NREL
NATIONAL RENEWABLE ENERGY LABORATORY

March 7th, 2017
Sustainability
NREL Biofuels Air Quality Analysis – WBS 4.2.1.30

Daniel Inman, PhD

Biofuels Air Quality Analysis Goals

Goal: Perform analyses to better understand air emissions from the biofuel supply chain; applicable air regulations; and implications for cost, operations, and environmental sustainability.

Project outcome: Information, data, and tools from this project will aid in many key decisions (process design teams, biorefinery investors, R&D efforts), including process design configuration, location, and supply chain considerations.

Relevance: To meet both the Office's mission and goal, the technologies developed must, at a minimum, meet federal air quality standards.

- *2016 MYPP* - "The mission of the Office is to: *Develop and demonstrate … for a sustainable nation." and* "The goal of the Office is to develop commercially viable … technologies"
- Air permitting is time consuming and expensive and impacts siting.
- Air permitting for biorefineries is nascent, and there is a dearth of understanding, data, and precedence.

Biofuels Air Quality Analysis Goals

Analysis from this project fills research and data gaps.

- Quantify potential air emissions from specific DOE biofuel design cases
- Improve understanding of applicable federal air quality regulations applied to biofuel production
- Identify technologies and strategies that mitigate air emissions from specific DOE design cases
- Understand the techno-economic implications of meeting federal air quality regulations
- Assess the air emissions associated with feedstock production, supply, and logistics
- Compare emissions from feedstock production to existing emissions inventories (e.g. National Emissions Inventory (NEI))

Quad Chart Overview

Timeline

- Project start date FY 2016
- Project end date FY 2018
- Percent complete ~ 50%

Budget

	FY 16 Costs	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 16 – FY 18)
DOE Funded	$600K	$650K	$650K	$1.9MM
Project Cost Share (Comp.) *	$0	$0	$0	$0

Barriers

- Sustainability data across the supply chain (St-C)
- Implementing indicators and methodology for evaluating and improving sustainability (St-D)
- Best practices and systems for sustainable bioenergy production (St-E)

Partners

- Partners: ORNL, INL, Eastern Research Group (ERG)
- Other interactions/collaborations: USDA, EPA (policy and research offices), Midwestern Governor's Association's biopermitting working group.

Project Overview

This research provides analysis that can facilitate the sustainable deployment of an advanced biofuel industry.

- This project provides estimates of air pollutant emissions across the supply chain.
- Our analyses incorporate spatial and temporal heterogeneity in air emissions inventories.
- Air pollutants relevant to permitting are assessed for supply chain elements.
- Analyses from this project identify high-emitting areas across the supply chain.
- Information from this project is actionable and is made available to key process design teams.

Management Approach

- Team members and responsibilities:
  - Daniel Inman, PhD – Project Task Leader
  - Yimin Zhang, PhD – Lead Analyst
  - Garvin Heath, PhD – Senior Analyst
  - Arpit Bhatt, MS – Analyst
  - Dylan Hettinger – Programmer (Python, PostgrSQL)
  - Rebecca Hanes, PhD – Analyst/Programmer
  - Ethan Warner – Lead Analyst (*Former*)
  - Annika Eberle – Post Doctoral Analyst (*Former*)

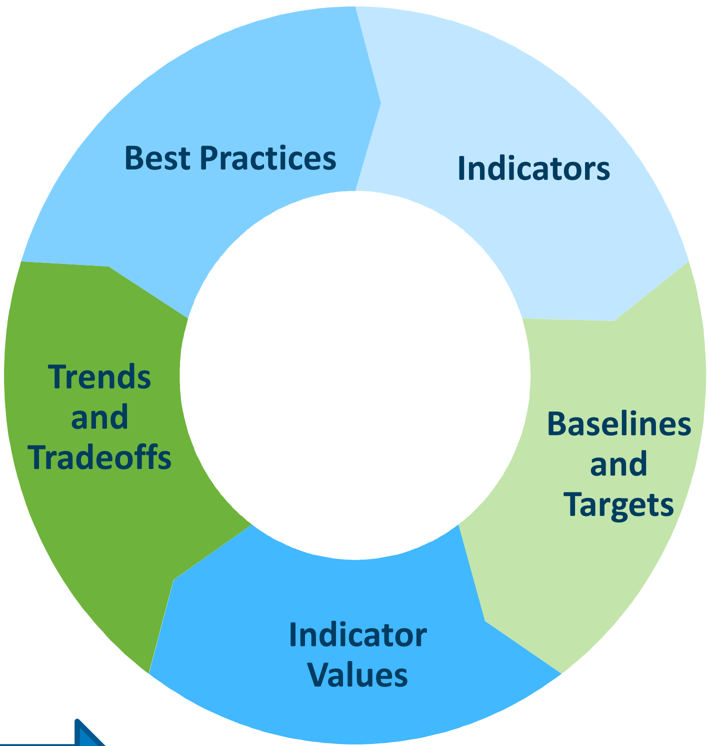
Management Approach

- Frequent interaction with BETO (e.g. Conversion, Demonstration and Market Transformation)
- Regular meetings among team members to stay informed about upcoming analyses, progress, issues, and financial tracking
- Dissemination of findings to stakeholders for the purpose of soliciting input on and socializing our results and analysis direction
- Quarterly milestones to drive our work towards high-impact Office and Department goals

