2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy





11.2.2.2 Opportunities for Biomass-Base Fuels and Products to Address the Entire Barrel of Oil in a Refinery

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Technology Area Review: Analysis and Sustainability

Organization: Pacific Northwest National Laboratory

PNNL-SA-95231

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Goal Statement

- The goal of the analysis to address the entire barrel of oil is to support meeting the strategic DOE program performance goals by "**developing analytical tools**, **models**, **methods**, and datasets to advance the understanding of bioenergy and its related impacts"*
- The goal of the pathways analysis portion of this project directly supports the DOE strategic analysis activities to "**by 2013**, select, complete techno-economic modeling, and **set goals and targets** for at least two hydrocarbon pathways"*

* BETO Multi-Year Program Plan

Quad Chart Overview

Timeline

- Start: October 1, 2011
- Continuing through FY14
- Completion: work is ongoing

Barriers

- At-A: Lack of comparable, transparent and reproducible data
- Im-F: Cost of production
- It-E: Engineering modeling tools

Budget

- Funding for FY11 $0
- Funding for FY12 $160k
- Funding for FY13 $160k
- 2 years funding at an average of 160k/year

Partners

- John Shinn (refinery expert, retired from Chevron)
- NREL (pathways analysis) – joint project management

Project Overview

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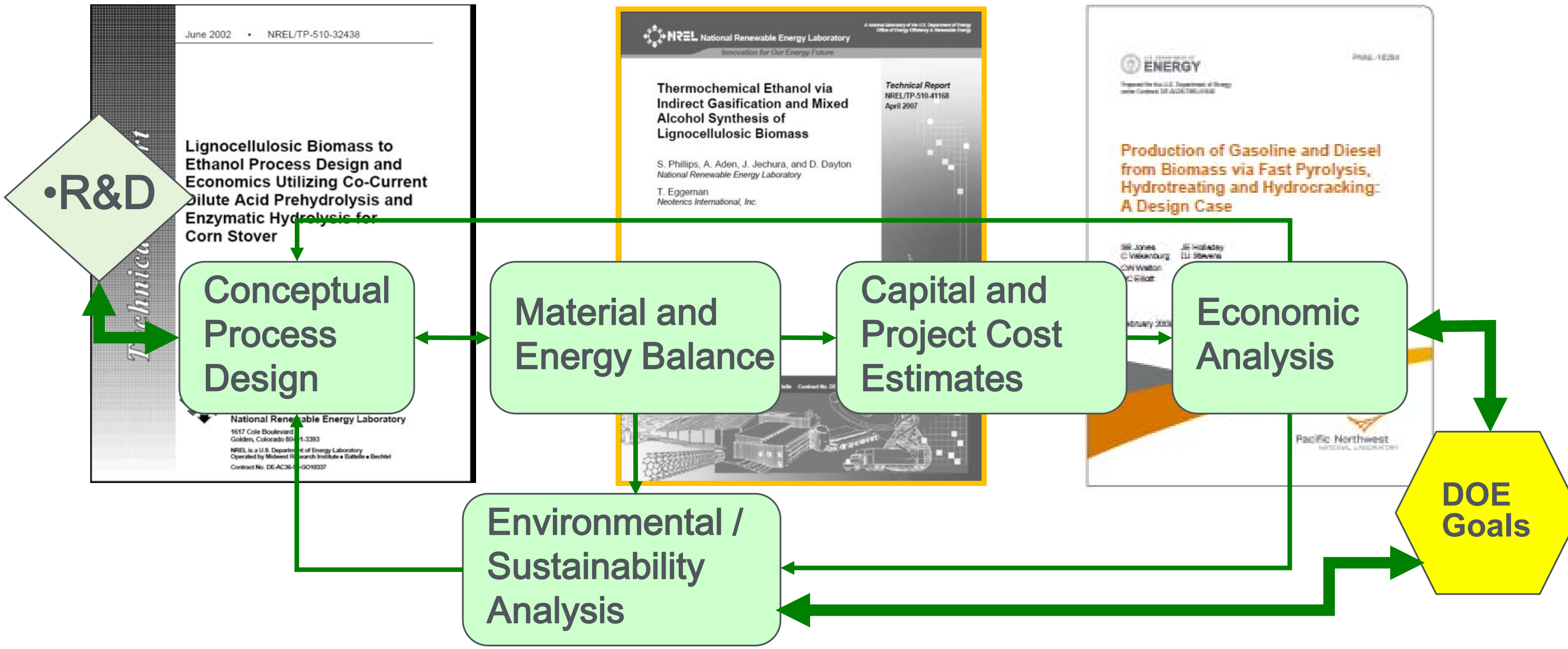
- **History**: new start for FY12
- **Context**: BETO's portfolio expands to hydrocarbon fuels
  - 12/11 CTAB* Roadmapping Workshop identified critical technology areas
  - BETO Pathway Selection Working Group prioritized pathways
  - DOE laboratories enlisted to leverage existing TEAs and rapidly develop new analysis for the pathways of interest
- **Objective:** Support the BETO pathways analysis to enable the production of hydrocarbon fuels
  - Develop preliminary economics in support of the FY12 pathway prioritization
  - Develop detailed economics and technical targets for FY13 &14 of select pathways
  - Analysis to support understanding of use of existing infrastructure

