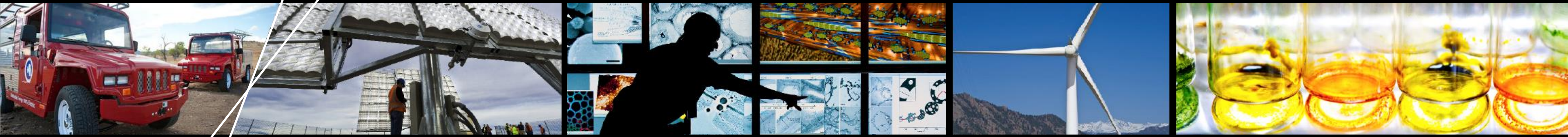
NREL Sustainability Analysis WBS 4.2.1.30



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Technology Area: Sustainability

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Organization: National Renewable Energy Laboratory

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Goal – Air Emissions from Bioenergy Systems

NREL's sustainability analysis program aims to better understand air emissions from the biofuel supply chain, applicable air regulations and implications for cost, operations and sustainability

Address research gaps

- Lack of analysis for DOE's advanced biofuel system designs that enable comparison of estimated air emissions to applicable air regulations.
- Lack of quantification of life cycle (supply chain) ozone and PM-precursor emissions from different cellulosic biofuel pathways based on DOE advanced designs
- Lack of spatially, temporally, and chemically resolved life cycle inventories of air pollutant emissions to enable
  - Examination of source-level emission reduction opportunities
  - Comparison to existing inventories (e.g., EPA's National Emissions Inventory)
  - Estimation of air quality and health impacts from large-scale cellulosic biofuel production and use.

Why important?

This analysis directly informs many of the sustainability goals outlined in BETO's 2014 Multi-Year Programmatic Plan (MYPP).

- By 2017, identify conditions under which at least one technology pathway for hydrocarbon biofuel production…..meets targets for consumptive water use, wastewater, and **air emissions**.
- By 2022, evaluate environmental and socioeconomic indicators across the supply chain for three cellulosic and algal bioenergy production systems to validate ….. **air emissions** that meet federal regulations.

BETO performance milestones for Sustainability Analysis and Communication:

- By 2016, coordinate with feedstock logistics and conversion R&D areas to set targets for …..**air emissions** for at least three renewable hydrocarbon pathways to be validated in 2017 and 2022.

Extensive outreach to the air quality management community (EPA, states, regional bodies) indicates that the topics of this project are of high interest and value and not being developed by any other group.

Quad Chart Overview

Timeline

- Project start date: FY 2012
- Project end date: FY 2017
- Percent complete: 75%

Budget

	Total Costs FY 10 –FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date
DOE Funded	$1.79MM	$500K	$600K	$1.65MM

Barriers

Barriers addressed

- *St-C. Sustainability Data across the Supply Chain (in particular, lack of temporal and spatial data for measuring sustainability hinders establishing baselines, determining targets, recommending best practices, and evaluating tradeoffs)*
- *St-D. Indicators and Methodology for Evaluating Sustainability (with appropriate consideration of spatial, temporal and context-specific factors)*
- *St-E. Best Practices for Sustainable Bioenergy Production.*

Partners

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

1 - Project Overview

- This research helps overcome hurdles towards ensuring that large-scale deployment of advanced biofuels will meet air quality regulatory requirements and maintains air quality in areas surrounding bioenergy supply chain systems.
  - Specifically, this project provides rigorous estimates of air pollutant emissions across the supply chain for advanced biofuels, including the biorefineries, biomass logistics and processing facilities, and feedstock production
  - The modeling framework used in this project incorporates spatial and temporal heterogeneity in air emissions inventories across the supply chain for multiple biomass feedstock and biofuel technologies
  - Air pollutants assessed include all relevant for permitting and of highest regulatory concern nationally, i.e., particular matter and its precursors; ozone precursors; volatile organic compounds (VOCs); nitrogen oxides; ammonia
- Analyses from this project identify the most important emission contributing activities across the supply chain to facilitate development of strategies to minimize negative impacts (e.g., best practices, emissions control measures).
- Data and analyses from this project are actionable and are made available to key process design teams (e.g., FS logistics, conversion, etc.) for process design improvements, including considerations of cost and operational impacts of meeting air quality regulations, as well as external air quality management community.