Analysis Approach

General Analysis Work Flow

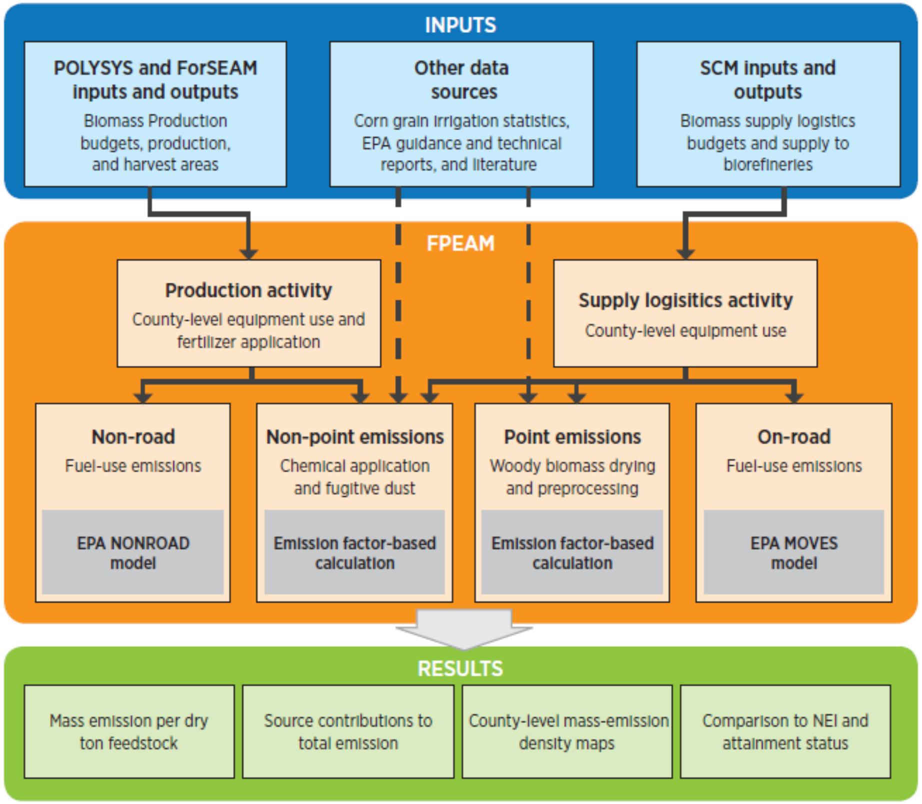
- Develop a spatially, temporally, and chemically explicit inventory
- Estimate air emissions
- Assess the regulatory Impacts
- Inform process design teams



Our analysis approach easily interfaces with other iterative system-level BETO sustainability efforts.

Technical Approach:
Feedstock Production Emissions to Air Model (F-PEAM)

- Resource assessment data (POLYSYS, ForSEAM), agricultural inputs, and logistics data are used as inputs.
- The model estimates mass emissions per ton of feedstock.
- Results are produced at the county-level for multiple timeframes.
- This is a unique application of these models – high spatial, chemical, and temporal resolution.
- Computationally unique – uses a supercomputing environment.



Technical Approach

Critical success factors

- Implementation of project finding by local and federal air quality boards and agencies
- Impact biorefinery and supply chain design considerations
- Provide air emission mitigation strategies to inform process and cost modeling
- Publish findings in the peer reviewed literature

Top challenges

- Lack of stack testing data to validate our estimates
- Maintenance of the modeling framework, including database, versioning, and cross-platform communication
- Effective communication and integration of results

Technical Accomplishments: AOP Milestones

"… a review of applicable federal regulations and potential to emit for the fast pyrolysis pathway …"	FY 15
"… air emissions from all non-combustion processes at the biorefinery for Davis et al. (2013) and Jones et al. (2013) …"	FY 15
"… strategies to ensure Davis et al. (2013) and Jones et al. (2013) meet federal air quality regulations …"	FY 15
"… cost implications of adopting selected emissions reduction recommendations for Davis et al. (2013)…"	FY 15
"… impact on minimum fuel selling price (MFSP) of integrating selected emission reduction strategies ..."	FY 16
"… expansion of F-PEAM to include additional biomass feedstocks …"	FY 16
"… air emissions estimates for the Billion Ton Study 16…"	FY 16
" … validation of air emission estimates for Davis et al. (2013) and Jones et al. (2013) …"	FY 16

Impact of Emissions Controls on MFSP for the Sugars to Hydrocarbons Pathway

- Novel contribution to the literature – first-of-a-kind assessment of minimum fuel selling price (MFSP) in the context of air emissions controls
- Provides emissions estimates, federal limits, and mitigations strategies
- Mitigation strategies were integrated into the process design models to asses their impact on the MFSP.

