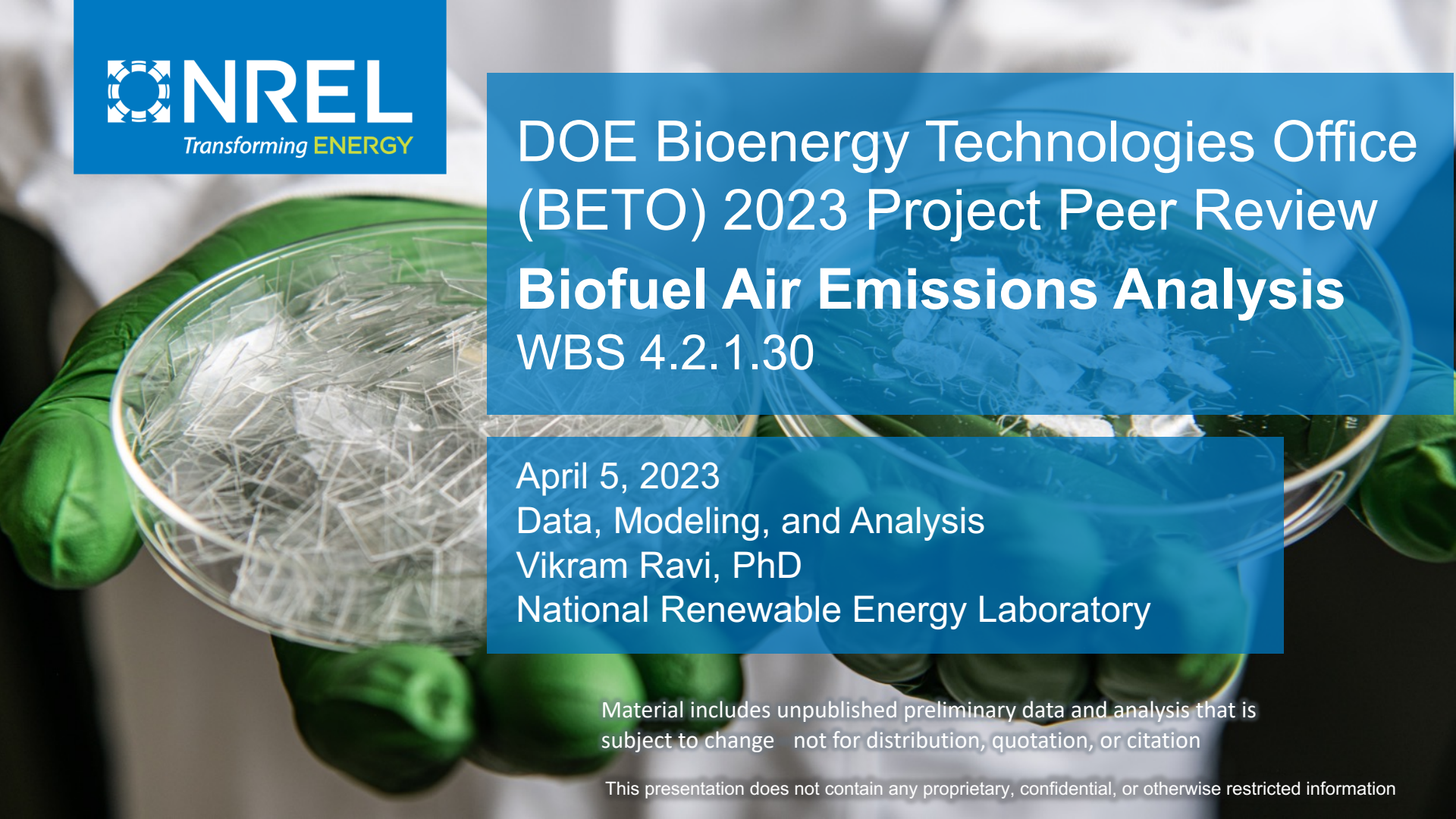


DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Biofuel Air Emissions Analysis

WBS 4.2.1.30

April 5, 2023

Data, Modeling, and Analysis

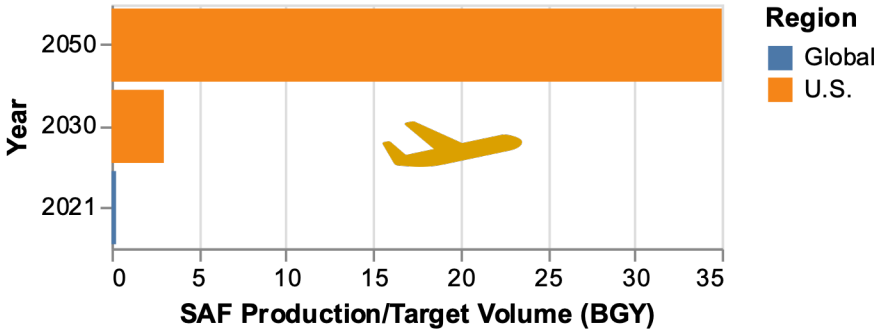
Vikram Ravi, PhD
National Renewable Energy Laboratory

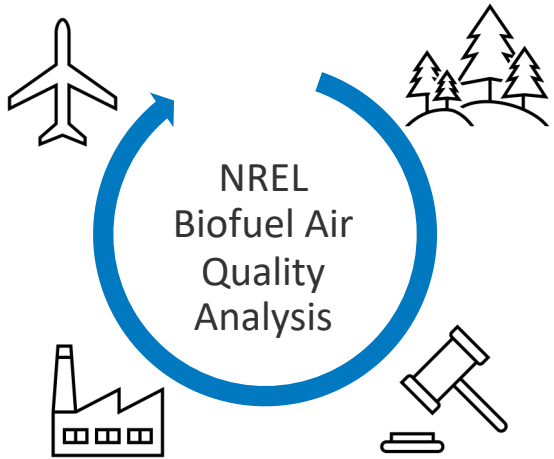
Disclaimer

- The data and analysis shown here is:
  - To obtain external technical review on methods and analysis and promote robust technical discussion within the technical community
  - Not to convey findings or conclusions to take away or inform activities
- Data, results, conclusions, and interpretations presented have not been reviewed by technical experts outside NREL
- Does not constitute a comprehensive treatment of the issues discussed or specific advice to inform decisions)

Project Overview

- DOE prepared the *flight plan* for Sustainable Aviation Fuel (SAF) Grand Challenge but important to understand barriers to *flight take-off* and find solutions
- One potential barrier is biorefinery air quality permitting.
- **Project goals:**
  - **how can future biorefineries producing large volumes of SAF get air quality permitting to operate?**
  - **help industry design processes that minimize impact to environment/communities**

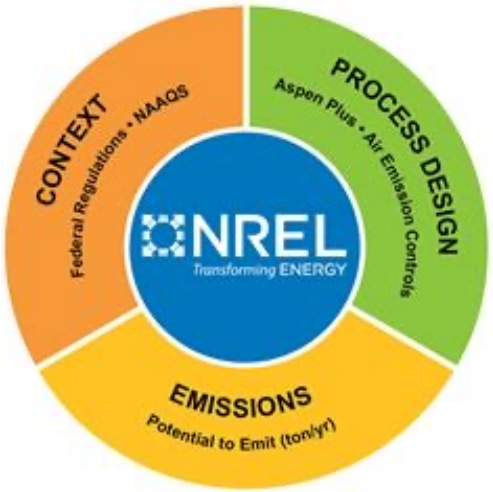




Uniqueness of NREL Biofuel Air Quality Program

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.