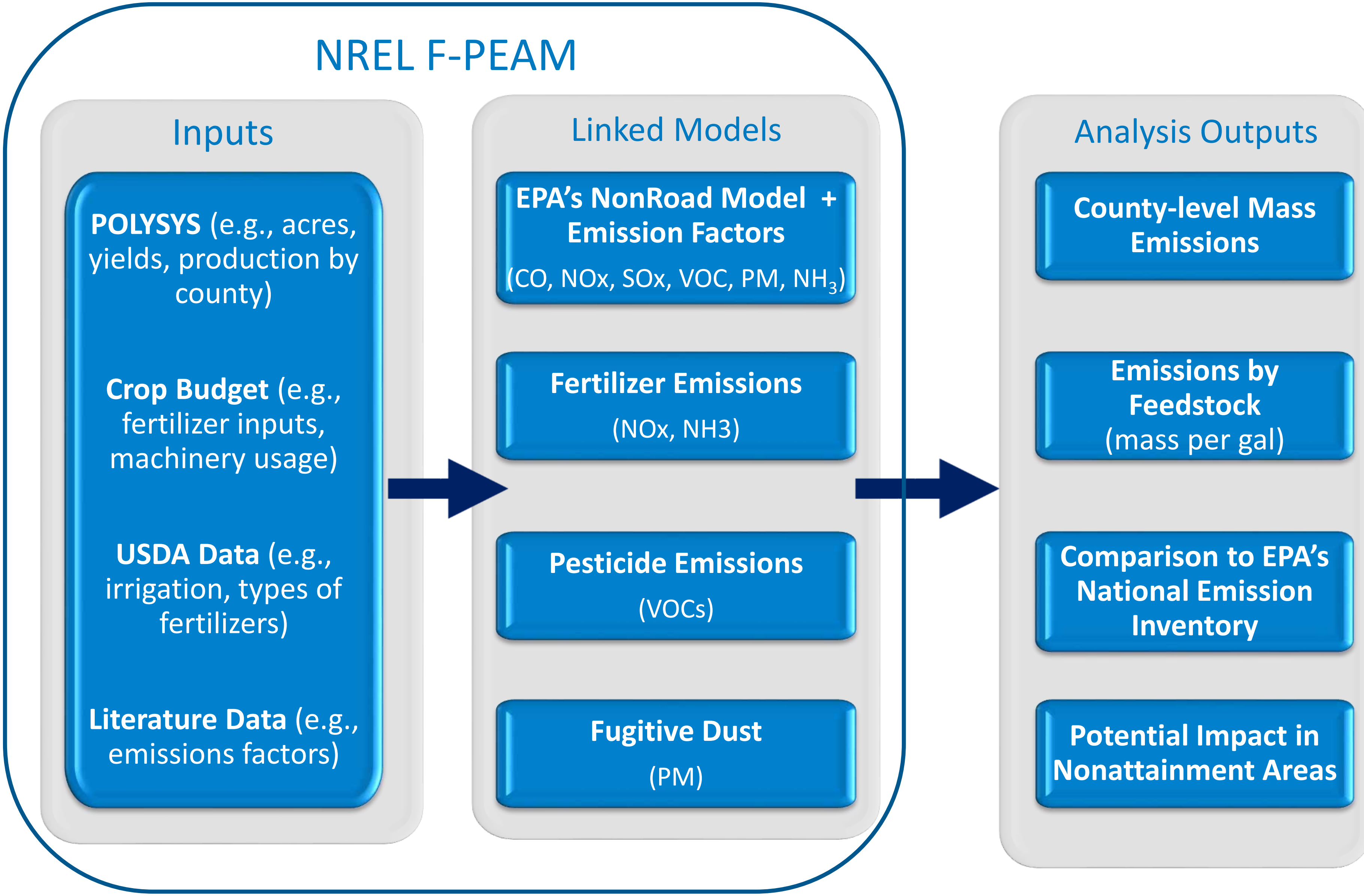
Progress

For each life cycle stage, based on inventory

For life cycle impact evaluation, considering all stages and net effects

- Spatially, temporally, and chemically explicit inventory
- Air quality modeling
- Regulatory and Impact assessment
- Inform process designs along the supply chain

