DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

Refinery Integration
4.1.1.31 NREL
4.1.1.51 PNNL

March 24, 2015
Analysis and Sustainability

Mary Biddy
NREL

Sue Jones
PNNL

Goal Statement

Leveraging existing refining infrastructure potentially **reduces costs** for biofuel production but we first need to **understand the impacts**

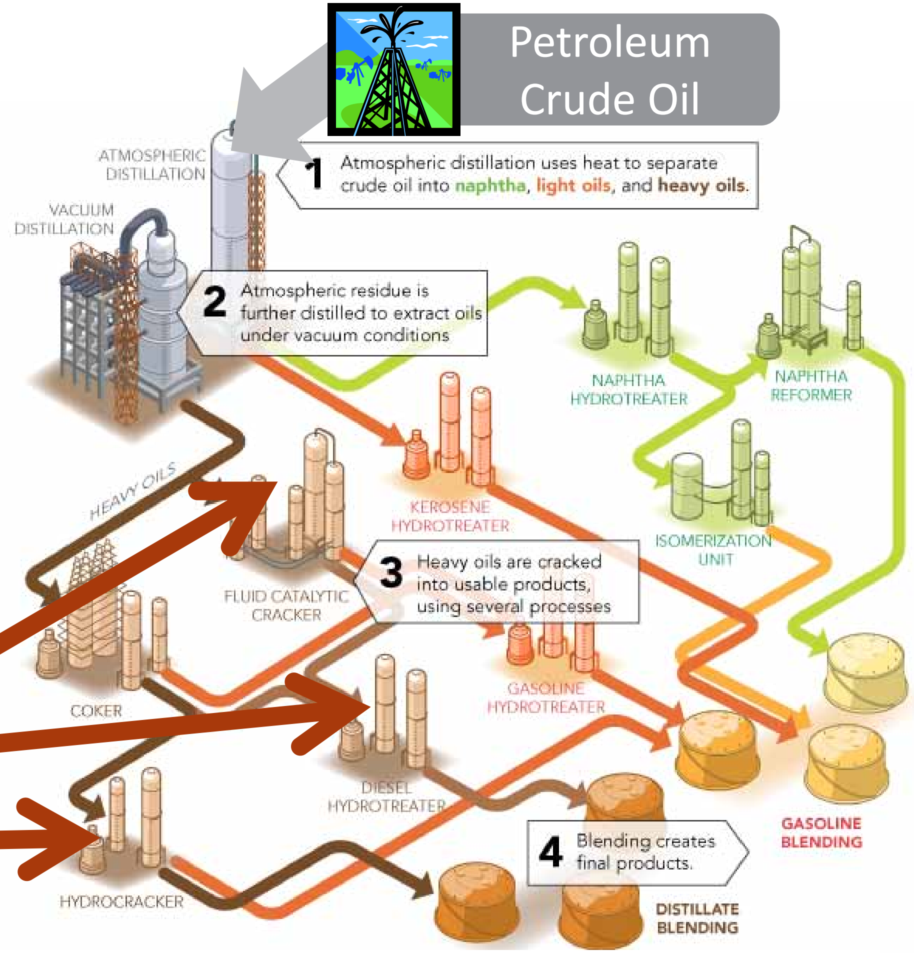
GOALS:

- **Model** bio-intermediates insertion points to better **define costs** & **ID opportunities**, technical **risks**, information **gaps, research needs**
- **Publish** results
- **Review** with stakeholders

Biomass

Bio-refinery Bio-intermediates

Lipids	Liquefaction Oils	C12+ Olefins



Petroleum Refinery Picture courtesy of http://www.bantrel.com/markets/downstream.aspx

Quad Chart Overview

Timeline

- Start: October 1, 2012 (PNNL only)
- Start: October 1, 2014 (NREL+PNNL)
- End: September 30, 2016
- Completion: 50% for joint project starting in 2014

Barriers

- Barriers addressed
  - **At-A** lack of transparent and reproducible analysis
  - **At-C** Inaccessibility and unavailability of data
  - **Tt-S** Petroleum Refinery integration of Bio-Oil intermediates

Budget

DOE Funded	Total Costs FY 10 – FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15 -16)
NREL	$0	$0	$128k	$422k
PNNL	$65k	$195k	$228k	$487k

Partners

- Partners:
  - For joint portion of project:
    NREL (44%), PNNL (56%)
- External Reviewers:
  - Refining catalyst vendor (2)
  - Refinery #1 modeling contact (2)
  - Refinery #2 modeling contact
  - Refining industry independent contractor

Project Overview

- **History**: Joint Lab FY14 start - **builds on previous work** at both labs
  - **NREL** refinery blending models for the **NABC**
  - **PNNL** high level **survey of refinery integration** potential (AOP project FY12-13)
  - **Complements** separate NREL AOP project for **refinery blending**
- **Context:** Economic deployment of biofuel
  - Understand how bio-fuels can **replace entire barrel of oil**
  - Understand how **existing infrastructure** can best be used
- **Objective**: FCC and HCK model development to understand impacts, opportunities and gaps
  - Develop **first-of-a-kind process models** to enable consistent modeling framework for economic and sustainability assessments
  - Understand and **review current state of technology** and information
  - ID **risks**, **research needs**, and **cost drivers**
  - **Review** with key industrial stakeholders
  - **Publish** results and findings

Approach (Technical)

