U.S. Department of Energy (DOE)
Bioenergy Technologies Office (BETO)
2017 Project Peer Review

Biofuels Air Emissions Analysis
WBS 4.2.1.30

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2019 BETO Peer Review

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Project Goal

- Compliance with federal and state air quality regulations is **required** for the construction and operation of a biorefinery.
- Non-compliance and/or lack of regulatory understanding is costly, time consuming, and potentially a non-starter.
- The biofuels industry needs process designs that meet federal air quality regulations as well as an understanding of the potential road blocks and mitigation strategies that may be employed
- The goal of this project is to provide crucial data, tools, and analyses to the biofuels and air regulatory community to enable the biofuels industry to develop sustainably.
- *At a minimum, biorefineries must be able to demonstrate compliance with federal air quality regulations to be permitted. Understanding the nuances of the regulatory code, what types of mitigation strategies may be considered, and potential impacts to the MFSP are critical pieces of information for the nascent industry. The air permitting stage can cause unplanned and protracted delays if not handled properly.*

Quad Chart Overview

Timeline

- Project start: FY2012
- Merit Review Cycle: FY 2018 - 2020
- Percent complete: ~ 17%

	FY 18 Costs	FY 19 Costs	FY 20 Costs	Total Planned Funding
DOE Funded	$375K	$375K	$375K	$1,125K

Partners: Antares Group, Exxon Mobil, Eastern Research Group, ORNL, ANL, PNNL, INL

Barriers addressed

- At-A. Analysis to Inform Strategic Direction
- At-B. Analytical Tools and Capabilities for System-Level Analysis
- At-C. Data Availability across the Supply Chain
- ADO-C. Codes, Standards, and Approval for Use
- ADO-G. Co-Processing with Petroleum Refineries

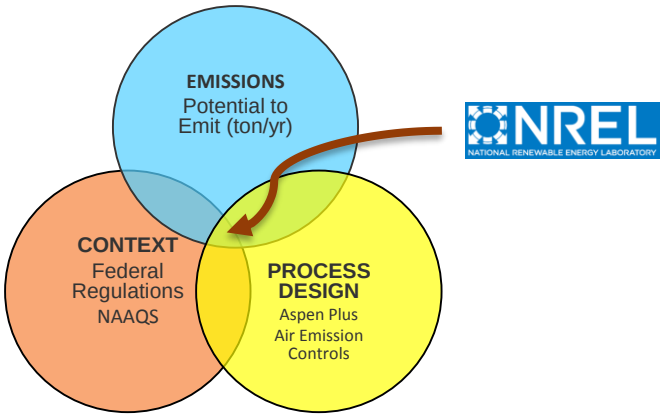
Objective: To provide critical air emissions analyses to process design teams, industry, and regulatory agencies to ensure biofuel production facilities can meet federal air quality standards.

End of Project Goal: Public release of enhanced air emissions model for feedstock production and logistics model (FPEAM). A full air-quality assessment of at least one BETO prioritized conversion pathway. This analysis will include all supply chain components from feedstock production through end-use. The analysis will include both mass emissions and air quality impacts.

1 – Project Overview

Process Design, Air Regulations, Potential to Emit

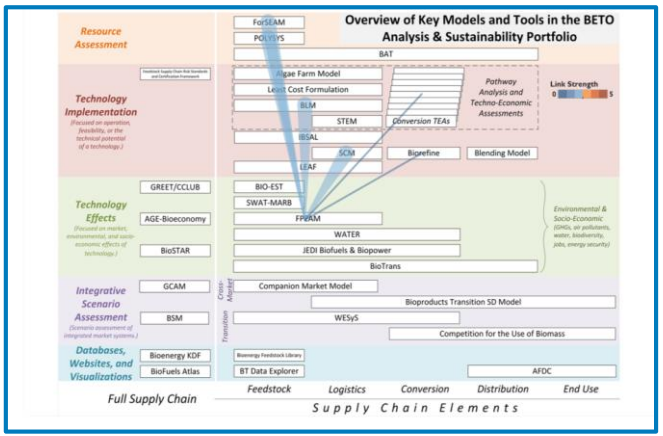
- NREL's Biofuel Air Emissions Analysis project is unique and innovative in terms of the tools, approaches, and analyses provided.
- NREL is the only national laboratory that is actively working at the intersection of federal air quality regulations, air emissions across the supply chain, and process design.