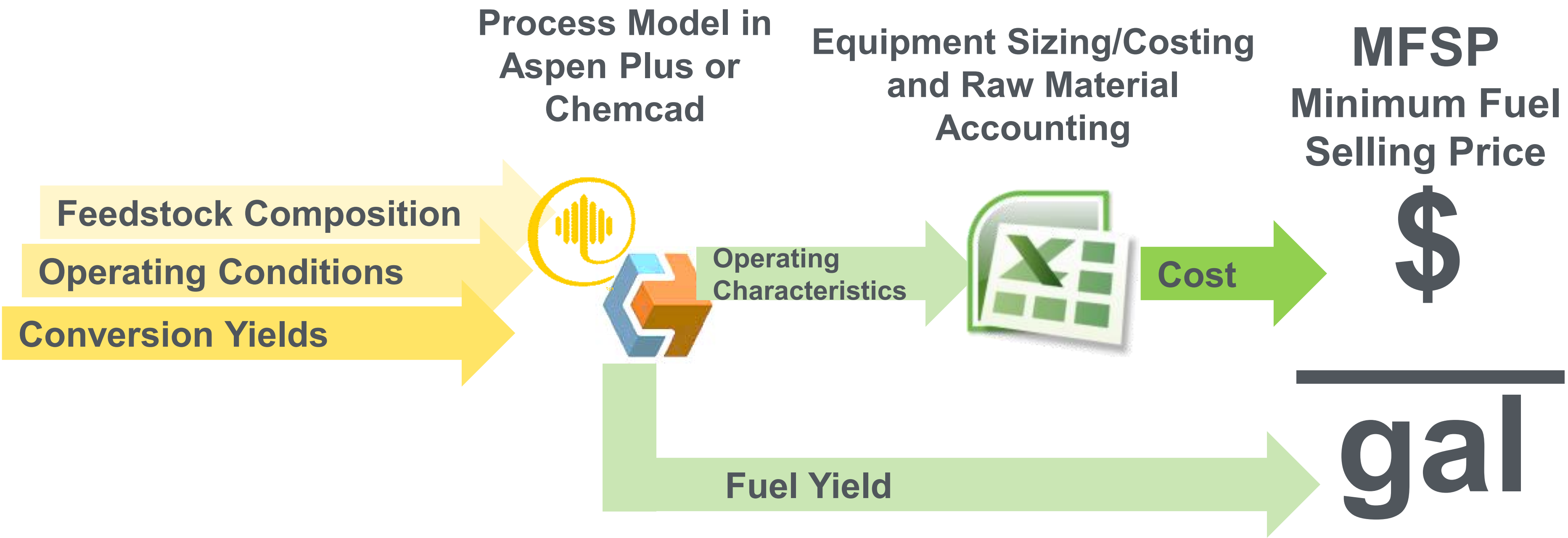
*CTAB: Conversion Technologies for Advanced Biofuels

