



Air Pollutant Emissions and Regulatory Implications of a Biorefinery Producing Raw Bio-Oil

Preprint

Arpit Bhatt and Yimin Zhang

National Renewable Energy Laboratory

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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

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INTRODUCTION

Pyrolysis oil, also referred to as bio-oil, has attracted considerable attention because of the high carbonaceous matter and high heating value compared to the original biomass before conversion.¹⁻³ Utilizing the existing fossil fuel infrastructure by introducing raw bio-oil in the fluidized catalytic cracking (FCC) unit in petroleum refineries to produce renewable hydrocarbon fuels (i.e., repurposing existing assets) offers a promising opportunity to reduce the carbon intensity of transportation fuels and would present a relatively low capital requirement to existing facilities.^{1,4} However, a facility (biorefinery) producing raw bio-oil is considered a chemical process plant under the Clean Air Act (CAA)⁵ permitting program and is expected to emit air pollutants that could pose threats to the environment and public health. Based on the type and magnitude of the regulated pollutants emitted, the biorefinery may be subject to regulations under the New Source Performance Standards (NSPS) or National Emission Standards for Hazardous Air Pollutants (NESHAP) for New Source Review (NSR) and/or Title V program.^{6,7} This paper examines the potential regulatory implications (in terms of emissions and federal regulations) of a biorefinery producing raw bio-oil.

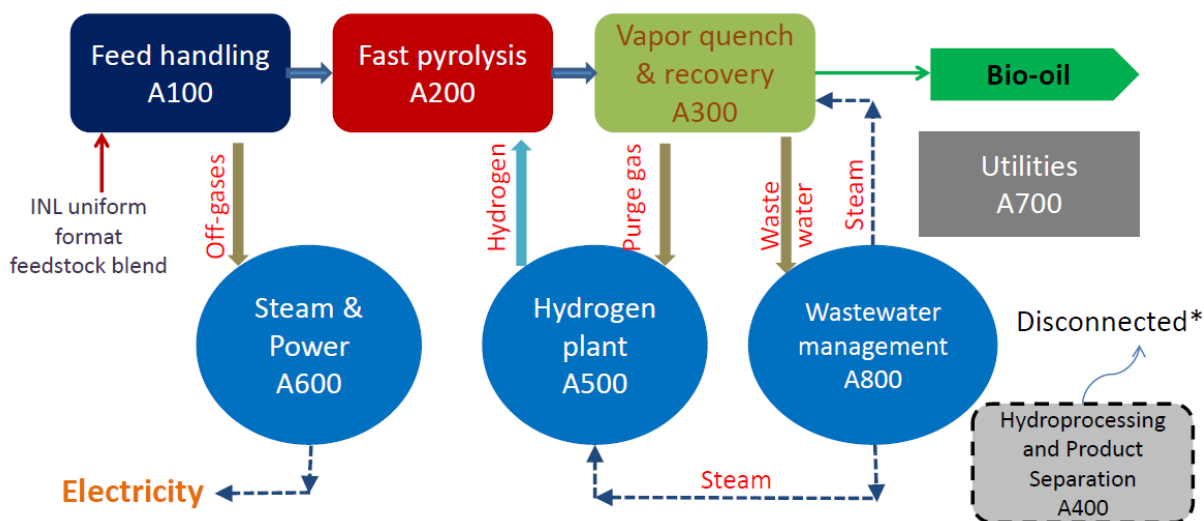
In this analysis, we examine the air pollutant emissions (preliminary potential to emit (PTE)) and evaluate the potential air pollutant regulatory and permitting implications for a biorefinery utilizing an ex situ fast pyrolysis process, with a design capacity of 2,000 dry metric tons of biomass per day to produce 4,200 barrels of raw bio-oil.⁸ The raw bio-oil produced from the biorefinery can be blended with petroleum-based intermediates (vacuum gas oil) in the FCC units of existing petroleum refineries to produce gasoline and diesel blendstocks with renewable content. We also discuss selected emissions control technologies, which could be used to further reduce potential emissions (alternative PTE) and help biorefineries avoid being subject to the major source permitting requirements (e.g., prevention of significant deterioration (PSD)) if desired. This analysis is expected to provide insights for new bio-oil project developers to identify opportunities to mitigate emissions and develop strategies to overcome challenges and risks associated with air permitting. Our previous analysis investigated permitting ramifications of co-processing partially upgraded bio-oil in petroleum refineries while this analysis looks into regulations and permitting classification for a biorefinery producing raw bio-oil.

