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DOE Bioenergy Technologies Office (BETO) 2017 Project Peer Review

2.1.0.100 NREL Biochemical Platform Analysis
2.1.0.302 NREL Thermochemical Platform Analysis
2.1.0.301 PNNL Analysis & Sustainability Interface

March 9, 2017
Feedstock-Conversion Interface Consortium

NREL: Mary Biddy, Ryan Davis, Michael Talmadge

PNNL: Sue Jones, Pimphan Aye Meyer

Goal Statement

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GOAL: model experimental data from the FCIC using existing models and design cases

Outcome: quantify fuel production costs and sustainability impacts as a function of feedstock quality for specific conversion routes.

Relevance: supports BETO key activity (MYPP) to

"understand relationship between feedstock quality and conversion"

Quad Chart Overview

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Timeline

- PNNL 2.1.0.301
  - Start: October 1, 2016
  - End: September 30, 2019
- NREL 2.1.0.100 & 2.1.0.300
  - Start: October 1, 2016
  - End: September 30, 2019

Budget

DOE Funded	FY12-14 Costs	FY 14 Costs	FY 15 Costs	FY16 Costs
	Analysis performed as subtasks under conversion related analysis projects			

Barriers Addressed

- **Im-E Cost of production**
  - Model key BETO supported biochemical and thermochemical conversion processes for variety of feedstock types
  - Assess impact on cost of production
- **St-C Sustainability data across the supply chain**
  - Use process models to extract fossil and water usage
  - Assess impacts as function of feedstock type

Partners

- INL
- NREL
- PNNL

Projects Overview

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- **Challenge:** production costs and sustainability impacts as a function of feedstock type and quality are not well understood
- **Question:** how can we use existing cost and performance models be used to assess experimental work from the FCIC?
- **Overall Objective:** employ BETO supported analysis projects to model FCIC data to understand impacts on three key conversion areas that align with BETO portfolio:
  - Analysis & Sustainability Interface (PNNL)
  - Biochemical Platform Analysis (NREL)
  - Thermochemical Platform Analysis (NREL)
- **Technical Objectives:**
  - Quantify relationships between feedstock characteristics and conversion performance and feedback results to researchers
  - Deliver product on-time, on-budget to meet BETO target dates:
    - Pyrolysis & Upgrading Verification 2017
    - All other pathways Verification 2022
  - Publish Results

Approach (Technical)

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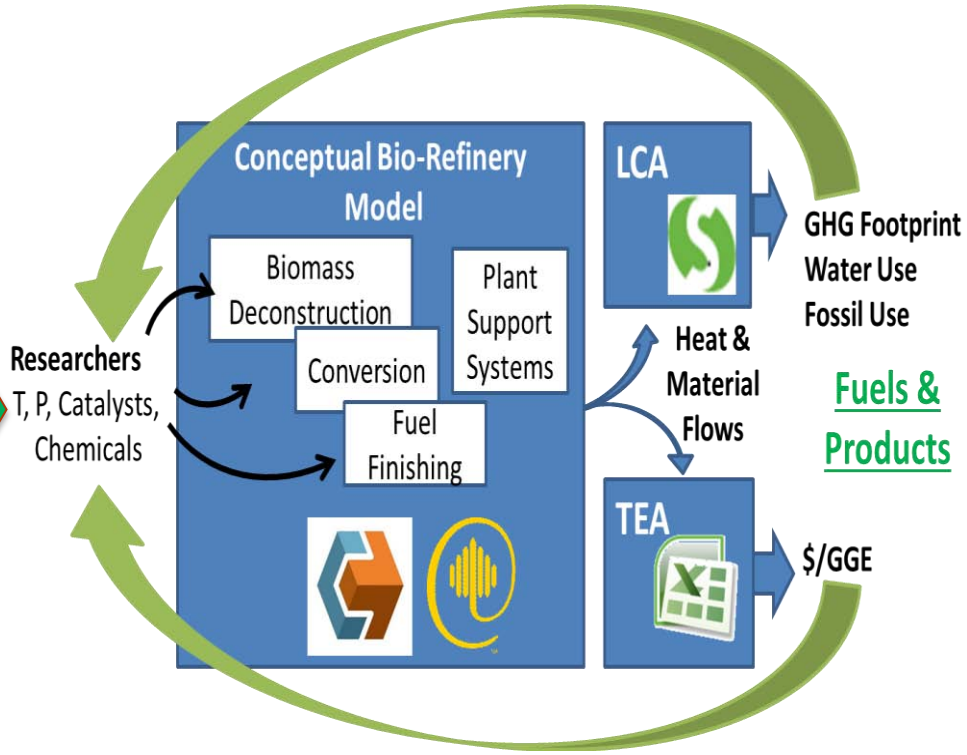
FCIC PROJECTS