2. Technical Approach (cont.)
Feedstock Production Emissions to Air Model (F-PEAM)



2 – Management Approach

- **Critical success factors**
  - Leverage latest process design cases for advanced systems developed by DOE labs
  - Close collaboration with process design teams
  - Inform design and cost modeling
    - Fermentation of sugars to hydrocarbons conversion pathway
    - Fast pyrolysis conversion pathway
    - Advanced feedstock supply and logistics
    - Billion-ton study update on cellulosic feedstock production
- **Top challenges**
  - Support required from external air quality engineering experts given complexity of air quality regulations that could be applicable to bioenergy systems, and in depth knowledge of air permits and permit inputs (e.g., emission factors for novel sources).
  - Lack of data (e.g., measurements), which can be used to validate our estimates for these novel bioenergy systems.
  - Maintaining an up-to-date modeling framework including database management, versioning, and effective data transfer/communication with multiple platforms.
  - Effective communication and integration of results. This includes dissemination of our high-level results to pertinent BETO platform managers and LRMs at collaborating national labs as well as detailed and iterative communication and data transfer to process design teams. It also includes communication with target audiences who have their own particular needs.

2 – Management Approach cont.

- **Approach to project management**
  - To maintain progress towards short- and long-term goals, we use quarterly milestones in our work plan. As milestones are met, the results/outcomes are communicated to BETO.
  - Meet weekly as a team to discuss specific task progress, monthly as a team to discuss over-arching project-related issues, and quarterly with BETO to share our overall fiscal year progress to-date.
  - Meet regularly with the process design teams at NREL and even have a process design engineer as one of our core team members; this person works in close liaison with the biorefinery process analysis group of NREL and the analogous group at PNNL.
  - Throughout the year we communicate with the larger BETO and national lab audience by giving presentations to pertinent DOE audiences.

3 – Technical Accomplishments: FY2013

Achievements

- Preliminary models were developed to predict six criteria air emissions for the fast pyrolysis and the sugars to hydrocarbons processes.
- Developed F-PEAM for estimating air t emissions from biofuel feedstock production and harvest. laboratories, and EPA's NONROAD model.
- Generated a spatially explicit air emissions inventory for NOx, CO, NH3, VOC, SOx, PM2.5, and PM10) from the production and harvest of five biofuel feedstocks (corn, corn stover, wheat straw, switchgrass and forest residues) to meet the volumetric mandates required by the RFS2 in 2022.
- An LCI was performed and documented in a preliminary report on the GHG and energy return on investment for sugars to hydrocarbons process.

Significance and Impact

- Results from our analysis advance understanding about how cellulosic feedstock compares to conventional biofuel crops (e.g., corn) in terms of air pollutant emissions
- The analysis is needed for establishing baselines and targets for air pollutant emissions for biomass feedstock production

Publications

- Air pollutant emission from large-scale bioenergy feedstock production in 2022 in relation to National Emissions Inventory. Presentation at the *2013 Air and Waste Management Association Conference*.
- Journal publication on same topic submitted in FY15

3 – Technical Accomplishments: FY2014

Achievements

- For BETO MYPP, proposed analytical targets for air emissions for two biofuel technology pathways: fast pyrolysis and biological conversion of cellulosic sugars to hydrocarbons
- Determined federal air pollutant emission regulations potentially applicable to a biorefinery using fast pyrolysis and sugars to hydrocarbons pathway, respectively
- Developed estimates of maximum potential emissions of regulated air pollutants identified in the regulatory analysis for a sugars to hydrocarbons biorefinery – *this analysis was identified by BETO as being "high impact"*
- Developed estimates of maximum potential emissions of regulated air pollutants for a biomass depot which supplies feedstock to the fast pyrolysis and sugars to hydrocarbons biorefineries

