Pacific Northwest
NATIONAL LABORATORY

DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

Green Aviation Research & Development Network (GARDN) Collaboration – International Aviation Fuels at PNNL

7th March 2019

Advanced Development and Optimization: Analysis and Modeling

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Goal Statement

Challenge: Sustainable aviation fuels require specifications testing and process data for determining (1) sustainability metrics and (2) viable near-term technology pathways

Goal*:* Evaluate the supply/value chain for the production of ***jet fuels from forest residues*** via various thermochemical conversion technologies with PNNL's contribution on ***upgrading the liquefaction intermediates*** to produce fuels

Outcome

- Demonstrated feasibility of hydrotreating technology for upgrading bio-oils and biocrudes from fast pyrolysis (FP), catalytic fast pyrolysis (CFP), and hydrothermal liquefaction (HTL)
- Model international collaboration network for building methodology and analysis of the complete supply/value chain:
  - For biojet from a single, representative forest residue feedstock
  - Through biomass conversion technologies including thermochemical liquefaction integrated with upgrading.

Relevance

- International collaboration including stakeholders for biojet
- Accelerate experience with, and acceptance of, biojet fuel from biomass thermal chemical conversion processes

Assessment of likely Technology Maturation pathways used to produce biojet from forest residues
(The ATM project)

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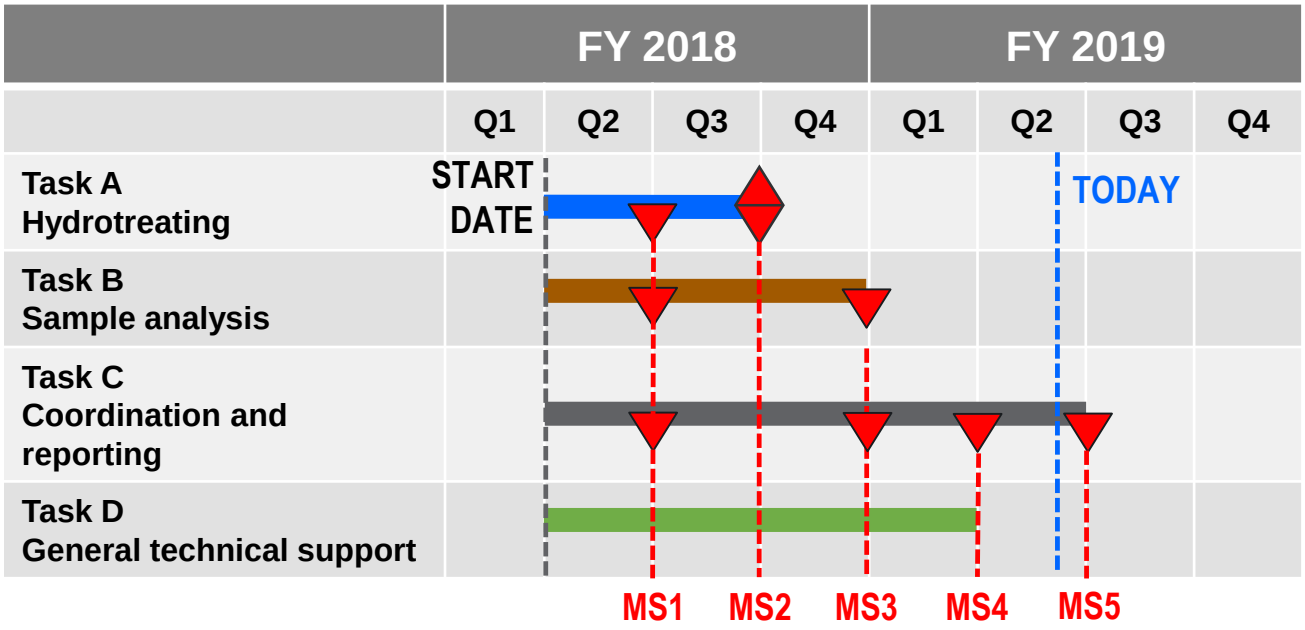
Forest Residue to Biojet

Key Milestones and Project Budget Table



Milestones

MS1: Report hydrotreating of CFP bio-oil

MS2: Finish hydrotreating and provide biojet fuel

MS3: Submit draft report

MS4: Participate in ATM project meeting

MS5: Finalize PNNL-related sections for final report

	Original Project Cost (Estimated)		Project Spending and Balance		Final Project Costs
Project tasks	DOE Funding	Project Cost Share	Spending to Date	Remaining Balance	What funding is needed to complete the project
Task A	$ 120 k		$ 123 k	$ 0 k	$ 0 k
Task B	$ 30 k		$ 20 k	$ 0 k	$ 0 k
Task C	$ 50 k		$ 31 k	$ 26 k	$ 26 k
Task D	$ 0 k	$ 15 k	$ 15 k	$ 0 k	$ 0 k