Feedstock Quality Data

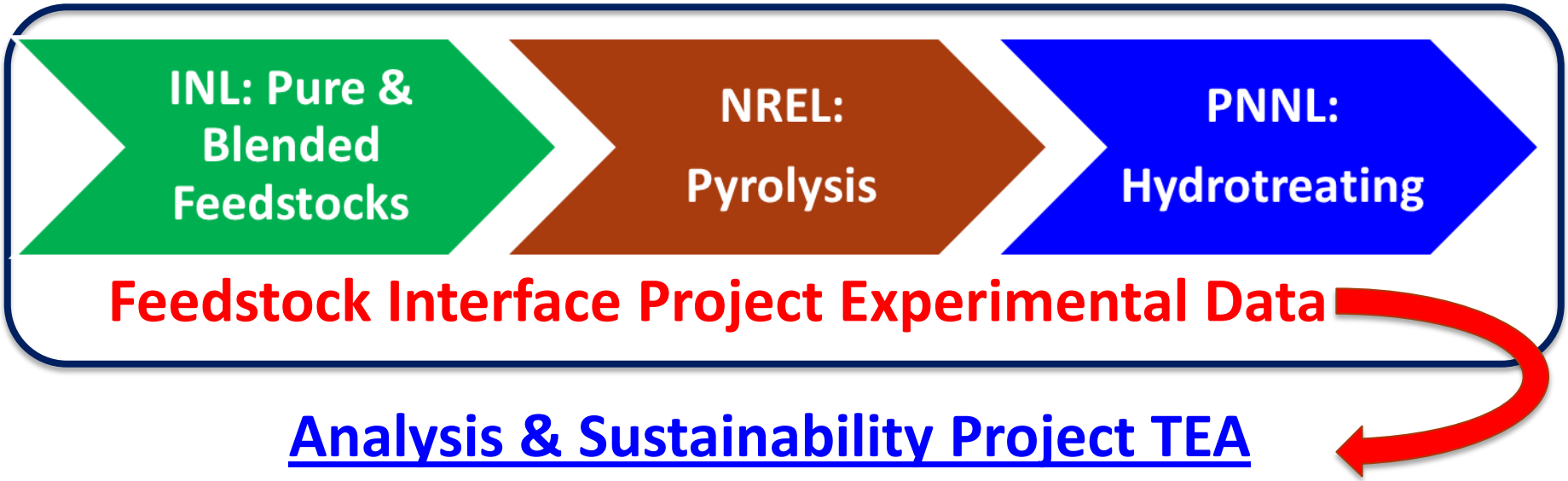
+

Experimental Conversion Data

ANALYSIS PROJECTS



Analysis & Sustainability Interface: *Pyrolysis & Upgrading*



Analysis & Sustainability Project TEA

- **Analysis Goal:** model process performance, assess economics and greenhouse gas (GHG) emissions
  - Identify formulations that reduce fuel production costs
  - Assess sustainability impacts
  - Understand relationship between feed type and conversion performance in context of the FY17 Verification
- One **TEA publication** (Meyer, et. al. 2016. Energy & Fuels 30(11):9427-9439) with a second in preparation