METHODS

Overview of process design

The ex-situ fast pyrolysis process to produce raw bio-oil is divided into 8 process areas: 1) feed handling, 2) fast pyrolysis and vapor upgrading, 3) product recovery, 4) hydroprocessing and product separation, 5) hydrogen plant, 6) steam and power generation, 7) utilities, and 8) wastewater management (Figure 1). Dried and heated biomass is fed to the non-catalytic fast pyrolysis reactor to produce pyrolysis vapors with low oxygen content. Char is separated using cyclones and sent back to char combustor for use as a heat source for pyrolyzer. The vapors are quenched in the series of absorbers to separate the organic fraction (raw bio-oil) from the non-condensable gases. The raw bio-oil is separated from the aqueous phase, and all the off-gases from different areas of the design plant are collected and utilized in the methane reformer to produce hydrogen. It is assumed that the process produces raw bio-oil as a final product and does not include any vapor upgrading and hydrotreating and hydrocracking operations.

Figure 1. Overview of the ex-situ fast pyrolysis conversion process producing raw bio-oil



INL = Idaho National Laboratory

To evaluate the potential-to-emit for ex-situ fast pyrolysis biorefinery, we carry out of series of steps outlined below:

Step 1: Identification of air pollutants

To determine pollutants likely to be emitted from the biorefinery, we analyze each unit operation to identify the emitting sources. We use the U.S. Environmental Protection Agency’s (EPA) guidelines (e.g., EPA’s Compilation of Air Pollution Emission Factors [AP-42]),⁹ conduct material balances using process engineering models (such as Aspen Plus), and examine air permits for analogous operations and equipment.

Step 2: Applicability of federal regulations

Based on the specific unit operation and equipment design along with the type of pollutants expected to be emitted, we review the applicability criteria for each federal standard to determine whether a facility or equipment is subject to it. Two federal standards that regulate the air pollutants from stationary sources are NSPS and NESHAP.

Step 3: Estimation of the PTE

We estimate the PTE using published emission factors (e.g., AP-42 emission factor database) and material balance method. We consider the maximum capacity of unit operation/equipment, worst-case emissions (in case of multiple fuel sources), physical and operational design limitations, and federally enforceable limits (e.g., from applicable federal regulations). We also assume that the air emission control equipment planned in the biorefinery design is included in the air permit issued by state and local permitting agencies under EPA-approved programs; therefore, the control equipment is considered federally enforceable.

Step 4: Permitting classification

The NSR program requires a facility to apply for a construction permit before a project is built or modified. If a source exceeds an applicable major source threshold for any regulated air pollutants, it will be classified as a major source. We compare the estimated PTE for each regulated air pollutant with the major source threshold to determine the permitting classification for the biorefinery design. In general, major source thresholds for pollutants emitted from a chemical manufacturing plant (such as the biorefinery) are 100 tons per year (tpy) for criteria pollutants, 10 tpy for any single hazardous air pollutant (HAP) or 25 tpy for any combination of HAPs.

Because biorefinery developers would prefer to avoid being subject to major source permitting, we examine selected controls technologies that could potentially allow the facility to reduce emissions to below major source thresholds. We use EPA's Reasonably Available Control Technology (RACT)/Best Available Control Technology (BACT)/Lowest Achievable Emission Rate (LAER) Clearinghouse database¹⁰ and air permit applications of similar processes to identify the potential emission controls. We then assume those controls to be a part of the conversion process and use the emission reduction efficiencies from published literature (e.g., EPA's air pollution control technology factsheets) to update the PTE estimates (referred to as alternative PTE here) to determine whether these controls could help the biorefinery achieve minor source classification.