Techno-Economic Analysis: Approach



- Collaborate with engineering & design firm to enhance credibility, quality
- Conceptual design reports are transparent, highly peer reviewed
- Iteration with researchers and experimentalists is crucial

Techno-Economic Analysis: Approach



- Modeling is rigorous and detailed with transparent assumptions
- Assumes n^{th}-plant equipment costs
- Discounted cash-flow IRR calculation includes return on investment, equity payback, and taxes
- Determines the minimum selling price required for zero NPV

Technical Accomplishments

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This project has two separate tasks:

Task 1: Technology Pathways Technical Memos

- Techno-economics to support Pathway Analysis (NREL & PNNL)
- Preliminary analyses for multiple pathways
- Assist BETO in assessing future R&D needs

Task 2: Biomass-Base Fuels and Products to Address the Entire Barrel of Oil

- Co-processing biomass derived intermediates
- Petroleum refinery capacity and capability assessment

Technology Pathways Technical Memos

- FY12 NREL and PNNL collaboration to perform analysis for hydrocarbon biofuels pathways
- Integrated efforts with INL for feedstock interface and costs
- 18 pathways identified with 13 TEAs performed
- Consistent economic assumptions utilized to estimate preliminary MFSP
- DOE BETO selected 7 pathways for further development
- Vetted assumptions and basis with researchers and scientists
- Reviewed by key stakeholders in DOE BETO

Technology Pathways Technical Memos

- FY13 collaborative TEA efforts between NREL and PNNL to document and publish 7 technology pathways
- Provides process design highlights and identifies data gaps, uncertainties and future research needs
- Starting point for developing joint NREL and PNNL design reports for hydrocarbon biofuels pathways in FY13 and FY14 for core platform tasks

Approach Task 2

Biomass-Base Fuels and Products to Address the Entire Barrel of Oil

- Assesses at a high level, the impact of introducing bio-derived intermediates into U.S. petroleum refineries
- Surveys availability of biomass near petroleum refineries in the 2022 timeframe
- Considers bio-intermediate compatibility with petroleum intermediates
- Offers a refiner's perspective

