DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

Pilot-Scale Biorefinery: Sustainable Transport Fuels from Biomass via Integrated Pyrolysis, Catalytic Hydroconversion and Co-processing with Vacuum Gas Oil

Raymond G. Wissinger

Manager, Renewable Energy & Chemicals Development

UOP, LLC

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Goal Statement

- Demonstrate a technically and economically viable approach for converting renewable biomass feedstocks to sustainable and fungible transportation fuels
- Meet desired goal of DOE to provide full commercial pathway for producing cellulosic biofuels from 2nd generation feedstocks
- Use non-food, non-feed cellulosic biomass to produce drop-in transportation fuels fully compatible with existing industry infrastructure
- Meet goals of DOE and EPA RFS2 program

Quad Chart Overview

Timeline

- Project start date – Dec 2009
- Project end date – Sept 2015
- Percent complete – 74%

Barriers

- Barriers addressed
  - Conversion of 2nd generation biomass feedstocks to transportation fuel
  - Produce drop-in quality biofuels without blend wall limitations
  - Provide integrated pathway from feedstock to commercial scale fuel production

Budget

(millions)	Total Costs FY 10 –FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date
DOE Funded	$15.4	$0.3	$2.4	$5.6
Project Cost Share	$12.5	$0.5	$1.2	$0.3

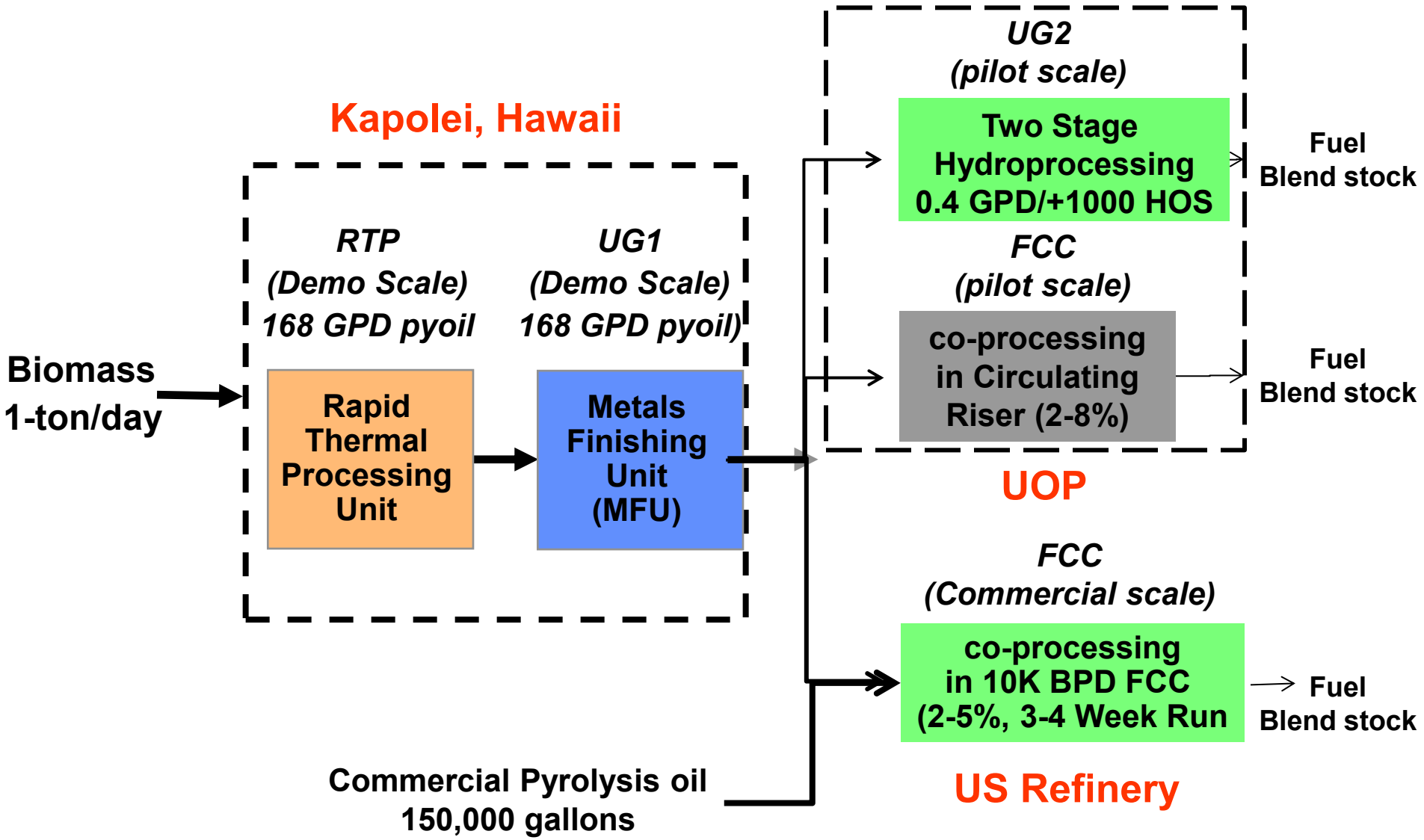
Partners

- DOE – Golden
- PNNL & INL
- Michigan Tech University
- Ensyn, Tesoro, HIE and Honeywell Process Solutions

