Project 39
Naphthalene Removal Assessment

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Motivation

- On average, naphthalenes (di-aromatic components) make up ~2 vol% of jet fuel, while mono-aromatics make up ~18 vol%[1]
- Naphthalenes in jet fuel identified as disproportionate contributor to non-volatile particulate matter (nvPM) emissions when compared to mono-aromatic compounds [2,3]
- Aviation-attributable nvPM emissions contribute to several cardiovascular and respiratory health issues, add to aviation's climate impact through direct black carbon radiative forcing, and act as ice nuclei which support contrail formation
- Jet fuel could be further processed at the refinery, via current finishing processes used on other petroleum derived products, to reduce or eliminate naphthalenes, reducing aviation's impact on air quality and climate

Objectives

A comprehensive cost-benefit analysis of reduction or removal of naphthalene from U.S. produced jet fuel and its effect on aviation's climate / air quality impacts

- Evaluate existing aromatic removal refinery technologies to determine feasibility, process energy and utility requirements, and capital costs of jet fuel naphthalene removal or reduction

Refinery Process Selection

Desired Process Characteristics

- Removal of naphthalenes with limited changes to overall fuel characteristics (mono-aromatic content and fuel properties like LHV, lubricity, thermal stability, etc.)
- Low process-attributable emission at the refinery
- Drop-in refining solution
- Secondary desired characteristics include: removal of sulfur and nitrogen impurities, high yield, and accessible to refineries of varying sizes and complexities