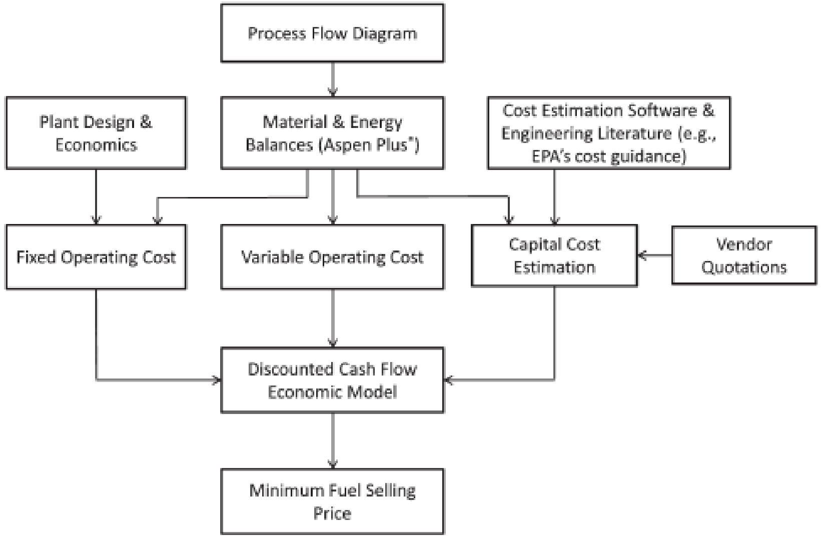
Modeling and Analysis

Biofpr Biofuels Bioproducts & Biorefining

Economic implications of incorporating emission controls to mitigate air pollutants emitted from a modeled hydrocarbon-fuel biorefinery in the United States

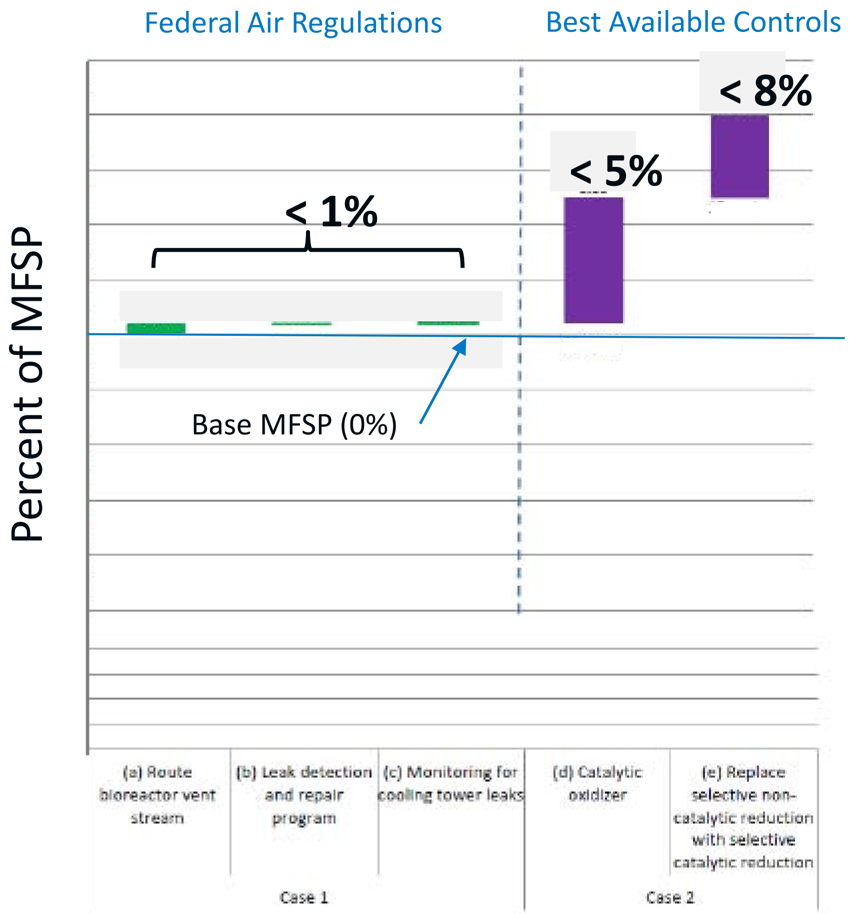
Arpit Bhatt, Yimin Zhang, Ryan Davis, Annika Eberle, Garvin Heath, National Renewable Energy Laboratory, Golden, CO, USA

Received February 22, 2016; revised May 26, 2016; and accepted May 27, 2016
View online July 15, 2016 at Wiley Online Library (wileyonlinelibrary.com);
DOI: 10.1002/bbb.1666; *Biofuels, Bioprod. Bioref.* 10:603–622 (2016)