Quad Chart Overview

Timeline

- Project start date: 10/1/2018
- Project end date: 3/31/2019
- Percent complete: 90%

	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19)
DOE Funded	0	$160 k	$40 k
Project Cost Share*	0	$ 15 K	$0 K

* Provided by NORAM

Barriers addressed

ADO-A. Process Integration

At-C. Data Availability across the Supply Chain

Objective

- Hydrotreat biocrudes from FP, CFP, and HTL of forest residues and provide fuel products for analysis
- Deliver processing data including yields, hydrogen consumption, and other metrics relevant to lifecycle analyses
- Support documentation of project outcomes for public dissemination

End of Project Goal

At the end of calendar year 2018, a comprehensive evaluation of the supply/value chain for production of jet fuels from forest residues via conversion technologies, including FP, CFP, and HTL, followed by bio-oil/biocrude hydrotreating, will be ready for dissemination to stakeholders

1 – Project Overview

ATM project of GARDN focuses on biojet from forest residues for sustainable growth of airlines

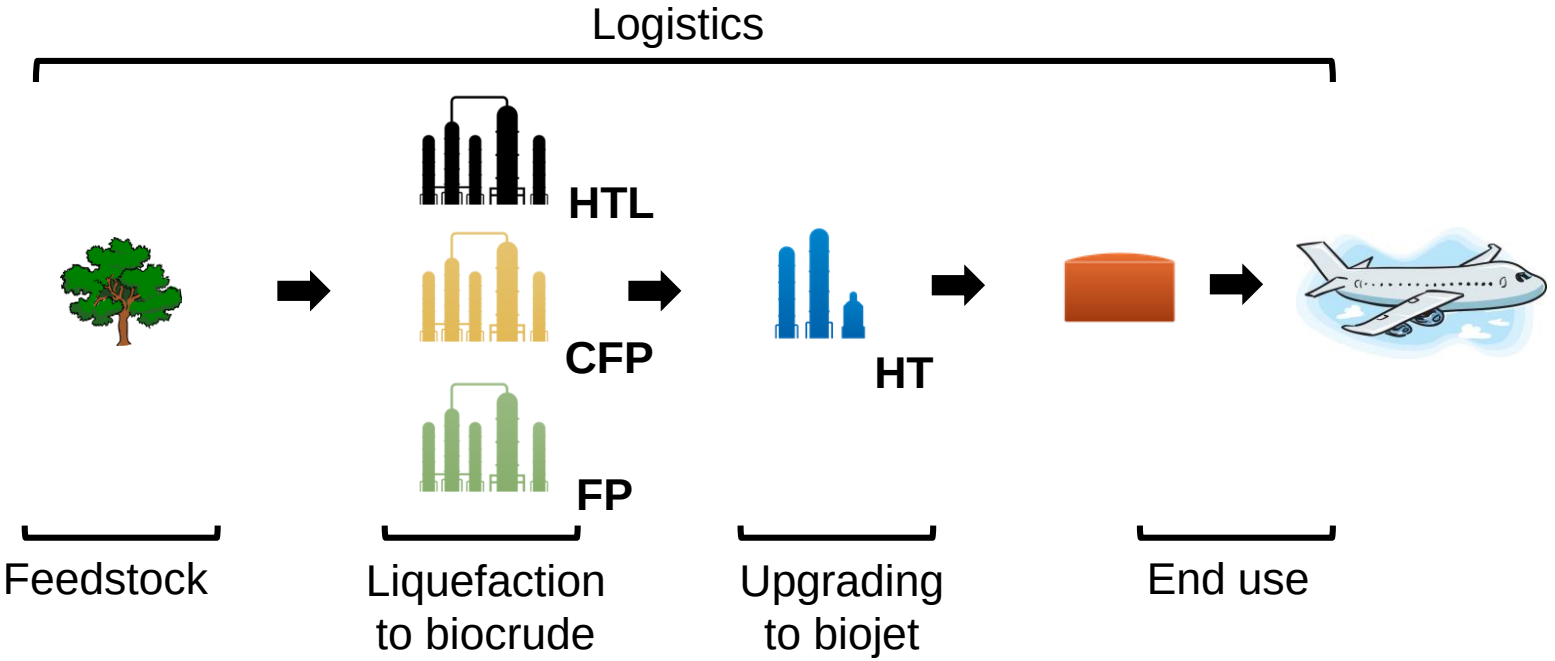
- Alternative jet fuels (AJFs) are expected to help airlines sustain growth, while reducing environmental impact
- ATM project will deliver studies tracking life cycle impacts and performance of a specific feedstock through different conversion schemes for biojet production
  - *A comprehensive report will published*