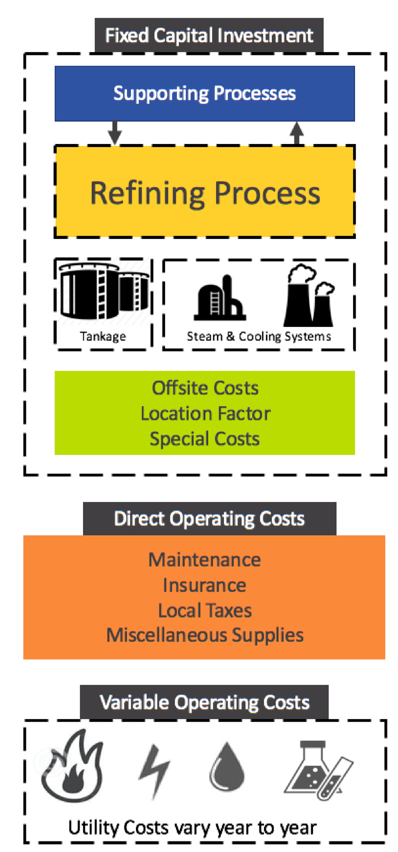
Selected Processes

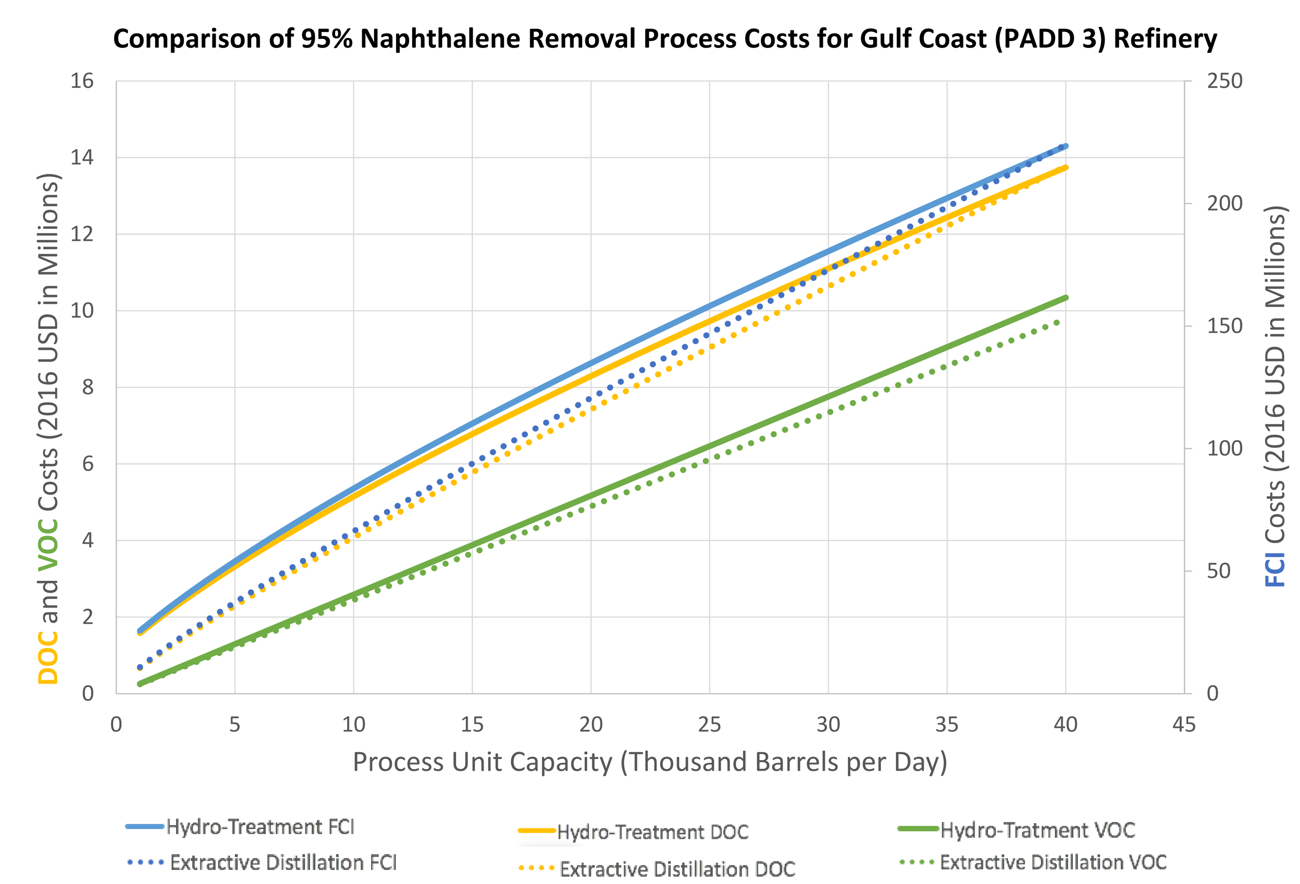
Process Name	Hydro-Treatment	Extractive Distillation
Description	Naphthalenes are hydrogenated to mono-aromatic and naphthenic components.	All aromatics are separated via a polar solvent. Mono-aromatics are separated from naphthalenes and blended back into jet fuel product
Process Type	Conversion (H_2 addition)	Aromatic Separation
Existing Uses	Desulfurization, impurity removal, aromatic hydrogenation	Separation of polar feed components, BTX separation
Removal of Naphthalenes	Assumed 95% efficient	Assumed 95% efficient
Effect on Mono-Aromatics	Limited (<10%) hydrogenation	Fully separated; fraction returned to product can be controlled
Impurity Removal	S, N removal to <50 ppm	Small removal of S, N impurities
Process Innovation Required	Minimal required. Very similar to existing units	Efficient solvent with impurity (S,N) resiliency

Refinery Cost Estimation Methods and Results

Process Model Costs

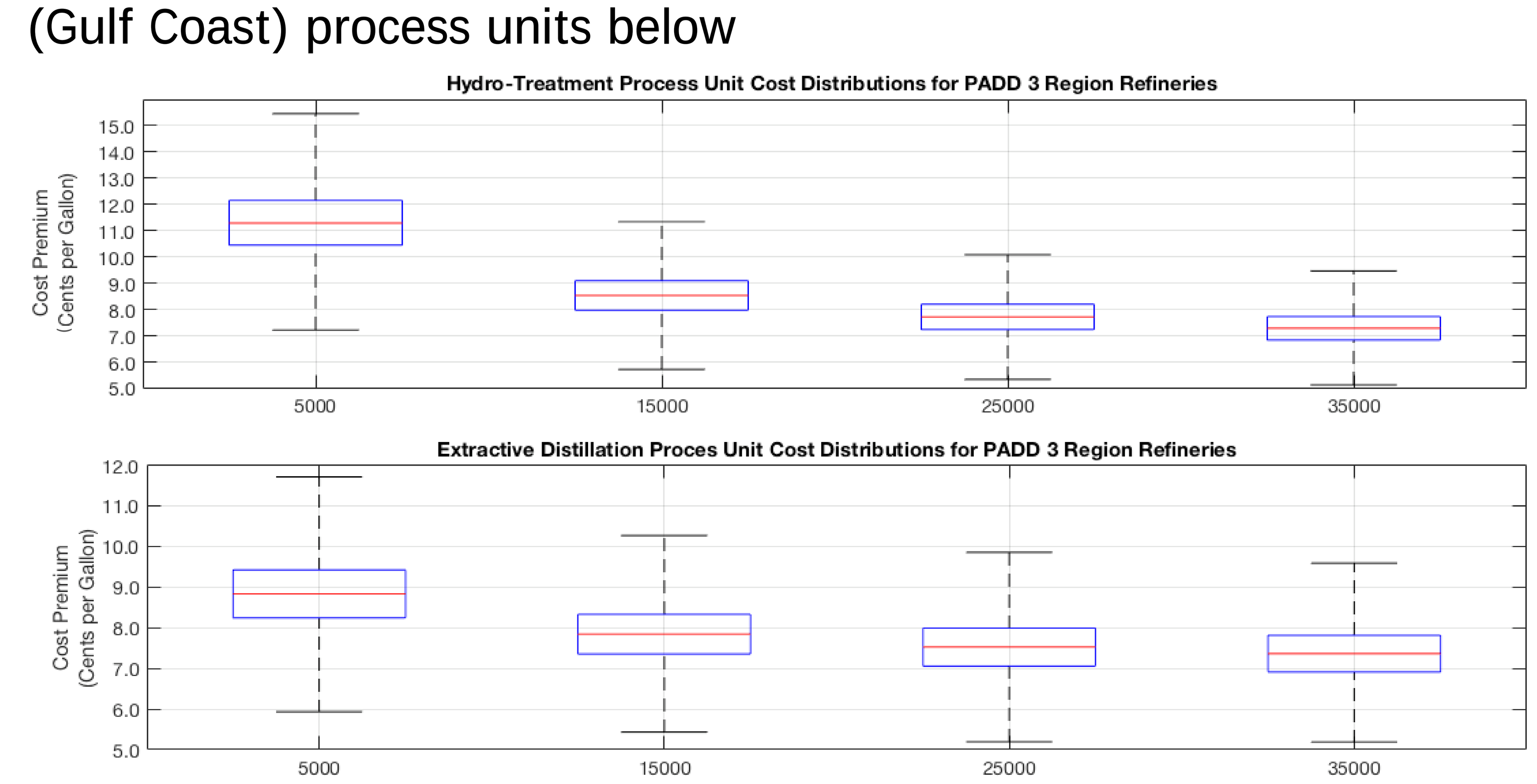
- Removal of naphthalenes is added as a jet fuel finishing process to a refinery's flow diagram, and costs are estimated without consideration of existing oil extraction and refining costs
- Fixed capital investment (FCI) includes all upfront costs of constructing and spooling-up the refinery process
- Direct operating costs (DOC) are static costs paid yearly during process operation, including allotment for unplanned maintenance
- Variable operating costs (VOC) include utility requirements and change based on market forcers