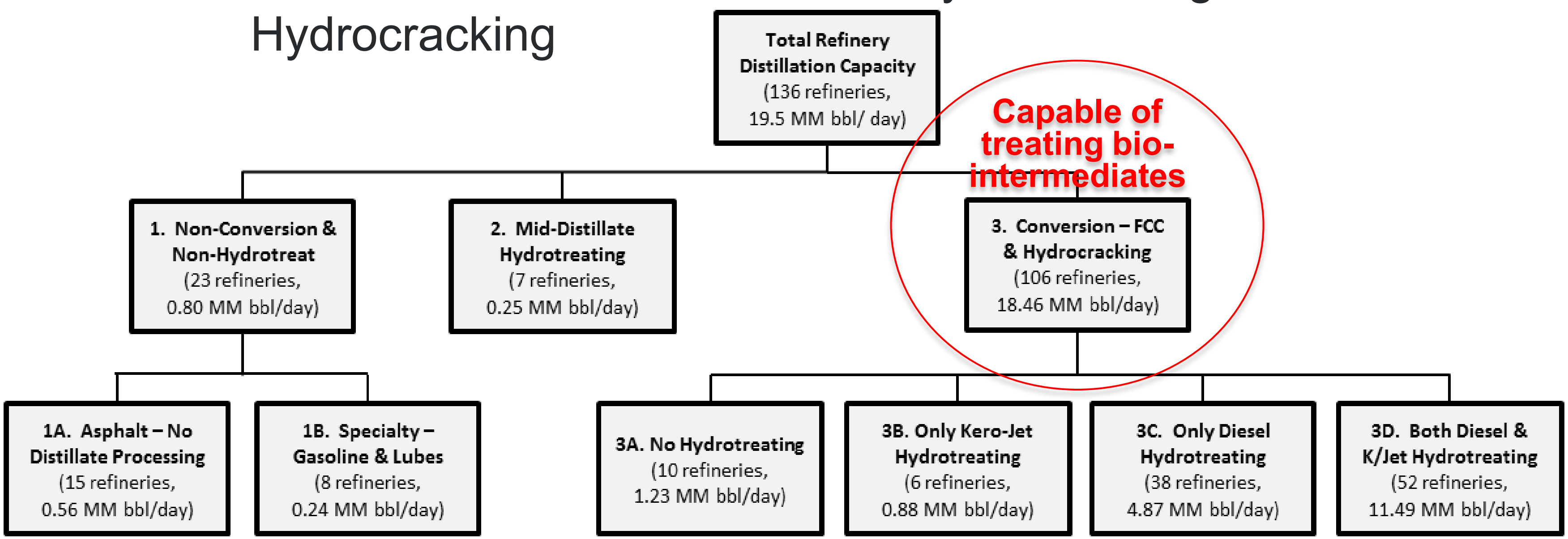
DOE Mission Impacts

- Supports understanding of infrastructure use and potential to reduce costs
- Addresses entire barrel
- Considers advanced biofuels

Technical Results
Task 2

What is the total US refining capacity and capabilities?

- Per EIA, 149 refineries total, 136 sufficiently detailed
- ~20 million barrels/day total capacity (136 refineries)
- Categorized into three main types:
  1. Non-conversion & non-hydrotreating
  2. Middle-distillate hydrotreating capability
  3. Full conversion – Fluidized Catalytic Cracking and Hydrocracking



Technical Results
Task 2

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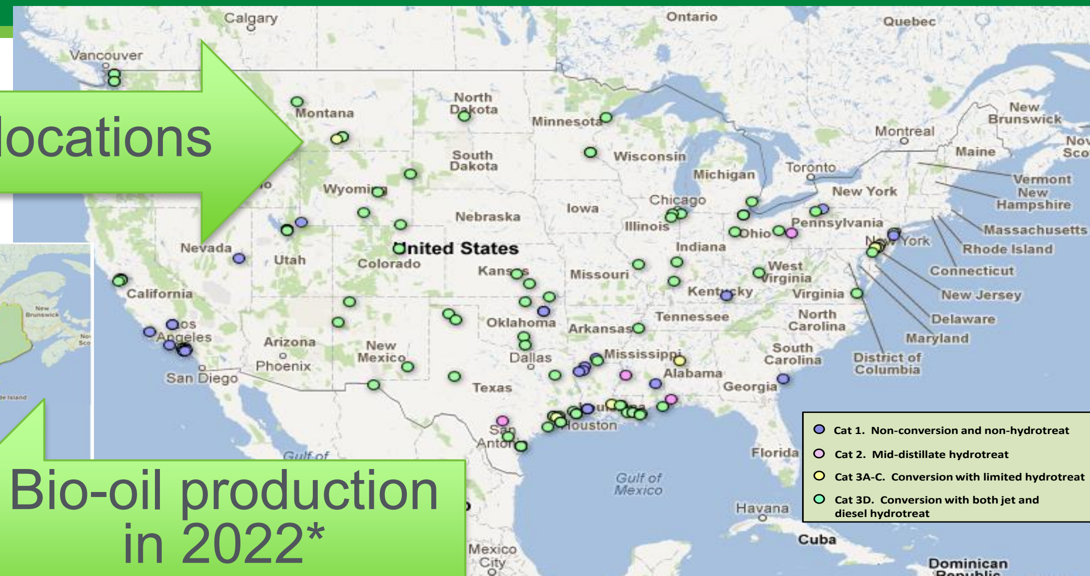
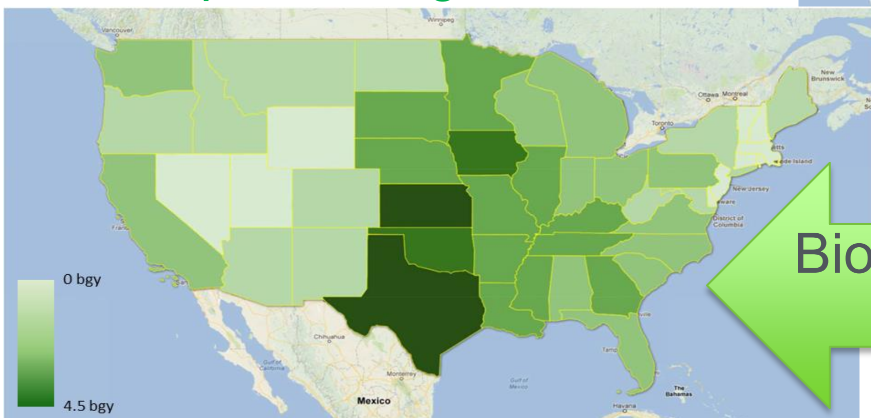
Q: Sufficient refining capacity in future for 20% co-processing?