GARDN Green Aviation Research & Development Network

The ATM project **Assessment of likely Technology Maturation pathways used to produce biojet from forest residues**

1 – Project Overview

Comprehensive evaluation of supply/value chain for forest residues to biojet is required



HTL: hydrothermal liquefaction; **CFP**: catalytic fast pyrolysis; **FP**: fast pyrolysis; **HT**: hydrotreating

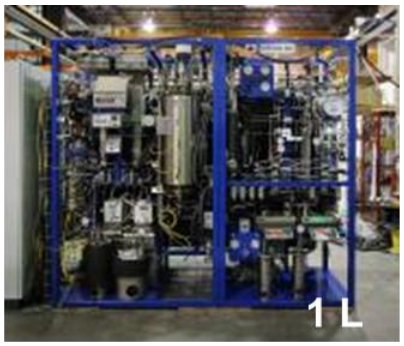
1 – Project Overview
Background on upgrading of biomass liquefaction intermediates at PNNL

BETO's upgrading efforts at PNNL:

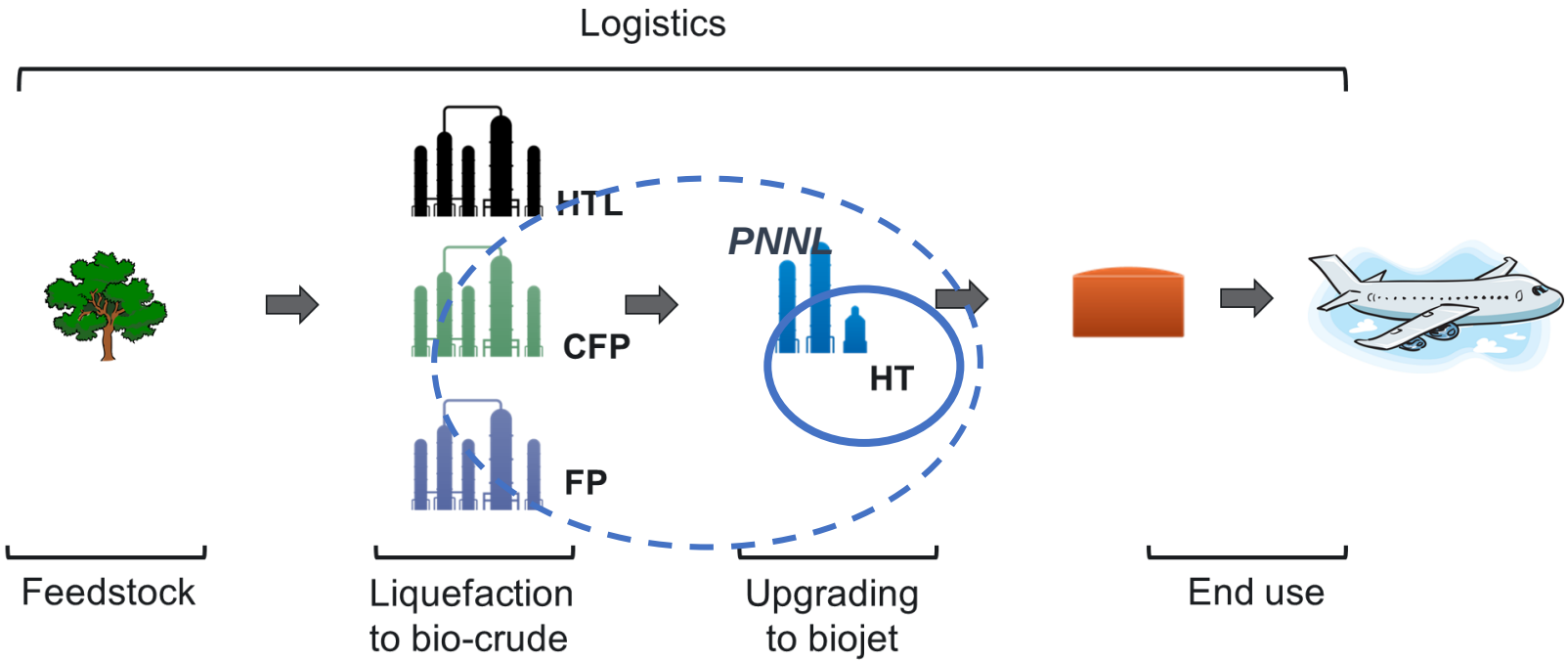
- FP bio-oil quality improvement and upgrading
  - Two-step process, stabilization and hydrotreating, developed
  - Longtime hydrotreating demonstrated (~1400 hours)