Project Overview

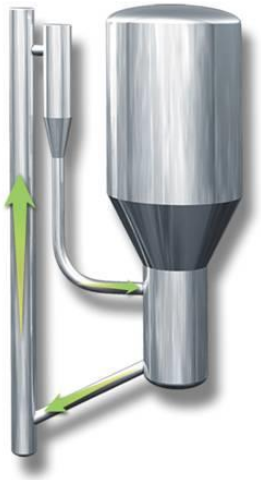
- RTP™ pyrolysis unit was commissioned and operated in 2012. Pre-commissioning work on UG1 (metals removal) was also completed during 2012
- Based on results of pilot plant testing of the UG2 process, UOP recommended to not proceed with design and construction of UG2 at Kapolei site
- Spring 2014, project re-scope proposed to provide faster path to commercialization through coprocessing of pyrolysis oil (pyoil) in an FCC unit
- Summer 2014, RTP unit restarted with plans to run UG1 at Kapolei and complete UG2 in UOP pilot plant in Des Plaines, IL
- Various operational issues with Kapolei unit have delayed schedule completion to late Spring 2015
- UG1 run successfully on pyoil for stabilization and metals removal
- Commercial coprocessing trial to be completed late Spring 2015 with US refiner to produce "drop-in" transportation fuel blend stocks

New IBR Project Scope



Co-Processing Of Pyrolysis Oil To Produce Transportation Fuel

Pyrolysis close to biomass source for densification



RTP Unit

Pyrolysis Oil

Co-process in FCC with VGO

Partially Renewable Fuel to Refinery Pool

Commercial scale production with existing refinery infrastructure

Technical Approach

- Use existing RTP technology as the backbone of an integrated biorefinery to produce commercial scale transport fuels from 2nd generation biomass
- Develop stabilization techniques to remove metals and prepare pyoil for conversion to transport fuel
- Develop 2-stage hydrotreating process to convert pyoil to gasoline and diesel fuel blend stocks
- Co-process pyoil in commercial scale refinery FCC unit to produce fuel blend stocks with existing infrastructure
- Create “drop-in” quality biofuels without pipeline blend wall concerns