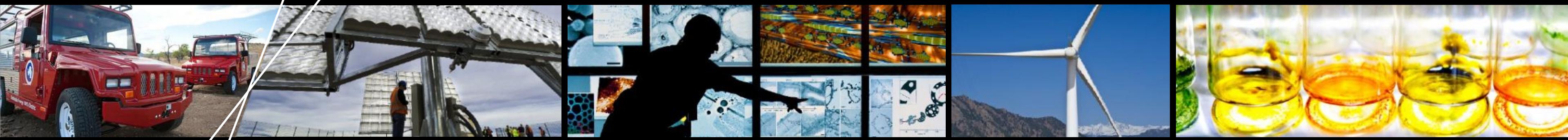
Significance and Impact

- One of BETO's goals for developing sustainable biofuels is to minimize air pollutant emissions to maintain and improve air quality. Our analysis enables BETO to establish sustainability targets for air pollutant emissions across the full bioenergy supply chain.
- Results from our analysis, along with other metrics identified by BETO (MYPP 2014), are important to guide sustainability improvement alongside techno-economic performance, and inform future design case updates.

Publications

- NREL technical report documenting federal air pollutant emission regulations potentially applicable to a biorefinery using sugars to hydrocarbons pathway and the development of estimates of maximum potential emissions of regulated air pollutants (to be published in FY15)
- NREL technical report documenting federal air pollutant emission regulations potentially applicable to a biorefinery using fast pyrolysis pathway and the development of estimates of maximum potential emissions of regulated air pollutants (to be published in FY15)

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



Potential Emissions from a Sugars to Hydrocarbons Biorefinery

Caveats on Preliminary Results

- Current design case (Davis et al. 2013) does ***not*** have all necessary information/data needed for making accurate emission estimates for permitting purpose – assumptions are unavoidable, and our results are ***preliminary***.
- Current sugars to hydrocarbons conversion is not designed with the goal of optimizing air emissions.
- Emissions factors are not readily available from literature, EPA guidelines, and existing permits for some novel unit operations – e.g., sugars to hydrocarbons boiler which burns a combination of biogas, sludge, lignin and other residues.
- We reviewed only federal regulations and permitting requirements; states or localities may have additional or more stringent requirements.

Preliminary Potential to Emit (PTE) estimates

Pollutant	PTE (tpy)	Major source threshold (tpy)
PM	69	100
PM_{10}	28	100
$PM_{2.5}$	9	100
Sulfur dioxide (SO_2)	110	100
Nitrogen oxides (NO_x)	290	100
Carbon monoxide (CO)	610	100
Volatile organic compounds (VOC)	99	100
Lead	<1	100
Hazardous air pollutants (HAP) (total)	41	25 (total)
Ammonia (NH_3)	2.0	Only reporting requirement[1]
Sulfuric acid (H_2SO_4) mist	21	100
GHG (CO_2 equivalent)	1,200,000	N/A[2]

PM10 = Particulate matter with less than 10 micrometers in diameter. PM2.5 = Particulate matter with less than 2.5 micrometers in diameter .

1. N/A – GHG alone cannot drive major source permitting. However, if a source is a major for non-GHG pollutant, the source will be subject to GHG PSD review if the PTE of GHG emissions exceed a certain threshold. (Some states use 0 and some states use 75,000 tpy. EPA is working on rulemaking to set this value.)
2. NH_3 is not regulated under new source review (NSR) program. If a source has a Title V permit, there is reporting requirement for NH_3.
3. The PTE has been calculated assuming that originally planned controls have been made federally enforceable in a permit and additional control measures, necessary to meet the requirements of federal regulations, are added to the design plans. The determination of applicable regulatory requirements was based on several assumptions that were considered to be the most likely. These assumptions could change as detailed engineering design is available; these changes could alter the PTE estimates of CO, VOC, and HAP.