- CFP and bio-oil upgrading
  - Single step hydrotreating demonstrated for CFP bio-oil

- HTL and biocrude upgrading
  - Higher space velocity, single-step hydrotreating of biocrude from algae, wastewater sludge, and forest residue demonstrated biocrudes from several intermediates



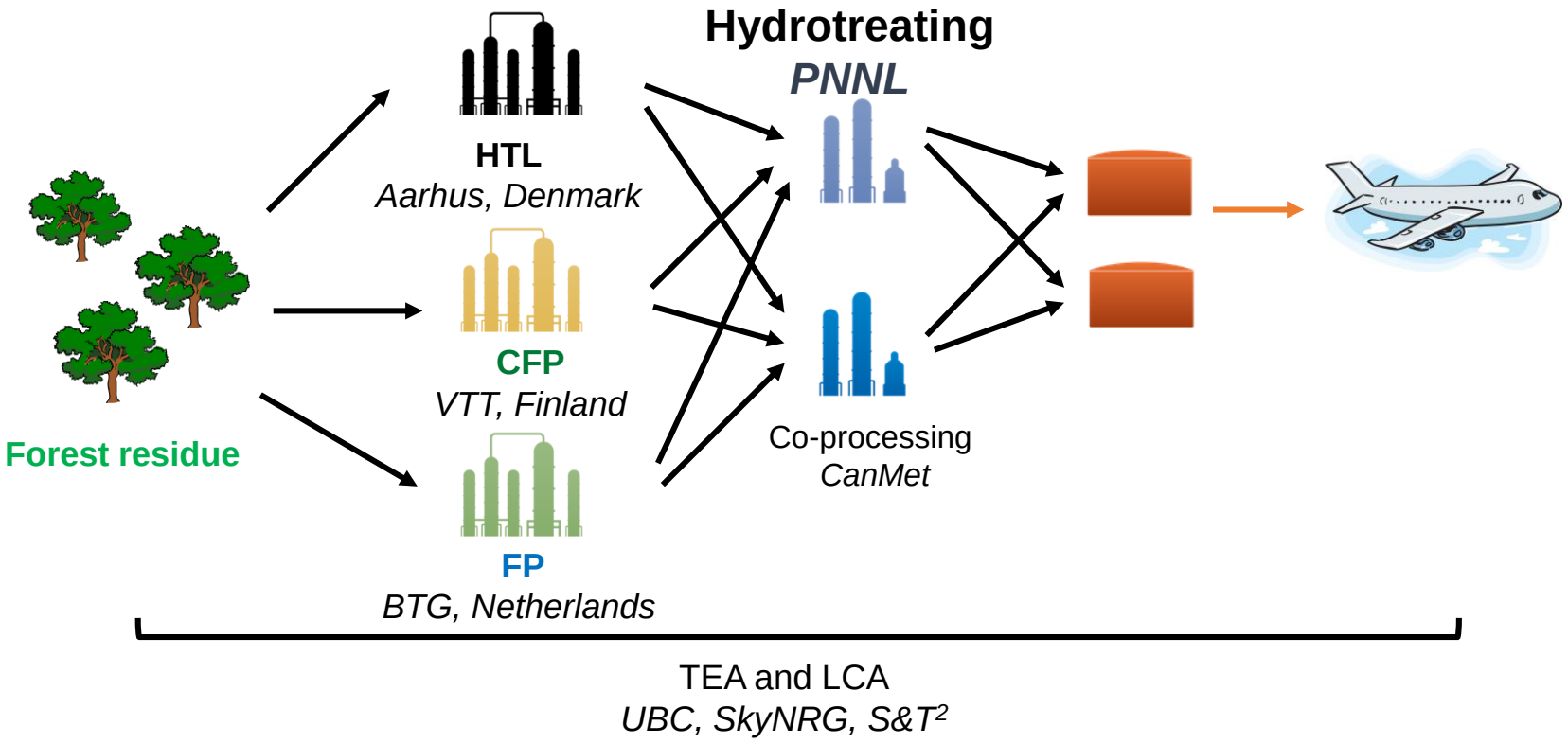
1 – Project Overview
PNNL was invited to contribute on conversion



PNNL was ***invited*** to participate in the ATM consortium, as a subject matter expert and practitioner, to contribute

- Capabilities in bio-oil and biocrude upgrading (performance data and product volumes)
- Expertise in conversion (deconstruction and upgrading), and measurement and documentation of metrics for conversion and lifecycle impacts

2 – Approach (Technical)
Integrated and collaborative efforts to evaluate forest residue to biojet conversion