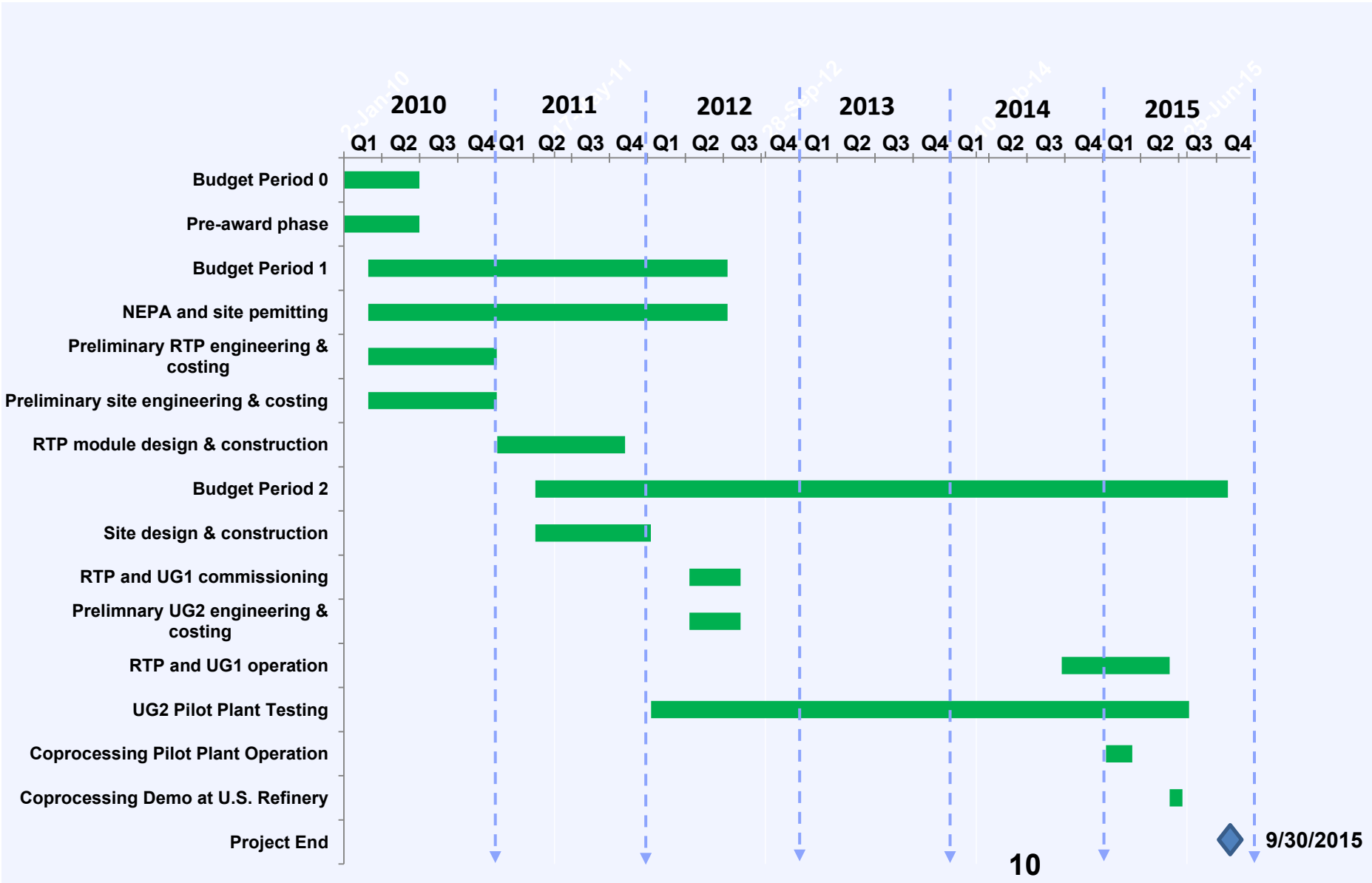
Management Approach

- Capitalize on UOP and partners experience in developing scalable technology with ability to expand to commercial scale operation
- Ensure development timeline meets commercial market need for 2nd generation transport fuels
- Provide fuel solution for different delivery options (100% renewable and partially renewable)
- Demonstrate to fuel refiners the renewable fuel delivery options using current infrastructure
- Use company and partner wide integration of expertise to solve challenges across multiple development areas

Technical Progress

- Constructed and operated RTP unit in Hawaii processing multiple biomass feedstock types
- Operated pyoil stabilization and metals removal unit
- PNNL completed catalytic hydrothermal gasification
- Demonstrated 1st stage pyoil hydrotreating in pilot plant (1000 hr on stream achieved)
- Demonstrated 2nd stage pyoil hydrotreating in lab plant
- Demonstrated pyoil coprocessing in FCC pilot plant to produce partially renewable drop in fuels
- Completed initial “proof of concept” pyoil coprocessing test in commercial scale FCC refinery unit

Technical Accomplishments/ Progress/ Results



Technical Accomplishments/ Progress/ Results

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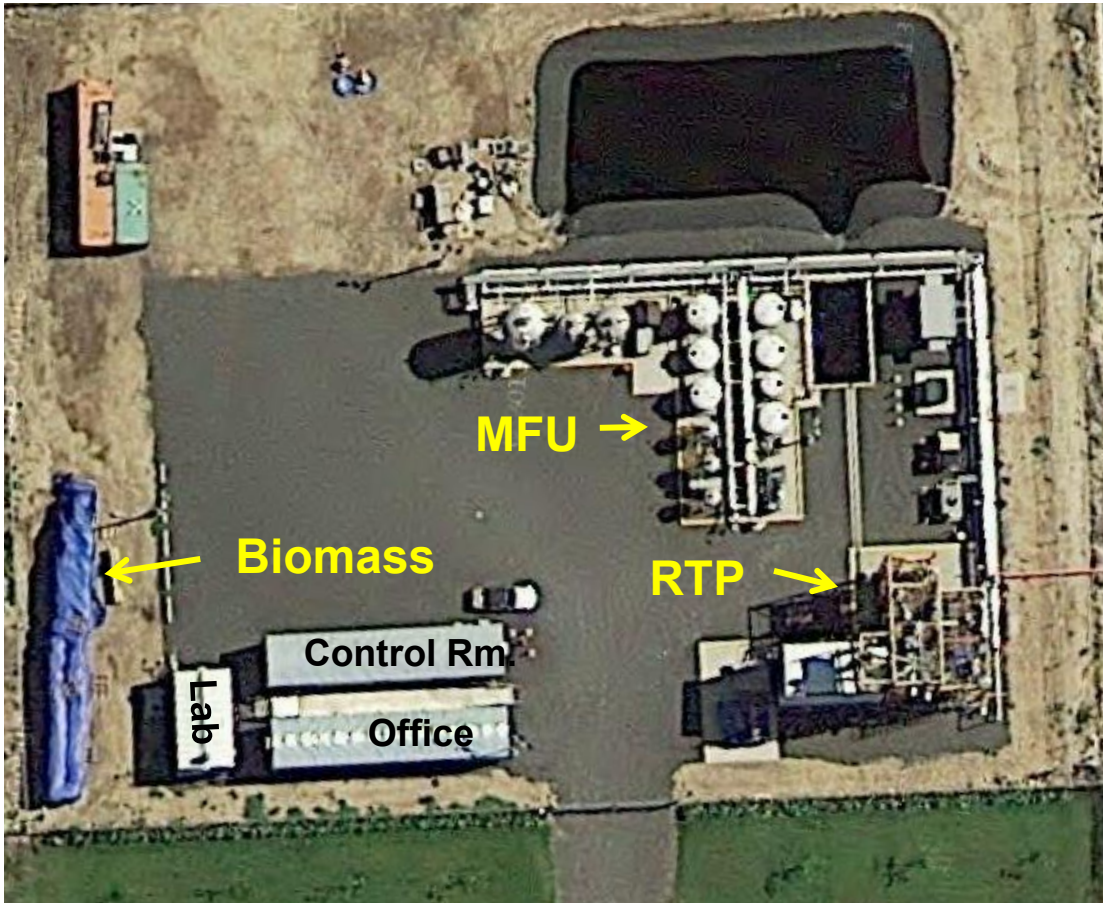
UOP IBR Site, Kapolei, Oahu, Hawaii



