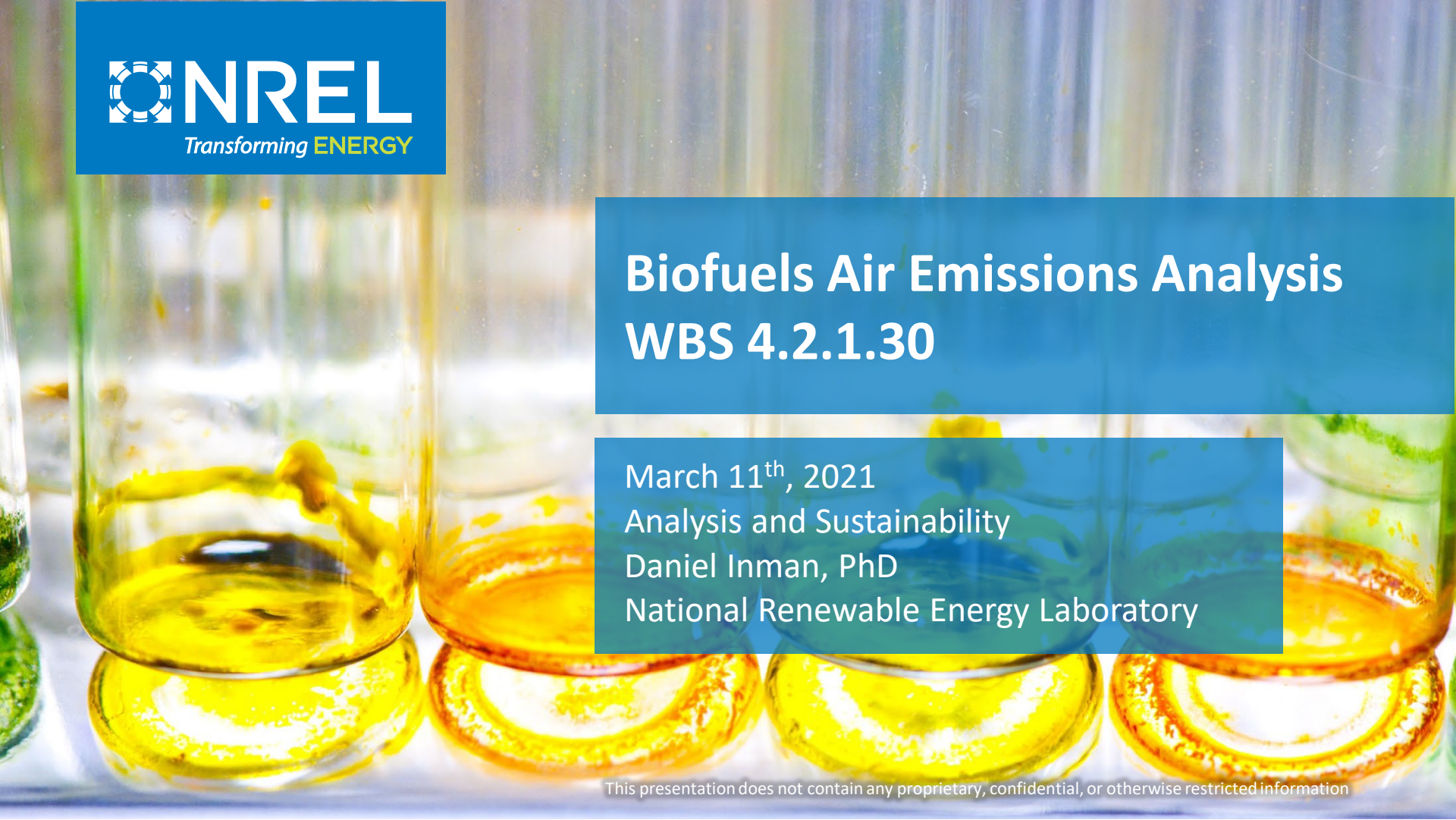
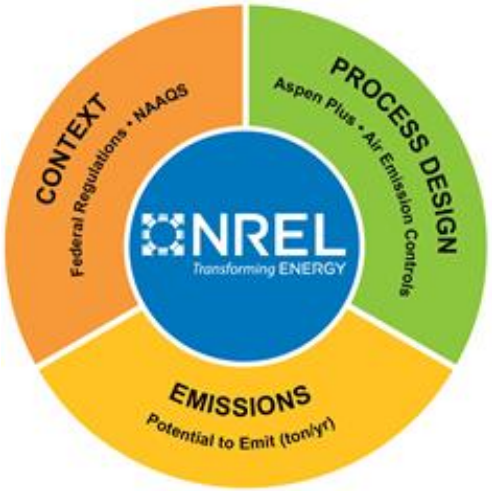


Biofuels Air Emissions Analysis
WBS 4.2.1.30

March 11th, 2021
Analysis and Sustainability
Daniel Inman, PhD
National Renewable Energy Laboratory

Project Overview

- Compliance with federal and state air quality standards is compulsory
- This project determines if process design cases can meet federal air quality regulations and at what cost.
- Prior to this project, air quality was not assessed at the process design stage
- If successful, this project will provide critical data and analysis to design teams, DOE platform leads, potential technology developers, regulatory agencies
- This project provides the following
    - Emissions analysis across the supply chain
    - Applicable regulations
    - Mitigation opportunities and approaches
    - Impact to process economics
    - Impacts to human health
    - Environmental justice implications
    - Regulatory precedence



Market Trends

NREL's Bioenergy Program Is Enabling a Sustainable Energy Future by Responding to Key Market Needs

Value Proposition

- Biorefineries must be able to demonstrate compliance with federal air quality regulations to be permitted.
- The air-permitting stage is complex, onerous, and can cause severe cost overages.
- We provide data, information, and precedence for the biorefinery air permitting process.