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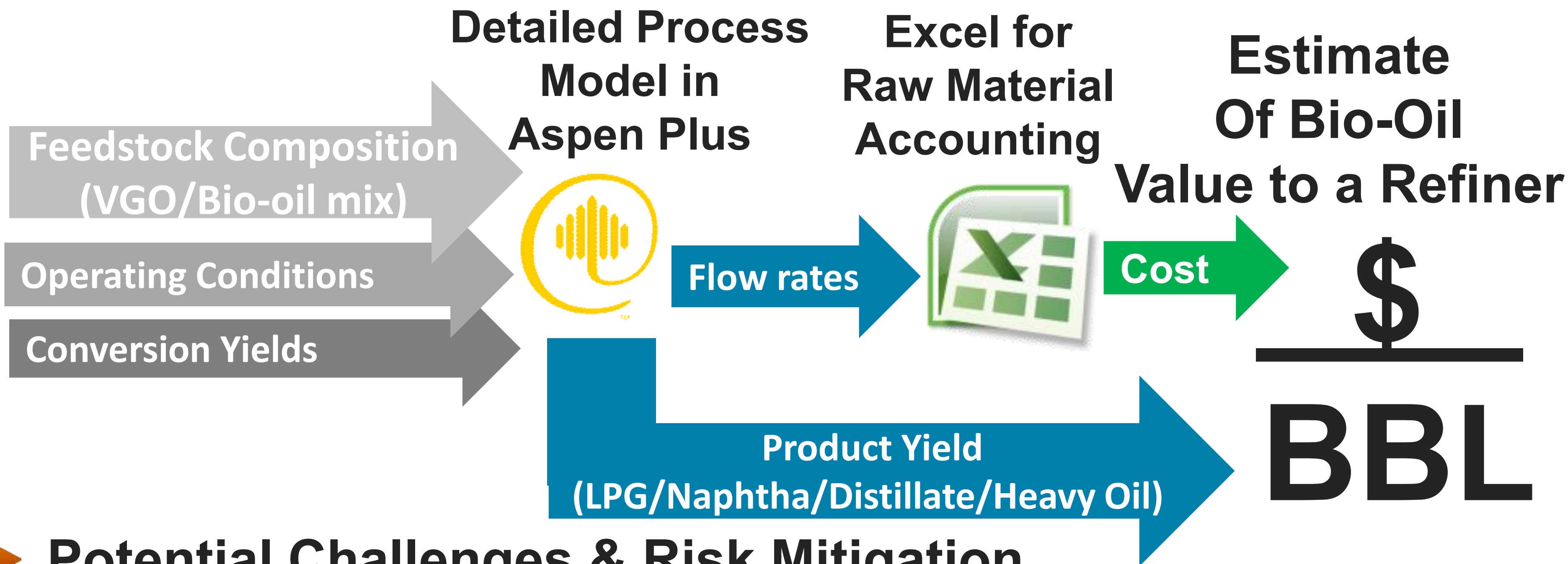

Potential Challenges & Risk Mitigation

- **Consistent** and **appropriate assumptions**: defined technical basis and economic assumptions at start of project & reviewed with BETO
- **Data availability**: engage researchers at both labs + literature data to estimate yields and product distribution
- **Meaningful cost impacts**: estimate value of bio-oil relative to crude oil from a refiner's perspective when considering quality, yield and process impacts

Approach (Technical)

- **Critical success factors: Stakeholder Review**
  - 4 separate refining related entities agreed to assist with project
    - FCC **catalyst vendor** (2 contacts from same company: 1 with refining technologies and renewables expertise; 1 with expertise in FCC evaluations focusing on catalysts and feedstocks)
    - **Refiner** #1 (2 contacts from same company – one with FCC expertise and one with HCK expertise)
    - **Refiner** #2 (17 years in refining processes modeling research)
    - **Retired refiners** now working as **independent consultants**
  - FY14:
    - **Sent the FY14 report document to all** and Aspen models to those interested
    - **Compiled feedback** for use in revising models and methods (details in upcoming slides)

Approach (Management)

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- **Approach structure**
  - **Joint NREL** and **PNNL effort** to **leverage capabilities** at both labs
  - **Project Management Plan** (PMPs) indicating scope, budget, schedule
  - **Annual Operating Plans** (AOPS) prepared prior to each fiscal year
    - Details quarterly **milestones** and **deliverables** (see additional slides)
    - **Go/No-go** point May 2015 to assess project value and direction
    - FY15-16 AOP passed **Merit Review** July 2014
  - **Quarterly reporting** to BETO (written and regularly scheduled calls)
- **Potential Challenges and Risk Mitigation**
  - **Researcher proximity**: we have regularly scheduled calls & data exchanges
  - **Data compatibility**: use same software platforms & exchange models for cross-check review
- **Critical success factors**
  - **Engage stakeholders**
  - Make **results public**
  - Deliver product **on-time**, **on-budget**

Technical Progress & Results: intermediates

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Currently Identified Bio-Oil Intermediates*

Bio-intermediates	# Properties Found	CHNOS	Density	Viscosity	TAN	Composition	Co-processing data		# Independent Sources	HDO Data
							FCCU	HCK		
Algae HTL	5	√	√	√	√	GC/MS			3	√
Algal LE	2	√				% acids, triglycerides			1	
Wood HTL	5	√	√	√	√	SimDis			3	√
Stover HTL	4	√	√	√	√				1	√
HYP	4	√	√		√	GC/MS, SimDis			3	√
CPO	5	√	√	√	√	GC/MS	√		14	√
HDO (partial)	5	√	√	√	√	GC/MS,SimDis	√		4	√
Biological Conv	4	√	√	√		SimDis			1	

HTL=hydrothermal liquefaction; LE= lipid extracted; HYP=hydropyrolysis; CPO=catalytic pyrolysis; HDO=hydrodeoxygenation

Petroleum Intermediates

VGO	Vaccuum gas oil	
VBGO	Visbreaker gas oil	
AGO	Atmospheric gas oil	
DAO	De-asphalter oil	
LCO	FCC light cycle oil	
HCO	FCC heavy cycle oil	
Resid	Residual oil	
H+LCGO	Heavy coker gas oil, light cycle gas oil	