Analysis & Sustainability Interface: *Pyrolysis & Upgrading*

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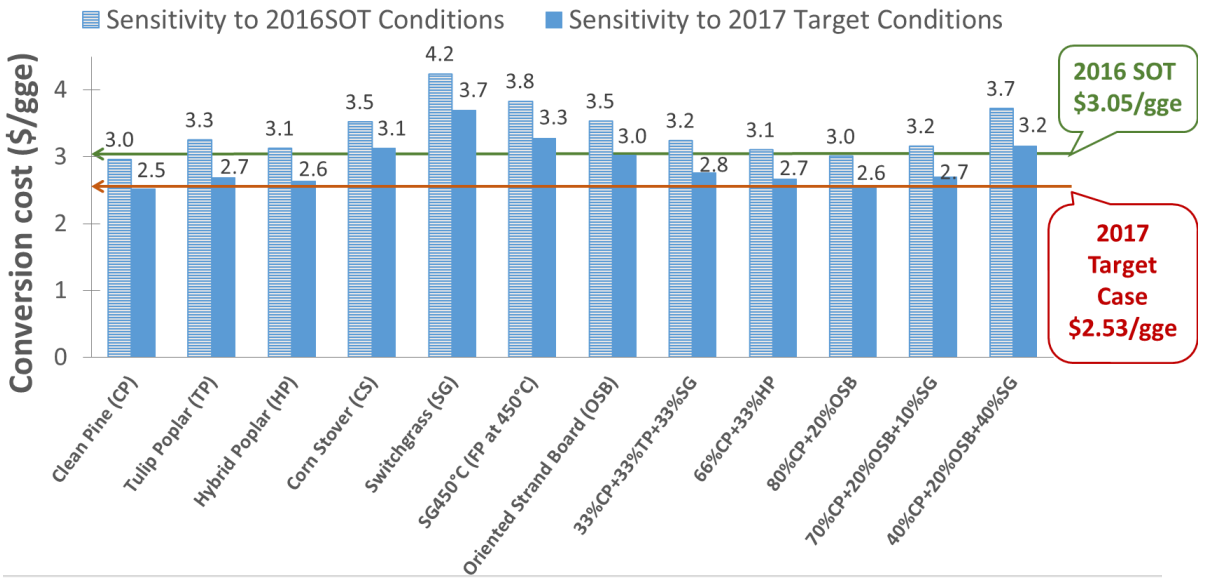
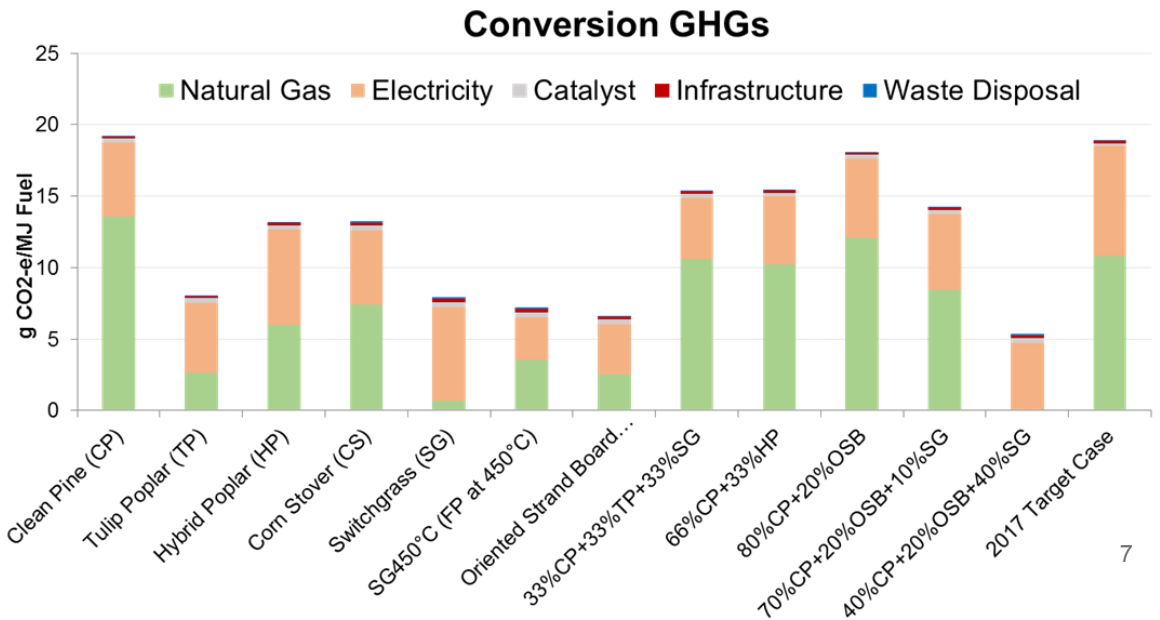
Conversion economics and GHG impacts shown for 6 pure and 5 blends

- **Key finding:** Yields, costs and GHG reduction do not always trend in the same direction
- Important to **assess Cost and Sustainability together**
- Experimental + TEA basis for determining FY 17 verification blend