Key Differentiators

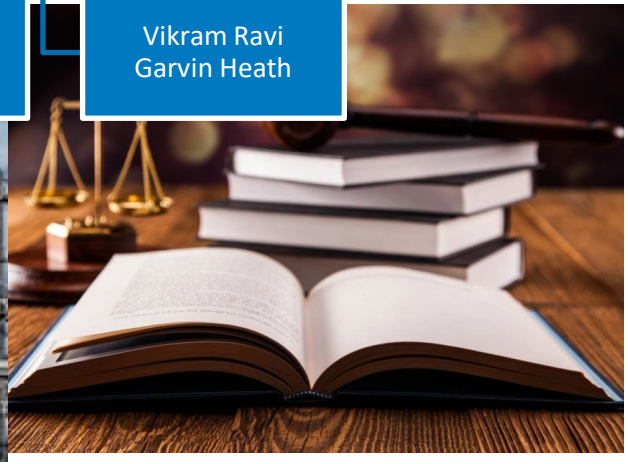
- Full suite of metrics: mass emissions, regulations, externalities, solutions
- Rigorous process engineering and Air Quality engineering approach
- Embedded in process design group

1. Management

1. Management: Staff Roles and Responsibilities

PI
Daniel Inman

Feedstock Production Emissions to Air Model	Process Design Aspen, ChemCAD	Regulatory Analysis	Air Quality Modeling
Dylan Hettinger Rebecca Hanes	Arpit Bhatt Yimin Zhang	Arpit Bhatt Yimin Zhang Garvin Heath	Vikram Ravi Garvin Heath



1. Management : Communication, Transparency, Outreach

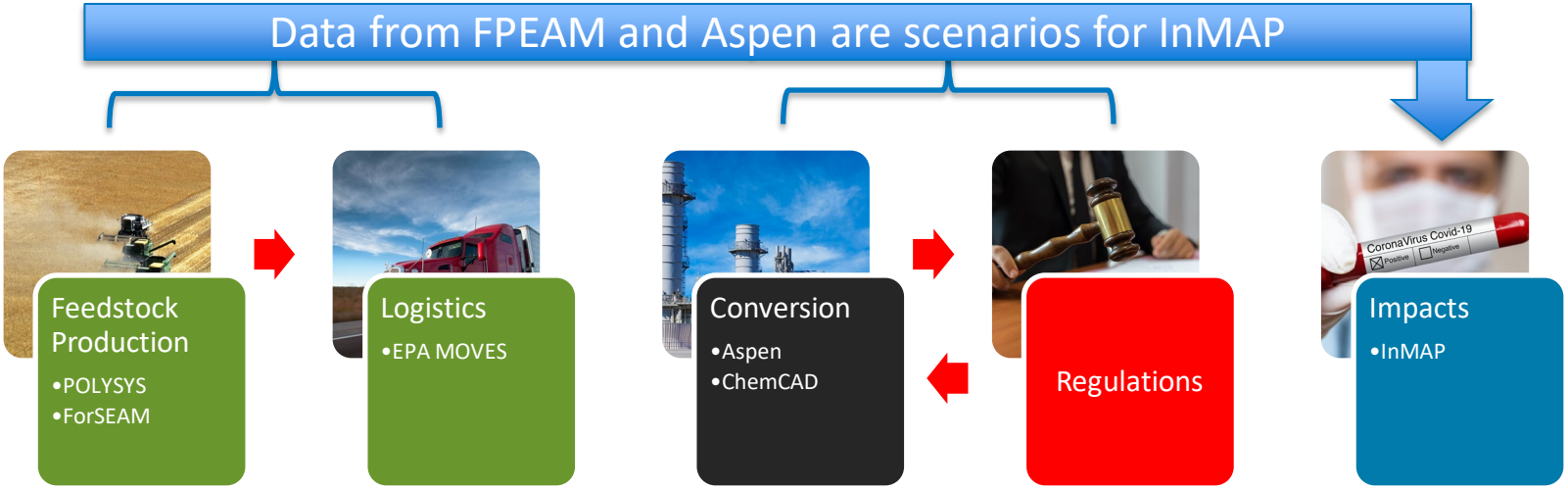
- Regular meetings
  - Team: < 1 per month
  - BETO: 1 per month
  - Other Labs: 1 per month
- Agile management of risks
  - Short term (regular meetings)
  - Long term (AOP)
- External advisory board
  - Guides model development
- Stakeholder engagement
  - Analysis, dissemination

1. Management : Risks

- Agile management of risks
  - Short term (regular meetings)
  - Long term (AOP)
- Major Risks Identified in the AOP:
  - Budget uncertainty
  - Shifting requirements
- Go/No-Go Milestones

2. Approach

2. Approach: Models, Linkages, Data



Feedstock Emissions to Air Model (FPEAM)

Process design approaches and tools

Intervention Model for Air Pollution (InMAP)

2. Approach: Feedstock Production and Logistics

Feedstock Production Emissions to Air Model (FPEAM)