Technical Accomplishments/ Progress/ Results

UG-I Tanks

Control Room

IBR Site - Looking South to HIE Refinery

Technical Accomplishments/ Progress/ Results

Feeding Biomass into RTP Unit

RTP Biomass Schedule

- Completed 30 days of hardwood biomass processing
- Currently processing sotwood, switchgrass and corn stover feedstocks
- Plan to run up to 70 days total by end of project (30 days each hardwood & softwood, 5 days each switchgrass & corn stover)

Technical Accomplishments/ Progress/ Results

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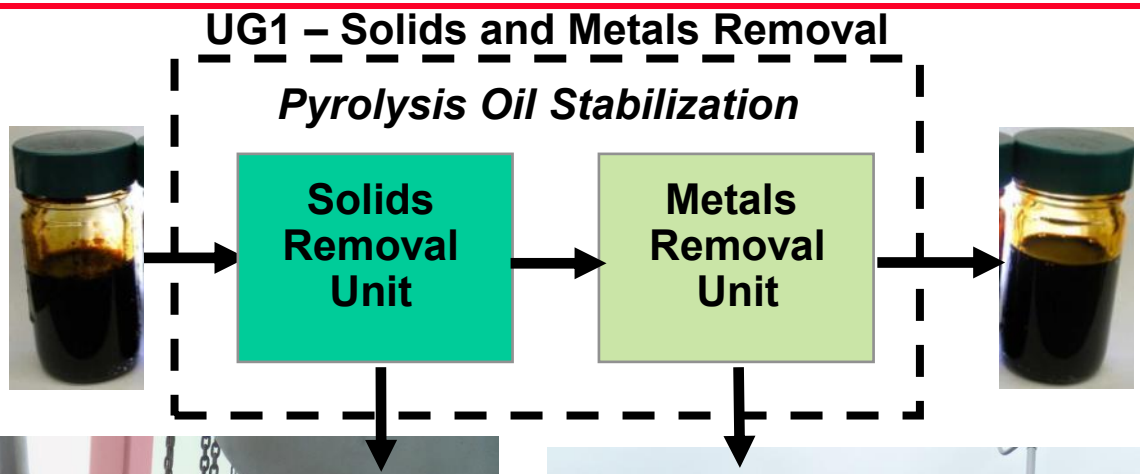

Technical Accomplishments/ Progress/ Results

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	MFU Feed	Run 1 -110 min	Run 2 Product	Run 3 Product
Al	17	11	1	2
Ca (max < 65 wppm)	252	148	11	2
Cr	1	1	2	2
Co	<1	<1	<1	<1
Cu	<1	<1	<.1	<1
Fe	86	52	11	4
Pb	<2	<1	<1	<1
Mg	96	59	3	<1
Mn	28	18	1	<1
Mo	<1	<1	<1	<1
Ni	8	4	1	<1
K (max < 35 wppm)	436	262	10	1
Na	31	27	7	8
Sr	2	1	<1	<1
Sn	<2	<1	<1	<1
Ti	<1	<1	<1	<1
V	<1	<1	<1	<1
Zn	21	13	17	<1
P	40	37	33	27
Total metals (wppm)	**1016**	**633**	**94**	**47**
Total metals - P (wppm)	**976**	**596**	**61**	**20**

Technical Accomplishments/ Progress/ Results

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Bulk Properties of Hydrogenated Product From Lab Scale Upgrading

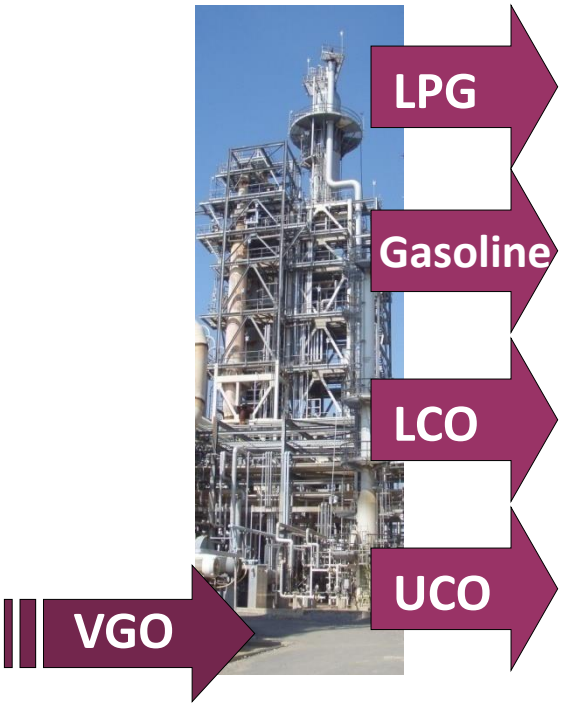
Elemental and Physical Properties	
Oxygen, mass%	<0.03
Carbon %	88.7
Hydrogen %	11
Nitrogen %	<0.10
Density	0.86
Degree API	33.2
Water, wppm	53

GCxGC, wt%	**Gasoline**	**Kerosene/ Jet**	**Diesel + Fuel Oil**
Paraffin	2.7	0.9	0.3
Isoparaffin	1.6	2.0	0.1
Naphthene	75.4	50.9	21.6
Aromatic	20.2	46.2	78.0
Estimated Fractions by SimDist D2887, wt%	~55	~23 - 31	~23 - 46