Key messages

1. A sugars to hydrocarbons biorefinery as per the design case (Davis et al. 2013) will likely be subject to major new source review under New Source Review and construction permit procedures, based on current design and our ***preliminary*** PTE estimates.
   - Further emission control technologies/devices can be employed to reduce PTE. We are in the process of investigating strategies to reduce emissions and the implications of additional emission controls on cost and performance.
2. Collocating with a biomass (preprocessing) depot could pose additional challenges to air permitting (i.e., making it harder for the biorefinery to reduce its PTE below the major source threshold) since collocated facilities are considered together in one permit. These preliminary results are for a ***stand-alone*** biorefinery.
3. Major source review is a greater burden of time and expense in the permitting process, and often results in the acceptance of operational limits or use of additional emission control technologies which can both impact facility economics, a topic being investigated in FY15.
4. The boiler is the single largest emitting source for CO, NOx, PM_{10}, $PM_{2.5}$, SO_2, GHG, and HAP. However, emission factors for similar facilities are not readily available. In our future work, stack test results from analogous unit operations will be collected (*if available)* to verify our estimates and we will also attempt to model combustion devices.
5. These preliminary results need to be validated once test results from newly constructed and operational cellulosic biorefineries are available. We are tracking all new/being constructed biorefineries, communicating with the state permitting authorities to review air permits and awaiting stack test data.

Relevance for BETO strategic goals

Support BETO in achieving the following MYPP goals:

- Identify emission control technologies to be incorporated into the design cases to reduce air emissions from advanced biorefineries
    - Corresponding MYPP goal: By 2015, identify practices that improve sustainability and environmental performance of advanced bioenergy, including results from a comprehensive case study of environmental, social, and economic sustainability indicators for a cellulosic feedstock production and biorefinery system.
- Quantify air emissions for biomass depots
    - Corresponding MYPP goal: By 2016, coordinate with feedstock logistics and conversion R&D areas to set targets for …..air emissions for at least three renewable hydrocarbon pathways to be validated in 2017 and 2022.
- Identify applicable air regulations for two advanced biorefineries
    - Corresponding MYPP goal: By 2017, identify conditions under which at least one technology pathway for hydrocarbon biofuel production…..meets targets for consumptive water use, wastewater, and air emissions.

Relevance

- Facilities along the biofuel supply chain must meet air quality regulations.
  - What are the applicable regulations?
  - Do current designs meet these regulations and if so, at what cost?
  - What does compliance portend for future operation?
  - Our research will answer these questions in a tight collaboration with biorefinery and logistics design teams.
- The public expects and the biofuel industry implicitly promises a more sustainable product across all environmental attributes as compared to conventional fuels.
- How will air quality be impacted if BETO's advanced biofuel designs are deployed at commercial scale?
  - We perform process-level investigation and validation of potential air emissions and help identify challenges early so design adjustments can be made.
- Outreach to EPA, states and regional air quality management organizations ensures results will fulfill their requests and ensure this project's results be factored in to planning decisions.
- Air quality permitting is practiced through precedent, which advanced biofuel systems lack. Guidance can be provided to both the industry and regulators through the novel research pursued in this project to help fill the gaps brought to our attention by these groups.

5 – Future Work: 2015 - 2016

- Review applicable federal regulations for all biofuel supply chain facilities for the latest process designs, estimate their emissions, and collaborate with process design teams at NREL and PNNL on design strategies to meet regulatory limits.
- Communicate our results to the air quality management community to inform their planning and decisions
- Collect air emission data to validate our modeled estimates
- Integrate estimates for each biofuel life cycle stage into a spatially, temporally and chemically explicit inventory, including net changes attributed to displacement of incumbent fuels.
- Continue to support BETO and ORNL for the Billion Ton Study 2016 (BT16) expanding the F-PEAM model to allow seamless assessment of air emissions from POLYSYS-evaluated feedstock and resource use.
- Ultimately perform a full air quality assessment of the biofuel supply chain including exposure, and health impacts

Summary

- Overview: This project is aimed at improving our 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: Analysis of air emissions for 1) feedstock production and harvesting, 2) feedstock logistics, 3) biofuel conversion processes, e.g., sugars to hydrocarbons, and fast pyrolysis
- Relevance: Analyses from this project support several short and mid-term MYPP goals.
- Future work: Coordination with the biorefinery process development teams to document the adoption of air-quality recommendations and strategies and support for the Billion-Ton Study 2016

Additional Slides

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Responses to Previous Reviewers' Comments

Recommendation 1 from the 2013 BETO peer review: "The first major element that could better support BETO's overall goals is improved integration of TEA and LCA."