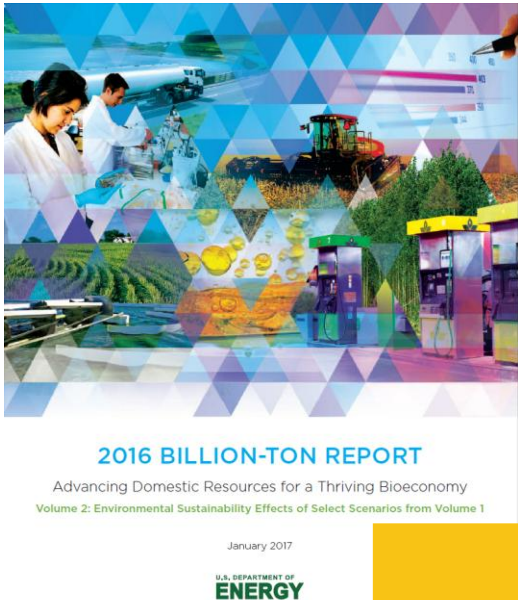


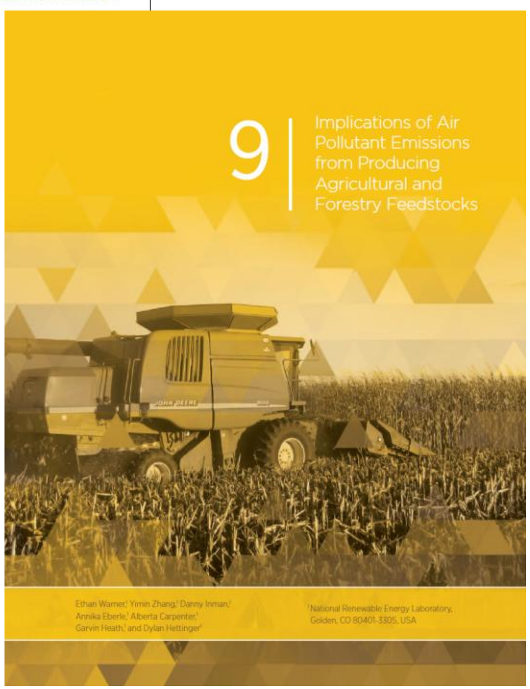
Cost Implications of Emission Controls

- The sugars to hydrocarbons design case (Davis et al. 2013) meets many applicable federal air quality regulations.
- The additional equipment required to meet ALL federal regulations has a less than 1% impact on the MFSP.
- If Best Available Control Technologies (BACT) are needed, the total impact on the MFSP is estimated to be circa 8%



Billion Ton 2016, Volume 2, Chapter 9 – Air Pollutant Emissions





- Future feedstock production emits fewer air pollutants, per ton, than corn grain production.
- Used FPEAM to estimate county-level emissions for the entire US and compared these to the EPA's Natioal Emissions Inventory (NEI)
- Evaluated three feedstock production cases (base 2017, base 2040, high 2040)
- Analysis was focused on quantifying direct, local emissions; upstream emissions were not included.

Spatial Assessment of Air Emissions from Feedstocks

- Future biomass production emits lower levels of air emissions, on a per-ton basis, because of anticipated improvements in the agricultural system.
- Between 2017 and 2040, feedstock production is expected to shift, with more production in the Southern Plains.
- The geographic shift in feedstock production and associated emissions does not impact areas in non-attainment.

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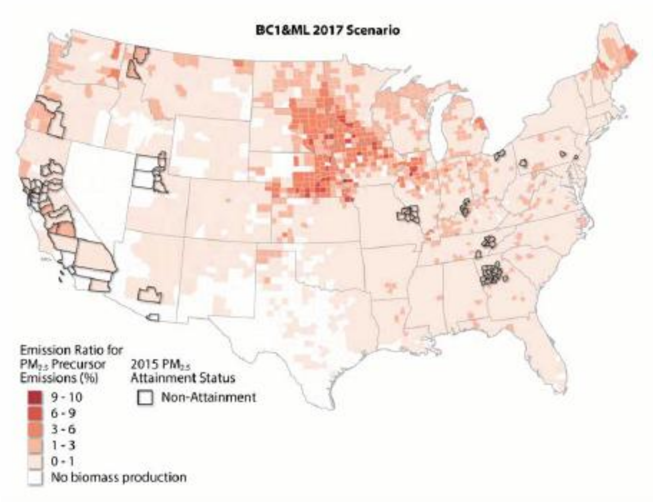
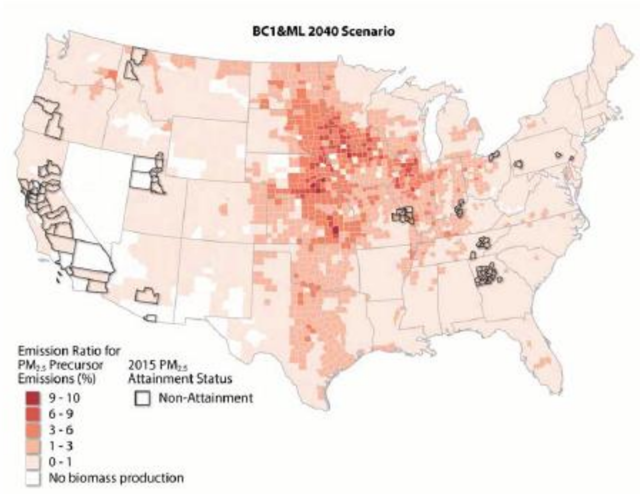




Relevance

The public expects biofuels to be more environmentally sustainable than conventional fossil fuels.

- We perform objective process-level analysis and validation of potential air emissions across the supply chain.
- This project identifies challenges early so design adjustments can be made.
- Our analysis determines what the applicable regulations are for specific designs and portions of the supply chain.
- Analysis from this project is used to determine if current designs meet these regulations and, if so, at what cost?
- Our work provides insights into what compliance may portend for future operations.

Relevance

Relevance to Stakeholders

- We perform outreach to EPA, states, and regional air quality management organizations.
- Biorefinery Air quality permitting lacks precedent – results from this project can help establish a precedent.
- Novel research pursued in this project can provide guidance to stakeholders
- Information from this project may expedite future permitting

Relevance to BETO

- This project provided analysis of feedstock production and logistics for the Billion-Ton Study 16 volume 2, which directly contributes to the MYPP key milestone: **FY16** - "Evaluate environmental sustainability … feedstock supplies…"
- Our analysis is focused on quantifying potential air emissions for DOE biofuel conversion technologies, which addresses the MYPP key milestone: **FY22** - "Evaluate environmental and socio-economic indicators across the supply chain … and air emissions targets …"; as well as the **FY19** - "Quantify and communicate … benefits of emerging bioenergy pathways..."