Technical Accomplishments/ Progress/ Results

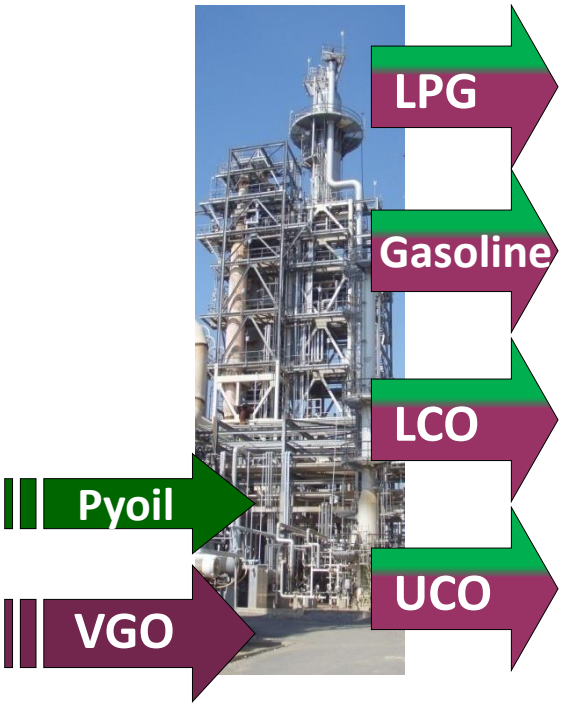
- **Short duration (1 day) commercial trial completed Oct. 2013**
- **Medium duration (~30 days) commercial trial in Spring 2015**

Standard FCC Unit Operation



100% petroleum based products sent downstream

Co-processing Pyoil in FCC



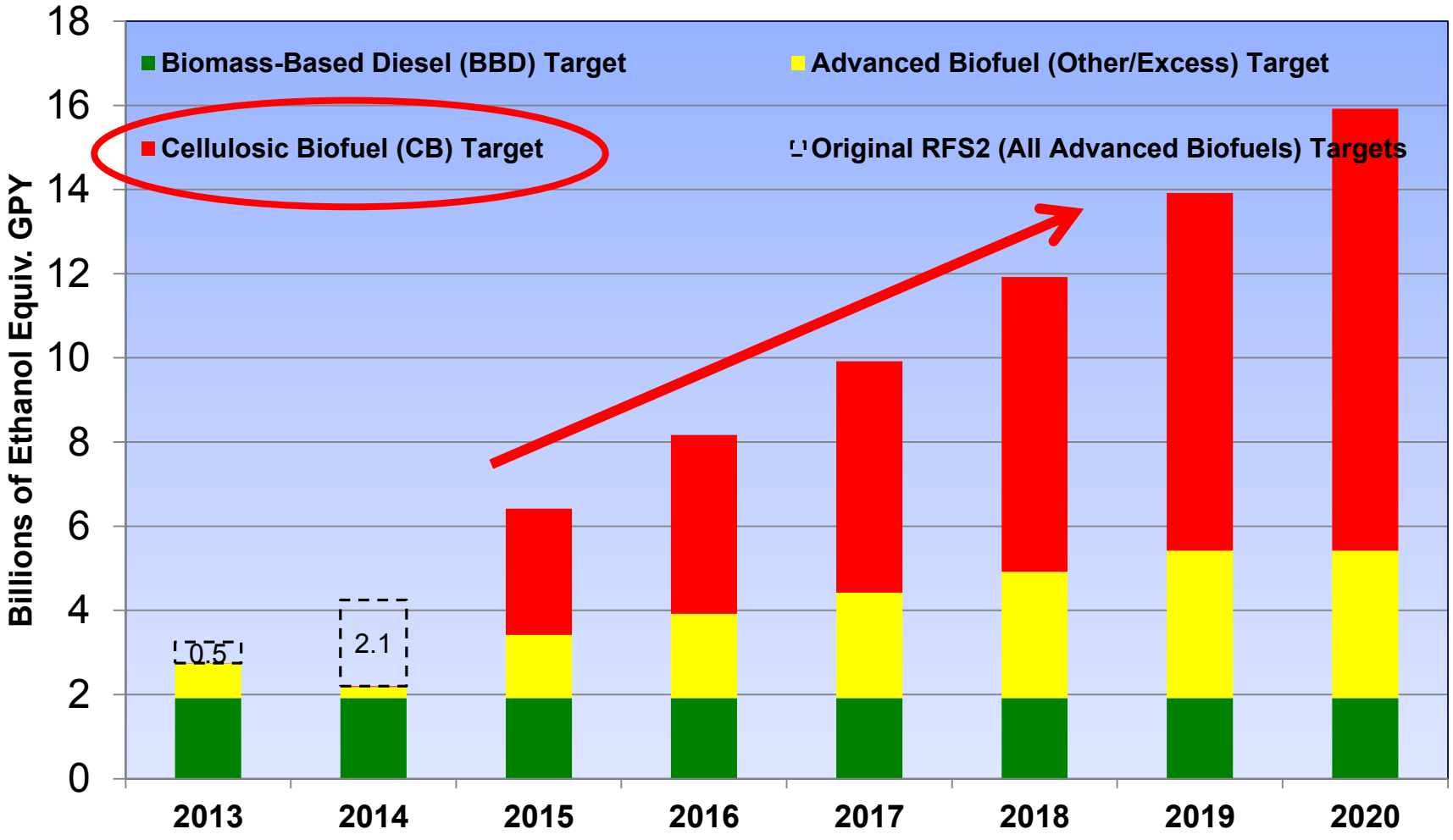
Partially renewable products sent downstream