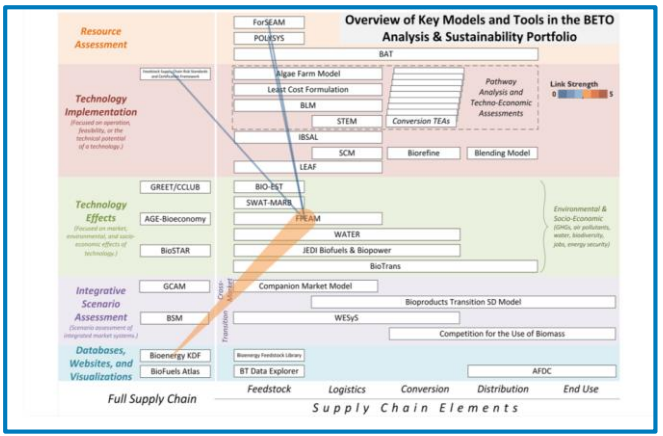
Air Emissions Across the Biofuel Supply Chain

Feedstock production & logistics are assessed separately from the conversion process and regulatory review.

Model Connectivity



Input Connections



Output Connections

This project is well connected to other DOE-BETO modeling and analyses efforts across the national lab space.

No Compliance = No Biorefinery/Industry

- Compliance with federal air quality standards is a prerequisite for biorefinery permitting.
- The air permitting process can be onerous.
  - Protracted delays
  - Cost overruns
  - Uncertainty
- The air permitting process relies on precedence, which the biofuels industry lacks.
- This project aims to fill gaps in the *biorefinery* air permitting process by providing stakeholders key information such as:
  - Data (e.g. emissions factors)
  - Pertinent regulations
  - Mitigation options/opportunities
  - Scenario analysis
  - Impacts on process performance and economics

2 – Approach

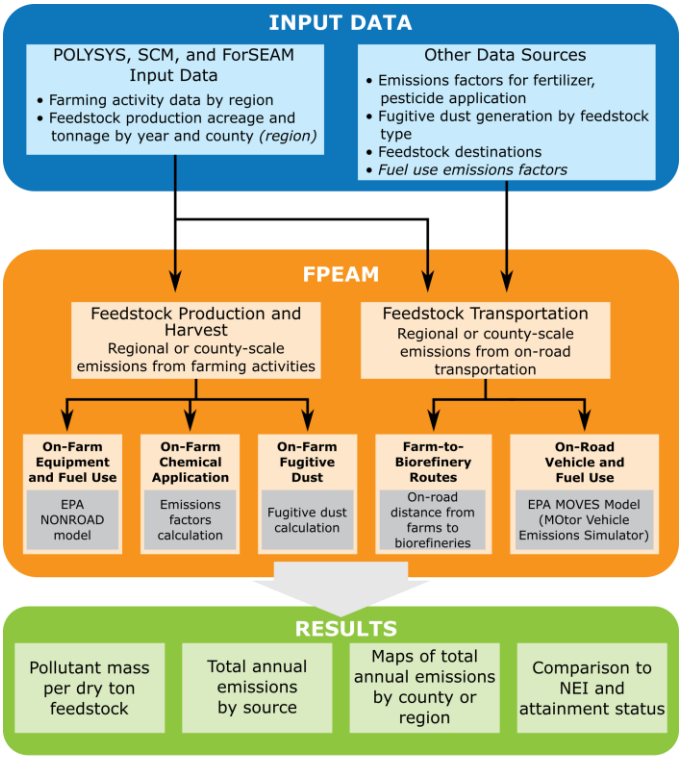
Management Approach: Team Expertise and Responsibilities

- **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
  - Yimin Zhang, PhD – Regulatory Analyst
  - Garvin Heath, PhD – Senior Analyst
  - Arpit Bhatt, MS – Process design and analysis
  - Dylan Hettinger – FPEAM development lead; programmer (Python, PostgreSQL)
  - Rebecca Hanes, PhD – FPEAM developer, analyst