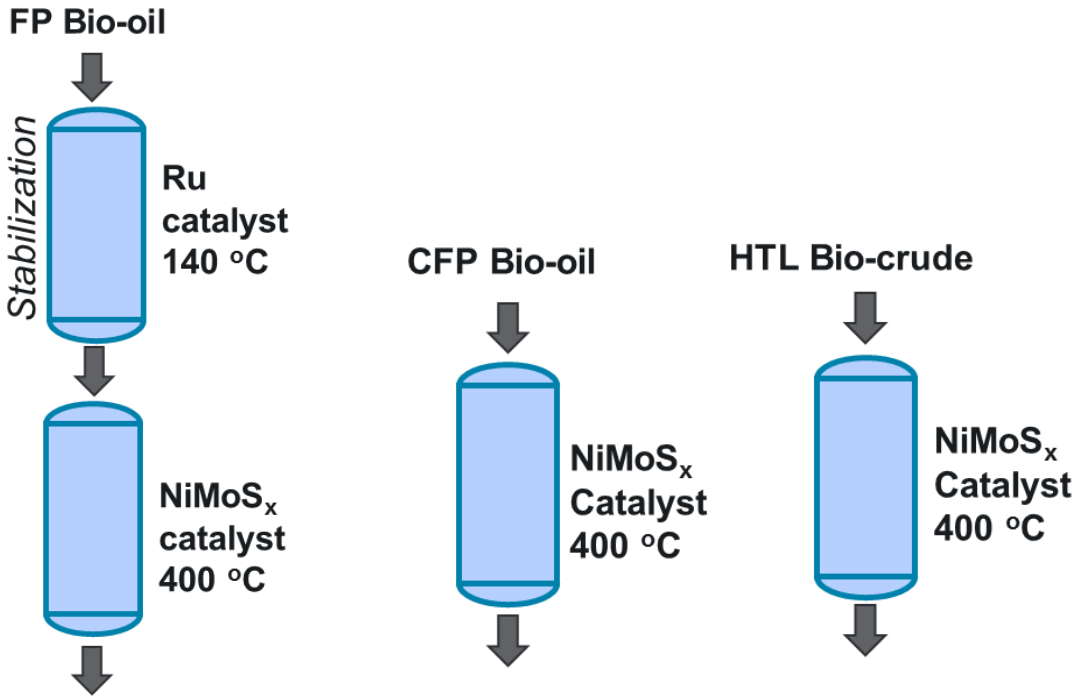


***Project Challenge*:** Access to process data and samples that represent state of the art

Success factor: Involve representative technologies and technology developers to have an integrated and collaborative effort

2 – Approach (Technical)

Apply technologies developed by BETO, at PNNL, for bio-oil/biocrude processing and feed and product analysis



Two-stage process

Single-stage process

400 ml hydrotreater

Project Challenge: Uncertainties and risks come with upgrading bio-oil/biocrudes having unclear quality and pedigree

Success factor: Demonstrate feasibility and effectiveness (robustness) of upgrading technologies at PNNL for processing various feedstocks

2 – Approach (Management)
AOP, PMPs, Milestones, Communication

Tasks

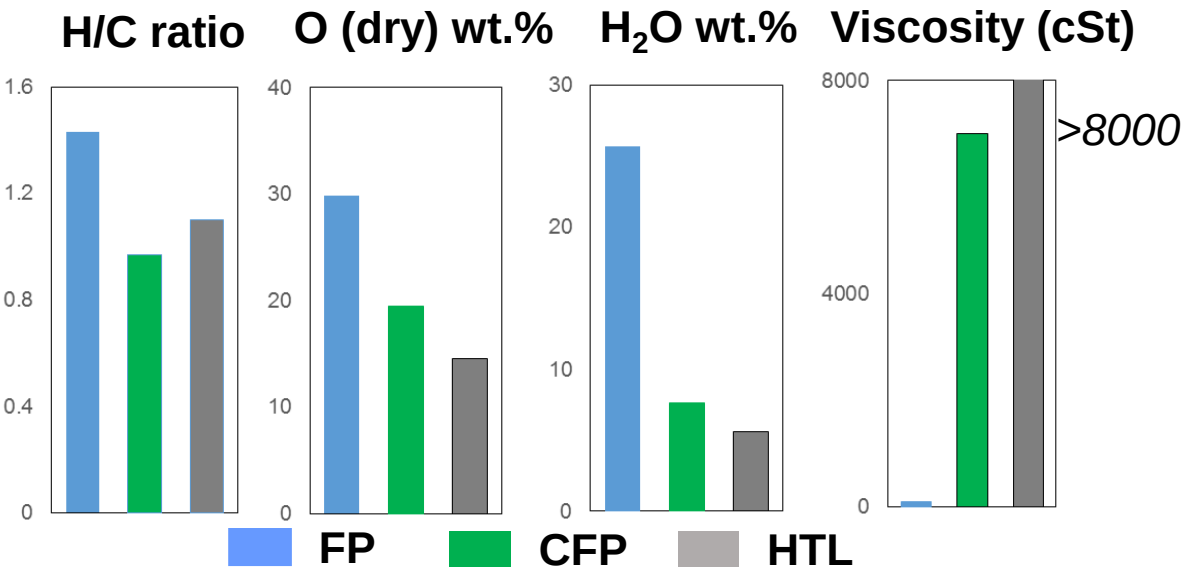
Hydrotreating and Biojet Production	Feed and Products Analysis	Coordination and Reporting	General Technical Support