Relevance

- Commercializing a complete pathway from biomass feedstock to transportation fuel would achieve a primary objective of the DOE and BETO
- Using forest residuals, corn stover and switchgrass feedstocks would create “drop-in” transportation biofuels compatible with existing industry infrastructure
- Pipeline compatible biofuels without blend wall limitations would reduce issues with meeting RFS2 volume goals of EPA
- Coprocessing of pyoil in commercial refinery FCC unit would provide immediate pathway to producing cellulosic transportation fuels

Market Relevance

- US Demand for cellulosic fuels increasing

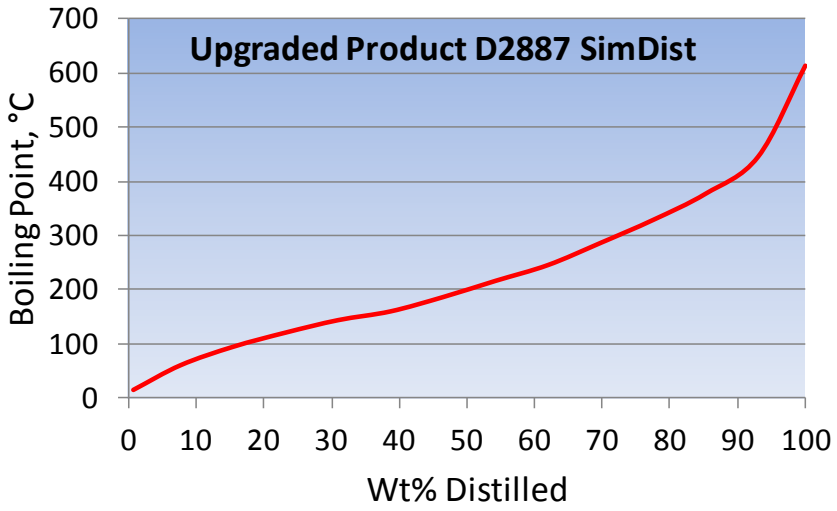


Relevance

Pyrolysis Oil Feed to Fuels Feed/Product Analysis			
	Pyrolysis Oil	Upgraded Fuel	Gasoline Requirements
Water, %	~25	0.03	<0.1
O, %	51	<0.1	<2.0
TAN, meq/g	91	<0.1	<0.1

Pyrolysis Oil Feed to Fuel Transportation Fuel Yield[1]	
	Overall Yield, % of Pyrolysis Oil
Mass	41
Volume	60[2]

1. Demonstrated yield from at multiple equipment scales.
2. Equals > 90 gallons per dry MT for woody biomass.

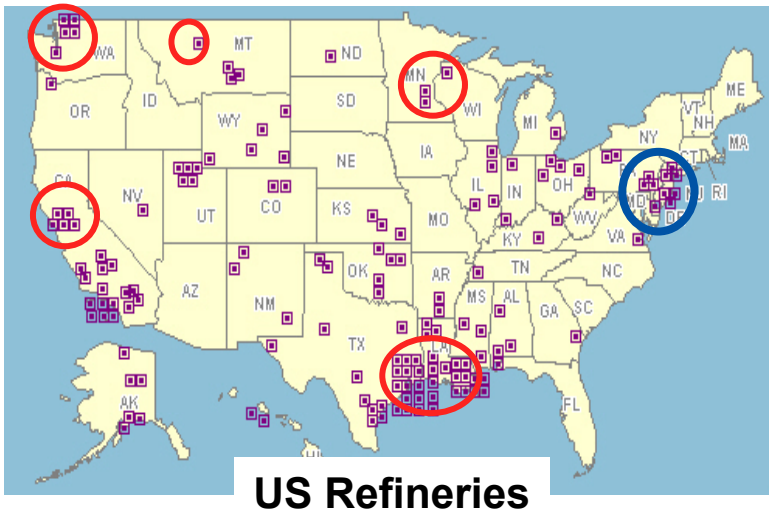


~50% of material in gasoline boiling range 40-200°C
RON of gasoline ~80-89
~40% of material in distillate boiling range

Upgraded Pyrolysis Oil Products

Relevance

Co-location of US refineries with Major Forestry Resources



US Refineries

>18,000,000 metric ton (MT)/year of Forestry Residue in close proximity to US refineries