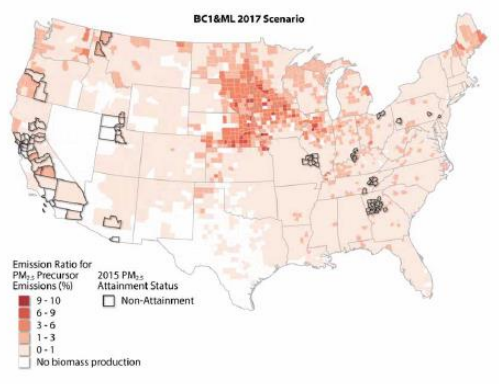
Management Approach: Communication, Transparency, Outreach

- Frequent interaction with key BETO platform contacts.
  - Sustainability and Analysis Platform
  - Conversion Platform
  - Advanced Deployment and Optimization Platform
- 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
  - Exxon Mobil
  - Local Air Quality Agencies – CARB
  - National Laboratories
  - University Researchers – Univ. WA
- Quarterly milestones to drive our work towards high-impact Office and Department goals
- Model sharing and dissemination
  - Beta Testers
  - GitHub

Technical Approach: Tools and Workflow: Feedstock Production and Logistics



Items in italics are currently being implemented.



- We developed the Feedstock Production Emissions to Air Model (**FPEAM**) to estimate criteria air emissions from the farm to the plant gate.
- High spatial resolution
- High chemical resolution
- Highly adaptable
- Currently in beta-review

Technical Approach: Tools and Workflow: Conversion Stage

Analysis Tool Box

We use industry-standard analytical tools and processes. This provides rigor and reproducibility in our analyses.

Analysis Workflow

Assess
- Identify the type of pollutants to be emitted by each emitting source

Review
- Review federal standards to determine the applicability of air regulations to specific equipment and unit operation(s)

Estimate
- Estimate air pollutant emissions considering federal compliance

Modify
- If the design case does not include all required air emission controls, it will need to be modified.

Inform
- Inform process design teams

Success Factors and Challenges

Critical success factors

- Address critical feedback from FPEAM beta testers
- Develop a robust handshake between FPEAM and large air quality models such as BenMAP
- Collaborative process design and modification with key process design teams
- Solicit feedback from and provide information and data to active stakeholders (e.g., Exxon, CARB)
- Empirical validation of our results via stack testing

Top challenges

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

3 – Technical Accomplishments and Results

All Planned Milestones Completed (FY 17 – Present)

- 2017
  - Database of all issued biorefinery air permits
  - Analysis of Potential to Emit (PTE) for bio-oil production via ex-situ upgrading of pyrolysis vapors process

- 2018
  - Interaction with the Antares project
  - FPEAM improvement and Beta testing/release

Manuscript preparation of the air permitting implications of co-processing raw bio-oil produced at an off-site biorefinery facility with petroleum intermediates in an existing petroleum refinery – *More detail on this study will be presented in the next section.*

- 2019
  - Summarize the results of the FPEAM Beta test and prioritize the issues/comments. Develop a workplan that addresses the prioritized issues that will be implemented over Q2 and Q3 (or longer is necessary).

Publications and Presentations (Since FY17 Peer Review)