Future Work: 2017 – 2018

- Refinement of the FPEAM model to create a decision tool for use by stakeholders
- Develop methods to (1) assessing displaced anthropogenic air emissions from prior land use and (2) displaced petroleum supply chain emissions
- Assess the air emissions for the full biofuel supply-chain for comparison to incumbent fuels

Summary

- **Overview:** This project is aimed at advancing the overall understanding of air emissions from the biofuel supply chain; applicable regulations; and implications for cost, operations, and sustainability.
- **Approach**: Our modeling approach combines work performed by other national laboratories, empirical data, emissions factors, process modeling, and review of existing permits.
- **Technical Accomplishments:** Air quality assessment of the BTS16, regulatory analyses of DOE conversion technologies, cost implications of AQ mitigation strategies, and air emission estimates for DOE conversion technologies.
- **Relevance:** The public expects biofuels to be more environmentally sustainable than conventional fossil fuels.
- **Future work:** Continued assessment of DOE conversion technologies, refinement of the FPEAM model.

Additional Slides

Technical Accomplishments: Publications 2015 – 2016

- Zhang, Yimin, et al. *Understanding Potential Air Emissions from a Cellulosic Biorefinery Producing Renewable Diesel Blendstock*. No. NREL/CP-6A20-63745. NREL (National Renewable Energy Laboratory (NREL), Golden, CO (United States)), 2015.
- Bhatt, Arpit, et al. "Economic implications of incorporating emission controls to mitigate air pollutants emitted from a modeled hydrocarbon-fuel biorefinery in the United States." *Biofuels, Bioproducts and Biorefining* 10.5 (2016): 603-622.
- Bhatt, Arpit, et al. *A Techno-Economic Analysis of Emission Controls on Hydrocarbon Fuel Production*. No. NREL/CP-6A20-67061. NREL (National Renewable Energy Laboratory (NREL), Golden, CO (United States)), 2016.
- Zhang, Yimin, et al. "Air pollutant emissions inventory of large-scale production of selected biofuels feedstocks in 2022." *Biofuels, Bioproducts and Biorefining* 10.1 (2016): 56-69.
- Warner, Ethan, et al. 2017. Billion Ton Study 16, Volume 2, Chapter 9. Air Quality

Background Materials for the BTS16 Analysis

Introduction

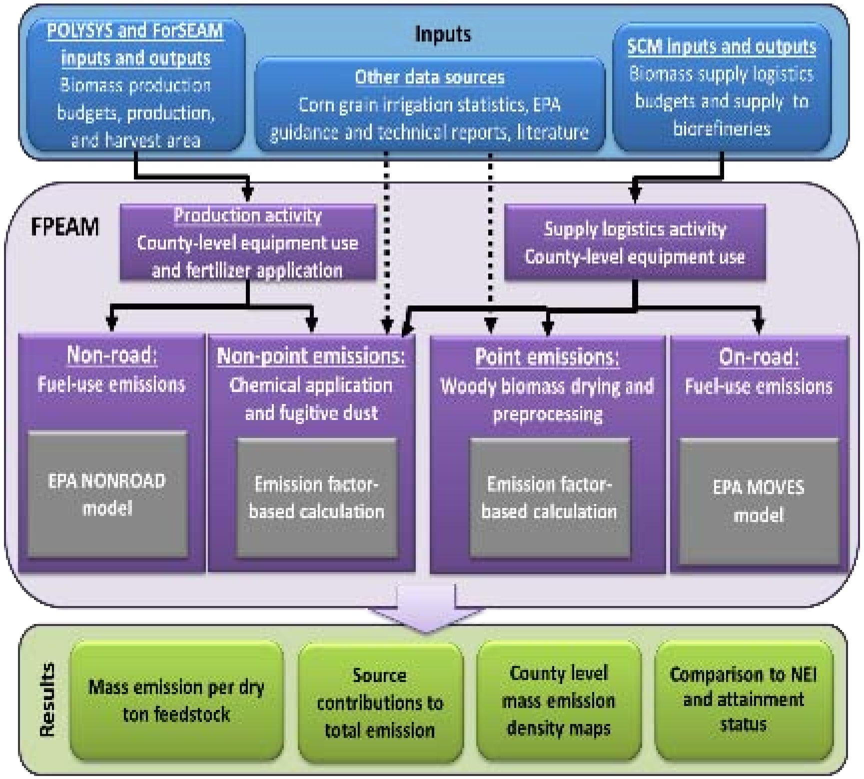
- There are inherent challenges in evaluating the sustainability of potential large-scale biomass production for converting biomass into bioenergy and bioproducts due to the complexity of the supply systems and the uncertainty of how future systems will operate.
- Air quality is an important aspect of sustainability because the location and magnitude of air pollutant emissions can have a considerable impact on human health and the environment.
- An emission's origin, location, and time signature are essential pieces of information for air-quality and human-health impact modeling. Since each element of the biomass supply chain has the potential to be a substantial, non-point source of air emissions, there are often no practical strategies for mitigating these emissions once they are released into the atmosphere.
- The objectives of this analysis are 1) to understand the air pollutant emissions for selected biomass production, harvest, transportation, and preprocessing scenarios that align with the core scenarios of the 2016 Billion Ton Study; 2) to understand the spatial distribution of air emissions and how these changes could potentially impact local air quality; and 3) to identify opportunities to minimize adverse impacts.