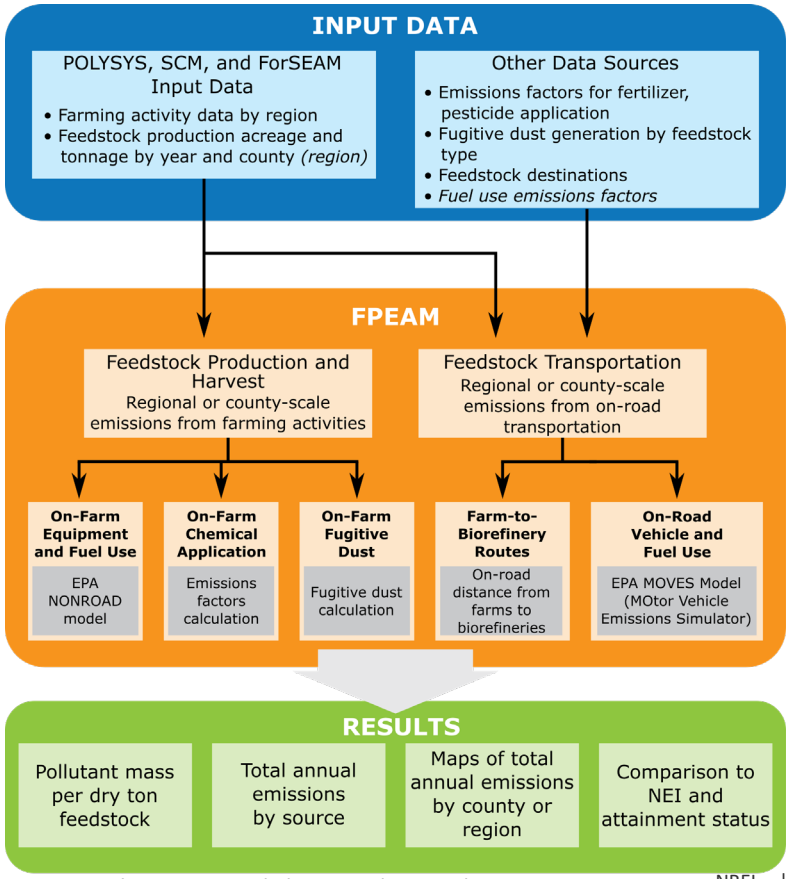
- Validated
- Peer reviewed
- Publicly available

Output:

- Mass emissions per ton of feedstock delivered to the refinery
- Field prep, planting, chemical application, harvest, loading, transport, unloading

Model Connections:

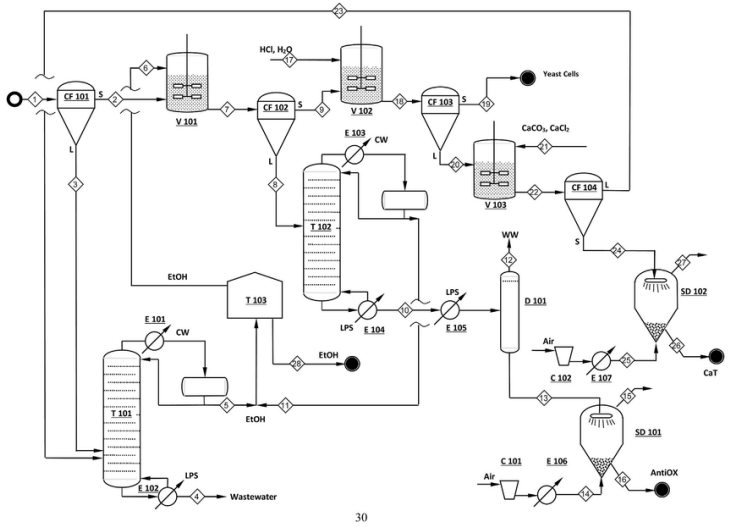
- ORNL Policy Analysis System Model (POLYSYS)
- EPA Motor Vehicle Emissions Simulator (MOVES)