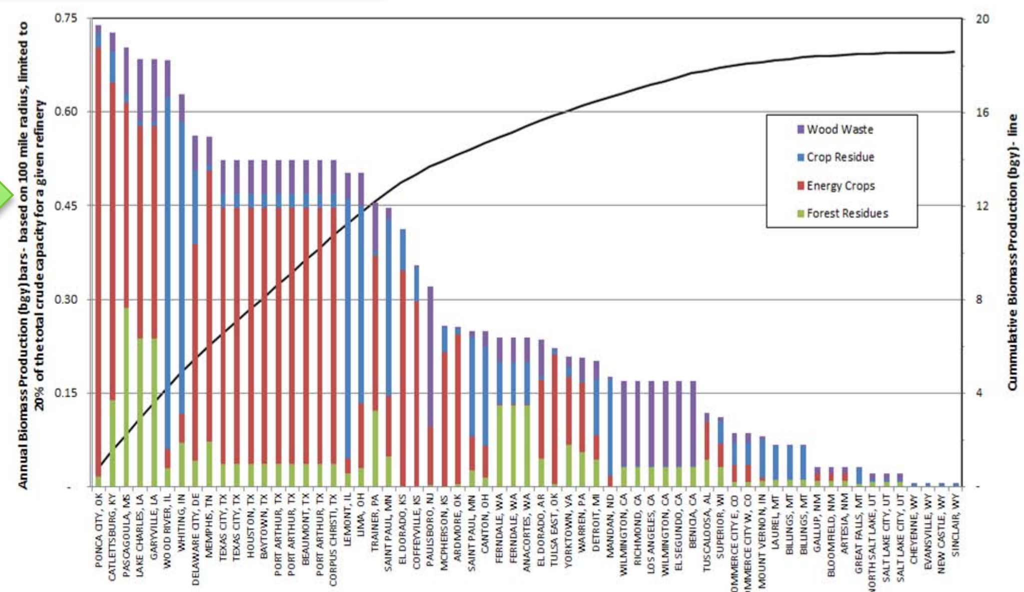
Refinery locations





Bio-oil production in 2022*

Refinery sites with highest biofuel production potential**



A: Initial look suggests capacity is available

* 20% additional yield loss
$60/ton farm gate
85 gal/dry ton conversion

**US refinery sites with highest est. fuel volumes
100 mile radius around each refinery
FCC and HCK refineries only (Cat 3)
Equiv. biofuel intermediate into any refinery limited to 20% of total crude capacity

Technical Results
Task 2

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How do bio-intermediate properties compare with conventional?