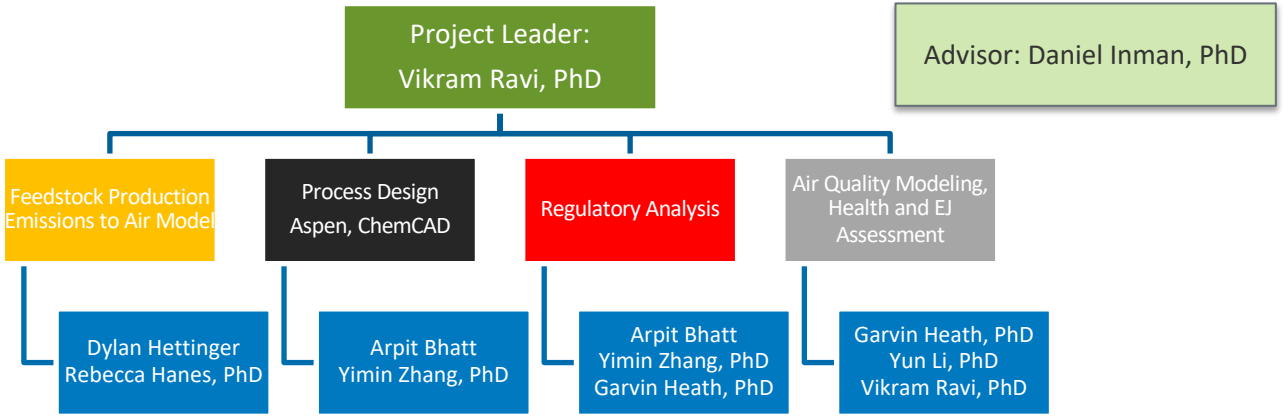


Key Differentiators

- Embedded in process design group
- Full suite of metrics: mass emissions, regulations, externalities, solutions
- Rigorous process engineering and air quality engineering approach, equity assessment