- Bhatt et al. 2017. Federal Air Pollutant Emission Regulations and Preliminary Estimates of Potential-to-Emit from Biorefineries: Pathway #2: Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels: Fast Pyrolysis and Hydrotreating Bio-oil Pathway. TR. NREL/TP-6A20-67333.
- Eberle et al., 2017. Potential Air Pollutant Emissions and Permitting Classifications for Two Biorefinery Process Designs in the United States. Eviron. Sci. Technol. 51, 5879-5888.
- Eberle, et al. 2017. Assessing Potential Air Pollutant Emissions from Agricultural Feedstock Production using MOVES. In: Proceedings of the 2017 International Emissions Inventory Conference, 14-18 August 2017, Baltimore, Maryland.
- Bhatt A., Zhang Y., Thomas M., and Crawford P. 2018. "Federal Air Pollutant Emission Regulations and Preliminary Estimates of Potential-to-Emit from Biorefineries. Pathway #3: Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels: Ex Situ Upgrading of Fast Pyrolysis Vapors." NREL Technical Report. NREL/TP-6A20-67333 (In review).
- Bhatt et al., 2018. Air Permitting Implications of a Biorefinery Producing Raw Bio-oil in Comparison with Producing Gasoline and Diesel Blendstocks. In: Proceedings of the Air & Waste Management Association Annual Conference, 5-8 June 2017, Pittsburgh, Pennsylvania.
- Bhatt et al., 2018. Air Pollutant Emissions and Regulatory Implications of a Biorefinery Co-Processing Bio-Oil in a Petroleum Refinery. In: Proceedings of the Air & Waste Management Association Annual Conference, 25-28 June 2018, Hartford, Connecticut.
- Hanes et al. 2018. Spatially Explicit Modeling of Criteria Air Pollutants from Agricultural and Forestry Feedstock Production. In: Proceedings from the 7th International Congress on Sustainability Science & Engineering, 12-15 August 2018, Cincinnati, Ohio.

3.1 – Technical Results

Potential to Emit and Regulatory Context of Co-Processing Bio-Oil in an Existing Petroleum Refinery

Co-Processing Bio-Oil in a Petroleum Refinery

- The addition of capacity to an existing refinery is subject to the federal air permitting process.
- Depending on the impact to the existing emissions, this additional capacity could result in significant time and financial costs.
- The objectives of this analysis is to:
  - Determine which FEDERAL air quality regulations are likely to apply to the modifications at the petroleum refinery when introducing bio-oil for coprocessing
  - Quantify any increase in air emissions of regulated pollutants at petroleum refineries due to co-processing
  - Evaluate permitting requirements for co-processing bio-oil in petroleum refineries with different fluidized catalytic cracking (FCC) unit capacities.
  - Estimate economic implications of compliance

Existing FCC Units and Capacity

- We assume that bio-oil is produced, off site via the ex situ pyrolysis, and delivered to the refinery.
- Co-processing of biooil is considered a potential near-term insertion point for biofuels.
- Modifications to the petroleum refinery are considered.
- Assuming a raw bio-oil coprocessing rate of 5% (by weight), there are 95 existing petroleum refineries that could, in theory, accept biooil.

# of Refineries by Fluidized Catalytic Cracking Feed Rate*	
5% of Fluidized Catalytic Cracking Feed Rate (barrels per day)	**# of Refineries (% of total refineries with FCC units)**
≤1,100	32 (33%)
>1,100 and ≤2,700	31 (66%)
>2,700 and ≤9,200	32 (100%)

Source: https://www.eia.gov/petroleum/refinerycapacity/refcap16.pdf

Two of three scenarios do not require Major Modification Permitting

- The first two scenarios (A and B) evaluated would not be subject to major modification permitting requirement under the New Source Review program.
- The third scenario (C) does exceed VOC emissions, and would be subject to Major Modification Permitting.
- The US petroleum refineries (with FCC units), which are not located in extreme ozone NAAs, could implement a 5% (by weight) bio-oil co-processing without triggering the major modification permitting requirements.

# of Refineries by Fluidized Catalytic Cracking Feed Rate*		
5% of Fluidized Catalytic Cracking Feed Rate (barrels per day)	# of Refineries (% of total refineries with FCC units)	NSR
≤1,100	32 (33%)	Minor Source
>1,100 and ≤2,700	31 (66%)	Minor Source
>2,700 and ≤9,200	32 (100%)	Major Source - VOCs

4 – Relevance

Relevance

- We provide critical air emissions analyses to process design teams, industry, and regulatory agencies to ensure biofuel production facilities can meet federal air quality standards.
  - *A 2014 report[1] cites biomass power plants as having difficulty meeting air emissions standards. The report cites many facilities that were permitted based on unrealistic emissions estimates.*
- We perform objective process-level ***analysis and validation*** of potential air emissions across the supply chain.
- We ***identify challenges*** early so design adjustments can be made.
- Our analyses ***determine 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.