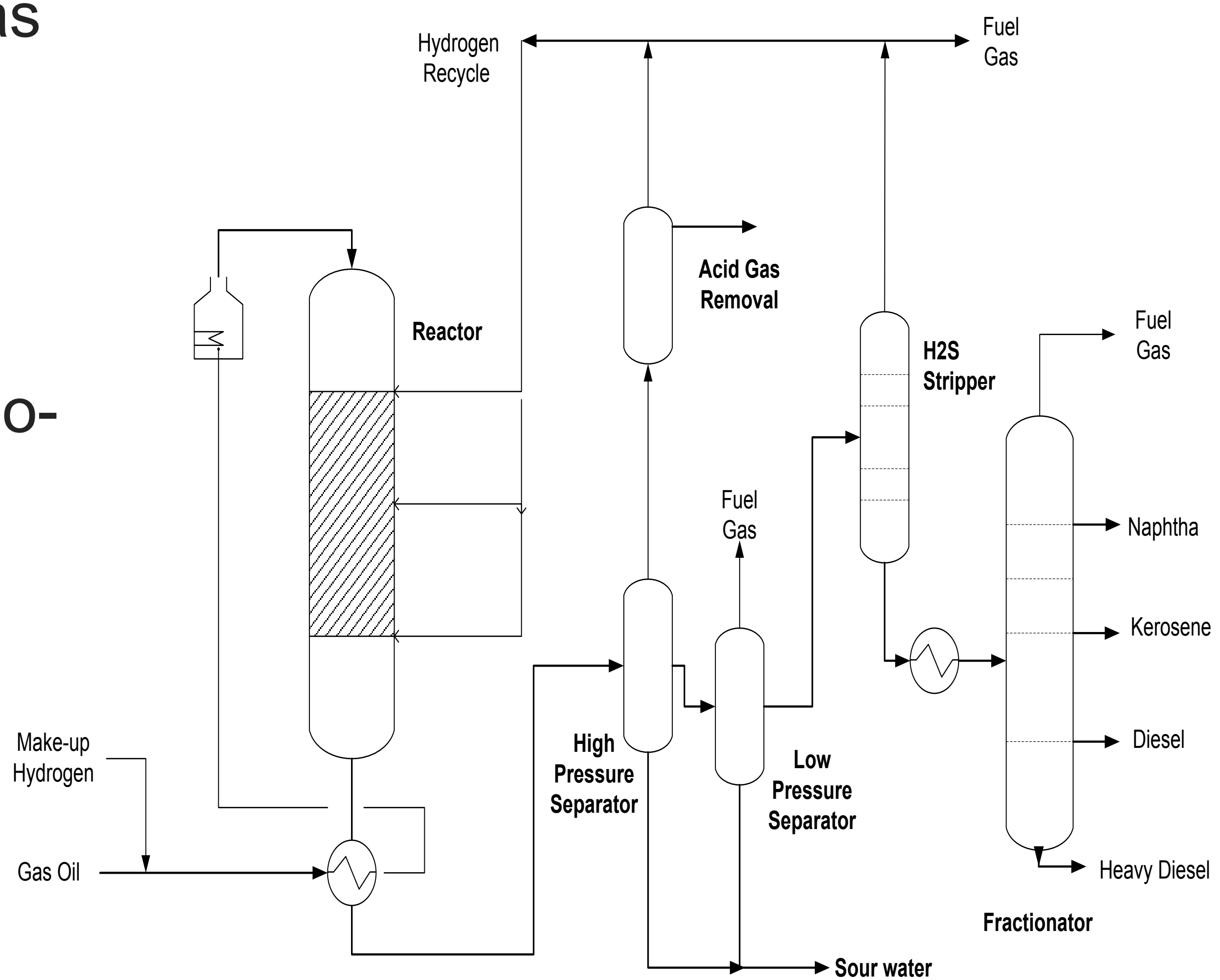
52 references: literature and experimental data

Initial Intermediates chosen:

- **Partially hydrotreated pyrolysis oil** (fair amount of information available regarding FCC co-processing; some hydroprocessing data)
- **VGO** as conventional feed

Technical Progress & Results: HCK Model

- Modeled reactor, gas separation and H2 recycle, product separation
- **Pure compounds** used (versus pseudo-components)
- **Stoichiometric Reactor** Model
- **Aspen model** flowsheet shown in additional slides



Technical Progress & Results: HCK Model

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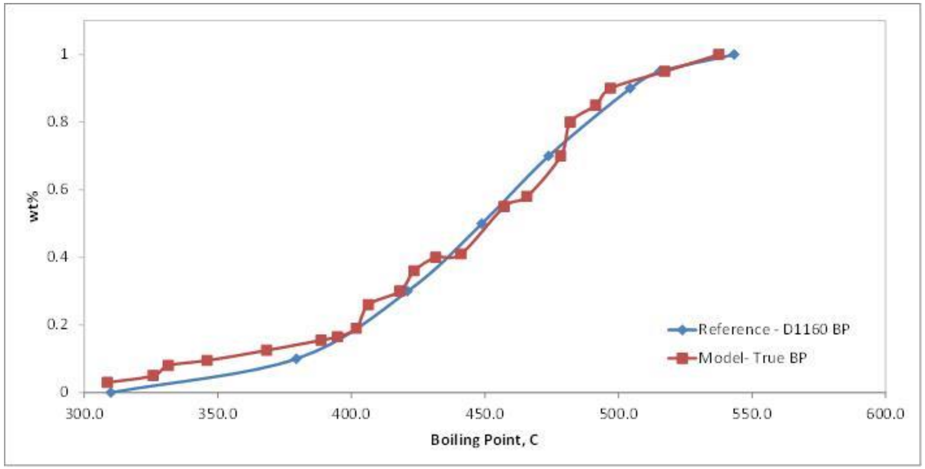
100% VGO feed model

- Back blended distilled products distillation curves* in Excel to estimate HCK effluent
- **Model check**: Compared resulting utilities and HCK model product distillation compared to literature