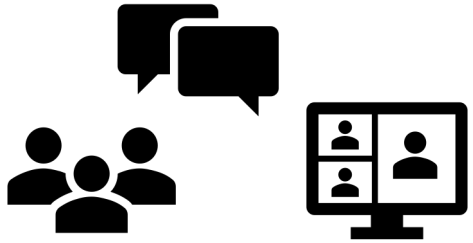
Approach

Approach: Management Plan and Staff Responsibilities

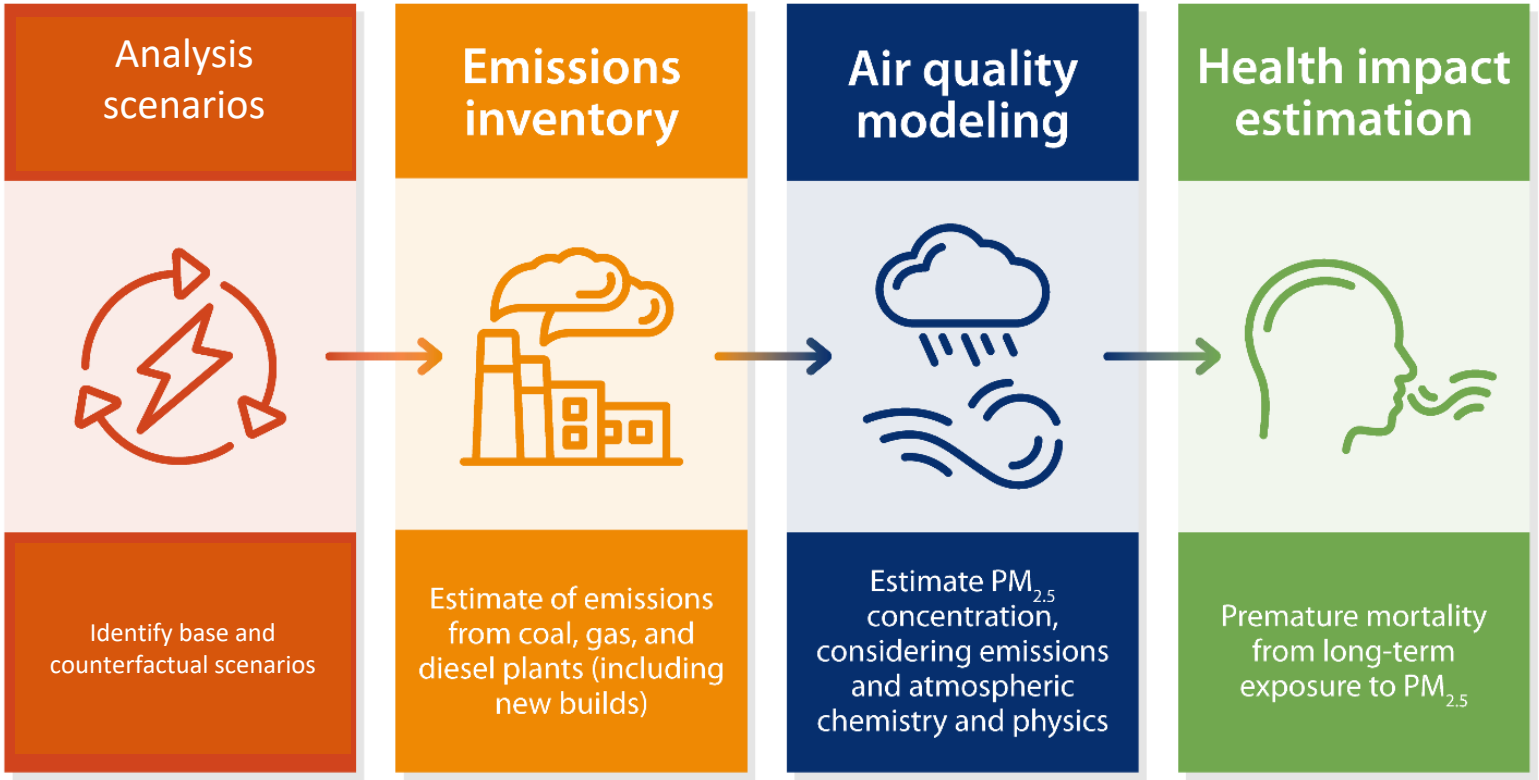


Approach : Communication, Transparency, and Risk Mitigation

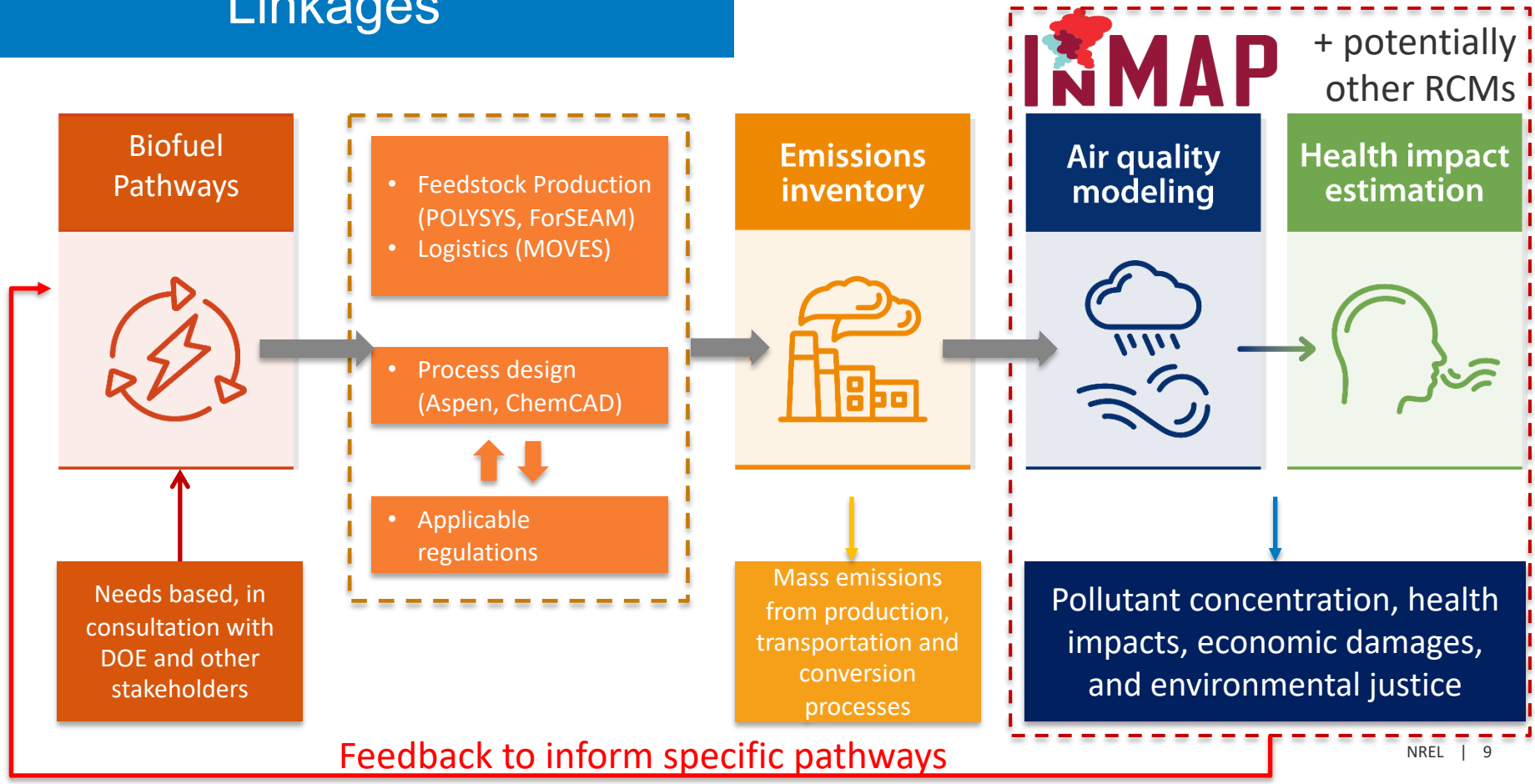
- Regular meetings
  - Team: ~1 per month
  - BETO: ~1 per month
  - Other Labs: as needed
- Agile management of risks
  - Short term (regular meetings)
  - Long term (AOP)
- Stakeholder engagement
  - Analysis, dissemination
- Shared learning with other DOE and non-DOE projects