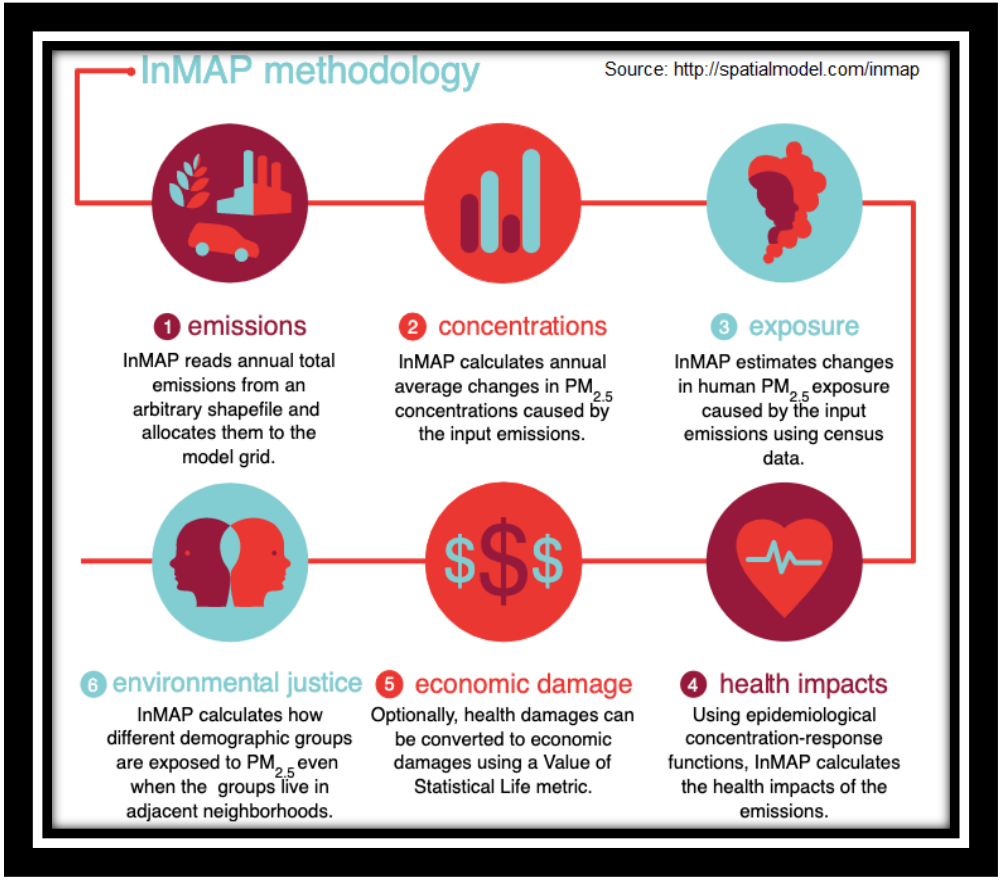
Items in italics are currently being implemented.

2. Approach: Tools and Workflow: Conversion Stage

- **Assess**
  - What pollutants and from where
- **Review**
  - Applicable Federal Air Quality Regulations
- **Estimate**
  - Potential to Emit (PTE) Analysis
- **Modify**
  - Mitigation controls
- **Inform**
  - Inform process design teams



2. Approach: Intervention Model for Air Pollution (InMAP)



PLOS ONE

RESEARCH ARTICLE

InMAP: A model for air pollution interventions

Christopher W. Tessum[1]*, Jason D. Hill[2], Julian D. Marshall[1]

1 Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington, United States of America, **2** Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, Minnesota, United States of America

* ctessum@uw.edu

PNAS

Inequity in consumption of goods and services adds to racial–ethnic disparities in air pollution exposure

Christopher W. Tessum[a], Joshua S. Apte[b], Andrew L. Goodkind[c], Nicholas Z. Muller[d], Kimberley A. Mullins[e], David A. Paolella[a], Stephen Polasky[f,g], Nathaniel P. Springer[h], Sumil K. Thakrar[i], Julian D. Marshall[a], and Jason D. Hill[j,1]

[a]Department of Civil and Environmental Engineering, University of Washington, Seattle, WA 98195; [b]Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin, Austin, TX 78712; [c]Department of Economics, University of New Mexico, Albuquerque, NM 87131; [d]Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213; [e]Energy Consulting, Lumina Decision Systems, Los Gatos, CA 95033; [f]Department of Ecology, Evolution, and Behavior, University of Minnesota, St. Paul, MN 55108; [g]Department of Applied Economics, University of Minnesota, St. Paul, MN 55108; [h]Institute on the Environment, University of Minnesota, St. Paul, MN 55108; and [i]Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, MN 55108

WASHINGTON STATE UNIVERSITY

3. Impact

3. Impact

Stakeholders

- Precedence
- Applicable Regs
- Strategies
- Costs

Process Design Teams

- Modifications
- Performance

DOE – BETO

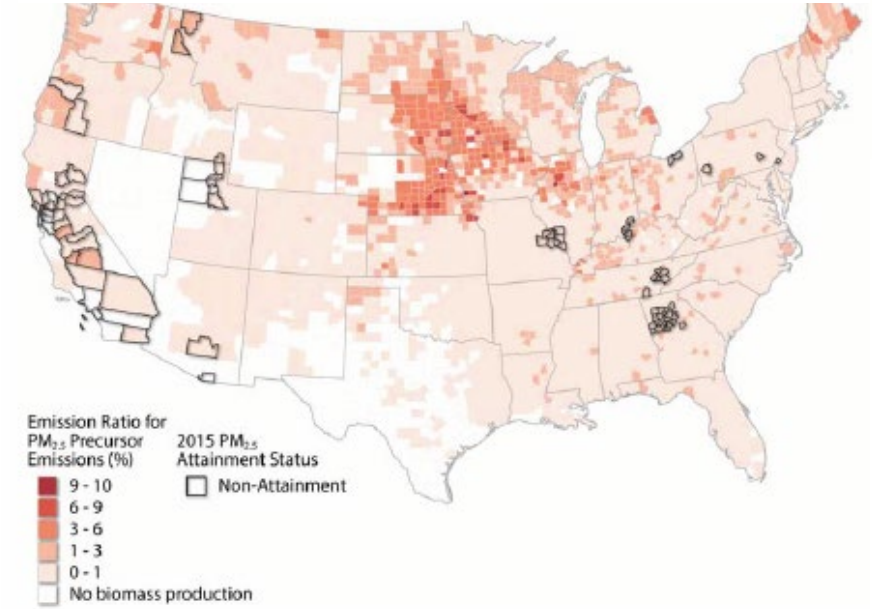
- Sustainable
- Environmentally Just
- Compliance

Will a biorefinery meet AQ regulations?