Biochemical Platform
Feedstock Logistics TEA Support

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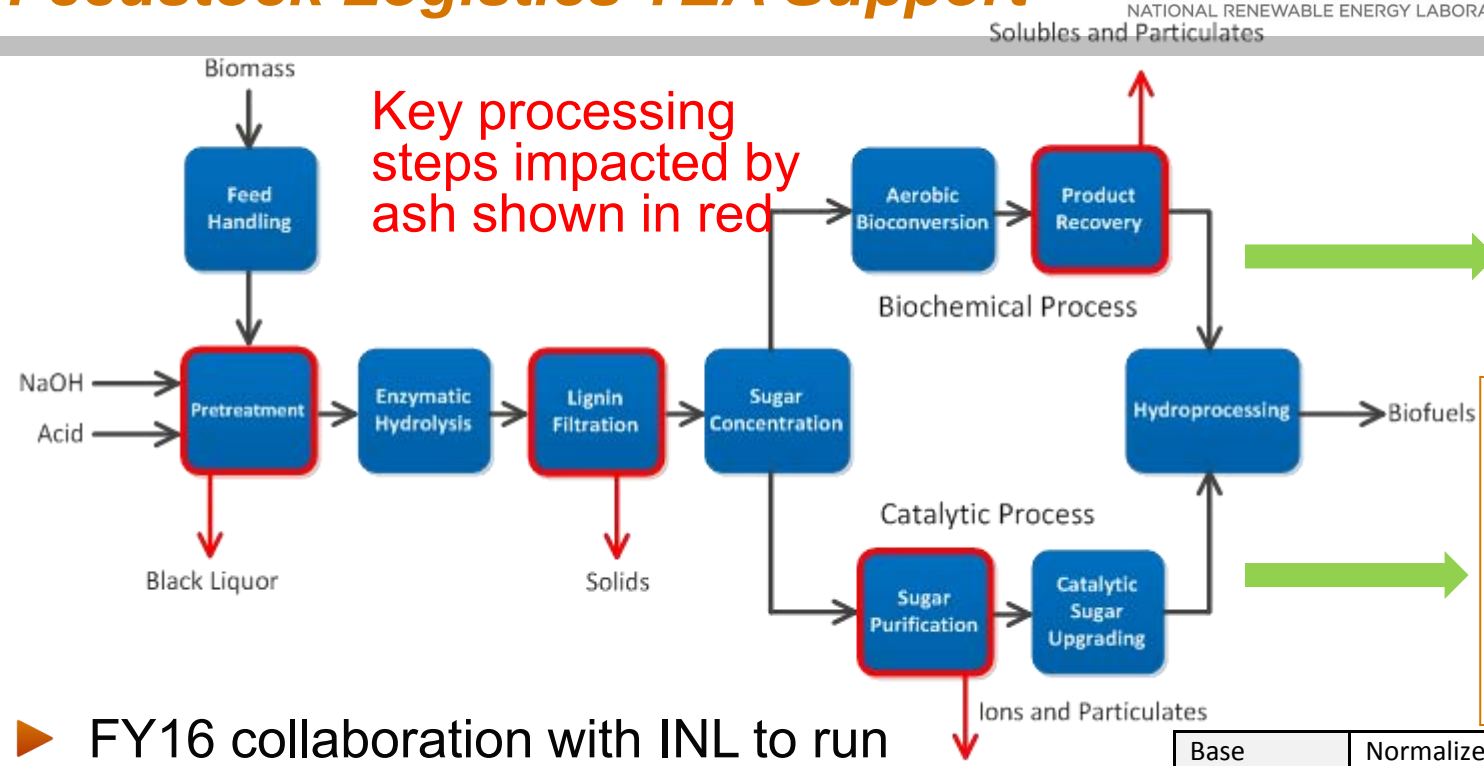

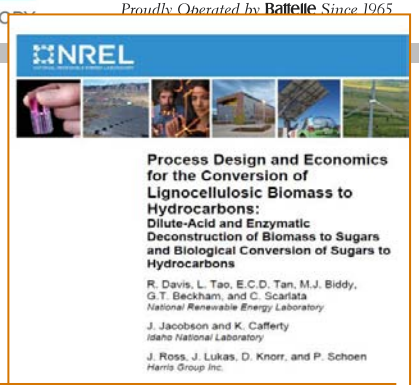

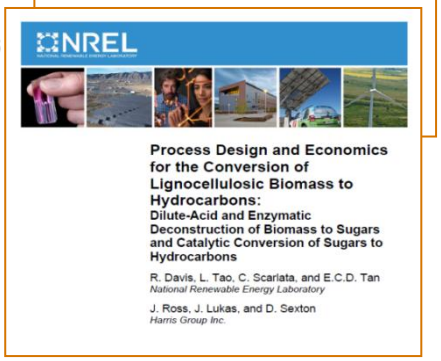

- FY16 collaboration with INL to run TEA over range of feedstock ash content
- Quantified impact of ash content changes on minimum fuel selling price (MFSP)
- Help validate/improve INL "dockage" cost estimates

	Base	Normalized non-ash Components		
Component	Ash= 4.93%	Ash= 3%	Ash= 8%	Ash= 12%
Glucan	35.1%	35.8%	33.9%	32.4%
Xylan	19.5%	19.9%	18.9%	18.1%
Lignin	15.8%	16.1%	15.2%	14.6%
Acetate	1.8%	1.8%	1.8%	1.7%
Protein	3.1%	3.2%	3.0%	2.9%
Extractives	14.7%	14.9%	14.2%	13.6%
Arabinan	2.4%	2.4%	2.3%	2.2%
Galactan	1.4%	1.5%	1.4%	1.3%
Mannan	0.6%	0.6%	0.6%	0.6%
Sucrose	0.8%	0.8%	0.7%	0.7%
Ash	**4.9%**	**3.0%**	**8.0%**	**12.0%**
Total	100%	100%	100%	100%