Estimation of Net Present Value and Fuel Premiums

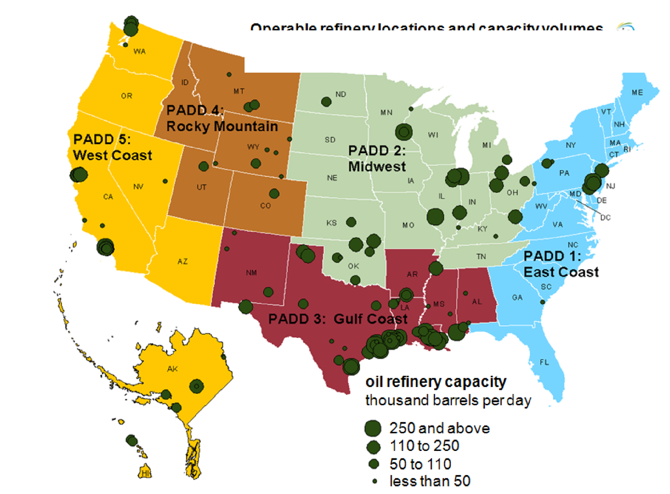
- FCI, DOC, and VOC are input into a stochastic discounted cash flow model designed to estimate societal costs of naphthalene removal
- Assumed discount factor (societal cost of capital) equivalent to the 5-year average U.S. 20-yr constant maturity rate of 2.74%[3]
- Location factors, utility prices, and percentage of crude-to-jet are determined using U.S. census regional divisions[4]
- FCI, DOC, natural gas prices, and electricity prices are defined as probability distributions in order to capture uncertainties in cost estimations and future prices; represented in example costs of PADD 3 (Gulf Coast) process units below