Approach: Methodology Overview

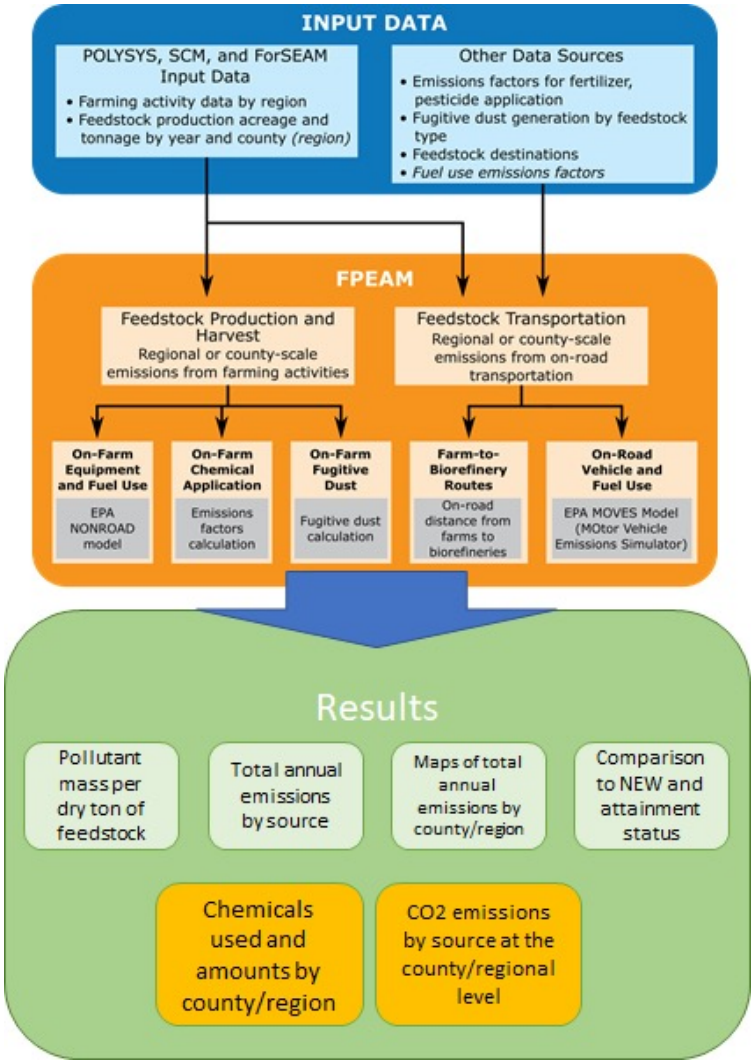


Approach: Models, Data, and Linkages

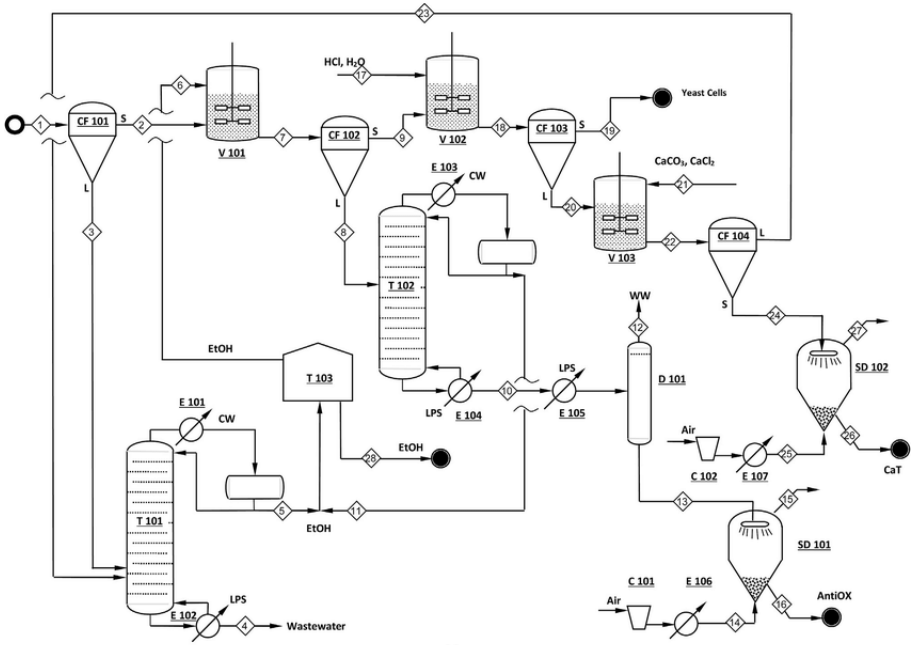


Approach: Feedstock Production and Logistics

- Feedstock Production Emissions to Air Model (FPEAM)
  - Peer-reviewed, publicly available
  - Project github repo: github.com/NREL/fpeam
- Outputs aligned to be ingested by air quality models

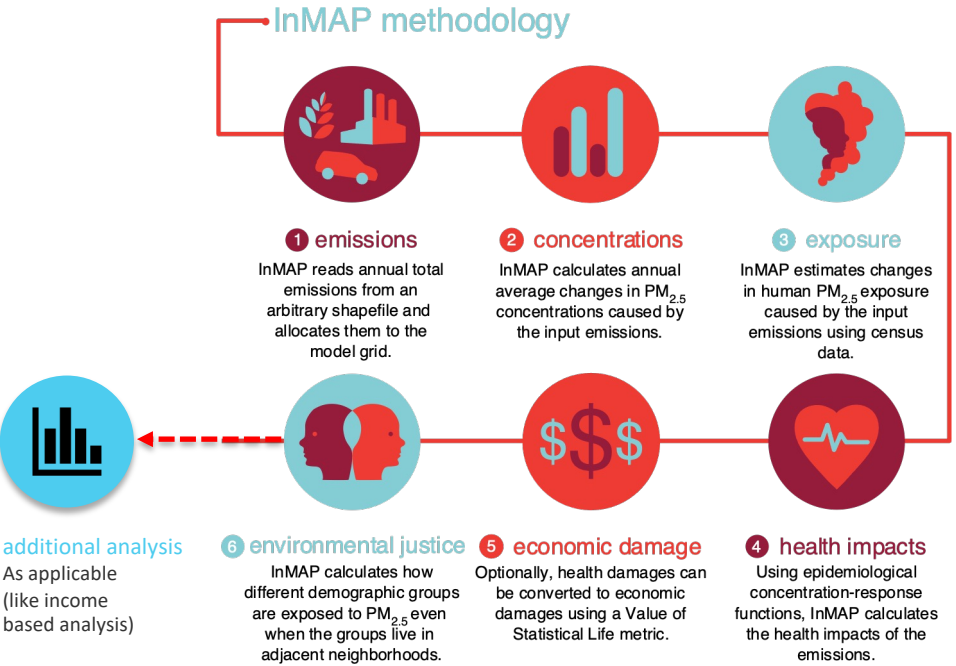


Approach: Tools and Workflow at Conversion Stage



- **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

Approach: Modeling Impacts on Air Quality and Environmental Justice



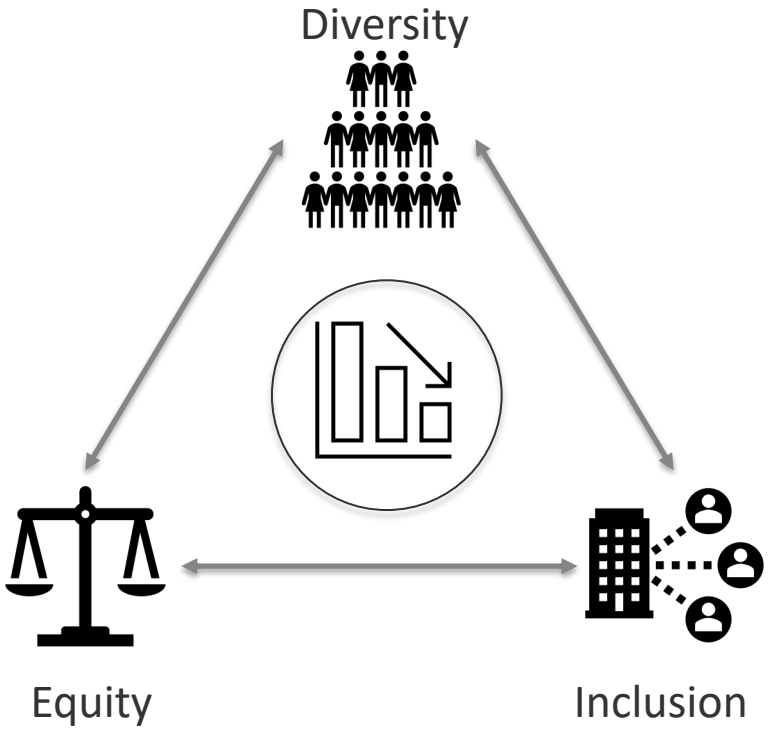
- InMAP, a **reduced complexity model**, has been optimized on NREL HPC.
- Fast run time allows for multiple simulations => easier to do **sensitivity analysis** and thus derive more robust insights.
- One of the key tool used for **equity analysis of bioenergy economy**