Partially hydrotreated pyrolysis more cyclic than crude derived cuts

Very little published data

No data for diesel or heavier cuts available

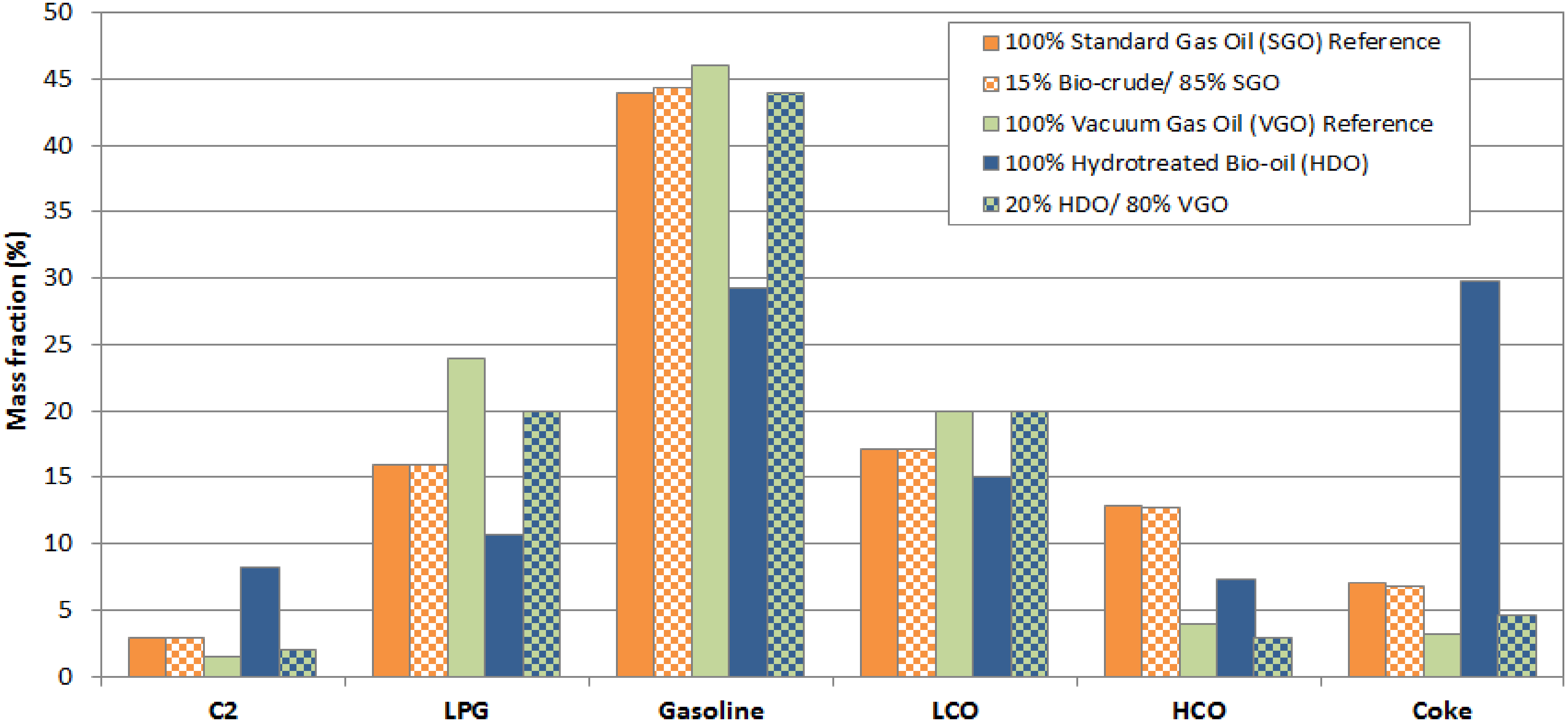
	Light Naphtha Cut			Heavy Naphtha Cut			Kerosene Cut			Diesel Cut		
	15 - 75 °C	C5 - 71 °C		75 - 165 °C	71 - 182 °C		165 - 250 °C	182 - 260 °C		250 - 345 °C	260 - 338 °C	
	North Slope Crude	Hydrotreated Pyrolysis Oil from Biomass		North Slope Crude	Hydrotreated Pyrolysis Oil from Biomass		North Slope Crude	Hydrotreated Pyrolysis Oil from Biomass		North Slope Crude	Hydrotreated Pyrolysis Oil from Biomass	
		8.2% O	0.4% O		8.2% O	0.4% O		8.2% O	0.4% O		8.2% O	0.4% O
Wt% Yield	5	5	14	13	20	30	12	19	22	17	17	21
Aliphatics (vol%)												
Paraffins	86	7.9	28.3	46	15.4	5.9	37	10	33	30		
Isoparaffins		32.8	14.9		26.8	38.8						
Naphthenes	13	31.8	51.3	39	46	20.3	44			38		
Aromatics (vol%)		10.9	5.6	14	11.8	27	15	52	38	31		
Olefins (vol%)		16.7	0.07		0.01	8.3						
Benzene (vol%)		0.3	0.5		0.4	0.8						
Unidentified								30	25			
TOTAL	**99**	**100**	**101**	**99**	**100**	**101**	**96**	**92**	**96**	**99**		
H/C molar ratio	2.23	1.96	2.04	1.96	1.88	1.85	1.89	1.69	1.7	1.75	1.56	1.55
Acidity*	0.001	102	ND	0.009	123	ND	0.03	67	ND	0.098	20	0.1
RON	71	79	64	64	71	88						