RESULTS

Identification of potential air pollutants

Table 1 shows the types of air pollutants expected to be emitted from ex-situ fast pyrolysis biorefinery including particulate matter (PM) (and PM with less than or equal to 2.5 micrometers in diameter [PM_{2.5}], PM with less than or equal to 10 micrometers in diameter [PM₁₀]), volatile organic compounds (VOC), nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO), lead, and HAPs (e.g., benzene, formaldehyde). Because a biorefinery is considered a chemical manufacturing plant, we also estimate fugitive emissions in the form of equipment leaks and truck traffic for inclusion in the PTE estimates.

Table 1. Air pollutants likely to be emitted from an ex-situ fast pyrolysis biorefinery

Plant Area	Equipment	Air Pollutants
Feed Handling & Drying	Biomass feedstock transfer and storage	PM, PM ₁₀ , PM _{2.5}
	Dryer	PM, PM ₁₀ , PM _{2.5} , VOC, HAP
Ex Situ Non-Catalytic Fast Pyrolysis	Char combustor	PM, PM ₁₀ , PM _{2.5} , SO ₂ , VOC, CO ₂
	Ash and sand handling operations	PM, PM ₁₀ , PM _{2.5}
	Leaking equipment	VOC, HAP
Pyrolysis Vapor Quench and Product Recovery	Leaking equipment	VOC, HAP
Hydrogen Plant	Methane reformer	PM, PM ₁₀ , PM _{2.5} , NO _x , SO ₂ , CO, CO ₂ , VOC, HAP
	Leaking equipment	VOC, HAP
Wastewater Management & Recycle	Aqueous regenerative thermal oxidizer	CO ₂ , VOC, HAP
	RO & Clarifier	VOC, HAP
Storage and Transfer	Product storage tanks	VOC, HAP
	Equipment for loading products	VOC, HAP
Utilities	Cooling tower	PM, PM ₁₀ , PM _{2.5} , VOC, HAP
	Emergency 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
Truck Traffic	Dust from trucks hauling feedstock, other raw materials, waste, and product	PM, PM ₁₀ , PM _{2.5}

Potentially applicable regulations and preliminary potential to emit

The federal regulations potentially applicable to the ex-situ fast pyrolysis biorefinery are listed in Table 2 below.

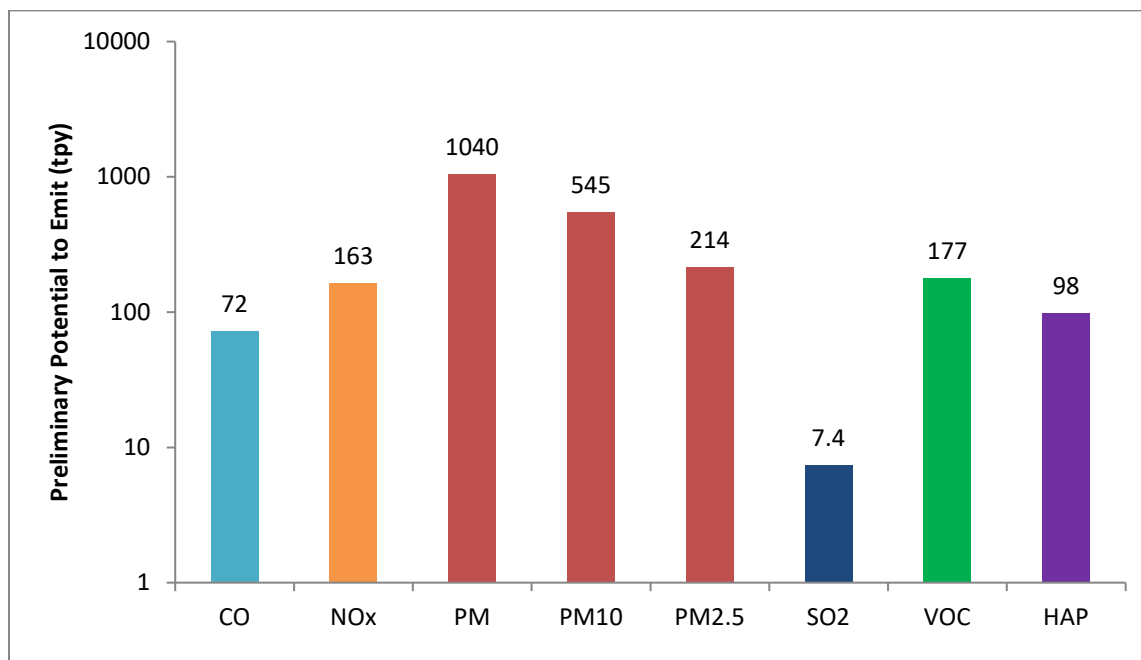
Table 2. Federal regulations potentially applicable to an ex-situ fast pyrolysis biorefinery