- AOP with scheduled **Milestones and Deliverables**
  - *Q2, FY18*: Finish hydrotreating of CFP and report data
  - *Q3, FY18*: Finish hydrotreating of FP and HTL and report data
  - *Q4, FY18*: Provide report to ATM
  - *Q2, FY19*: Finalize PNNL-related section for the final report

- Regular team meetings and updates to BETO (quarterly reports and milestone reports)
- Regular meetings with ATM
  - Frequent technical and management discussions
  - Two onsite ATM project meetings (July and September 2018)

3 – Technical Accomplishments
Three bio-oil/biocrudes analyzed and pretreated

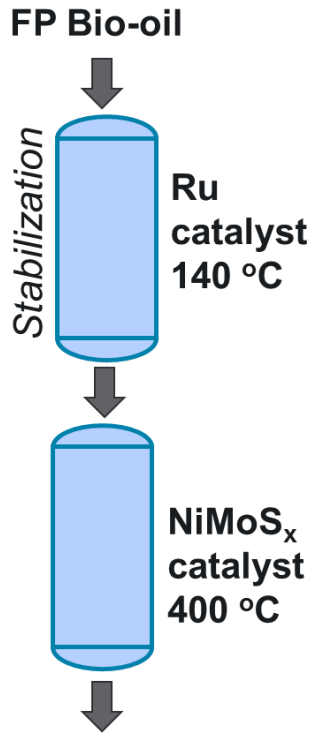
- Detailed analysis of FP bio-oil, CFP bio-oil, and HTL biocrude showed obvious difference in properties
  - CHNOS
  - Water
  - Density viscosity
  - HHV
  - CAN/TAN
  - Solid content



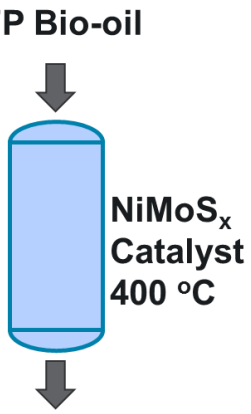
- Significant difference in properties of these feedstocks requires flexible and robust upgrading processes

Further information will be available in the final ATM report and publication

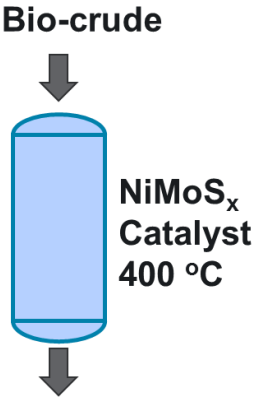
3 – Technical Accomplishments
Hydrotreating successfully executed with PNNL technologies



94 hours on stream for stabilization
188 hours on stream for hydrotreating
~7.5 L feed processed
3.0 L fuel production



36 hours on stream
~1.4 L feed processed
0.9 L fuel production



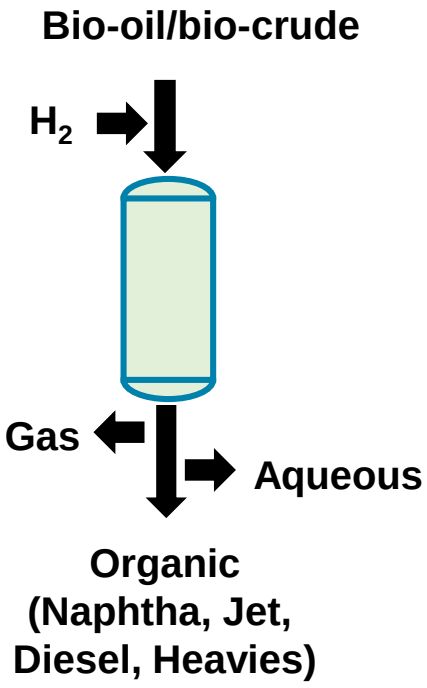
60 hours on stream
~2.4 L feed processed
2.0 L fuel production