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

Relevance to BETO and Stakeholders

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

- *BETO's mission is to develop industrially relevant, transformative, and revolutionary bioenergy technologies to enable* ***sustainable, domestically produced*** *biofuels, bioproducts, and biopower for a prosperous nation.*
- [BETO's] *Sustainability subprogram generates scientific knowledge that* ***proactively addresses issues affecting the scale-up potential, public acceptance, and long-term viability*** *of advanced bioenergy systems.*

5 – Future Work and Summary

Future Work

- BETO and the air quality community have asked us to prioritize the public release and subsequent support of FPEAM. Based on preliminary feedback, the initial FPEAM user base has indicated that the model should be able to interact with large spatiotemporal air quality models.
- BETO is actively developing novel biofuel processes – these processes should consider, at least, the federal air quality regulations in their design reports.
- Over the next two and a half fiscal years (FY19 – FY21) we will be focused on the following:
  - Expanding FPEAM to interact with large spatiotemporal air quality models such as InMAP and BenMAP.
  - Continue to perform regulatory and emissions analysis on emerging BETO pathways such as hydrocarbon fuels derived from waste sludge and algae.

Upcoming Milestones

- Upcoming key milestones:
  - **Q1 FY20**: Expand the capability of FPEAM to seamlessly generate outputs that can be used as direct model inputs to air quality models like InMAP (spatialmodel.org).
  - **Q3 FY21**: Use FPEAM to estimate emissions from feedstock production and potential-to-emit for one selected biofuel conversion process. The pathway will be chosen, in consultation with BETO and national lab process design teams and will serve as another point of comparison to the work completed in Q4 (FY19) and Q1 (FY20). We will use InMAP to perform one case study that simulates the local and regional air quality impacts from biomass production and conversion to fuel. Preliminary results from this will be summarized in a milestone report.
- **Go/No-Go**: 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.

Summary

Goal: to provide crucial data, tools, and analyses to the biofuels and air regulatory community to enable the biofuels industry to develop sustainably.

Approach: combines modeling supply chain components, process modeling, regulatory review. We use industry best practices for modeling, versioning, and data management. We use active project management and client engagement along with frequent community outreach.

Technical Accomplishments: beta testing and limited release of FPEAM and air quality and regulatory assessment of prioritized BETO hydrocarbon pathway configurations

Relevance: the public expects biofuels to be more environmentally sustainable than conventional fossil fuels.

Future work: two major thrusts – (1) public release of FPEAM and enhancement to interface with industry-standard spatiotemporal air quality models and (2) continued air quality analysis and regulatory assessment of DOE conversion technologies.

Questions?

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Additional Slides

2017 Peer Review Comments and Responses

- ***Discussion of particular tasks and outputs would have been appreciated.*** Thanks for the input. In the future we will provide more detail on tasks and output specifics.
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- ***Define more specifically the regulatory and supply chain planning needs and how this project could help.*** We have performed several regulatory analyses that directly address the federal regulatory framework and how a given design case fits into that framework. Within these analyses, we define that pertinent federal regulations that apply to the given design case, what adjustments could be made to meet the federal regulations and finally what adjustments may be required to meet "best available control technology" (BACT) requirements, which are an upper bound. The state-level regulations vary by state, which makes a state-specific assessment difficult to perform unless we are assessing a specific case study. We do have plans in FY18 to begin looking at a case study which will entail state-level regulations. Successful application of our work would include design cases that incorporate mitigation options as defined by our work as well as collaborating with biorefinery designers working on the ground. As for other agricultural AQ models, FPEAM fills the gap in that we assess the major emissions sources related to agricultural production. We do not tie directly into any specific agricultural AQ models, though we have met with researchers from the USDA and presented our FPEAM model to them.

- ***Whether there were any surprising findings, as a result of the more sophisticated modeling, relative to what was expected at the beginning.*** We aim to perform more sophisticated modeling and case studies as we move forward. We are objective in our approach and if we come across findings that are contradictory or surprising we will investigate and understand the insights thoroughly.