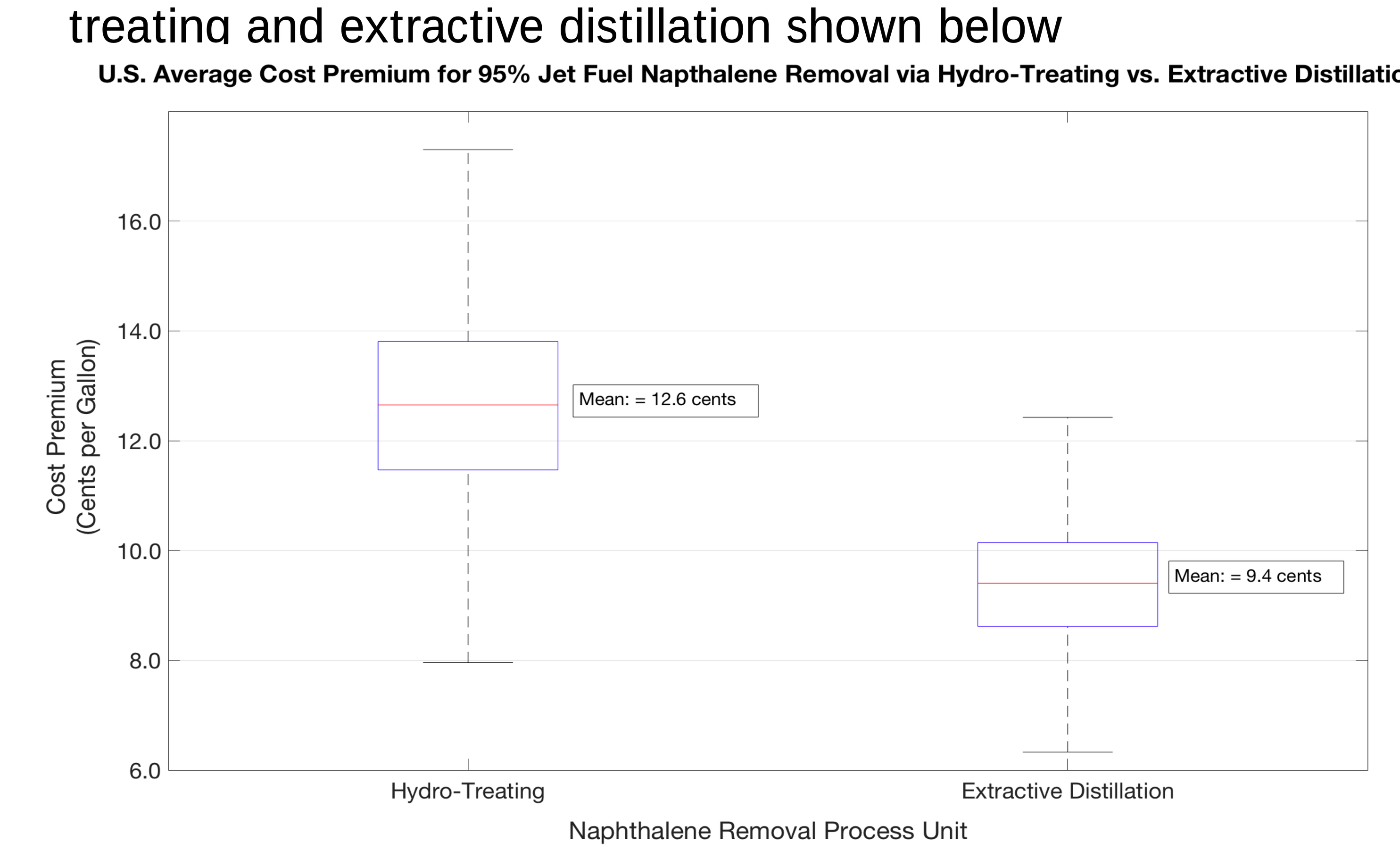
U.S. Cost Estimation Methods and Results

Methods

- Estimation of U.S.-wide cost based on 125 active refineries[5]
- Each refinery is input into a stochastic discounted cash flow model which includes size, location, and complexity (hydro-skimming, cracking, or coking)



- U.S. average fuel cost premium calculated by summing all refinery costs, divided by the quantity of jet produced nation-wide
- Fuel premiums for 95% jet fuel naphthalene removal via hydro-treating and extractive distillation shown below



- Costs will be compared to the benefits associated with reduced climate and air quality impacts to determine the viability of a jet fuel naphthalene removal policy

Future Work

- Estimate how naphthalene removal impacts fuel composition, refinery emissions, and aviation emissions
- Quantify monetized health benefits and avoided damages from expected changes to air quality impacts and climate forcing of aviation emissions associated with naphthalene removal

Contributors & Collaborators

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References:

[1] B. T. Brem *et al.*, "Effects of Fuel Aromatic Content on Nonvolatile Particulate Emissions of an In-Production Aircraft Gas Turbine," *Environ. Sci. Technol.*, vol. 49, no. 22, pp. 13149–13157, Nov. 2015.
[2] R. H. Moore *et al.*, "Influence of Jet Fuel Composition on Aircraft Engine Emissions: A Synthesis of Aerosol Emissions Data from the NASA APEX, AAFEX, and ACCESS Missions," *Energy Fuels*, vol. 29, no. 4, pp. 2591–2600, Apr. 2015.
[3] "Daily Treasury Yield Curve Rates" *U.S. Department of the Treasure*, 2017 https://www.treasury.gov
[4] U.S. Census Bureau, "Census Regions and Divisions of the United States," U.S. Department of Commerce, 2017.
[5] "Downstream Analytics" *Global Data Oil and Gas*, 2017. https://oilgas-globaldata.com

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