*Table Sources: Christiansen, Earl, et al. "Biomass Fast Pyrolysis Oil Distillate Fractions" Energy & Fuels 2011, 25, 5462-5471
BP Crude Marketing, Alaska North Slope Crude Assay http://www.bp.com/extendedsectiongenericarticle.do?categoryId=16002777&contentId=7020196

Technical Results
Task 2

Co-processing bio-derived oils up to 20% of FCC feed appears feasible

- Raw pyrolysis oil needs pre-treatment to be miscible with petroleum feeds
- Little published data, mostly small scale FCC type applications



Graph Sources: Agblevor, F.A., et al., Co-processing of standard gas oil and biocrude oil to hydrocarbon fuels. Biomass and Bioenergy, 2012. 45: p. 130-137
Fogassy, G., et al., Biomass derived feedstock co-processing with vacuum gas oil for second-generation fuel production in FCC units. Applied Catalysis B: Environmental, 2010. 96(3-4): p. 476-485

Technical Results
Task 2

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Refiner's Perspective: Safety, Reliability, Predictability, Profitability

Risk	Type of Bio-oil Intermediate	Insertion	Refinery Challenges
Lowest	Well defined, consistent quality, such as single molecules (e.g., ethanol, butanol, farnesene)	Blending units	• Blending, product performance and distribution of products that include the bio-component. • Evaluating and managing potential stability, toxicity and environmental issues
Medium	Intermediates requiring only minor treating (e.g. triglycerides, some direct liquefaction oils, some catalytically derived sugar oils)	Hydrotreating followed by blending	Challenges identified above, plus: • Understanding process performance on new feeds and blends with petroleum-based feeds. • Enabling larger fractions of bio-oil blending stocks while still meeting product specs. • Providing sufficient hydrogen to meet hydrotreating demands (for reducing oxygen or aromatic contents).
Highest	Intermediates needing boiling range & composition changes for acceptable gasoline, diesel and jet fuel blending stocks (e.g. fast pyrolysis oils, some hydrothermal liquefaction oils, some catalytic pyrolysis oils).	Off-site or dedicated on-site hydrotreating followed by cat- or hydro-cracking	Challenges identified above, plus: • Understanding the impact of bio-oils on all refinery processes. • Meeting product quantity and quality needs with feedstocks with less data on conversion behavior.

Technical Results
Task 2

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- Conclusions:
  - Most U.S. refineries have capabilities and capacities (at least at this level of analysis) to process bio-intermediates
  - Gulf Coast refining important – bulk of capacity & proximity to projected biomass volumes
  - Partnerships with refiners is key
- Gaps identified:
  - More experimental co-processing data needed (in addition to that expected from the 2012 Bio-oil Commoditization solicitation)
  - Methods and standards needed to characterize and predict impact
- Summary report completed: PNNL 22432
- FY13 task to begin development of process models to assess biomass intermediate co-processing

Milestones/Metrics and Progress

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Title/Description	Due Date	Completed
Categorize refinery types and capacities	Mar -12	✓
Review of assumptions and refineries	Jun -12	✓
Complete initial mapping of biomass blendstocks to refinery processes	Sep -12	✓
Identify gaps and opportunities for meeting MYPP reference case target	Dec-12	✓
Complete characterization of HCK and FCCU	Dec-12	✓
Develop process models for HCK and FCCU	Mar-13	✓

Relevance

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- **Task 1 supports** the Bioenergy Technologies Office **strategic goal** "*to develop technologies for converting feedstocks into cost-competitive liquid transportation fuels*" through **pathways analysis** leading to **technical targets** for cost reduction

- **Task 2** helps DOE and industry **understand critical issues and risks** related to hydrocarbon production particularly through the **use of existing infrastructure**