Biochemical Platform
Feedstock Logistics TEA Support

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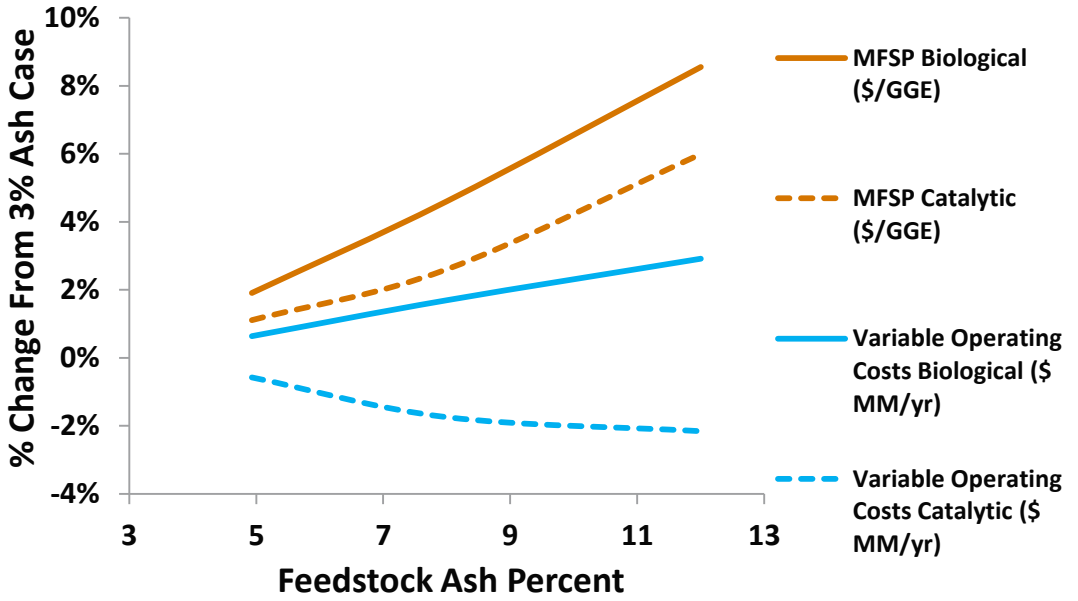
Found that MFSP is more sensitive to ash for biological vs catalytic pathway

- **Trends driven by differences in operating costs**: higher ash disposal costs + lower boiler heat generation are offset by lower H2 and catalyst costs in catalytic pathway
- **Yields, capital cost behave similarly** in both pathways

**May not fully capture cost impacts for ash cleanup, catalyst lifetimes in catalytic pathway -- will work with Separations Consortium to inform future analyses



TEA results: % change from 3% ash case:

Ash Content	%	4.9	8	12
2013 Biological Conversion Pathway				
MFSP	% increase	1.9%	4.6%	8.6%
Yield	% increase	-2.0%	-5.2%	-9.3%
TIC	% increase	-0.8%	-3.0%	-5.4%
OPEX	**% increase**	**0.6%**	**1.7%**	**2.9%**
2015 Catalytic Conversion Pathway				
MFSP	% increase	1.1%	2.6%	6.0%
Yield	% increase	-1.9%	-4.9%	-9.2%
TIC	% increase	-1.0%	-3.3%	-5.6%
OPEX	**% increase**	**-0.6%**	**-1.8%**	**-2.2%**

Thermochemical Platform
Feedstock Logistics TEA Support

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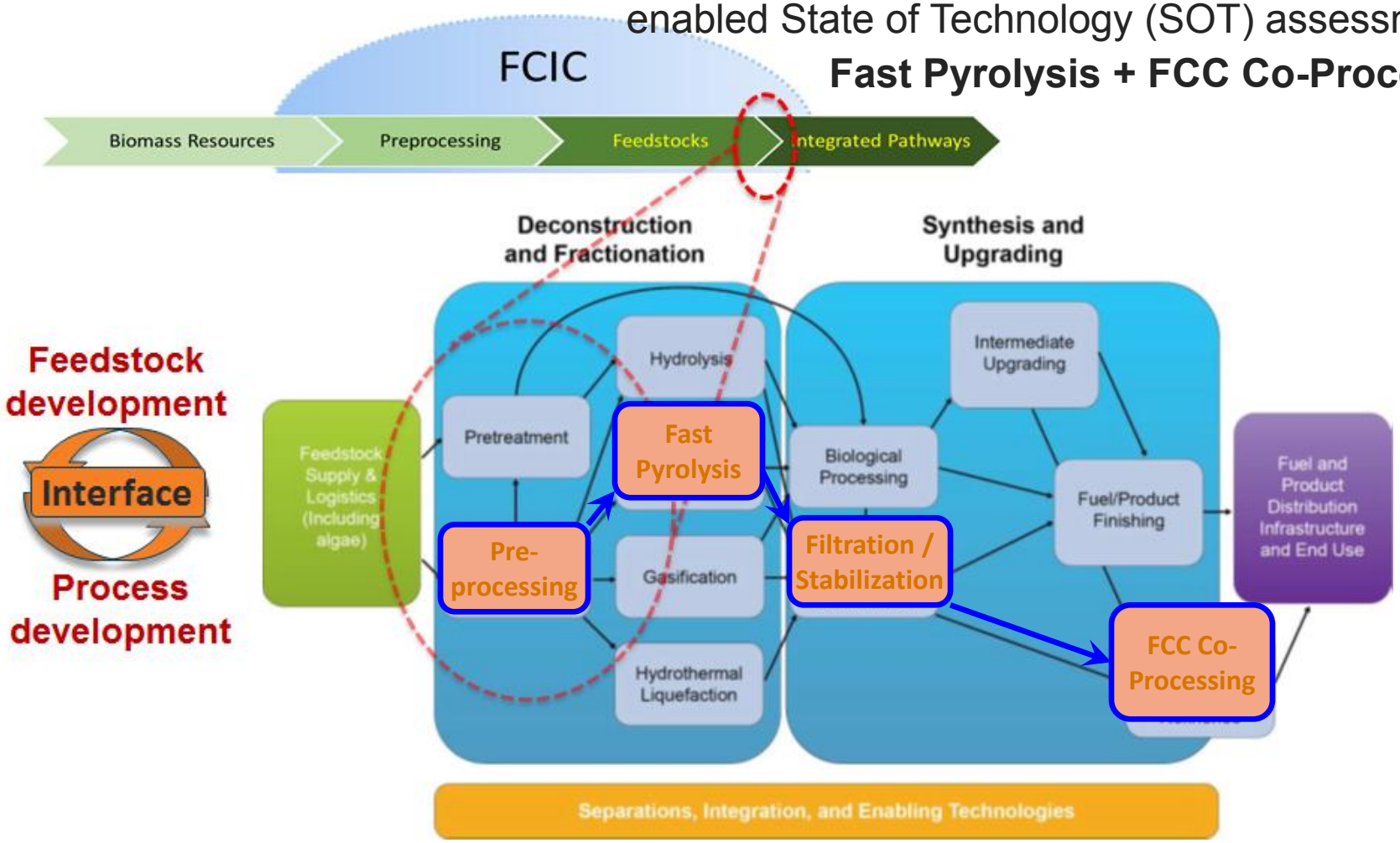
Integrated approach to develop analysis – Refinery Integration Analysis