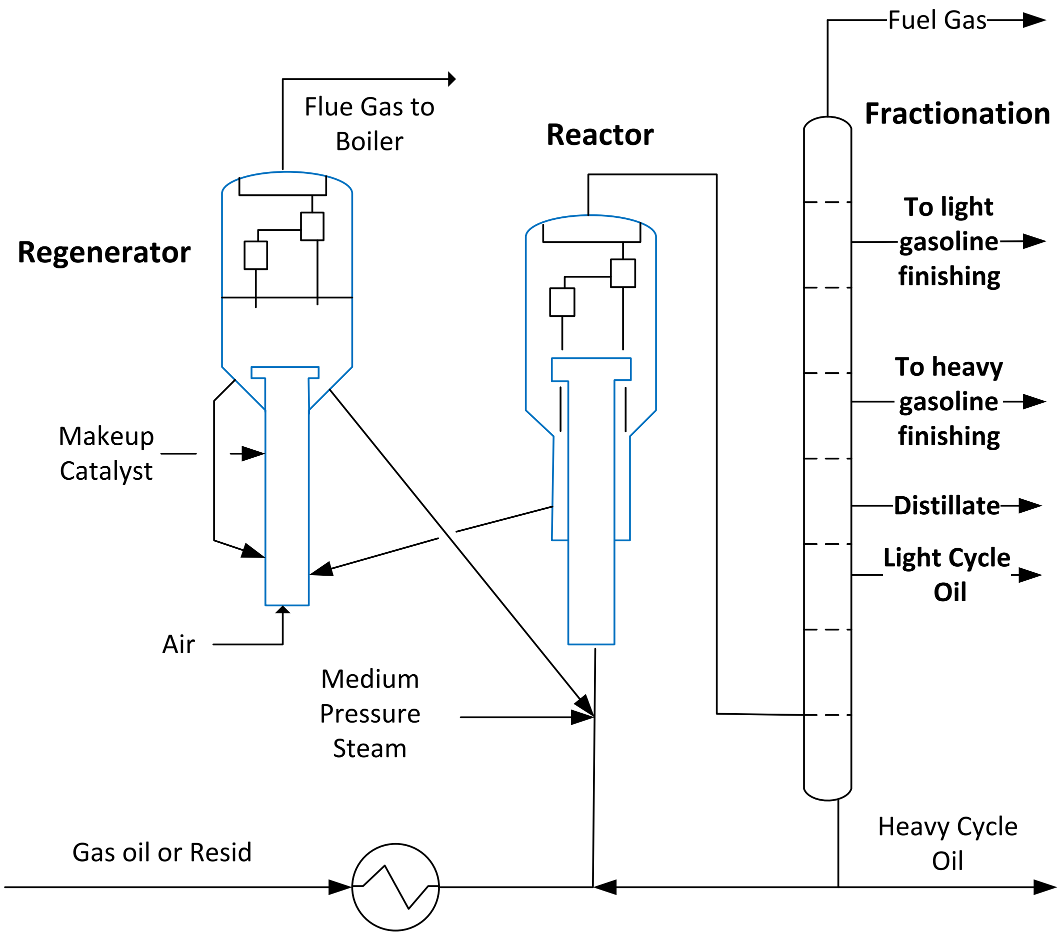
* Parkash **Refining Processes Handbook**, 2003

Blended feed models

- Used best judgment for HCK products of blended feed based on experience with hydrotreating pyrolysis oils; some lit on HCK of VGO with vegetable oils
- **90/10 wt%** and **80/20 wt% VGO/bio-oil**
- Consistent throughput and reactor inlet temperature for all three cases

Technical Progress & Results: FCC Model

- Modeled reactor, gas separation and H2 recycle, product separation
- **Pure compounds** used (versus pseudo-components)
- **Stoichiometric Reactor** Model
- **Aspen model** flowsheet shown in additional slides



Technical Progress & Results: FCC Model

100% VGO feed model

- Back blended distilled products distillation curves* in Excel to estimate FCC effluent
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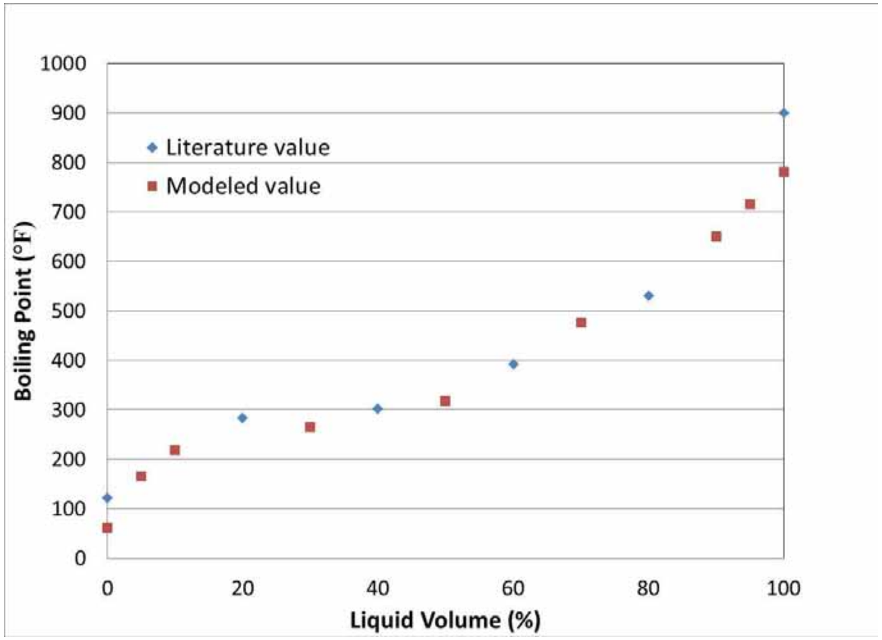

Blended feed models

- Overall yields are based on published literature for comparable blends of partially upgraded bio-oil for FCC products
- Oxygen removal is either through the formation of water or CO2 and the yields are consistent with recent experimental results (60-70% of oxygenated species converted)
- **90/10 wt%** and **80/20 wt% VGO/bio-oil**
- Consistent throughput and reactor inlet temperature for all three cases