Note: Underlying data on population, C-R function, etc. updated as new information becomes available

Figure credit: adapted from https://www.inmap.run/

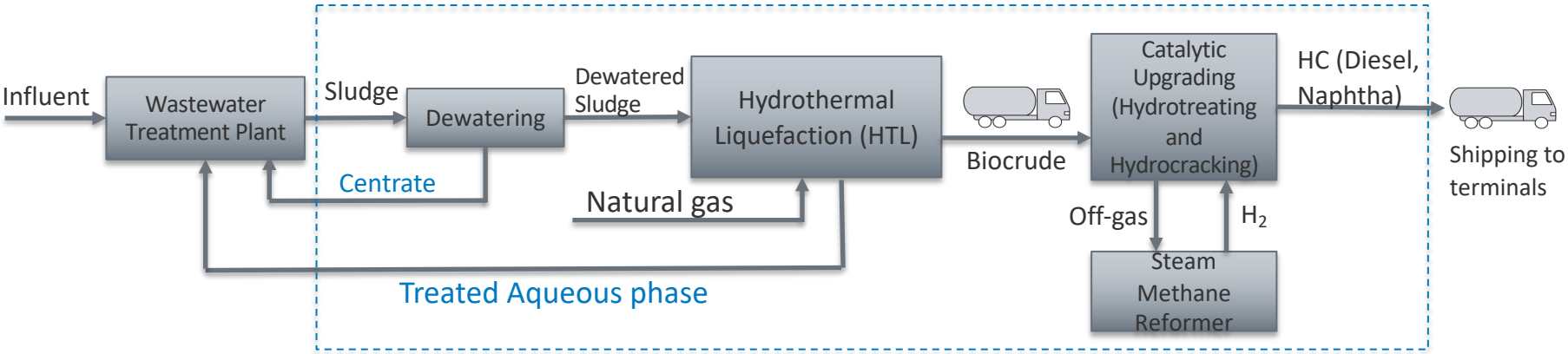
Approach: Equity Assessment

- Provide methods and analysis to support an equitable transition to bioenergy economy
- Focused on environmental impacts (specifically, exposure and health)
- All analysis outcomes include quantifiable metrics



Progress and Outcomes

Wastewater Sludge-to-Biocrude Conversion Analysis



Technical boundaries considered; Shipping of hydrocarbon outside biorefinery facility and tailpipe emissions are not considered

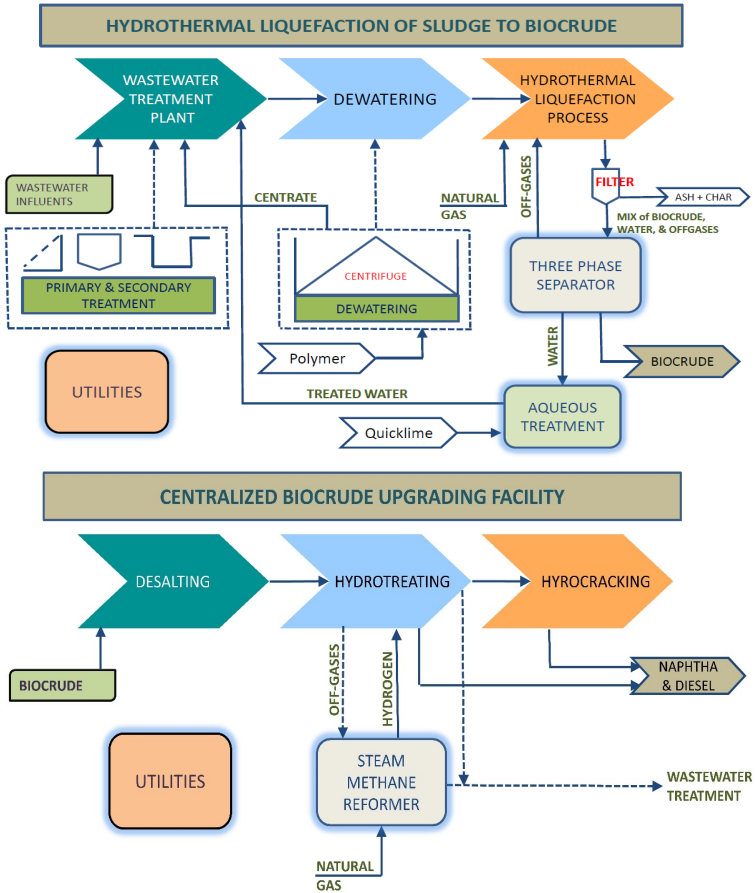
Progress & Outcomes: HTL Process Evaluation

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.

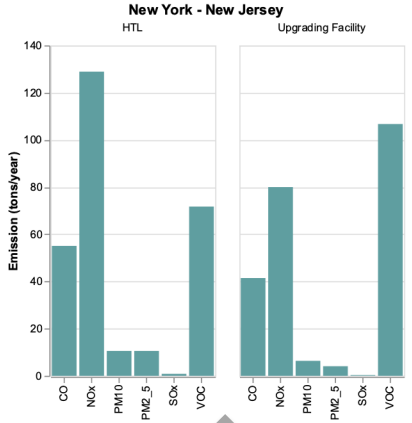
Centralized Biocrude Upgrading to HC Fuels

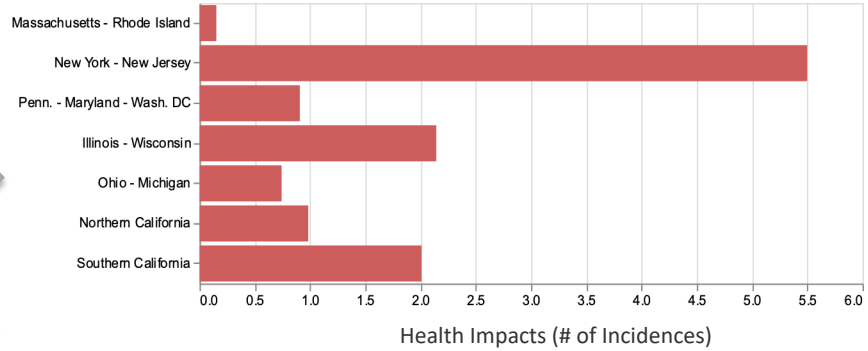
- ***Will not*** be subject to major source permitting unless it is in **serious**, **severe** or **extreme** area of nonattainment for O_3.
- Control options should be carefully evaluated.