400 ml Hydrotreater

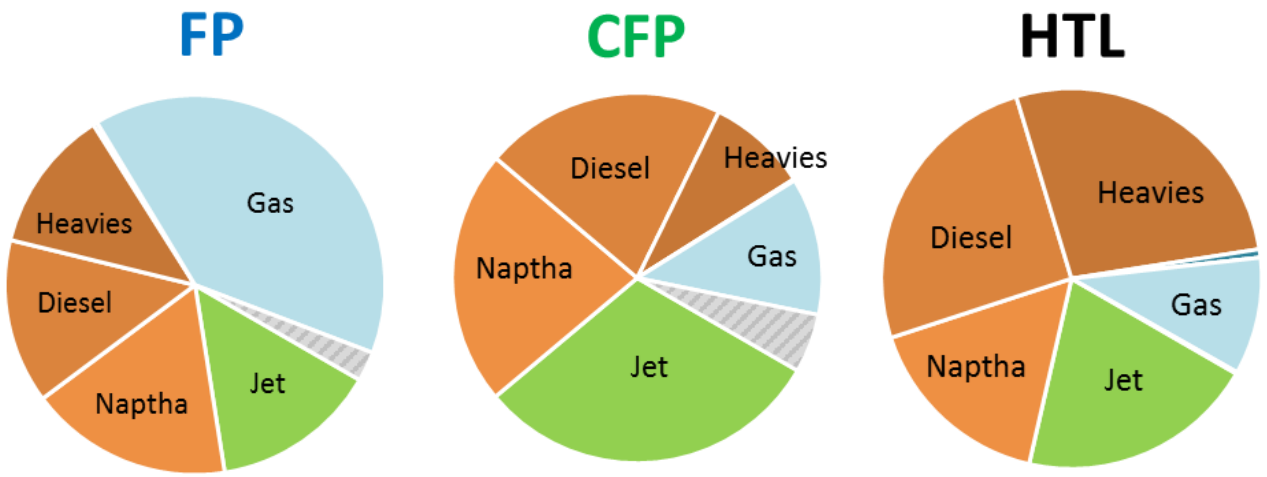
- Successful demonstration of hydrotreating technology for upgrading bio-oil/biocrudes
- Successful production of fuel products for detailed property evaluation

Further information will be available in the final ATM report and publication

3 – Technical Accomplishments
Hydrotreating performance evaluated



Carbon mass balance of hydrotreating process*

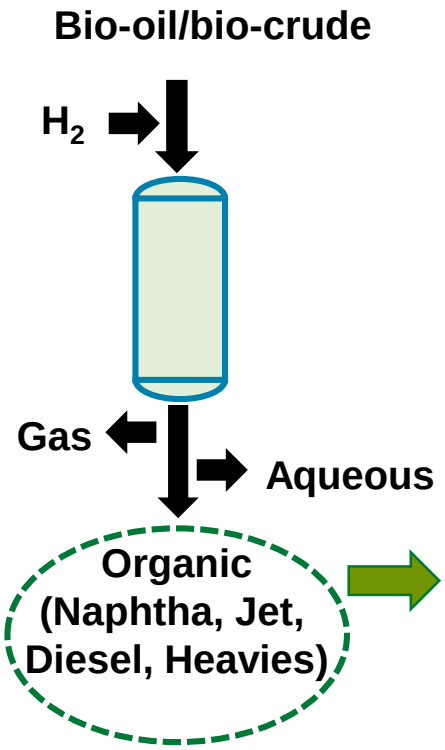


** Carbon yield of bio-oil/biocrude from FP, CFP, and HTL processes vary widely (overall carbon yield from biomass to jet will be reported in the final ATM report)*

- Significant difference in yield of products and hydrogen consumption for hydrotreating of three bio-oil/biocrude

Further information will be available in the final ATM report and publication

3 – Technical Accomplishments
Fuel products properties determined



Properties of HT organic products

	H/C	O% (dry)	Jet (wt.%)*
FP	1.83	1.1	28
CFP	1.46	0.95	37
HTL	1.61	<0.5	28

** Based on sim-dist*

Fuel products from HT of CFP bio-oil

- Produced organic products, as hydrocarbon fuels, were analyzed in detail and showed different properties (H/C and fractionation)

Further information will be available in the final ATM report and publication

3 – Technical Accomplishments
Biojet fuel properties determined

Jet fraction from CFP HT products

- Detailed fuel quality analysis of jet fraction
- Properties of other fractions, naphtha, diesel, and gas oil are also analyzed