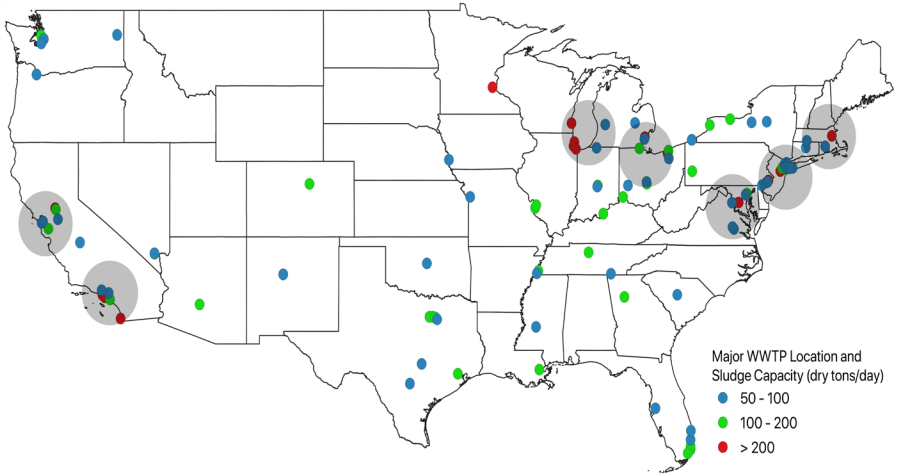
1. Partnership for policy integrity. 2014. Trees, trash, and Toxics. https://www.pfpi.net/wp-content/uploads/2014/04/PFPI-Biomass-is-the-New-Coal-April-2-2014.pdf

3. Impact: Supply Chain and Citing Risk

Impact of Feedstock Supply and Logistics



Potential HTL Process Locations



1. Partnership for policy integrity. 2014. Trees, trash, and Toxics. https://www.pfpi.net/wp-content/uploads/2014/04/PFPI-Biomass-is-the-New-Coal-April-2-2014.pdf

4. Progress and Outcomes

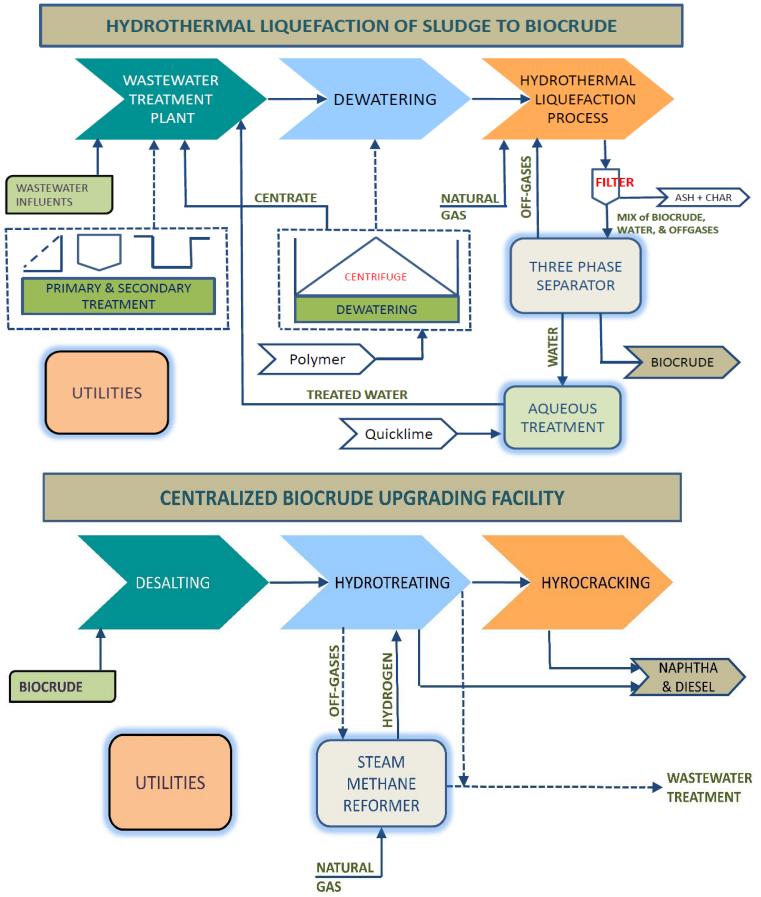
4. Progress and Outcomes: HTL Process Evaluation

Sludge to Biocrude via HTL

- **Does not** trigger major New Source Review (NSR) or Nonattainment NSR unless it is in an area of extreme nonattainment for O_3.

Centralized Biocrude Upgrading to HC Fuels

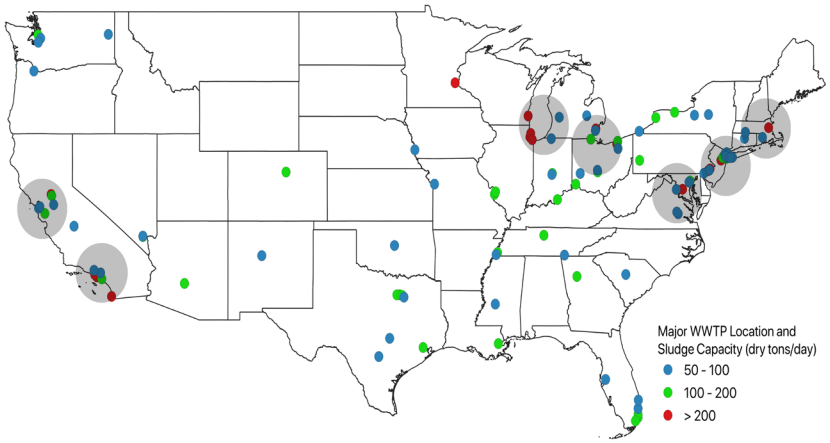
- **Is not** be subject to major source permitting unless it is in **serious**, **severe** or **extreme** area of nonattainment for O_3.
- Control options should be carefully evaluated.