Progress & Outcomes: Emissions/AQ/Health/EJ

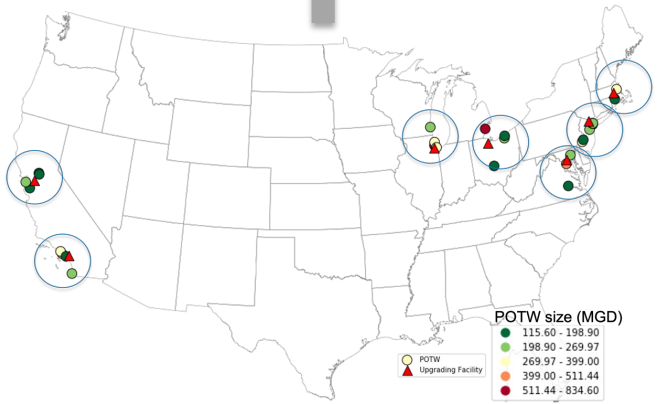
Emissions Analysis

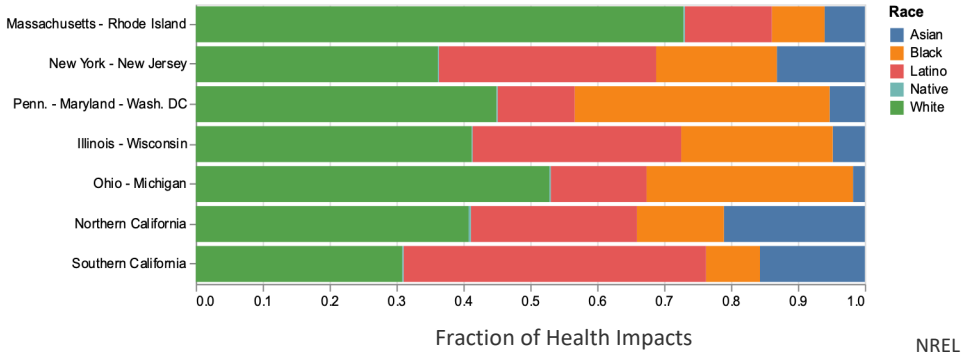




Air Quality / Health Modeling

Resource Assessment (collaborative)

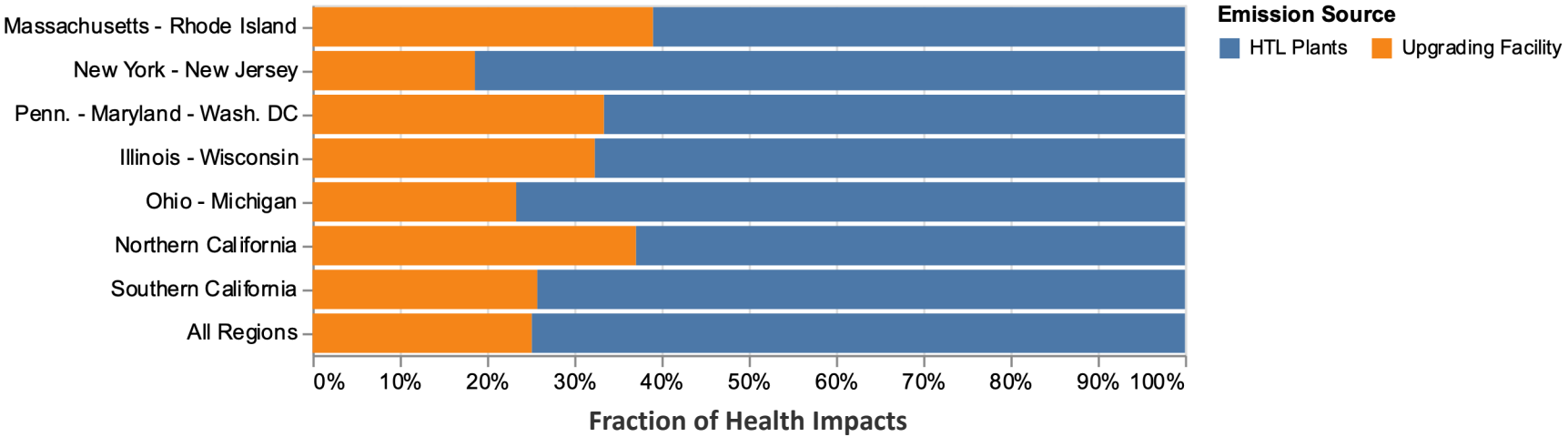




Health and EJ Analysis

PRELIMINARY RESULTS - DO NOT DISTRIBUTE, QUOTE, OR CITE

Progress & Outcomes: Potential Strategies to Reduce Impacts



- Relative impacts vary significantly across regions
  - Upgrading facility accounts for 20% of total health impacts in the New York – New Jersey region whereas 40% in the New England region.
- **Informs where to strategize and focus efforts to reduce impacts**

Progress & Outcomes: FPEAM Update

- Mobile source emissions update: FPEAM updated to use the most recent version of the EPA Motor Vehicle Emissions Simulator (MOVES3) model reflected in FPEAMv2.5.
- Updates improve the estimates for:
  - Heavy-duty diesel emission rates for exhaust, idling, and auxiliary power units
  - Start activity, fuel properties, hoteling assumptions, organic gas speciation
- **Improved emission estimates provides robustness to analysis outcomes**

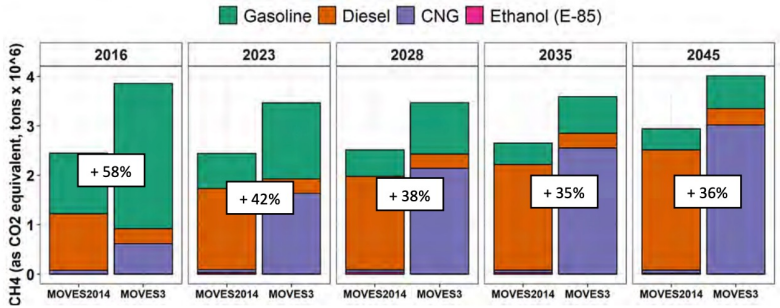


Figure 6-3—National onroad methane in MOVES3 as compared to MOVES2014b

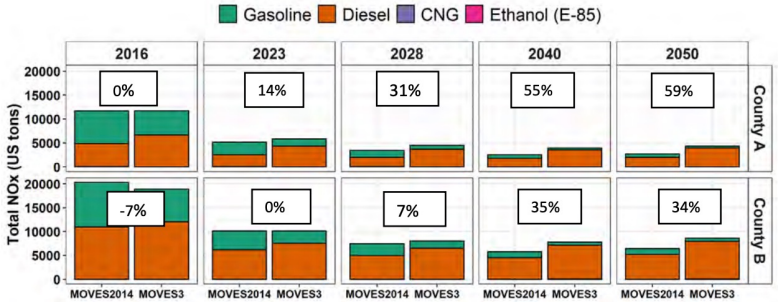


Figure 6-5—Onroad NO_X from two sample urban counties in MOVES3 as compared to MOVES2014b

USEPA. Overview of EPA's MOtor Vehicle Emission Simulator (MOVES3). March 2021. EPA-420-R-21-004. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1011KV2.pdf. Accessed August 23, 2022.