Technical Accomplishments

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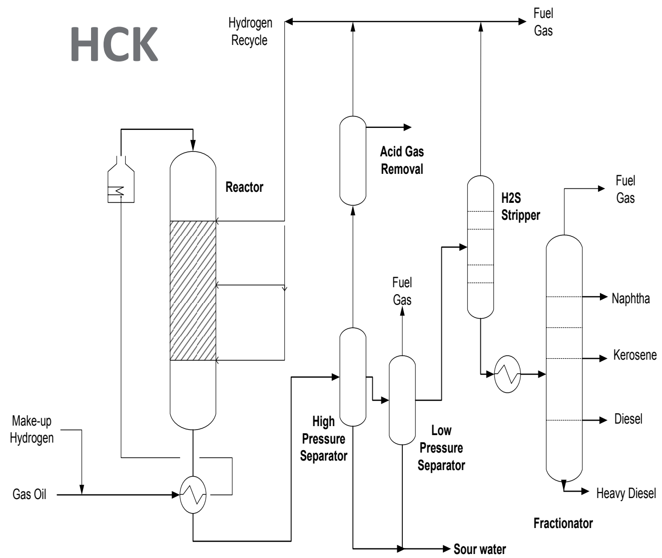
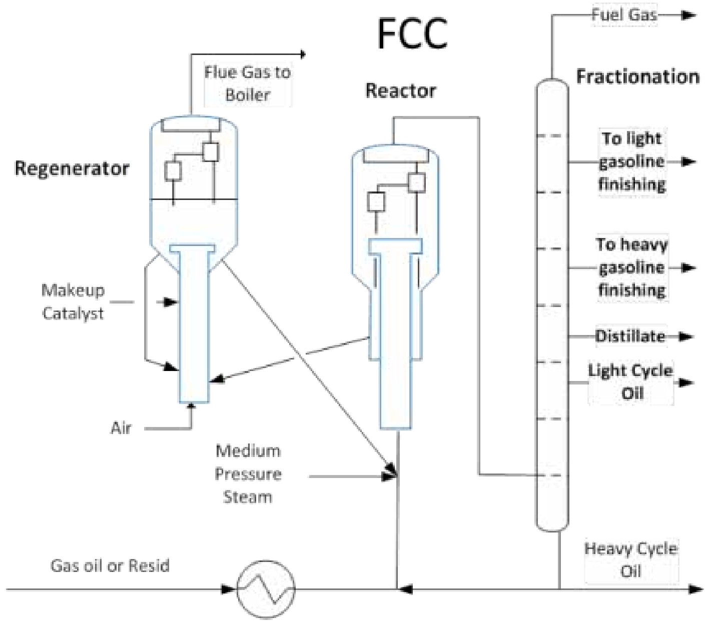
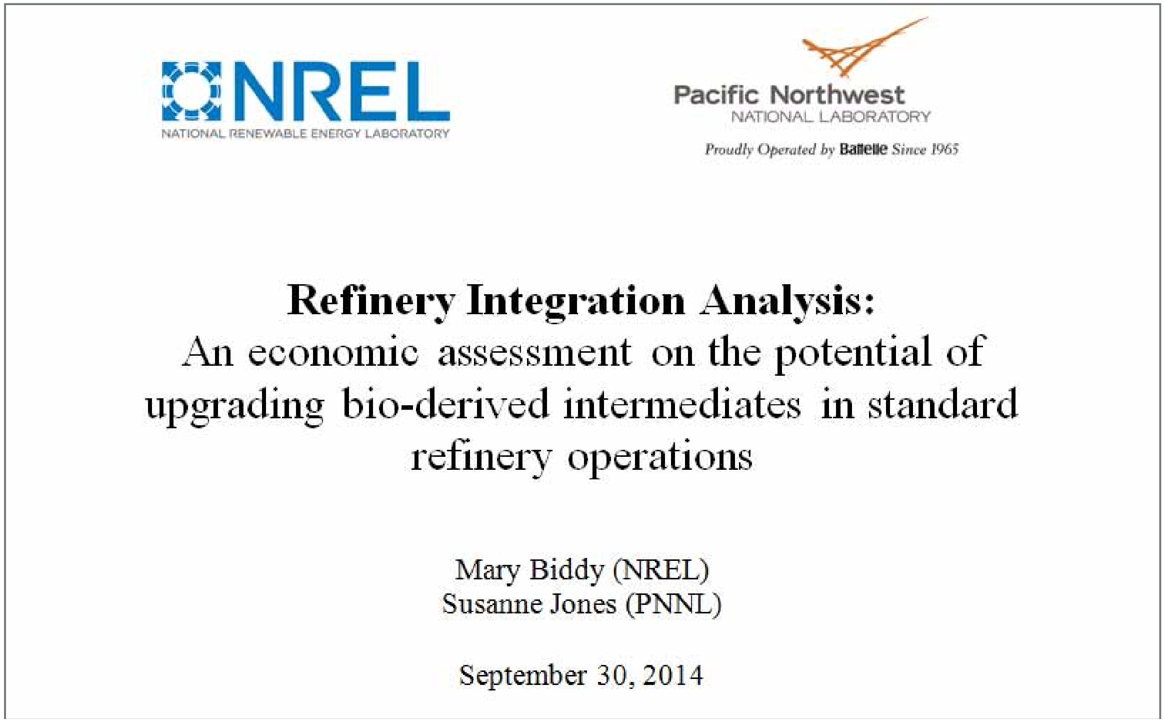




- Developed **first of a kind process models** for **hydrocracker and fluidized catalytic cracker** units
- Developed **baseline models** for traditional petroleum vacuum gas oil (VGO)
- **Introduced partially upgraded pyrolysis oil** at 10wt% and 20wt% blend
- Performed **preliminary economic analysis** to estimate the value of bio-oil to a refiner based on set price of crude and process impacts

Technical Accomplishments: Key Milestone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Refinery Integration Analysis:
An economic assessment on the potential of upgrading bio-derived intermediates in standard refinery operations

Mary Biddy (NREL)
Susanne Jones (PNNL)

September 30, 2014

- **Completed report** summarizing process design and assumptions and economic analysis of integrating upgraded bio-oil in refinery FCC and HDO processes
- Report provided **to 4 different external stakeholder organizations**. Feedback received from 5 total independent reviewers.