Air Quality Approach

- Our approach is to estimate a spatially explicit air pollutant emissions inventory by expanding on the methods described in Zhang et al. (2016) to incorporate air emissions associated with biomass feedstock transportation and preprocessing. Assumptions regarding biomass production, harvest, transport, and preprocessing are consistent with those in the *BTS 16* volume 1 (DOE 2016). Biomass conversion and fuel combustion are not a part of this analysis.
- Scenarios evaluated are the 2017 base yield (conventional supply logistics), 2040 base yield (advanced supply logistics), and 2040 high yield (advanced supply logistics).
- Our inventory approach allows for a more narrow assessment of biomass feedstocks as compared to a set of reference conditions. In particular, this chapter focuses exclusively on estimating air emissions from biomass supply systems to
    - Understand how emissions differ among advanced biomass feedstocks and regions of the United States and how these emissions may evolve over time in different scenarios
    - Identify the major emission contributors along the biomass supply chain to inform emission-mitigation strategies depending on local/regional air quality status
    - Compare the magnitude of feedstock-related emissions in reference to current county-level emissions (derived from the NEI) to identify geographic areas at higher risk for potential negative air quality impacts, especially for those counties in noncompliance with National Ambient Air Quality Standards (NAAQS) as of 2016.

Air Quality Methods

- County-level air pollutant emissions are estimated from anthropogenic sources for each scenario assessed.
- The air pollutants analyzed include carbon monoxide (CO), particulate matter ($PM_{2.5}$, PM_{10}), oxides of nitrogen (NO_X), oxides of sulfur (SO_X), volatile organic compounds (VOCs), and ammonia (NH_3). Air pollutants emitted from fuel used by equipment (e.g., agricultural machinery, transport vehicles); fertilizer and pesticide (collectively referred to as "chemicals") applications; soil disturbance by mechanical force (e.g., wheels); and feedstock-drying processes (if applicable) are quantified.
- Our analysis is focused on quantifying direct, local air pollutant emissions. Indirect upstream emissions associated with fuel and chemical production are not included in this analysis.



Biomass Production Scenarios Evaluated in *BTS16*

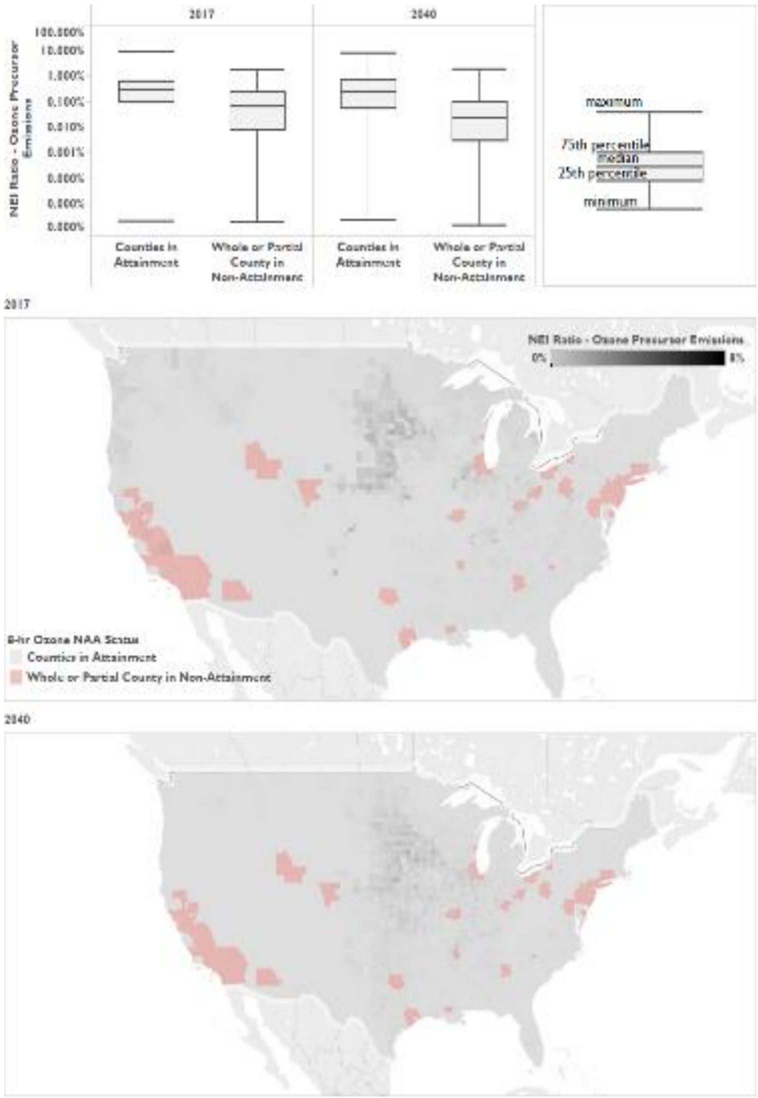
Feedstock Type	Segment of the Supply Chain	Base Yield[a]		High Yield[b]
		2017	2040	2040
Conventional Agricultural Crops and Forestry Biomass	Biomass Production	Up to $60/dry ton (dt)	Up to $60/dt	Up to $60/dt
	Biomass Supply Logistics, Conventional	NM[c]	NM[c]	NM[c]
	Biomass Supply Logistics, Advanced	NM[c]	NM[c]	NM[c]
Cellulosic Agricultural Residues, Energy Crops, and Forestry Biomass and Residues	Biomass Production	Up to $60/dt	Up to $60/dt	Up to $60/dt
	Biomass Supply Logistics, Conventional[c]	Up to $100/dt[d]	NM[c]	NM[c]
	Biomass Supply Logistics, Advanced[c]	NM[c]	Up to $100/dt[d]	Up to $100/dt[d]