In FY2016, research and analysis from **TC Feedstock Interface**, **Integration & Scale-Up**, **Petrobras-NREL CRADA** and **NREL/PNNL Refinery Integration** efforts enabled State of Technology (SOT) assessment for **Fast Pyrolysis + FCC Co-Processing.**



Relevance

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- **GOAL:** model experimental data from the FCIC using existing models and design cases to assess outcomes
- **Importance:** addresses need for quantification of fuel production costs and sustainability impacts as a function of feedstock quality for specific conversion routes

Provides Support for BETO Key Activities (2016 MYPP)

- "Acceptable ranges of quality parameters for different conversion processes are poorly understood…. (p2-20)"
  - Integration of analysis and on-going R&D through FCIC interface have begun to **quantify the economic and sustainability impacts** as well as further R&D needs due to compositional variations
- "The Office **actively identifies and evaluates feedstock and technology risks through analyses** of data from research, development, and demonstration (RD&D) into a broad-based set of feedstocks and conversion technologies. (p1-3)"

Relevance

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Provides Support for Bio-Industry:

- Key output of analysis that addressed feedstock sensitives are incorporated in design reports and journal publications
- Integrated FCIC data and analysis advances industry understanding of risks/rewards for use of available feedstocks

Technology Transfer:

- One TEA publication (Meyer, et. al. 2016. Energy & Fuels 30(11):9427-9439) for the pyrolysis and upgrading conversion route
- Plans to publish additional analysis results in FY17-19 for use by stakeholders

Future Work

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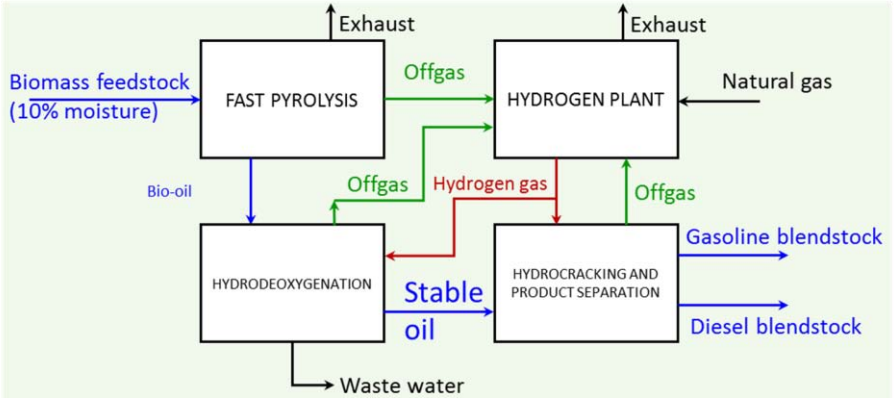
Crosscutting efforts

- On-going work to align conversion supported TEA projects with FCIC activities.
- INL, NREL, and PNNL have a monthly joint analysis call with BETO via the sustainability integration discussions
- On-going efforts establishing further integration of teams including, but not limited to:
  - Co-Optimization of Engines and Fuels **(Co-OPTIMA)**
  - Clean Energy Manufacturing Analysis Center **(CEMAC)**
  - Agile Bio-manufacturing
  - Separations Consortium