4. Progress and Outcomes

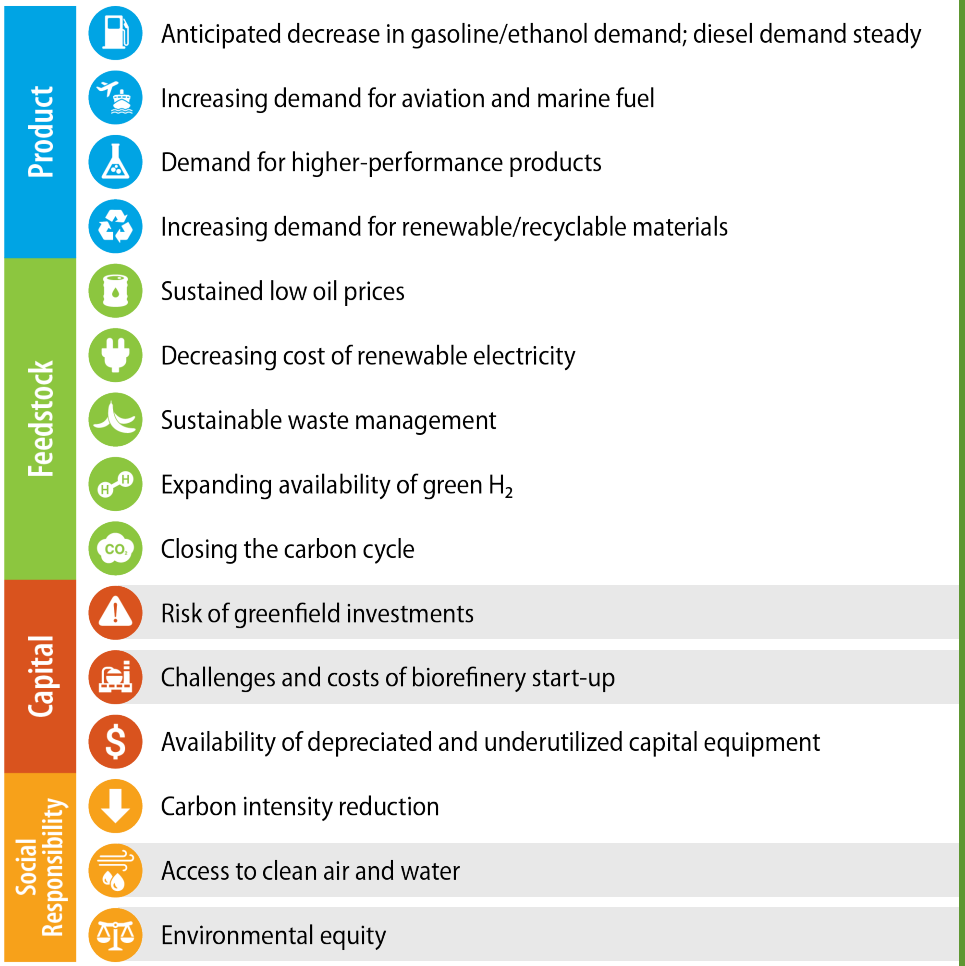
Full air quality analysis of the conversion and upgrading of municipal sewage sludge to hydrocarbon fuels

- Improved FPEAM by developing a reduced-form version of EPA MOVES model
  - Enables batch runs of FPEAM on HPC
  - Oder of magnitude faster run time
- Programmatically linked our key models: FPEAM and InMAP
  - Allows for continuity across modeling platforms
  - Runs on HPC
  - Enables high spatial resolution runs
  - Reduces run time allowing for faster analysis cycles
- Outputs:
  - Human health, monetized impacts, environmental justice



Seven regions identified for the wet-waste to biofuel conversion where enough sludge is available for HTL to biocrude conversion at $3.50 per gasoline gallon equivalent (gge).
Figure data source - Sieple et al. (2017).

Market Trends



NREL's Bioenergy Program Is Enabling a Sustainable Energy Future by Responding to Key Market Needs

Value Proposition

- Provide critical analysis to ensure the production of biofuels meet federal air quality standards

Key Accomplishments

- External stakeholder review and public release of FPEAM
- Reduced form of the EPA MOVES model
- EPA Report to Congress – Chapter 10
- Published Air Quality Assessment of the HTL to biocrude pathway
- Integration of FPEAM with InMAP for full state-of-the-art AQ analysis.

Quad Chart Overview

Timeline

- 10/01/2018
- 09/31/2021

	FY20	Active Project
DOE Funding	*$415,000*	$1,090,000

Project Partners

- Eastern Research Group
- The Environmental Protection Agency
- Pacific Northwest National Laboratory

Barriers addressed

- At-A. Analysis to Inform Strategic Direction
- At-B. Analytical Tools and Capabilities for System-Level Analysis
- ADO-G. Co-Processing with Petroleum Refineries

Project Goal

Provide critical air emissions analyses to:

- Process design teams
- Industry
- Regulatory agencies
- Ensure BETO designs meet federal air quality standards

End of Project Milestone

Full Air Quality Impact Assessment of the HTL design process.