- We have greatly improved our coordination with the process design teams and their techno-economic assessment work. We have joint milestones that demonstrate our coordination of air quality assessment work and TEA development. We have also made great effort to communicate to other BETO process development teams outside of NREL such as INL and ORNL.

Responses to Previous Reviewers' Comments

Reviewer comment:

"This project contributes in important ways to DOE's efforts to ensure sustainability of the advanced bioenergy industry. Its findings will take DOE to a much deeper understanding of the air quality impacts of the industry. Up to now, impacts of air quality have been limited to inventories of specific emissions and some simplistic impact categories. Adding geospatial specificity to the emissions allow for more rigorous public health and ozone formation calculations. The team is making very good progress, and is on track to establish a modeling tool that can be used to quantify and minimize human health effects from criteria air pollutants. Likewise, the project is generating useful modeling results for lignin combustion. Here, however, a more concerted effort to collect real-world data on combustion would greatly enhance this project. The biggest concern for this project is the suggestion made in the review of turning to monetizing of human mortality and morbidity estimates as a metric for air quality. Such monetizing is fraught with difficulties, and should be considered only after consultation with the broader research community working on measuring and defining sustainability for bioenergy."

- We are currently focused on providing detailed emissions estimates, interpretation of federal air quality permitting requirements, and integration of these into supply chain process analyses. Although our capabilities enable lifecycle quantification of air quality impacts attributed to biofuels, our focus over the last two years has shifted somewhat away from monetization of impacts.

Publications, Patents, Presentations, Awards, and Commercialization

- Presentation to the Feedstock Supply and Logistics Group of BETO: Development of preliminary estimates of permitted potential emissions for biomass depots (October 15, 2014)
- Presentation to EPA and USDA Air Quality Task Force Meeting: Air Quality Considerations for Biofuels: Development of preliminary estimates of potential emissions for the bioenergy supply chain (January 7, 2015; December 4, 2014)
- Presentation to Midwestern Biopermitting Group and Demonstration & Market Transformation Team of BETO: Air pollutant emissions from the life cycle of biofuel: cellulosic biorefineries (October 3, 2014; December 3, 2014)
- NREL technical report documenting federal air pollutant emission regulations potentially applicable to a biorefinery using sugars to hydrocarbons pathway and the development of estimates of maximum potential emissions of regulated air pollutants (to be published in FY15)
- NREL technical report documenting federal air pollutant emission regulations potentially applicable to a biorefinery using fast pyrolysis pathway and the development of estimates of maximum potential emissions of regulated air pollutants (to be published in FY15)
- Journal paper: Air pollutant emissions inventory for production of biomass to meet the Renewable Fuel Standard in 2022 (to be submitted)

Additional Backup Slides
Sugars to Hydrocarbons

Equipment/activities likely to generate air pollutants

Plant Area	Equipment/activities	Air Pollutants
Area 100: Feed handling	Feedstock loading, storage, and conveyance	PM, PM_{10}, $PM_{2.5}$
	Dust from roads due to traffic of trucks hauling feedstock, other raw materials, waste, and product	PM, PM_{10}, $PM_{2.5}$
Area 200: Pretreatment and conditioning	Presteamers (M-204) and Pretreatment Reactors (M-207)	VOC, HAP, SO_2, H_2SO_4 mist
	Flash tank (T-204)	VOC, HAP, SO_2, H_2SO_4 mist
	Ammonia addition tank	NH_3
	Leaking equipment	VOC, HAP
Area 300: Enzymatic hydrolysis, hydrolysate conditioning, and bioconversion	Enzymatic hydrolysis reactors (F-300A)	VOC, HAP
	Filter press (S-205)	VOC, HAP
	Aerobic bioreactors (F-300B) and storage tank (T-306B)	CO_2, VOC, HAP
	Leaking equipment	VOC, HAP
Area 400: Cellulase enzyme production	Bioreactors (F-400, F-401, F-402, and F-403), and tanks (T-405, T-406, and T-410)	CO_2, VOC, HAP
	Leaking equipment	VOC, HAP