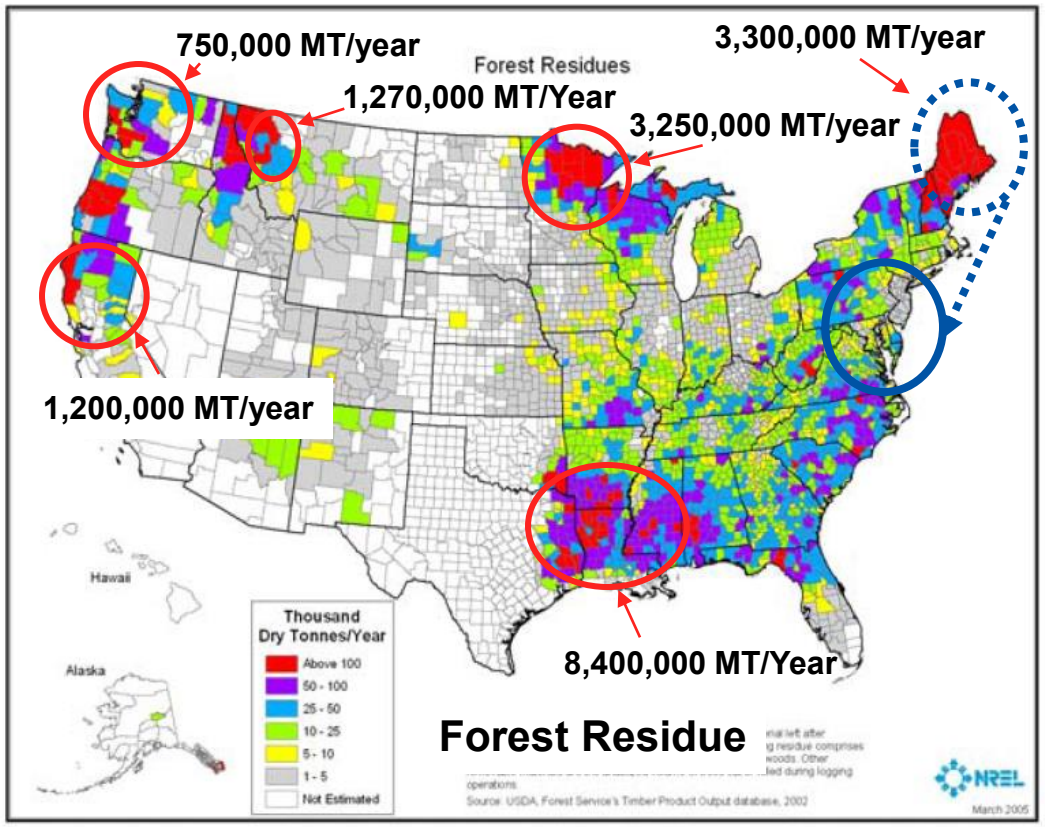


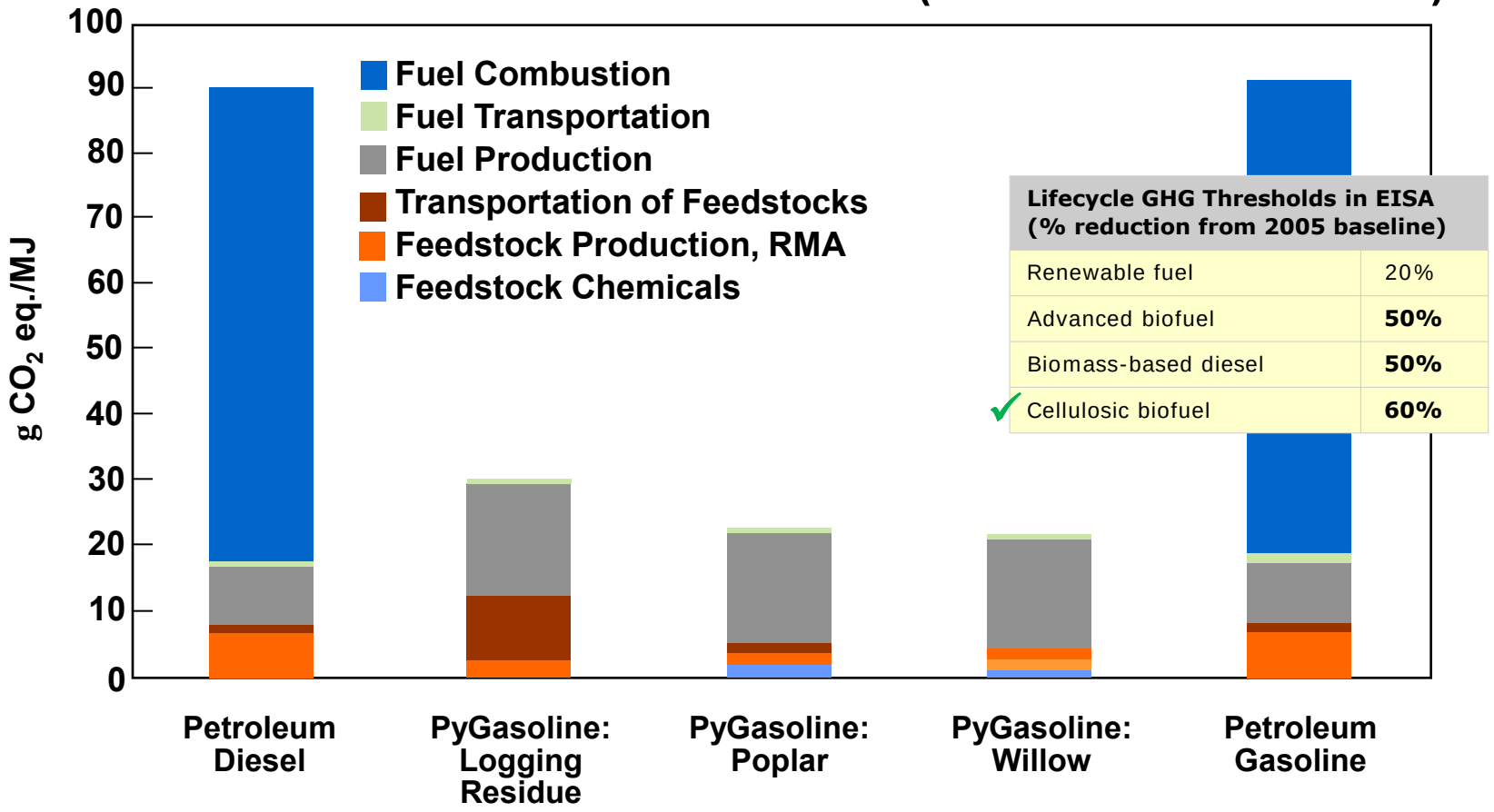
Figure 13 Estimated Forest Residues by County