- Conversion of wastewater to bio-intermediate
- Transport of the bio-intermediate to an upgrading facility
- Upgrading to a finished fuel product.
- Analysis will include mass emissions, human health impacts, and environmental justice implications

www.nrel.gov

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Bioenergy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Additional Slides

Responses to Previous Reviewers' Comments

General Comment	
Reviewer Comments	**RESPONSE TO COMMENTS**
Overall, this is a well-focused, well-teamed, high value-added project that could help reduce time and financial burdens (and uncertainty) associated with permitting commercial biorefineries.	We thank the reviewers for their helpful and supportive feedback. We will work to incorporate these suggestions in our project plans as we move forward.

Responses to Previous Reviewers' Comments

Criteria 1: Approach	25%
• The project performers have implemented technically sound research, development, and deployment approaches, and have demonstrated the results needed to meet their targets. • The project performers have identified a project management plan that includes well-defined milestones and adequate methods for addressing potential risks. • The project performers have clearly describe critical success factors which will define technical and commercial viability, and that they have explained and understand the challenges they must overcome to achieve success.	

Criteria 2: Accomplishments/Progress	25%
• The project performers have made progress in reaching their objectives based on their project management plan. The project performers have described their most important accomplishments in achieving milestones, reaching technical targets, and overcoming technical barriers. • The project performers have clearly described the progress since the period of the last review.	

Criteria 3: Relevance	25%
• The project performers have describes how the project contributes to meeting Program/Technology Area goals and objectives and the Bioenergy Technologies Office, as cited in the MYPP. • The project performers have considered applications of their expected outputs. • The project performers have presented the relevancy of this project and how successful completion of the project will advance the state of technology and impact the viability of commercial bioenergy applications.	

Criteria 4: Future Work	25%
• The project performers have outlined adequate plans for future work, including key milestones and go/no go decision points. • The project performers have communicated key planned milestones and addressed how they plan to deal with upcoming decision points and any remaining issues.	

Publications, Patents, Presentations, Awards, and Commercialization

- Bhatt, Arpit H, Zhang, Yi Min, and Heath, Garvin A. Air Pollutant Emissions and Regulatory Implications of Co-Processing Raw Bio-Oil in U.S. Petroleum Refineries. United States: N. p., 2020. Web.
- Arpit H. Bhatt, Yimin Zhang, Garvin Heath. Bio-oil co-processing can substantially contribute to renewable fuel production potential and meet air quality standards. Applied Energy. Volume 268.2020

Staff Roles and Responsibilities

- **Key team members have expertise in:**
  - Air quality engineering
  - Chemical engineering
  - Federal and state air quality regulations and permitting
  - Lifecycle assessment
  - Geospatial analysis
  - Object-oriented programming
- **Team members and responsibilities:**
  - Daniel Inman, PhD – Project Task Leader
  - Vikram Ravi, PhD – Lead Air Quality Modeler and Analyst
  - Yimin Zhang, PhD – Regulatory Analyst
  - Garvin Heath, PhD – Senior Analyst
  - Arpit Bhatt, MS – Process design and analysis
  - Dylan Hettinger – FPEAM development lead; geospatial analyst
  - Rebecca Hanes, PhD – FPEAM developer, analyst

Challenges, Go/No-Go, Metrics

Top challenges

- Dearth of empirical emissions data from biorefineries
- Maintenance of the modeling framework, including database, versioning, and cross-platform communication

Go/No-Go Milestone

Name	Description	Criteria	Date
FPEAM scheduled release	The scheduled release of FPEAM will be based on feedback from our beta-tester group in Q1 of FY19, we will assess the feedback and in consultation with BETO, decide on an on-time release.	**Go**: feedback and suggested improvements to FPEAM are manageable within the timeframe and allotted budget for FY 19.	2/28/2019

Metrics

- Impact to Minimum Fuel Selling Price
- Emissions to Air (Criteria Air Emissions)
- Externalities

Progress and Outcomes

Major Project Accomplishments FY 19 – FY 21

- External stakeholder review of the FPEAM model
- Public release of FPEAM
- Reduced form of the EPA MOVES model
- EPA RTC3 – Chapter 10
- Integration of FPEAM with InMAP for full state-of-the-art AQ analysis.
- Published paper on AQ implication of coprocessing raw biooil in existing refineries
- Published Air Quality Assessment of the HTL to biocrude pathway
- Published AQ impacts of a centralized HTL processing facility (in-process)
- Full AQ impacts assessment of the HTL pathway (forthcoming)

Impact

Relevance to Stakeholders

- Our work has been recognized as impactful by Exxon Mobil's Research and Engineering Corp.
- 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