Future Work

Pyrolysis & Bio-oil upgrading (FY17&18)

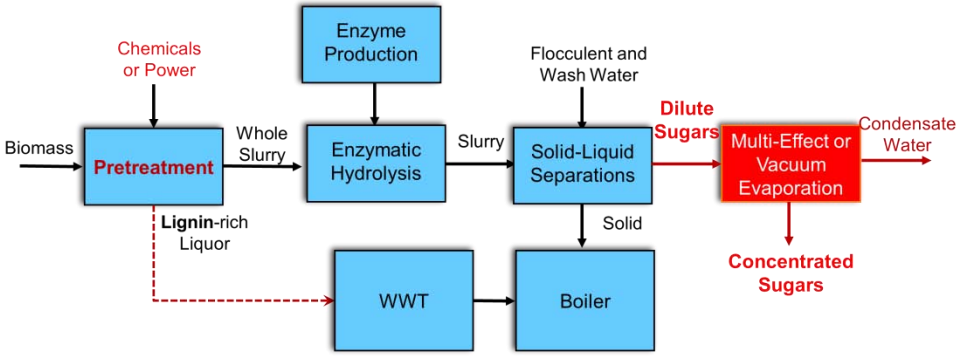
- Complete evaluations of 6 pure and 5 feedstock blends for their impact on sustainable costs; publish results
- Complete all FY17 Verification analysis for publication, including modeled results of FCIC data



Pyrolysis & Upgrading Model

Biochemical conversion (FY17)

- Evaluate three feedstock densification formats
- Evaluate impacts on sugar selling price given
  - varying feedstock compositions and sugar yields/conversion
  - performance provided by NREL FPI project