Equipment/activities likely to generate air pollutants (cont'd)

Plant Area	Equipment	Air Pollutants
Area 500: Product recovery and upgrading	Pre-heater (no ID provided)	PM, PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, CO_2, VOC, HAP
	Hydrotreating process (S-570)	CO_2, VOC, HAP
	Leaking equipment	VOC, HAP
Area 600: Wastewater treatment	Anaerobic digester (T-606)	CH_4, CO_2, VOC, HAP
	Aerobic digester (T-608)	CO_2, VOC, HAP
	Leaking equipment	VOC, HAP
Area 700: Storage	RDB product storage tank	VOC, HAP
	Sulfuric acid tank	H_2SO_4 mist, SO_2
	Two ammonia storage tanks	NH_3
	Loading operations	VOC, HAP
Area 800: Combustor, boiler, and turbogenerator	Boiler (M-803)	PM, PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, CO_2, VOC, HAP
Area 900: Utilities	Cooling towers	PM, PM_{10}, $PM_{2.5}$, VOC, HAP
	Fire Pump	PM, PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, CO_2, VOC, HAP
	Emergency generator	PM, PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, CO_2, VOC, HAP

Regulations potentially applicable to the Sugars-to-HC biorefinery per the design case (Davis et al. 2013)

Plant Area	Affected Equipment (Tag Number)	Federal Rule	Target Pollutant(s)
Area 800	Boiler [M-803]	Boiler NSPS, 40 CFR 60, Subpart Db	SO_2, PM, and NO_x
Area 800	Boiler [M-803] Pre-heater [located in Area 500 of design plant]	Depending on whether the source is a major or area source of HAP, one of these Boiler NESHAP will apply: 40 CFR 63, Subpart JJJJJJ Or Subpart DDDDD. The preheater would be subject to Subpart DDDDD.	HAP
Areas 200 through 900	**Emission Release Points:** Process Vents, Equipment Leaks, Storage Tanks, Wastewater, Heat Exchange System (including cooling tower)	Depending on whether the source is a major or area source of HAP, one of these Chemical Manufacturing NESHAP will apply: MON (40 CFR 63, Subpart FFFF) or CMAS (40 CFR 63, Subpart VVVVVV)	HAP
Area 900	Fire Pump and Emergency Generator	Depending on the size and design, the fire pump and emergency generator may be subject to: Engine NSPS 40 CFR 60, Subpart IIII	PM, VOC, NO_x
Area 900	Fire Pump and Emergency Generator	Depending on the size and design, the fire pump and emergency generator may be subject to: Internal Combustion Engine NESHAP, 40 CFR 63, Subpart ZZZZ	HAP

Factors considered in PTE calculations

Pollutants	Regulatory requirements	Originally planned controls in the design case (Davis et al. 2013)
PM, PM_{10}, and $PM_{2.5}$	Boiler NSPS and major source NESHAP limits	Baghouses for feedstock handling and boiler
VOC	1) Assumed VOC reduction due to HAP limits under MON (40 CFR 63, Subpart FFFF), and 2) take federally enforceable limits to less than 100 tpy	-
NOx	Boiler NSPS limitations	Low NOx burner
CO	CO limit of Boiler Major Source NESHAP	-
SO_2	Boiler NSPS limit	Boiler flue gas desulfurization system
H_2SO_4	None	-
CO_2	None	-
HAP (including lead)	Boiler major source NESHAP limits; MON limits	Boiler flue gas desulfurization system (reduces HCl)
NH_3	None	-

Preliminary determination of PSD applicability

Pollutants	**PSD Applicability**
PM, PM_{10}, and $PM_{2.5}$	Not Major, above SER
VOC	Not Major, above SER
NOx	Major, above SER
CO	Major, above SER
SO_2	Not Major, below SER
H_2SO_4	Not Major, above SER
CO_2	Above SER
HAP (including lead)	Major
NH_3	Not Major

Note: 1) assuming the biorefinery is located in an attainment area for all criteria air pollutants; 2) PSD = Prevention of significant deterioration; 3) SER = Significant emission rate