Test	Standard	Units
Aarhus		
Aromatics	ASTM D1319	vol. %
Carbon	ASTM D5291	wt. %
Copper corrosion (2 h 100°C)	ASTM D130	-
Corrected flash point	ASTM D56	°C
Density @ -20°C	ASTM D7042	kg/m3
Density @ 15°C	ASTM D4052	kg/m3
Dynamic viscosity @ -20°C	ASTM D7042	mPa.s
Electrical conductivity @ 18.5°C	ASTM D2624	pS/m
Existent gum	IP 540	mg/100 mL
Freezing point	ASTM D5972	°C
Heat of combustion (gross)	ASTM D4809	MJ/kg
Heat of combustion (net)	ASTM D4809	MJ/kg
Hydrogen	ASTM D5291	wt. %
MSEP-A	ASTM D3948	-
Naphthalene content	ASTM D1840	vol. %
Nitrogen	ASTM D4629	mg/kg
Nitrogen	ASTM D5291	wt. %
Olefins	ASTM D1319	vol. %
Oxygen	SNCUT (in-house)	wt. %
Saturates	ASTM D1319	vol. %
Smoke point	ASTM D1322	mm
Sulfur (mercaptan)	ASTM D3227	wt. %
Sulfur	ASTM D5291	wt. %
Sulfur	ASTM D5453	mg/kg
Sulfur	ASTM D7039	mg/kg
TAN	ASTM D3242	mg KOH/g
Viscosity @ -20°C (bias-corrected)	ASTM D7042	cSt
Viscosity @ -20°C	ASTM D7042	cSt
Water content	ASTM D6304	mg/kg

Further information will be available in the final ATM report and publication

4 – Relevance
Accelerate the acceptance of biojet fuel

This project provides evaluation of the supply/value chain for the production of ***jet fuels from forest residues*** through various thermochemical conversion technologies with PNNL's contribution on ***upgrading of the liquefaction intermediates*** to produce fuels

- Directly supports BETO's barriers
  - ADO-A. Process Integration
  - At-C. Data Availability across the Supply Chain

- Provide critical information for sustainable aviation fuels stakeholders, including biofuels producers, airlines, airframe manufacturers (e.g., Boeing), policy makers, air and marine port authorities, and end users
  - Accelerate experience with and acceptance of biojet fuels

- Leverage expertise and capabilities developed with BETO's support and demonstrate robustness of technologies developed in BETO projects

5 – Future Work
This is a sunsetting project

- Support ATM to finish the report
  - Evaluation of supply/value chain for production of jet fuels from forest residues through various thermochemical conversion technologies
  - Expected to be published in 2019
- Close out project

- Identify future efforts and develop proposal for Phase II ATM project scope
  - Optimization of upgrading process to improve yield and quality of biojet fuel
  - More efficient processes targeting biojet fuel should be evaluated
  - Technologies that yield high-quality biojet fuels from forest residues (and other feedstocks) should be evaluated

Summary

This project provides evaluation of supply/value chain for production of jet fuels from forest residues through various thermochemical conversion technologies

Overview	ATM involves partners from stakeholders of biojet fuels to evaluate biomass to biojet fuel production
Approach	PNNL contributes capabilities in upgrading and expertise in conversion and lifecycle impacts
Technical Accomplishments	• Hydrotreated three bio-oil/biocrude from different thermochemical liquefaction process • Provided performance data and biojet fuel products • Supported ATM with expertise in conversion and lifecycle impacts • Comprehensive report expected in 2019
Relevance	Provide important experience and information to stakeholders of biojet fuels
Future work	Project closeout and report; develop proposal for Phase II ATM project scope

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Additional Slides

Responses to Previous Reviewers' Comments

This project was not reviewed previously.

Project start date: 10/1/2018

Publications, Patents, Presentations, Awards, and Commercialization

Presentation

- Douglas Elliott, Huamin Wang, Corinne Drennan, Hydrotreating of Bioliquids for Jet Fuel Production, *ATM Technical Meeting and Workshop*, Vancouver, Canada, July 2018.

Risk Registry Table

Risk Identified			Mitigation Strategy		Current Status
Risk Name	**Risk Description**	**Severity (High/ Med/Low)**	**Mitigation Response**	**Target Completion Date**	**Active/ Closed**
Difficulty in hydrotreating of low quality bio-oil/biocrude	The bio-oil and biocrude will be provided by ATM partners. Based on the upfront conversion technology provider, it is possible that the intermediate quality is low regarding sulfur content and polymer formation and its upgrading could be challenging.	Low	Alternative catalyst and reactor configuration will be considered to process the bio-oil to meet the production goal.	6/30/2018	Closed