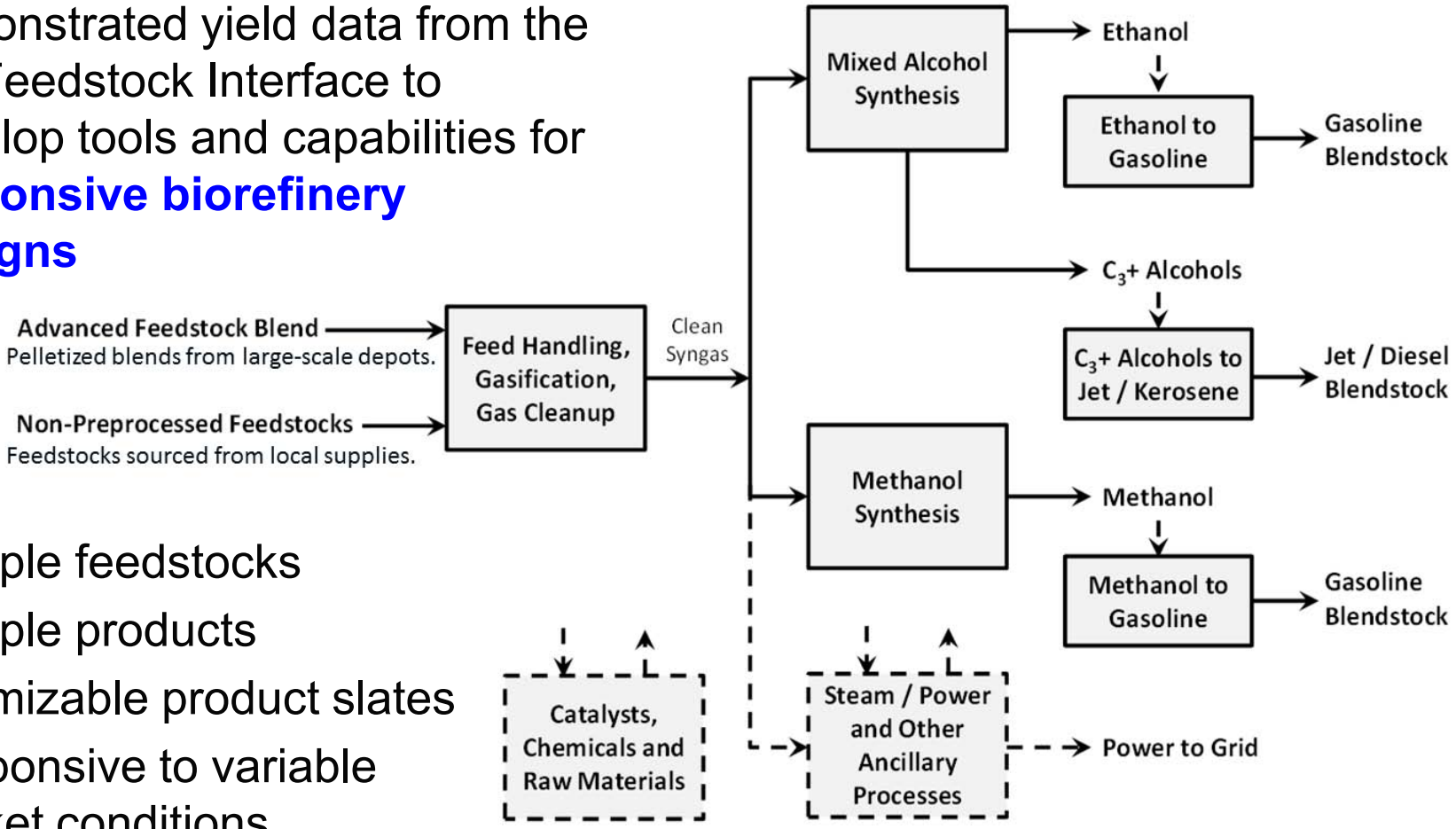


Biochemical Sugar Model

Future Work

Thermochemical analysis (FY19)

- Leverage feedstock cost and demonstrated yield data from the TC Feedstock Interface to develop tools and capabilities for **responsive biorefinery designs**



- Multiple feedstocks
- Multiple products
- Optimizable product slates
- Responsive to variable market conditions

Summary

Overview: Understand how feedstock quality affect economics and sustainability and apply this to achieving modeled cost reductions

Approach: work with FCIC experimentalist's data to model costs and performance using standard BETO techniques that can be compared to the results published in the MYPP

Technical Accomplishments/Progress/Results

- Pyrolysis and upgrading: feedstock impacts assessed
- Biochemical: feedstock impacts assessed
- Integrated approach to analysis – Refinery Integration

Relevance: addresses a key BETO activity: "understand relationship between feedstock quality and conversion" (MYPP)

Future work: continue to work closely with FCIC experimentalists to assess feedstock-conversion interactions

Acknowledgements

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Additional Slides

Publications and presentations
Data inputs for Pyrolysis & Upgrading Analysis
Abbreviations and acronyms

Publications and Presentations

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- Meyer PA, LJ Snowden-Swan, KG Rappe, SB Jones, T Westover, and KG Cafferty. 2016. "Field-to-Fuel Performance Testing of Lignocellulosic Feedstocks for Fast Pyrolysis and Upgrading: Techno-economic Analysis and Greenhouse Gas Life Cycle Analysis." Energy and Fuels 30(11):9427-9439. doi:10.1021/acs.energyfuels.6b01643

- Meyer PA, LJ Snowden-Swan, KG Rappe, SB Jones, T Westover, and KG Cafferty. 2016. "Field-to-Fuel Performance Testing of Lignocellulosic Feedstocks for Fast Pyrolysis and Upgrading: Techno-economic Analysis and Greenhouse Gas Life Cycle Analysis." Presented by Aye Meyer at Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products, CHAPEL HILL, NC on November 1, 2016. PNNL-SA-121916.

Analysis & Sustainability Interface
Pyrolysis Oil and Upgrading

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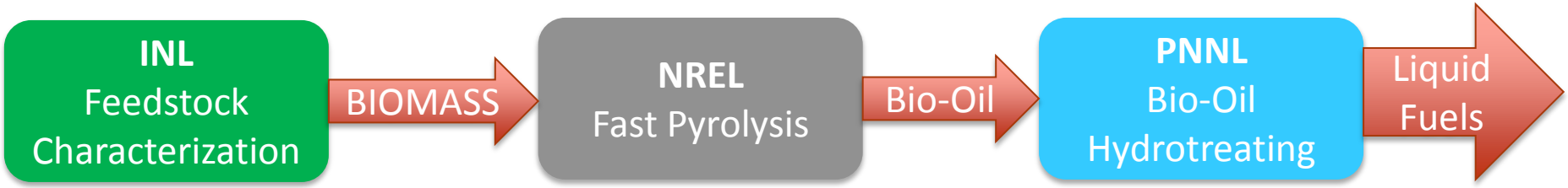
- Experimental data from FCIC project used in models



- 6 Pure Feeds
  - Clean Pine (CP)
  - Hybrid Poplar (HP)
  - Tulip Poplar (TP)
  - Corn Stover (CS)
  - Switchgrass (SG)
  - Oriented Strand Board (OSB)
- 5 Blends
  - CP/TP/SG
  - CP/HP
  - CO/OSB
  - CP/OSB/SG #1
  - CP/OSB/SG #2

- Temperature
- Pressure
- Mass Yields & CHNOS analysis
  - Gas
  - Liquid
  - Char
- Bio-Oil Density
- Bio-Oil water content
- Gas composition

- Stage 1 & 2 HDO
  - Temperature
  - Pressure
  - Catalyst type
  - Liquid hourly space velocity
- Hydrogen consumption
- Off-gas composition
- Liquid hydrocarbon yield
- Liquid hydrocarbon CHNOS and density