	Mg ha^{-1}	3.7	8	5.8	Uniform
Prairie costs	$ ha^{-1}	345.6	725.8	535.7	Lognormal
Carbon price	$ Mg C^{-1}	0	771.1	133.1	Custom
Carbon storage	Mg ha^{-1}	0.14	0.95	0.5	Uniform
Phosphorus retention	$ ha^{-1}	24.8	157.6	56.2	Custom

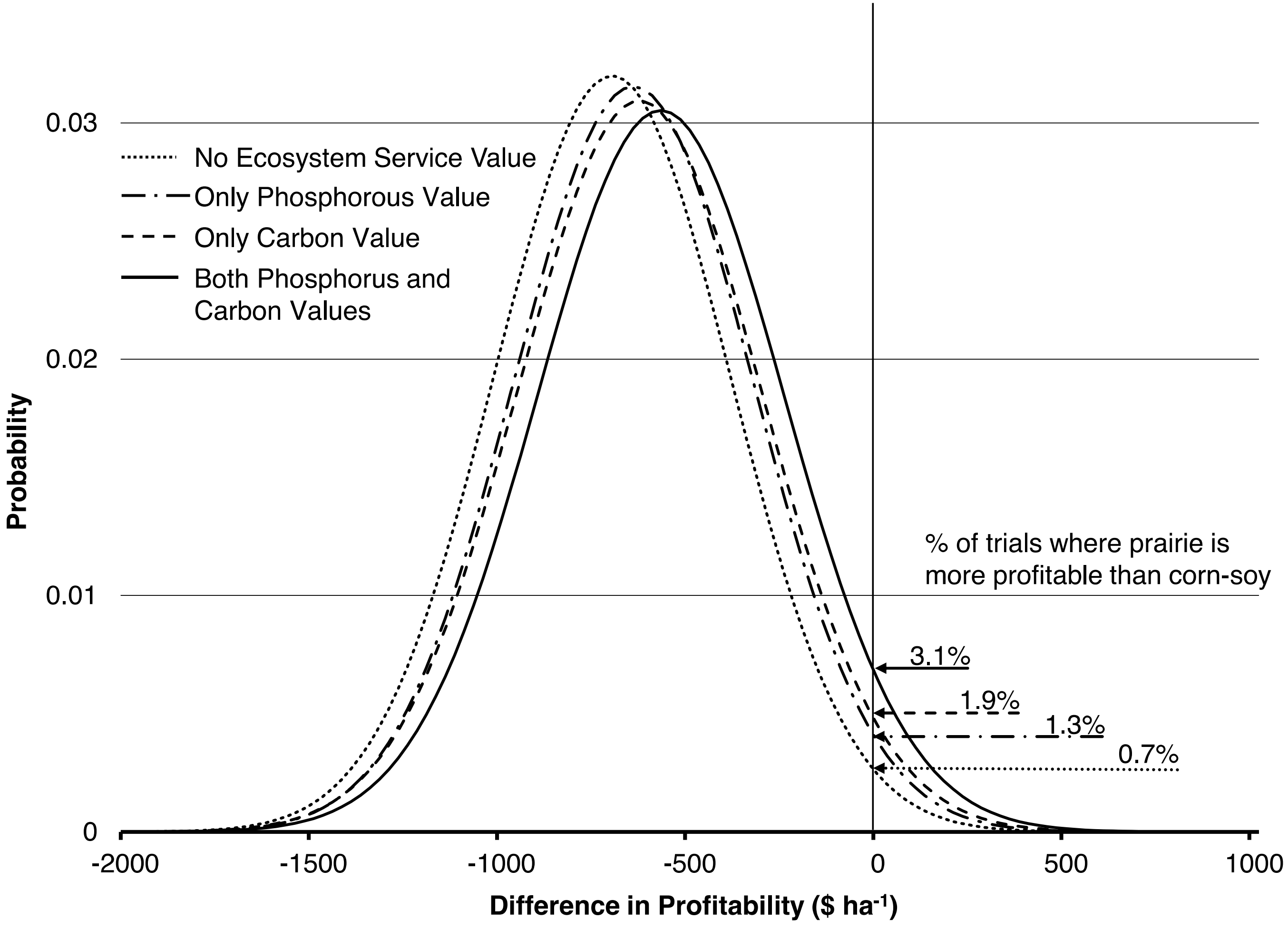
Noe *et al.* (*In review*)