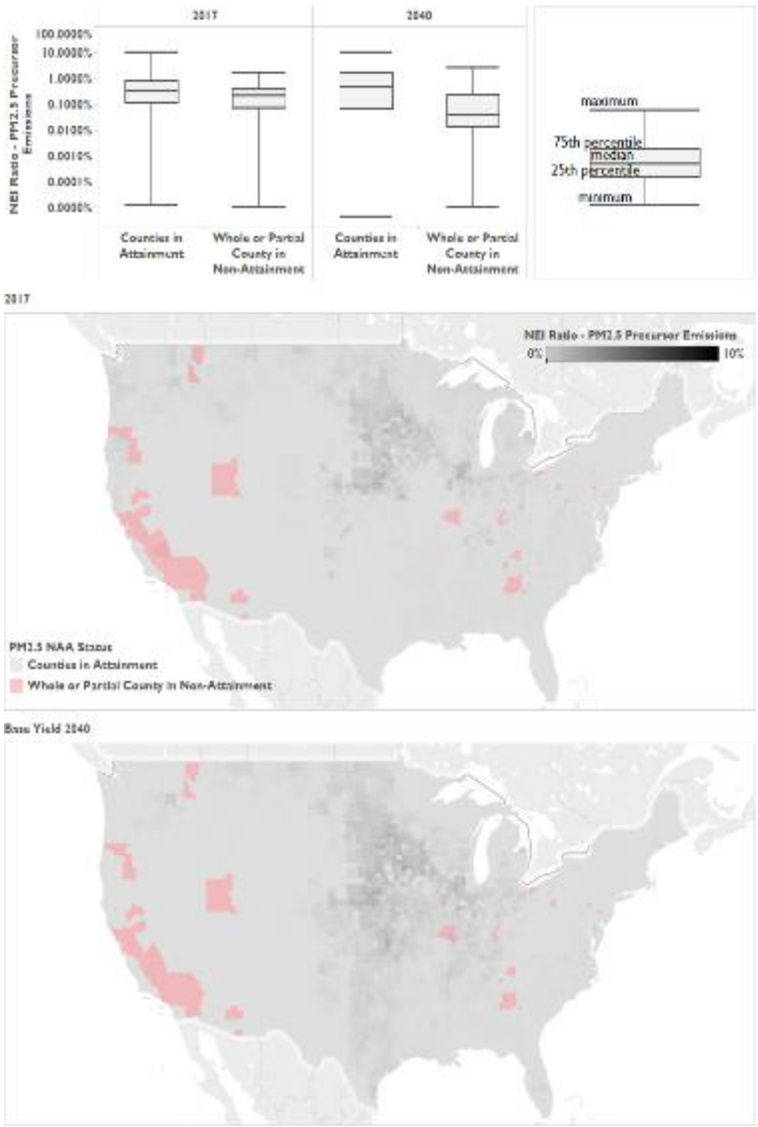
Table 8.1. Potential Biomass Production and Supply Logistics Scenarios Evaluated in This Chapter
from DOE (2016)
[a] Base -yield scenario assumes 1% yield growth per year.

BTS 16 Air Quality Scenarios

Biomass Feedstock Description	Biomass Feedstock Categories in This Chapter	Base Yield[a] (million dt annually)		High Yield[b] (million dt annually)
		2017	**2040**	**2040**
Conventional Agricultural Crop				
Corn grain	Corn grain	390	450	510
Subtotal		390	450	510
Agricultural Residues[c]				
Corn stover	Stover	89	150	160
Sorghum stubble		0.71	1.1	1.5
Wheat straw	Straw	13	21	37
Barley straw		0.41	0.57	0.48
Oats straw		0.0049	0.0081	0.0066
Subtotal		100	180	200
Energy Crops[d]				
Miscanthus	Miscanthus	0	160	370
Switchgrass	Switchgrass	0	160	190
Biomass sorghum	-	0	0 (19)	0 (31)
Energy cane	-	0	0 (0.33)	0 (5.2)
Eucalyptus	-	0	0 (0.94)	0 (2.1)
Pine	-	0	0 (0.12)	0 (0.15)
Poplar	-	0	0 (45)	0 (74)
Willow	-	0	0 (25)	0 (65)
Subtotal		0	320 (410)	560 (740)
Forestry Biomass/Residues				
Hardwood Trees	Forest Biomass	39	25	18
Softwood Trees		28	33	20
Mixed Wood Trees		2.8	2.4	2.4
Hardwood Residues	Forest Residues	6.9	8.0	7.9
Softwood Residues		6.8	10	9.6
Mixed Wood Residues		4.2	2.7	2.4
Subtotal		88	81	61
Grand Total		590 (590)	1,000 (1,100)	1,300 (1,500)

BTS 16 Air Quality Results





Background Materials on the MFSP study of Davis et al. (2013)

Approach for the Analysis

- Step 1: Identification of the air pollutants that are likely to be emitted from the sugars to hydrocarbon* biorefinery.
- Step 2: Review of federal regulations potentially applicable to the sugars to hydrocarbon* biorefinery.
- Step 3: Emissions controls and work practice standards (other than planned) are incorporated in the design based on the regulatory analysis to meet the emission limits.
- Step 4: Determine the economic implications of emission controls on the minimum fuel selling price (MFSP).
- Step 5: Estimate the potential-to-emit after adding additional controls and compare it with the major source threshold values.