Critical Success Factors

- **Provide robust analysis of costs and benefits**, sustainability metrics and environmental impacts
  - Ensure consistent and appropriate assumptions across all Biomass design cases
  - Frequent meetings with platform leads and laboratories
  - Monthly Analysis & Sustainability telecons
  - Quarterly formal reporting to HQ

- **Availability of up-to-date information** on the technical status, barriers and markets in order to assess costs and risks and direct research towards areas of greatest impact
  - Early identification of barriers, gaps and research needs
  - Collaboration with and review from labs and industry
  - Draw on existing relationships with refining experts to provide input and review for refinery co-processing analysis; forge new partnerships as needed

Future Work

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ML, DL or Go/No Go	Description	FY13 Q3	FY13 Q4	FY14 Q1	FY14 Q2	FY14 Q3	FY14 Q4
B.1.ML.3	Develop cost models for HCK and FCCU with potential for bio-intermediates to achieve $3/gal target						
B.1.ML.4	Complete summary report of completed costs per refining functional area and impact of bio-intermediates towards the $3/gal goal						
C.1.ML.1	Refinery operation characterization for two processes						
C.1.ML.2	Refinery process model						
C.1.ML.3	Refinery process cost model						
C.1.ML.4	Summary report						

TASK 1: Pathways Analysis (with NREL)

- 2-3 additional gasification based tech memos (FY13)
- Updated design case for Fast Pyrolysis and Upgrading and technical targets (FY13)
- Algae HTL Design Case and targets (FY13)
- Catalytic Pyrolysis Design Cases (In-Situ and Ex-Situ) and technical targets (FY14)
- FY15 reduce number of pathways

TASK 2: Leveraging Conventional Refinery Infrastructure (with NREL)

- Complete preliminary models for FCCU and HCK
- Expand model (partner with NREL), engage industry
- FY15 determine if sufficient data available for continuation

Summary

1) ***Approach***

- Tech Memos: multi-lab analysis with iterative review between researchers, modelers, and headquarters; Refinery project reviewed with refining expert

2) ***Technical accomplishments***

- 7 published Tech Memos (with NREL), after assessment of 18 pathways and development of 13 TEAs
- Preliminary refinery insertions analysis report completed: PNNL-22432

3) ***Relevance***

- Provides new pathways input for the MYPP

4) ***Critical Success factors and challenges***

- Robust analysis through consistent basis and vetted assumptions
- Collaboration with labs and industry

5) ***Future Work***

- Task 1: New design cases to further detail pathways and set research targets
- Task 2: Enhance refinery modeling to better understand co-processing costs

6) ***Technology transfer***

- Published documentation

Acknowledgements

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PNNL Team – Aye Meyer, Asanga Padmaperuma, Miki Santosa, John Shinn (Retired Chevron consultant to PNNL project)

NREL – Mary Biddy

Additional Slides

Responses to Previous Reviewers' Comments

- This project was a new start in FY12 and hence has not been previously reviewed

Publications, Presentations, and Commercialization

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Publications

Whole Algae Hydrothermal Liquefaction Technology Pathway

http://www.nrel.gov/docs/fy13osti/58051.pdf

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-22314.pdf

Algal Lipid Extraction and Upgrading to Hydrocarbons Technology Pathway

http://www.nrel.gov/docs/fy13osti/58049.pdf

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-22315.pdf

Ex-Situ Catalytic Fast Pyrolysis Technology Pathway

http://www.nrel.gov/docs/fy13osti/58050.pdf

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-22317.pdf

Biological Conversion of Sugars to Hydrocarbons Technology Pathway

http://www.nrel.gov/docs/fy13osti/58054.pdf

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-22318.pdf

Catalytic Upgrading of Sugars to Hydrocarbons Technology Pathway

http://www.nrel.gov/docs/fy13osti/58055.pdf

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-22319.pdf

In-Situ Catalytic Fast Pyrolysis Technology Pathway

http://www.nrel.gov/docs/fy13osti/58056.pdf

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-22320.pdf

Syngas Upgrading to Hydrocarbon Fuels Technology Pathway

http://www.nrel.gov/docs/fy13osti/58052.pdf

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-22323.pdf

PNNL-22432 Initial Assessment of U.S. Refineries for the Purposes of Potential Bio-Based Oil Insertions