- ***Greater emphasis on how deliverables may be used.*** We are still in the development phase of the FPEAM model as a tool. As we proceed through this FY and next (FY18) we anticipate having beta testers of the tool as well as conducting outreach efforts to local and state agencies as well as academia. Specific users already identified include the EPA, CARB, and the University of Minnesota. We hope to expand that list of users as we proceed and will tailor the tool based on feedback from beta testers.

- ***Why the project did not consider the processing and combustion emissions, which are critical to understanding the overall lifecycle impact.*** This project has progressed in a linear fashion moving down the supply chain from feedstock through fuel production. We have not taken on the end-use phase of the lifecycle because the needs of BETO and budget have not allowed for a thorough exploration of this phase of the lifecycle. That said, one of our long-range goals has been to conduct a full supply chain assessment for a given fuel pathway.

- ***Milestones and decision-points and challenges were not provided in sufficient detail.*** This is good feedback and we will work to address these items more clearly in future presentations.

- ***Spend some time refining the FPEAM model so that it is user friendly and in a format, that can be used by others.*** We want to make the FPEAM tool as useful as possible. given obvious budget constraints. That said, we will be following standard software development and release protocol as we move forward. This includes a beta and alpha testing phase prior to release.

- ***Ensure that this framework either directly or in complement with other modeling.*** We will be working with stakeholders, including other modelers, to seek feedback on our work. Though this effort we will strive to ensure cross-model compatibility, at least in-terms of inputs and outputs.

Appendix

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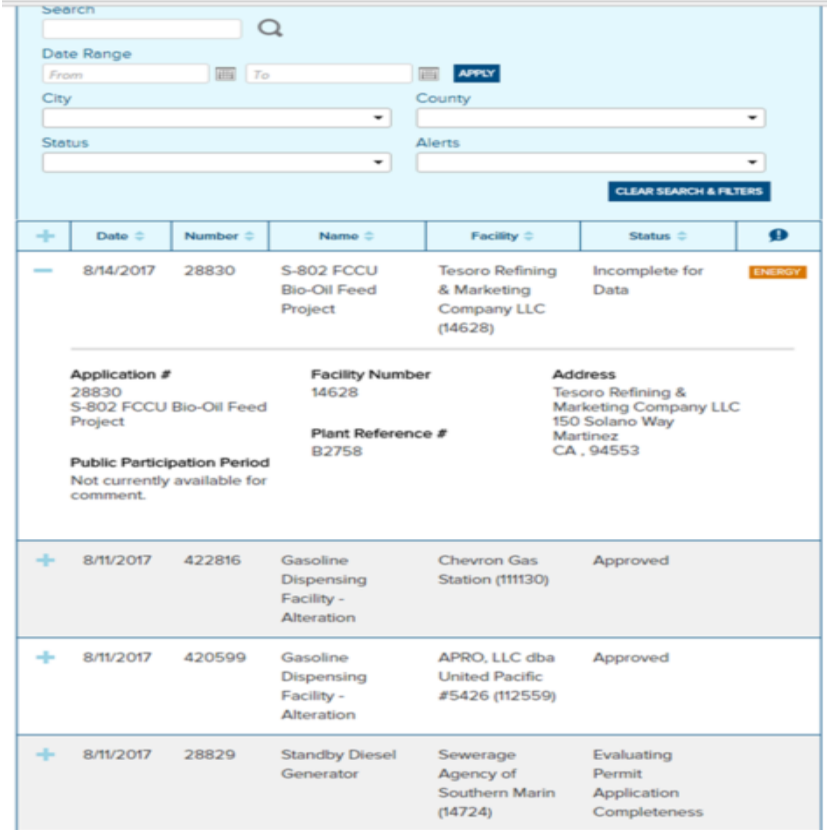
Tesoro co-processing permit application



SERs vs. NNSR major modification

Emission thresholds for major modifications in attainment areas

Pollutants	NSR Significant Emission Rate (tons per year)
PM	25
PM_{10}	15
$PM_{2.5}$	10
VOC	40
NOx	40
CO	100
SO_2	40
Pb	0.6