*Davis et al. 2013., *Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons: Dilute Acid and Enzymatic Deconstruction of Biomass to Sugars and Biological Conversion of Sugars to Hydrocarbons*. Available at http://www.nrel.gov/docs/fy14osti/60223.pdf.

BETO 2015 Peer Review Comments and Responses

2015 Peer Review

SUSTAINABILITY ANALYSIS

(WBS#: 4.2.1.30)

Image Courtesy of NREL

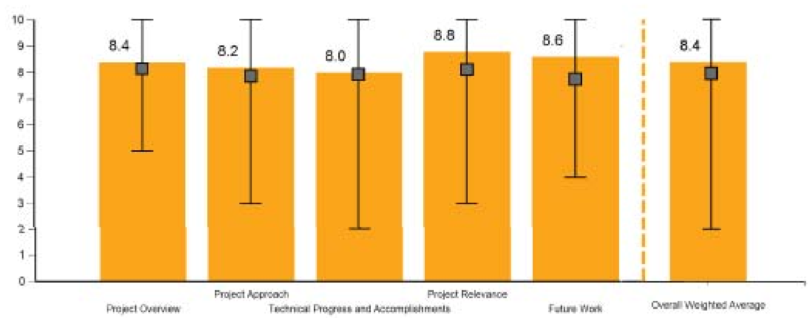
Recipient:	NREL
Presenter:	Daniel Inman
DOE Funding FY14:	$1,114,290
DOE Funding FY13:	$1,130,608
DOE Funding FY10-12:	$2,017,886
Planned Funding:	$1,501,218
Project Dates:	10/1/2011 - 9/30/2017

Project Description

This project addresses the air quality impacts of large scale development of advanced biofuels and focus on the two major challenges in assessing the environmental impacts of the biofuel industry in order to meet regulatory requirements. The project will incorporate spatial and temporal heterogeneity in air emissions inventory and develop rigorous estimates of air pollutant emissions for advanced biorefineries and feedstock preprocessing facilities. This project provides BETO and other stakeholders (e.g., EPA, regional and state air quality managers and planners) with information necessary to understand the potential air quality and human health impacts of large-scale production of advanced biofuels, and enables the consideration of multiple aspects of sustainability throughout the biofuel supply chain. In addition, the results will provide insights into identification of important emission-contributing activities and facilitate development of strategies (e.g., best practices, emissions control measures) to minimize negative impacts. Future work includes continued formulation, characterization, and reactivity study of carbides to obtain fundamental insights and data necessary for the optimization of catalytic performance, pilot-reactor

Overall Project Score: 8.4

This Project
2015 Sustainability and Strategic Analysis Peer Review Average for 2015 Existing Project Evaluation Criteria



Whiskers represent the range of scores for each evaluation criteria across all projects reviewed in this technology area.

Reviewers' Comments and PI responses

- This research expands on the conventional analysis of estimating air emissions from a potential process to looking at how well the process design meets current air regulations. This work is important in understanding the emissions generated at a specific local refinery. It also informs where needed design changes could be made to further reduce the environmental impact. This is critical as we move toward large-scale deployment and biofuel commercialization. The project has made great progress. So far, they have been able to complete life cycle inventories for five feedstocks and two key conversion pathways—sugars to hydrocarbons and fast pyrolysis. The current analysis doesn't look at mitigation strategies, but does point out areas of concern such as potential problems that may arise from the co-location depots at conversion sites. There is still a need to get good temporal and spatial data to understand the source-level impacts. They are working with Abengoa and other commercial plants and hope to have access to real emission data as soon as it is made public. During the 2016-2017 time frame, the project aims to look at the distribution and end use portions of the value chain. There are many studies that may be of help in developing this portion of the study. The National Petroleum Council Future Transportation Fuels Study is one such study. It contains a vehicle choice model to estimate vehicle penetration and fuel use under a variety of conditions.

- This project offers a powerful approach that brings spatially explicit context to air emissions associated with biorefinery supply chains. Air quality impacts, like water impacts, are highly influenced by temporal and geospatial factors. The spatially explicit LCA analysis in this project will greatly improve the ability to assess real impacts of supply chain air emissions on local air quality and public health. The current focus on assessing maximum potential emissions associated with the biorefineries themselves is critical, and the team has appropriately identified the boiler system as central to understanding air emissions.

- Air quality is a central component of environmental and socio-economic assessments of bioenergy systems, and this project is positioned to offer comprehensive insights to the supply chain impacts of various bioenergy operations. The project has done a thorough job of collaborating with research partners and stakeholders to inform modeling assumptions. The future success of the model will largely center on its versatility in considering different feedstocks, growing practices, and supply logistics (such as biomass depot systems), as well as the cost effectiveness of different supply chain options—a component of this project that was not given much weight in the presentation (though the PI indicated that work was being performed in this area).

We appreciated the reviewer's constructive comments and are taking them all into consideration as we develop our future work plans. Specifically, we are beginning to examine ways to mitigate and/or reduce emissions at the biorefinery for a number of conversion pathways. Additionally, we are working to gather stack testing data to validate our modeling efforts.

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