Affected Source	Potential Federal Regulations
Dryer, char combustor	If facility is a major source of HAP, NESHAP Subpart FFFF applies or If facility is an area source of HAP, NESHAP Subpart VVVVVV applies
Methane reformer	Only if facility is a major source of HAP and meets the applicability criteria, NESHAP Subpart DDDDD applies
Emergency fire pump and emergency generator	NSPS Subpart IIII
	NESHAP Subpart ZZZZ
Equipment leaks	If facility is a major source of HAP, NESHAP Subpart FFFF applies or If facility is an area source of HAP: NESHAP Subpart VVVVVV applies

NSPS = New Source Performance Standards, NESHAP = National Emission Standards for Hazardous Air Pollutants

Based on the design and process characteristics, the emissions from an ex-situ biorefinery are estimated to be above the major source threshold for several pollutants. Therefore, NESHAP (40 CFR 63) Subpart FFFF applies to the whole biorefinery along with other regulations as shown in Table 2. We then include additional control options (in the form of control technology and monitoring requirements) to the dryer, cooling tower, and equipment leaks under NESHAP, Subpart FFFF (see Fig. 3 for emission estimates) to meet the regulatory limitations.

Figure 2. Preliminary PTE estimates for an ex-situ fast pyrolysis biorefinery (y-axis is shown on a log-scale)



Notes:

1. Assume 98% reduction of HAPs from dryer under NESHAP, Subpart FFFF
2. Assume high efficiency drift eliminators and monitoring requirements for cooling towers for reducing PM and HAP emissions, respectively, under NESHAP, Subpart FFFF.
3. Assume a quarterly monitoring system for equipment leaks to reduce HAP emissions under NESHAP, Subpart FFFF.

Preliminary permitting classification

As shown in Figure 2, the estimated preliminary PTE of several regulated pollutants (PM, NO_x, VOC, and HAP) exceeds the major source thresholds. Thus, the ex-situ fast pyrolysis biorefinery would likely be subject to the major source permitting classification. In addition, the biorefinery would also be subject to Title V permitting program as the overall HAP emissions exceed the major source threshold value (i.e., 25 tons per year).