3 – Technical Accomplishments/ Progress/Results (cont’d)



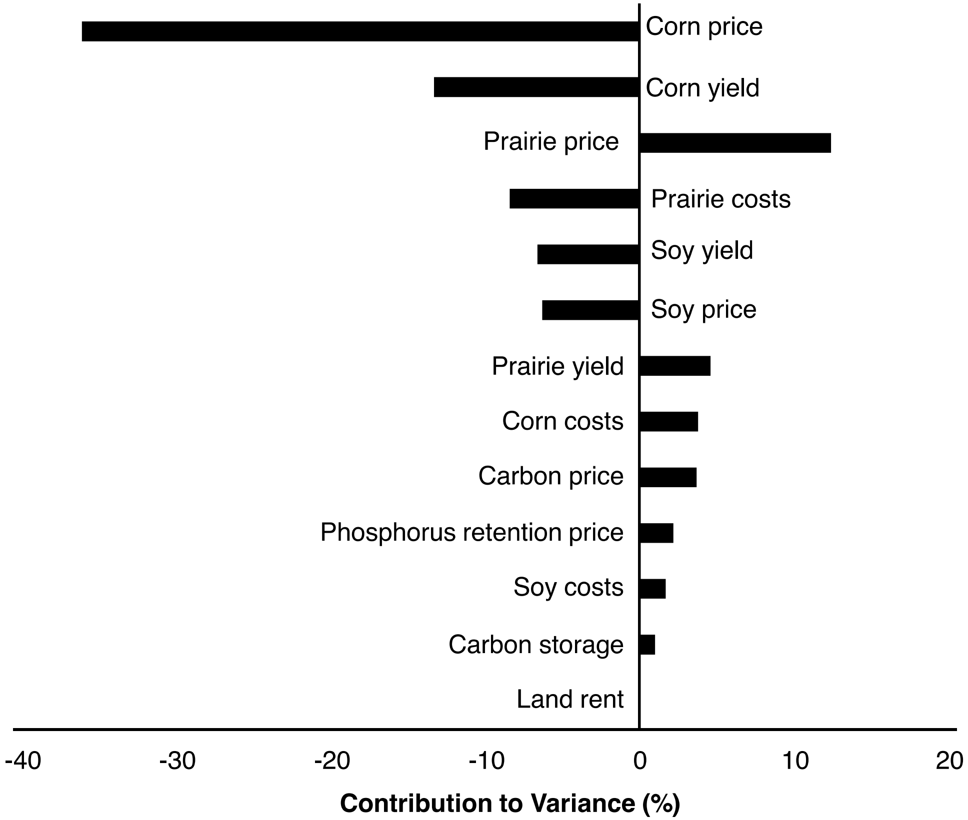
Noe *et al.* (*In review*)

3 – Technical Accomplishments/ Progress/Results (cont’d)