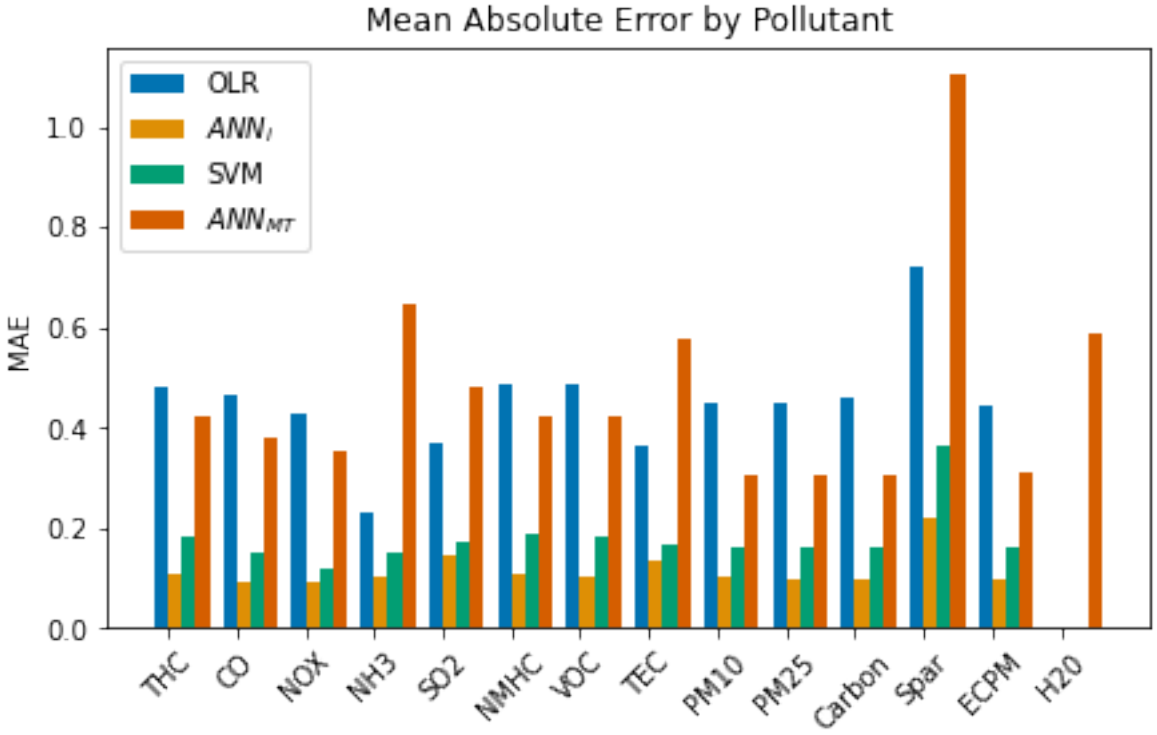
Relevance to BETO

- We interface directly with process design teams across the national lab space (NREL, PNNL)
- Our work is focused on pathways that are currently of interest to BETO
- We keep BETO informed of our findings through interactions with key platform leads (Conversion Technologies, System Development and Integration, Feedstock Supply and Logistics)

Reduced form of EPA MOVES

Reduced Form of the EPA's MOtor Vehicle Emissions Simulator (MOVES) model

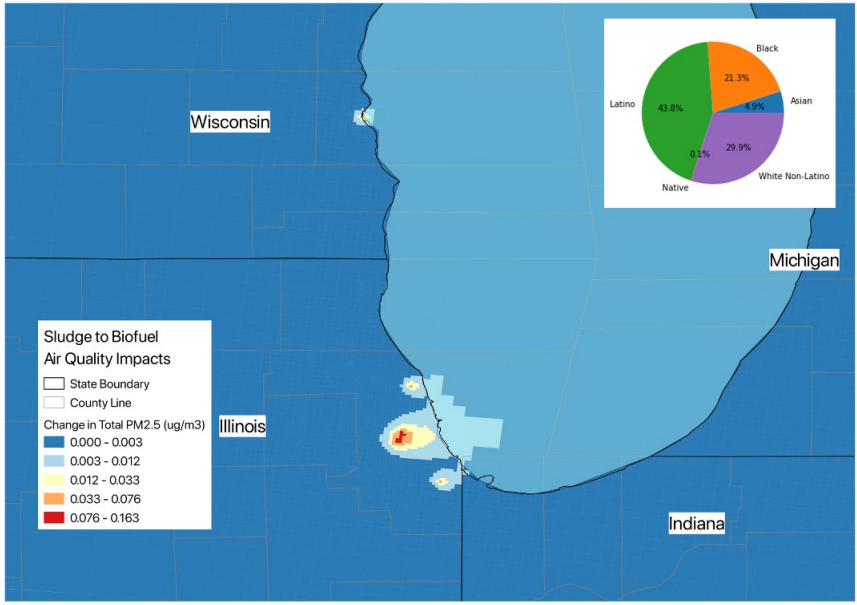
- Developed framework to execute MOVES at scale
- Completed a sensitivity analysis of relevant MOVES inputs
- Produced a reduced form model of MOVES (artificial neural network) with mean error of 10%



Linking FPEAM and InMAP

Integration of FPEAM with InMAP for full state-of-the-art AQ analysis

- We conducted a proof-of-concept analysis using FPEAM and InMAP demonstrating analytical compatibility of the two models.
- We considered emissions from various supply chain components:
  - Sludge to biocrude conversion, assumed collocated with POTW.
  - Feedstock transportation from HTL conversion facility to biocrude upgrading site.
  - Process emissions from upgrading the biocrude to hydrocarbon fuel.
- Model output provides change in concentration of $PM_{2.5}$, and health metrics for different demographics.
  - Example – maximum modeled change in the case study was 0.16 $\mu g/m^3$.



Modeled change in annual concentration of $PM_{2.5}$ from a wet-waste-to-biocrude conversion case. Shown in inset is relative the exposure to different demographics. Based on a case study with domain over Midwestern U.S.