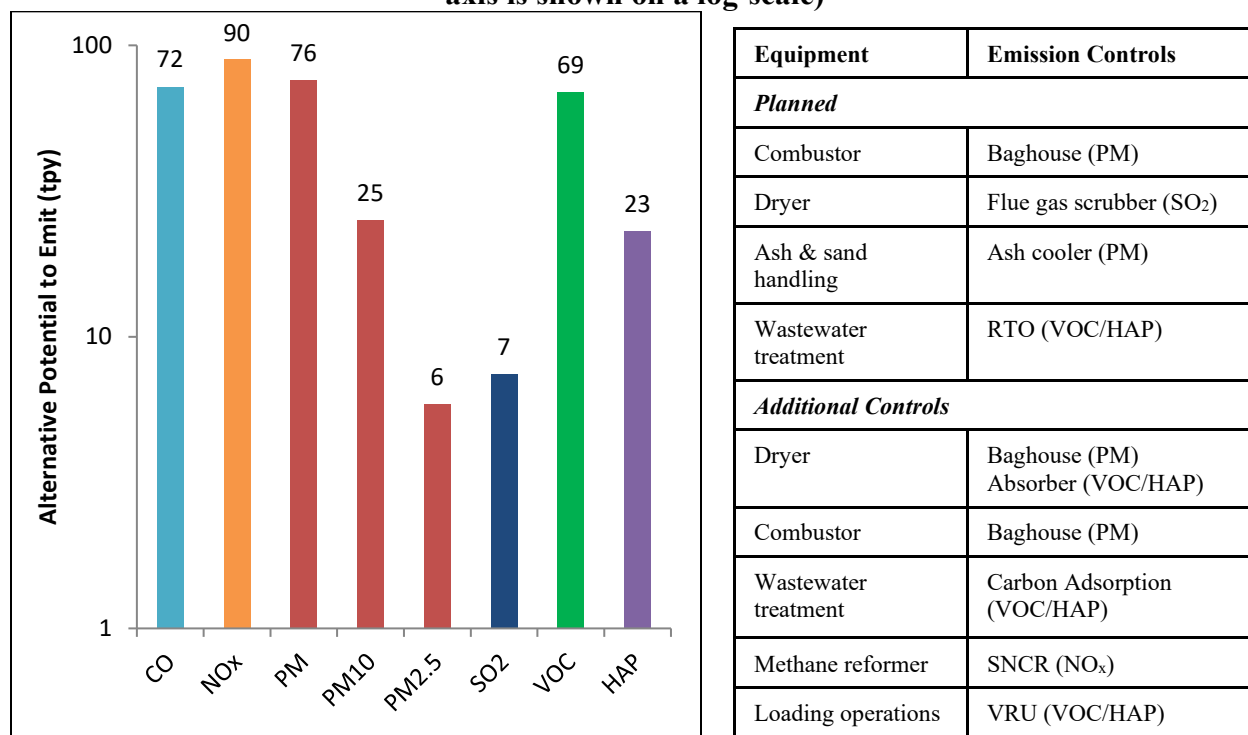
Emission reduction through control technologies (alternative potential to emit)

As described previously, if a facility prefers avoiding being subject to major source permitting requirements, it could take a step further to identify and adopt additional emission control technologies that may reduce emissions below major source thresholds (alternative PTE). For the ex-situ biorefinery, the dryer and char combustor are the primary contributor to PM emissions,

wastewater treatment is a primary contributor of VOC and HAP emissions, and the methane reformer is responsible for majority of the NO_x emissions. If a baghouse is assumed to be utilized to reduce PM emissions from the dryer, char combustor and catalyst regenerator along with a selective non-catalytic reduction (SNCR) to reduce NO_x emissions from the methane reformer, the facility-wide PTE for PM (including PM_{2.5} and PM₁₀) and NO_x could be reduced to below the 100 tpy major source threshold.^{12,11}

In addition, the current ex-situ design utilizes a regenerative thermal oxidizer (RTO) to reduce 98% of the organic species from the wastewater management area. However, information on the specific organic species is unavailable. Without such information, it is difficult to suggest the most efficient emission controls to reduce the specific VOC and HAP species present in the wastewater and likely emitted into the air. However, we assume that a carbon adsorption system would be able to reduce VOC and HAP emissions by 95% from wastewater¹² along with a vapor recovery unit to reduce 90% of VOC and HAP emissions from loading operations.¹³ This would help the biorefinery achieve minor source classification (reduce emissions below 100 tpy for VOC and 25 tpy for HAP). Figure 3 shows the modeled alternative PTE after additional controls.

Figure 3. Alternative potential to emit estimate for the ex-situ fast pyrolysis biorefinery (y-axis is shown on a log-scale)



SUMMARY

We evaluated the potential air pollutant regulatory and permitting implications for a 2000 dry metric ton per day biorefinery producing raw bio-oil via ex-situ fast pyrolysis. We also analyzed an alternative set of PTE by identifying and adopting additional emission controls to reduce regulated air pollutants to assess the feasibility of avoiding being subject to major source air permitting requirements under the NSR and Title V permitting programs. Our preliminary results

indicate that the ex-situ biorefinery with planned emission controls would be classified as a major source under the NSR permitting program. However, feasible emission control options are available to avoid major source permitting, though the costs of adopting these controls should be evaluated before making the final investment decision. Our analysis provides insights into the potential challenges and risks associated with air permitting, which are often overlooked for the deployment of new technologies. Our analysis could help stakeholders make more informed decisions and help develop strategies to minimize permitting time and risks.

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KEYWORDS

Biorefinery, potential-to-emit, permitting, bio-oil, emission controls, federal regulation