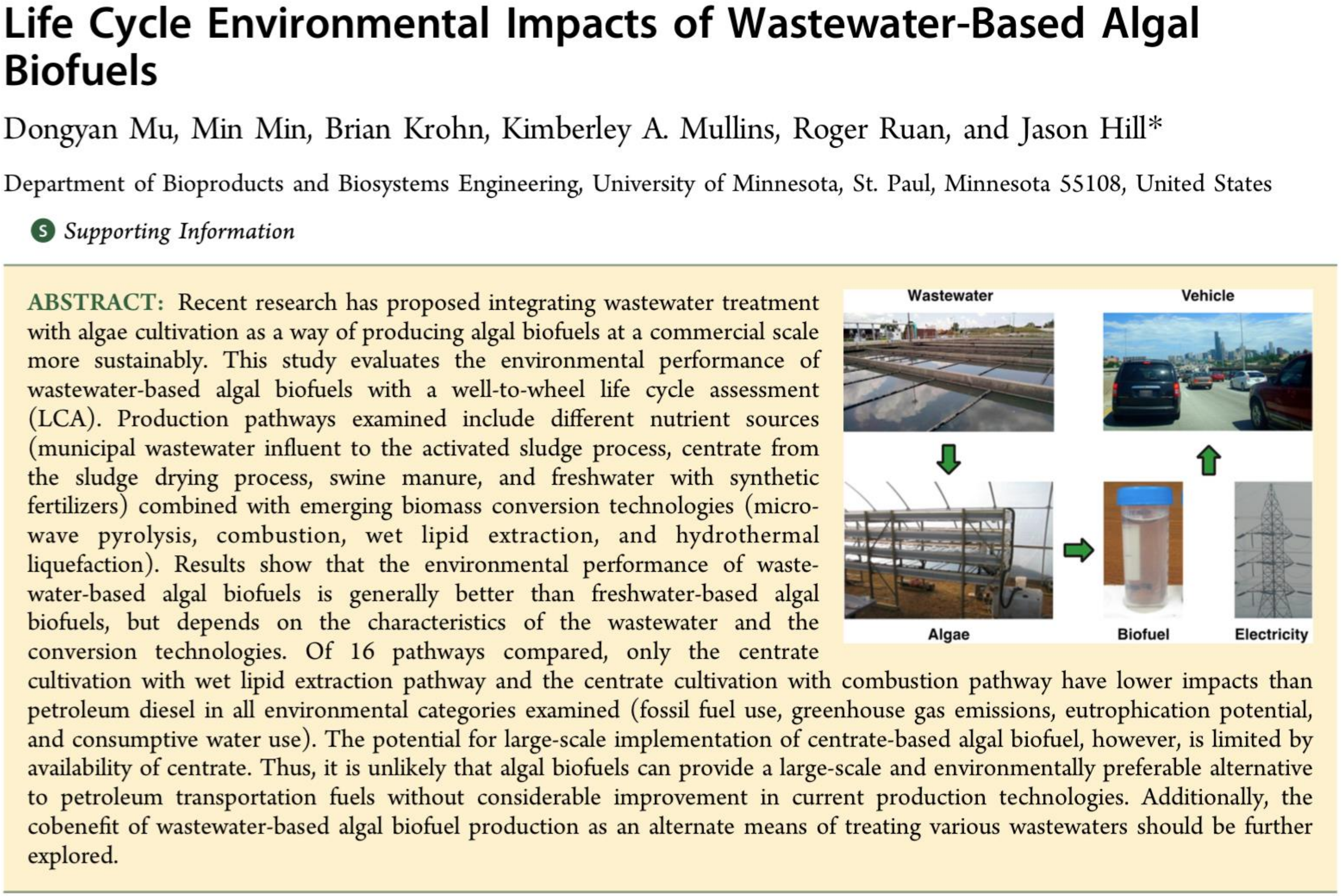
Noe *et al.* (*In review*)

3 – Technical Accomplishments/ Progress/Results (cont'd)



Noe *et al.* (*In review*)

3 – Technical Accomplishments/ Progress/Results (cont'd)



Life Cycle Environmental Impacts of Wastewater-Based Algal Biofuels

Dongyan Mu, Min Min, Brian Krohn, Kimberley A. Mullins, Roger Ruan, and Jason Hill*