Technical Accomplishments: Industrial Assistance

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- **General comments**:
  - Reduce flowrates (or add capital) for blended feeds to account for process constraints such as
    - FCC coke make
    - HCK hydrogen availability
  - Heating value vs. volume swell
  - Re-evaluate co-product basis (gasoline & diesel fraction, vs offgas, LPG) and consider a range of values
  - Consider fixed costs: labor, maintenance, depreciation in addition to variable costs
- **Unit specific comments**
  - FCC: heat balance methods; consider higher catalyst loss
  - HCK: losses to light material; catalyst deactivation (increase cost or reduce throughput; consider heavy oil hydrocracker
- **Feedback on sensitivities**
  - Vary crude prices
  - Capital expenses to accommodate 20 wt% bio-oil
  - Re-consider 100% conversion of oxygenates and discount products accordingly
  - Coke production in both units
  - Other variable costs such as waste water treatment, gas clean-up, additional wastes
- **Feedback on data gaps**
  - Bio-oil and petroleum miscibility
  - Metallurgy impacts
  - Effect of oxygenates on pump seals
- **Feedback on data sources: parallels with other work**
  - Oil shale and tight oil pilot work
  - Vegetable oil/triglyceride cc-processing work
  - Coal liquid co-processing work

Project Relevance

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- **Project directly contributes to BETO goals per 11/2014 MYPP:**
  - "The market potential of bio-oils as a feedstock for petroleum refineries is largely unknown. There is a need to **gather information** to understand the **technical risks** and to illustrate the **economics** and **sustainability of integration** so that refineries will consider the bio-oil intermediate an acceptable refinery feedstock." (Thermochemical Conversion)
  - "**Convey the results** of analytical activities **to a wide audience**, including DOE management, Congress, the White House, industry, other researchers, other agencies, and the general public" (Analysis and Sustainability)
- **Positive impact on commercial biofuel viability:**
  - Determine bio-fuel production **cost reduction opportunities**
  - Determine realistic **estimates of how much biomass** could potentially be co-refined and the impact on the Renewable Fuels Standards (RFS)
- **Target Audience:** BETO and industrial stakeholders
  - **Engage key stakeholders** in the industry for their review and feedback on underlying assumptions, and share their insight on the issues of risk and technical information needs for risk assessment
  - Feed results to **related BETO projects** (experimental and analysis)
  - Identify data gaps needed for further consideration to BETO conversion platform

Project Relevance

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- **Expected outcomes and applications**
  - Understand & review **current state of technology** and information available to integrate biomass derived intermediates into existing petroleum refineries
  - Begin to assess if refinery integration will be successful in the future in terms of **economics, sustainability and technical risks**. Assess cost requirements from the refiner's perspective
  - Identify the **technical risks, research needs** and **primary cost drivers** in using biomass derived intermediates in petroleum refinery hydrocracker and fluid catalytic cracker units
  - Given the underlying uncertainty in the current data, identify which data **gaps are critical to address** in the near term to understand the cost implications and/or risk for refinery integration
  - Help **identify specific properties favorable for integration** as well as properties that may limit the ability to integrate biomass intermediates and estimate the economic implications of meeting these desired properties

Future Work

- **FY15:**
  - Continue **model updates** per reviewer feedback; leverage Aspen HYSYS capabilities in addition to AspenPlus
  - Begin to **identify data needs** for Life-Cycle Analysis (**LCA**)
  - Continue **stakeholder reviews**
  - **Stakeholder Dissemination:** Present work to date at **AIChE Spring Meeting**
  - **Go/no-Go in May** to determine whether to continue on or change course
  - **Key Milestone:** Complete **draft journal manuscript** of co-processing information to date
- **FY16:**
  - Expand models to consider co-processing of **distilled bio-oil** in **hydrotreaters**
  - Potentially work with ANL regarding **sustainability** assessments
  - Investigate **supply chain integration** (biomass type, location, proximity to petroleum refineries)
  - **Continue stakeholder reviews**
  - **Key Milestone:** Summary white paper
  - Project ends: Not the last word, results feed into a bigger picture (Refinery Blend LP model for example)

Summary

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Overview: Begin to understand co-processing issues

Approach: Iterative, NREL & PNNL **share inputs** & **review results** with external experts

Technical Accomplishments/Progress/Results

- **FY14**: Completed preliminary FCC and HCK cost and performance models with external review
- **FY15**: received external review feedback & began incorporation
  - Conducting on-going literature search
  - Preparing data requests

Relevance: by assessing use of existing infrastructure, this project **aligns with BETO's mission** to reduce biofuel production costs

Future work: **Go/No-go**, journal draft, sensitivity analysis, sustainability analysis

Status since 2013 Review: PNNL FY12-13 AOP project had review from one retired refiner. Peer reviewers recommended bringing in additional expertise. Joint NREL/PNNL project started in FY14 and added multiple industrial assistance.

Acknowledgements

- Bioenergy Technologies Office – Alicia Lindauer

<u>NREL TEAM</u>

Mary Biddy

Michael Talmadge

<u>PNNL TEAM</u>

Sue Jones

Mark Bearden

Yunhua Zhu

Steve Phillips

Asanga Padmaperuma

Additional Slides

Response to reviewers comments

Publications and presentations

Project milestones

Modelling detail example

Abbreviations and acronyms

Responses to Previous Reviewers' Comments

- **2013 Peer Review of PNNL AOP project from FY12-13:**
  - "Broader engagement with more refineries and with downstream stakeholders is a key factor to make this and follow-up efforts worthwhile"
  - "Needs much more collaboration with industry and labs"
- **Response:** Per reviewer recommendations, PNNL partnered with NREL to leverage previous and ongoing work at both labs and also increased the number of industry contacts from 1 to 4 separate entities (6 reviewers total)
- **Go/No-Go Reviews:** scheduled for May 31, 2015