Progress & Outcomes: FPEAM Expansion

- FPEAM now estimates GHG emissions from transportation, agricultural equipment, and fertilizer application
  - **Transportation, agricultural equipment**: based on MOVES
  - **Nitrogen fertilizer application**: Emission factors for N_2O sourced from the IPCC

Fertilizer	Nitrogen Content (lb N/lb fertilizer)	N_2O Emissions (lb CO_2eq/lb fertilizer)
Anhydrous ammonia (NH_3)	0.822	3.82
Ammonium nitrate (NH_4NO_3)	0.350	1.63
Ammonium sulfate $(NH_4)_2SO_4$	0.212	0.986
Urea $(NH_2)_2CO$	0.466	2.17
Nitrogen solutions	0.3 (approx.)	1.39

Impacts

Impacts: Significance and Importance

- Provides **critical data and analysis to design teams, DOE platform leads, potential technology developers, and regulatory agencies on biorefinery air quality regulations and strategies to minimize risk => *Relevant to any future biorefinery***
- Open-source tool development and analysis:
  - Upgrades to FPEAM model – allows for emissions estimation using state-of-the-science tools for various assessments
  - Air quality – health – environmental justice analysis:
    - Assessment of sludge-to-biofuel scenarios
    - Allows for regional and process specific strategies to minimize the impacts
  - Can inform investment decisions considering equity
- Models and methods will be employed for assessment of SAF in the current project cycle

Impacts: Shared Learning with Other Projects

- Approach and methods developed also used in other DOE and non-DOE projects
- Examples:
  - USEPA led Third Triennial Report to Congress on Biofuels and the Environment
  - MarkeRs and EEJ: Assessment of CO_2 to fuel technologies
  - ExxonMobil: Cellulosic biomass to hydrocarbon assessment
  - BILD-AQ: Strategies for charging infrastructure investments

Impacts: Informing the Stakeholders

- Findings are regularly shared with BETO through:
  - Technical memorandum and reports
  - Periodic presentations
- Feedstock and logistics emissions model:
  - FPEAM is publicly available (https://github.com/NREL/fpeam) and a detailed documentation is provided
  - Training conducted in the past
- Findings are also shared through journal articles (Bhatt et al. (2020), Ravi et al. (forthcoming))

FPEAM
Graphical User Interface

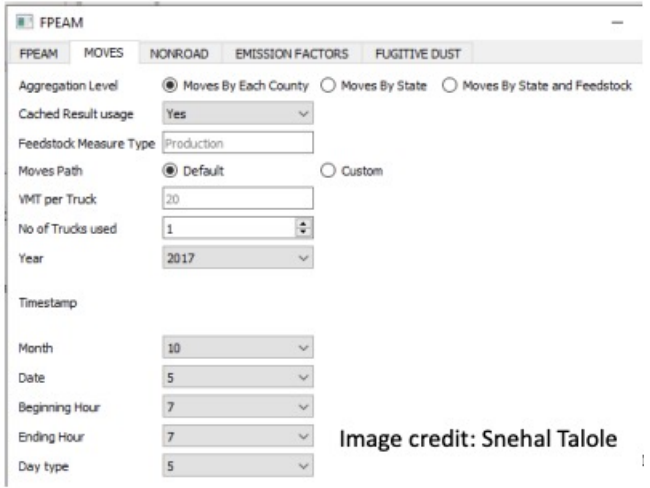


Image credit: Snehal Talole

Summary

Summary

- The NREL **Biofuels Air Emissions Analysis** project provides critical tools, data and analysis that mitigates risks for biorefineries. This includes:
  - Regulatory assessment for federally applicable standards, which can inform process design teams, provides support for emissions and air quality analysis.
  - Development and enhancement of Feedstock Production Emissions to Air Model (FPEAM) model which provides emissions
  - Emissions – air quality – human health – equity analysis at different scales, can inform strategies on how to minimize impacts
- Application of the tools and analysis for:
  - Wastewater sludge –to-biofuel conversion pathways
  - Assessment of sustainable aviation fuel (SAF) pathways
  - Environmental sustainability component of the Billion Ton Studies
  - US EPA's third triennial report to Congress on Biofuels and the Environment

Quad Chart Overview

Timeline

- 10/01/2021
- 09/31/2024

	FY22 Costed	Total Award
DOE Funding	$200,000	$400,000
Project Cost Share*	N/A	

TRL at Project Start: N/A
TRL at Project End: N/A

Project Goal

The goal is to provide critical data and analysis to design teams, DOE platform leads, potential technology developers, regulatory agencies. This is achieved through a detailed regulatory assessment, emissions analysis, and air quality, health and equity assessment.

End of Project Milestone

- Full Air Quality Impact Assessment of the HTL design process.
- Enhancements to the Feedstock Production Emissions to Air Model (FPEAM) to include CO2(e) in the emissions inventory
- Assessment of the decarbonization potential of the biofuel supply chain
- Air quality assessment, including emissions of carbon, for two potential SAF production facilities

Project Partners*

- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory
- The Environmental Protection Agency

Thank You

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NREL/PR-6A20-85539

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Additional Slides

Approach: Feedstock Production and Logistics

Feedstock Production Emissions to Air Model (FPEAM)

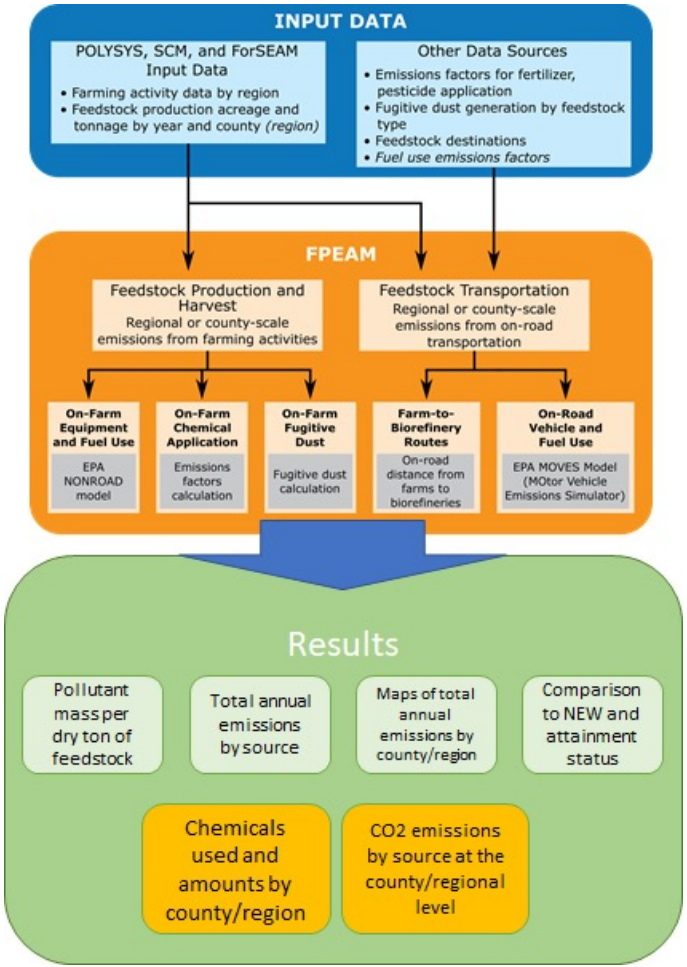
- Validated
- Peer reviewed
- Publicly available