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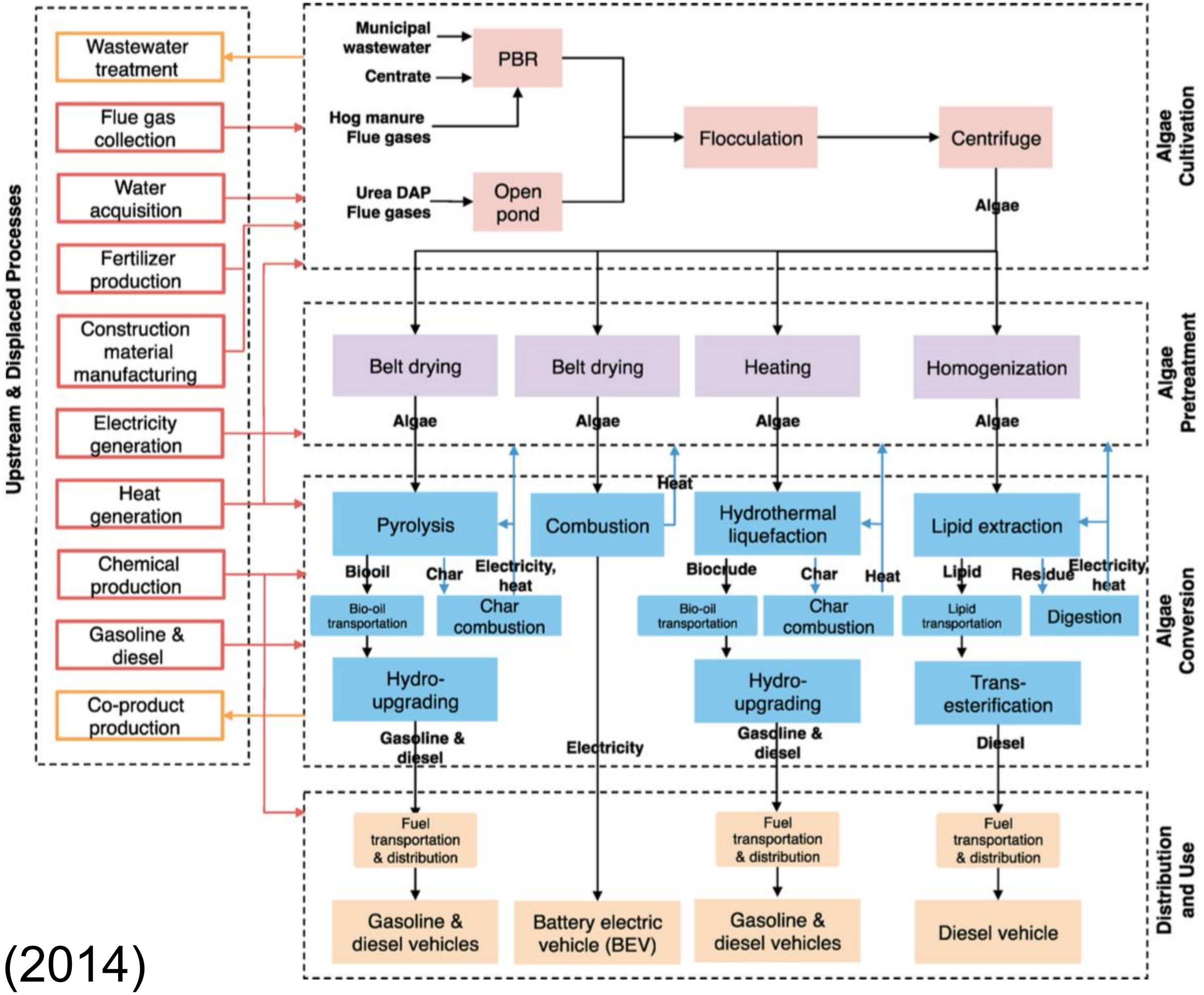
Ⓢ *Supporting Information*

ABSTRACT: Recent research has proposed integrating wastewater treatment with algae cultivation as a way of producing algal biofuels at a commercial scale more sustainably. This study evaluates the environmental performance of wastewater-based algal biofuels with a well-to-wheel life cycle assessment (LCA). Production pathways examined include different nutrient sources (municipal wastewater influent to the activated sludge process, centrate from the sludge drying process, swine manure, and freshwater with synthetic fertilizers) combined with emerging biomass conversion technologies (microwave pyrolysis, combustion, wet lipid extraction, and hydrothermal liquefaction). Results show that the environmental performance of wastewater-based algal biofuels is generally better than freshwater-based algal biofuels, but depends on the characteristics of the wastewater and the conversion technologies. Of 16 pathways compared, only the centrate cultivation with wet lipid extraction pathway and the centrate cultivation with combustion pathway have lower impacts than petroleum diesel in all environmental categories examined (fossil fuel use, greenhouse gas emissions, eutrophication potential, and consumptive water use). The potential for large-scale implementation of centrate-based algal biofuel, however, is limited by availability of centrate. Thus, it is unlikely that algal biofuels can provide a large-scale and environmentally preferable alternative to petroleum transportation fuels without considerable improvement in current production technologies. Additionally, the cobenefit of wastewater-based algal biofuel production as an alternate means of treating various wastewaters should be further explored.