Publications and Presentations

PNNL FY12-13 work

- Publications:
  - Freeman C. J.; Jones, S. B.; Padmaperuma, A. B. *et al* Initial Assessment of U.S. Refineries for Purposes of Potential Bio-Based Oil Insertions, April 2013, PNNL-22432
- Presentations:
  - 2013. Freeman, C. J.; Jones, S. B.; Padmaperuma, A. B. *et al* Initial Assessment of U.S. Refineries and the Potential for Bio-Based Oil Insertions" Presented to the Bioenergy Technologies Office March 22, 2013
  - 2013. "Opportunities for Biomass-Based Fuels and Products in a Refinery - A Preliminary Investigation" Presented by Corinne Valkenburg (Invited Speaker) at Biomass 2013, Washington, DC on August 1, 2013. PNNL-SA-97258
  - 2014. "Preliminary assessment of potential bio-based oil insertions to US refineries" Presented by Asanga Padmaperuma at 2014 Spring Meeting and 10th Global Congress on Process Safety, New Orleans, LA on March 31, 2014. PNNL-SA-101771
  - 2014. "Initial Perspectives on Biomass and Bio-oils in Existing Infrastructure." Presented by Corinne Drennan (Invited Speaker) at Bio-oil Co-processing Workshop, New Orleans, LA on May 23, 2014. PNNL-SA-102992.

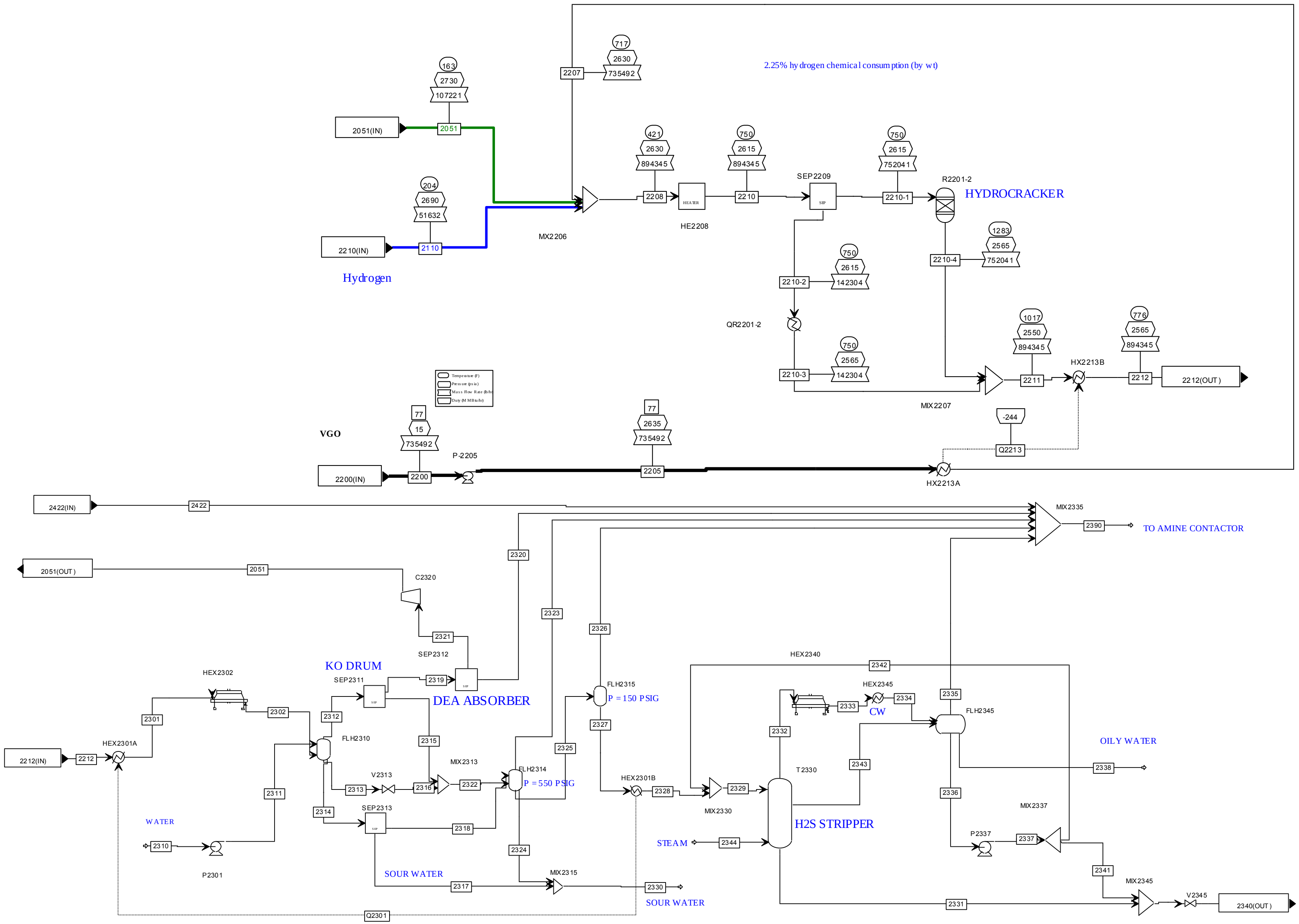
NREL/PNNL FY14-17 work

- Presentation planned for AIChE Spring meeting (April 2015)
- Publication draft planned for Q4FY15