Output:

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

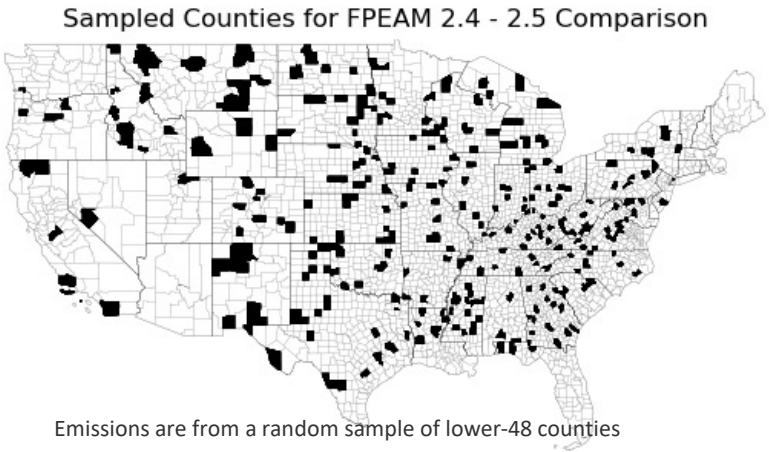
Model Connections:

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



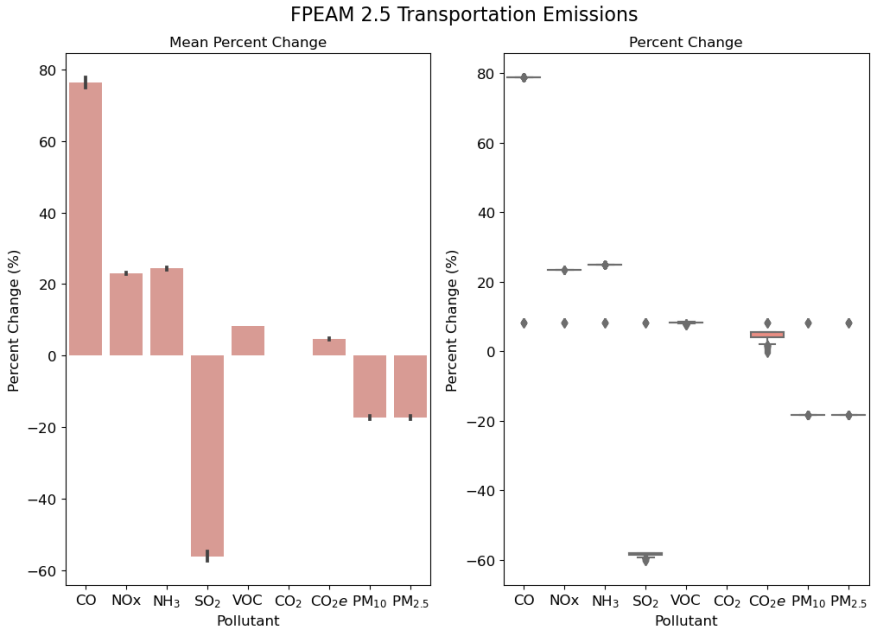
Progress & Outcomes: FPEAM Update (Evaluation)

- On average, changes that do occur are large (≳20%)
- CO, NOx, and NH_3 generally increase
  - All statistically significant (p-value < 0.001)*
- SO_2, PM_{10}, and $PM_{2.5}$ generally decrease
  - All statistically significant (p-value < 0.001)*
- VOC, CO_2, CO_2e generally stay the same
  - Not statistically significant (p-value > 0.010)*



Emissions are from a random sample of lower-48 counties

- BTS2016 BC1060 2017 scenario
- Normalized by production amount
- Totaled by pollutant and county across all tillage types
- Only MOVES module had non-zero differences



Progress & Accomplishment: FPEAM Expansion

- FPEAM now calculates estimates GHG emissions from transportation, agricultural equipment, and fertilizer application
- **Transportation, agricultural equipment**: based on MOVES
- **Nitrogen fertilizer application**: Emission factors for N_2O was sourced from the IPCC 2006 Tier 1 emission factors table.
  - FPEAM's existing Emission Factors dataset was updated to include these factors.
  - Caveat: N_2O emissions from agriculture are known to be highly uncertain.

Pollutant	MOVES Pollutant Processes
CO_2	Running exhaust, start exhaust, extended idle exhaust, auxiliary power exhaust
N_2O	Running exhaust, start exhaust, crankcase running exhaust, crankcase start exhaust
CH_4	Running exhaust, start exhaust, crankcase running exhaust, crankcase start exhaust, crankcase extended idle exhaust, extended idle exhaust, auxiliary power exhaust

Fertilizer	Nitrogen Content (lb N/lb fertilizer)	N_2O Emissions (lb CO_2eq/lb fertilizer)
Anhydrous ammonia (NH_3)	0.822	3.82
Ammonium nitrate (NH_4NO_3)	0.350	1.63
Ammonium sulfate $(NH_4)_2SO_4$	0.212	0.986
Urea $(NH_2)_2CO$	0.466	2.17
Nitrogen solutions	0.3 (approx.)	1.39

Responses to Previous Reviewers' Comments

- Response to reviewer comments from FY21:
  1. Comment: "…An important consideration for continued work is the discrepancy between modeled and real-world emissions at biorefineries. Additional work may be necessary to validate and ground-truth these estimates."

     Response: Our current analysis now includes emissions from monitored data at refineries or other point sources where applicable.
  2. Comment: "… A more robust approach to stakeholder engagement, and connections across other DOE modeling efforts, should be made."

     Response: Based on reviewer feedback, we have continued to communicate with teams at other national labs.

Publications, Patents, Presentations, Awards, and Commercialization

- Publication:
  - Ravi. et al. *Air Quality and Environmental Justice Impacts of Municipal Sewage Sludge-to-biofuel Conversion Using Hydrothermal Liquefaction (HTL) Pathway for Seven U.S. Regions*. To be submitted in 2023.
  - Internal presentations to DOE/DMA.