Mu *et al.* (2014)

3 – Technical Accomplishments/ Progress/Results (cont’d)



Mu *et al.* (2014)

4 – Relevance

- This project directly benefits multiple platforms goals and objections of the BETO Multi-Year Program Plan
  - Feedstock Supply and Logistics R&D
  - Sustainability
  - Strategic Analysis
- Critical success factors
  - Helps ensure success of biomass sources with the highest net return to society
  - Helps support markets for non-valued ecosystem services
  - Plays an important role in verification and certification of sustainable biomass
- Advancing the state of technology and positively impacting commercial viability and environmental performance
  - Supplying sustainability data across the supply chain
  - Defining indicators or a methodology for evaluating sustainability
  - Defining best practices for sustainable bioenergy production
  - Considering potential interactions and trade-offs among different goals (energy security, environmental protection, and low-cost commodities) and different bioenergy scenarios.

5 – Future Work

- *Expanded air quality modeling efforts*
  - *Stand-alone reduced form air quality impact model*
  - *Integration with GREET*
  - *Integration with InVEST*
- *Regional assessment of switchgrass production costs and returns*
- *Expanded ecosystem service valuation*
  - *Nitrogen (with Natural Capital Project)*
  - *Air quality for perennial grass production*

Summary

1) Approach – This project seeks to estimate life cycle changes in ecosystem services under different biomass production regimes.
2) Technical accomplishments – This project advances our ability to make informed decisions that account for ecosystem services values.
3) Relevance – Sustainability includes environmental, economic, and social goals. This project promotes the integration of all three.
4) Critical Success factors and challenges – Success will be seen in the use of ecosystem services in decision making processes.
5) Future Work – Expand our work in impacts on air quality and from nitrogen, in particular
6) Technology transfer – Continued high level of communication with academic and public audiences through publication and presentations

Additional Slides

Responses to Previous Reviewers' Comments

"Additional transparency, enhanced level of user comfort, and potential policymaker engagement would be needed to realize great potential and relevance."

All of our underlying data and models are freely available to the public. We engage with policy makers at the state and federal levels regularly to discuss the findings of our research.

"This approach is somewhat undermined by the subjective nature of establishing ecological costs. For this reason, sensitivity to cost/value assumptions is critical to correctly utilize the product of this study."

We have greatly expanded our efforts in understanding the sensitivity of our results to our underlying assumptions. We now conduct Monte Carlo simulations to estimate the likelihood of achieving certain outcomes given the distributions of underlying parameters.

Publications, Patents, Presentations, Awards, and Commercialization

- Tessum C, Hill J, Marshall J (2014) Life cycle air quality impacts of conventional and alternative light-duty transportation in the United States. *Proc. Natl. Acad. Sci. U.S.A*. **111**:18490–18495.
- Tessum C, Hill J, Marshall J (2014) Twelve-month, 12-km resolution North American WRF-Chem air quality simulation: Performance evaluation. *Geosci. Model Dev. Discuss* **7**: 8433–8476.
- Mu D, Min M, Krohn B, Mullins K, Ruan R, Hill J. Life Cycle Environmental Impacts of Wastewater-Based Algal Biofuels. *Environ. Sci. Technol.* **48**: 11696–11704**.** http://dx.doi.org/10.1021/es5027689
- Keeler B, Krohn B, Nickerson T, Hill J. (2013) "U.S. Federal Agency Models Offer Different Visions for Achieving Renewable Fuel Standard (RFS2) Biofuel Volumes" *Environ. Sci. Technol.* **47**: 11095–10101. DOI: 10.1021/es402181y
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- Tessum, C. W., J. D. Marshall, J. D. Hill. 2012. A spatially and temporally explicit life cycle inventory of air pollutants from gasoline and ethanol in the United States. *Environ. Sci. Technol*. doi:10.1021/es3010514.