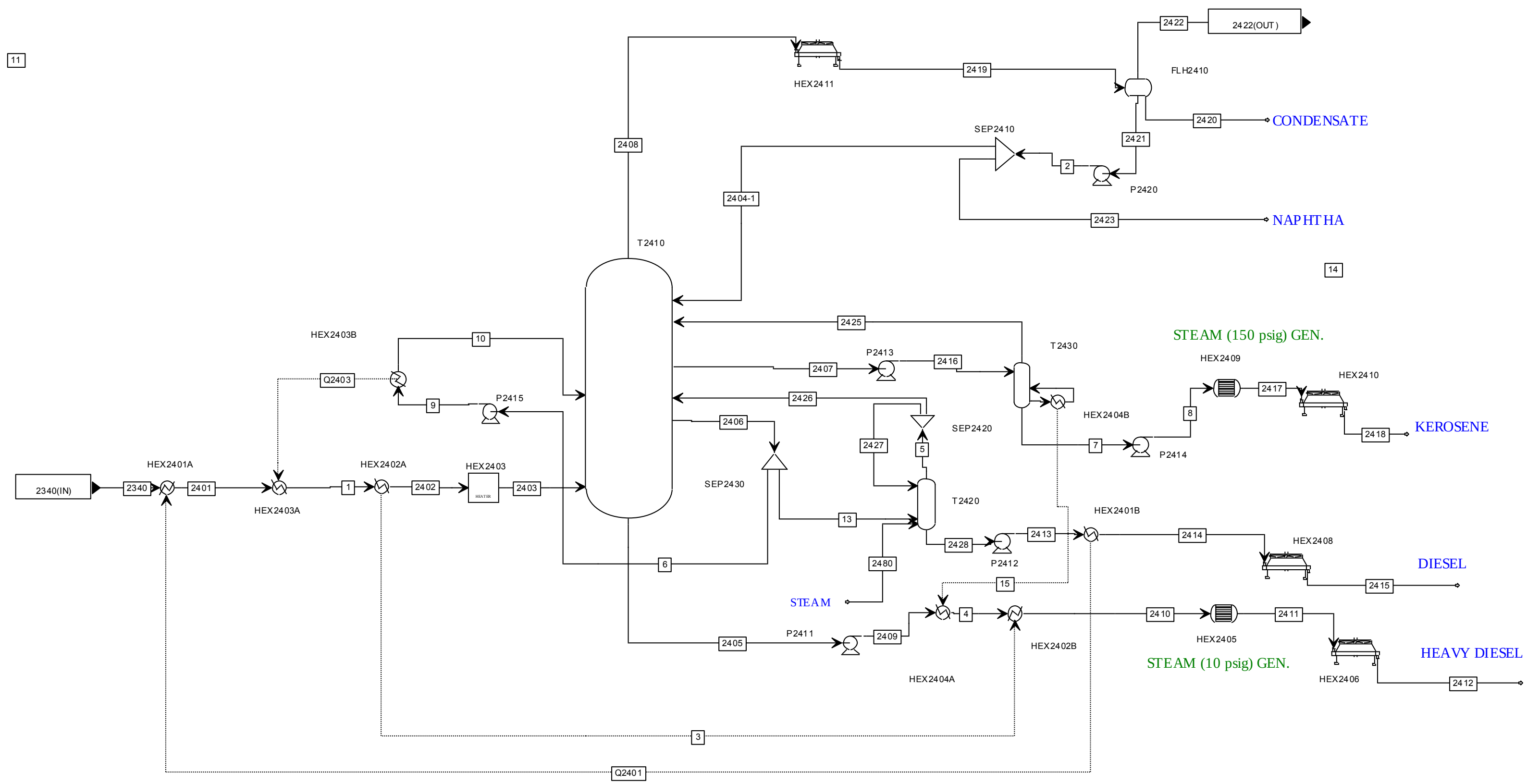
Milestones and Metrics

Title/Description	Due Date	Completed
Define conventional feedstocks and up to 5 bio-intermediate streams to feed hydrocracker and FCCU processes (joint PNNL/NREL)	Dec-13	On-time
Complete base Aspen models for the 2 refinery processes (joint PNNL/NREL) to include a stoichiometric based reactor, heat integration and product separation and summarize in a brief (joint PNNL/NREL	Mar-14	On-time
Complete co-processing cost estimates for at least two intermediates (oils with different oxygen contents)	Jun-14	On-time
Complete reviewed hydrocracker models with 2-3 process configurations (PNNL), FCC models with 2-3 process configurations (NREL) and report (PNNL/NREL) summarizing model assumptions, and outcomes identifying gaps, potential issues and opportunities for co-processing. - ML/DL).	Sep-14	On-time
Revise models (HCK PNNL and FCC NREL primary focus) to incorporate industrial/stakeholder reviewer feedback from FY14 and new literature/ experimental data leading towards the Q2 deliverable and summarize in a brief to BETO	Dec-14	On-time
Define and use models (HCK PNNL primary focus; FCC NREL primary focus) to collect sustainability metrics (e.g. GHG emissions, net fossil energy consumption) that are relevant to BETO's economic and sustainability goals, and summarize in a brief to BETO	Mar-15	
Go/No-Go decision: Model Utility	May-15	
Joint NREL-PNNL publication including a literature review of refinery integration data, and key economic results with a focus on data gaps, roadblocks and opportunities for bio-fuel cost reduction	Sep-15	
Consider alternative biomass derived feedstocks for co-processing, potentially produced from hydrothermal liquefaction or via fermentation, and develop hydrotreating model. Develop list of sustainability metrics to be collected and summarize in a brief to BETO	Dec-15	
Complete base and co-feed hydrotreater models from Q1 FY16 and summarize in a brief to BETO	Mar-16	
Complete biomass availability on a county level and proximity analysis to existing petroleum refineries for current and future scenarios; leverage HCK, FCC and hydrotreater model outputs. Summarize in a brief	Jun-16	
Final deliverable: NREL, PNNL ANL white paper draft for publication	Sep-16	

Aspen HCK and Gas separation



Aspen HCK Product Separation



Abbreviations and Acronyms

- ANL: Argonne National Laboratory
- AOP: Annual operating plan
- BETO: Bioenergy Technologies Office
- BBL: Barrel
- FCC: Fluidized catalytic cracker
- GGE: Gasoline gallon equivalent
- HCK: Hydrocracker
- LCA: Life-cycle analysis
- MFSP: Minimum fuel selling price
- MYPP: Multi-year program plan
- NABC: National Advanced Biofuels Consortium
- NREL: National Renewable Energy Laboratory
- PMP: Project management plan
- PNNL: Pacific Northwest National Laboratory
- VGO: Vacuum gas oil