Emission thresholds for major modifications in nonattainment areas

Pollutants	Nonattainment Area Classification	NNSR Major Source Modification (tons per year)
Ozone as VOC or NO_x	Moderate	40
Ozone as VOC or NO_x	Serious	25
Ozone as VOC or NO_x	Severe	25
PM_{10}	Moderate	15
Pb	No classification	0.6
SO_2	No classification	40

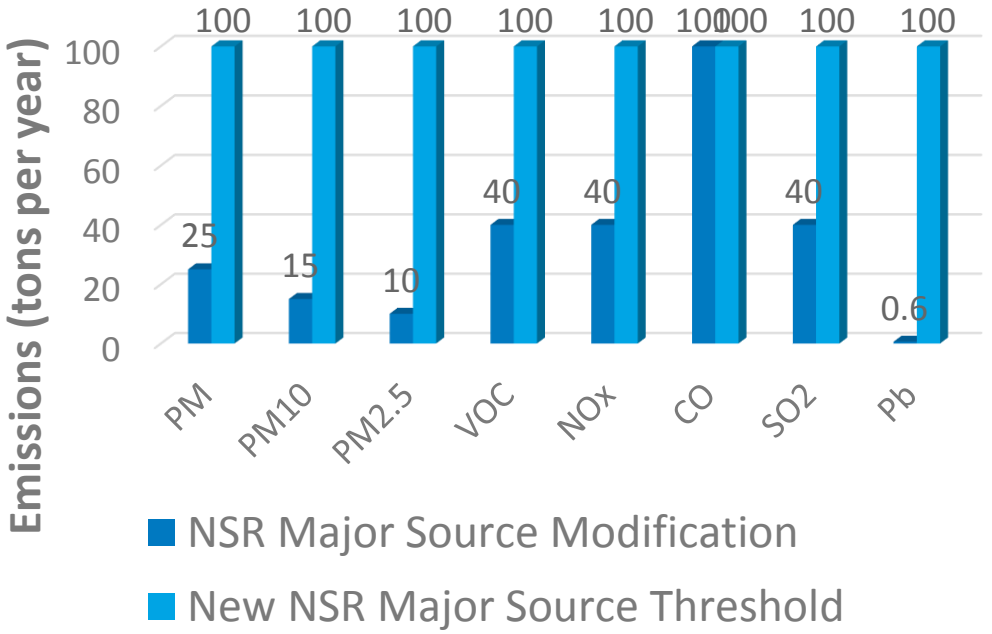
Background and Context

- New Source Review (NSR), a Clean Air Act (CAA) program, requires a permit before new construction or modification if it results in an increase in ***criteria air pollutants*** (SO_2, NO_2, PM, CO, Pb, O_3) as well as (H_2SO_4 mist, H_2S)
- Under the NSR program, there are three types of permits:
  - Prevention of significant Deterioration **(PSD) permit** – major sources in attainment areas
  - Nonattainment NSR **(NNSR) permit** – major sources in non-attainment areas (NAAs)
  - **Minor source permit**
- Title V permitting program under the CAA – operating permit
  - Required for all major sources under NSR and major sources for hazardous air pollutants (HAPs)
  - Primary purpose is to specify all the emission standards, monitoring, recordkeeping, and reporting requirements in one document

Background and Context cont.

- All U.S. petroleum refineries with FCC units are categorized as major sources (for NSR regulated pollutants and/or HAPs)
- NSR Permitting considerations:
  - Co-processing will require the petroleum refinery to apply for a NSR permit
  - Net emissions < significant emission rates (SERs) in attainment areas, the facility will require a minor source modification permit
  - Net emissions > SERs in attainment areas, the facility will require a PSD permit
  - Net emissions > NNSR major modification emission rates in non-attainment areas, the facility will require a NNSR major modification permit
- Revise the Title V permit of a petroleum refinery to incorporate all of the compliance requirements that apply to facility modifications for bio-oil co-processing
  - New Source Performance Standards (NSPSs) and National Emission Standards for Hazardous Air Pollutants (NESHAPs) need to be included
  - Emission limits, air regulations applicable to the modifications, reporting and recording requirements need to be included

Thresholds for a new major source vs. major modification permit



*NSR major source modification - For existing major sources in attainment areas only

Process Modifications