There is sufficient forestry residue alone co-located with refining assets to support commercialization
Additional feedstocks are available on a regional basis

Relevance

Renewable Gasoline GHG Emissions

PRELIMINARY MODEL RESULTS (WOODY FEEDSTOCK)

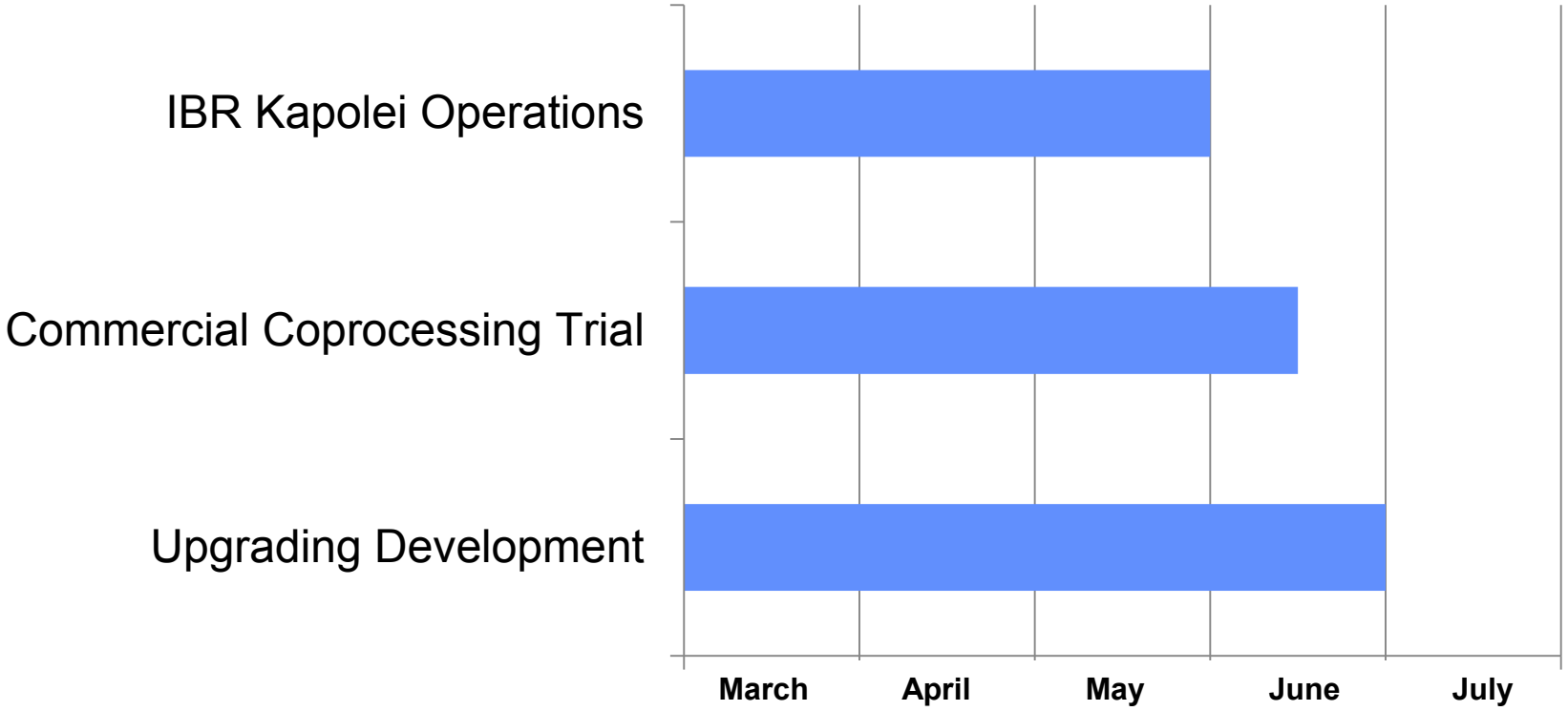


Lifecycle GHG Thresholds in EISA (% reduction from 2005 baseline)	
Renewable fuel	20%
Advanced biofuel	**50%**
Biomass-based diesel	**50%**
✓ Cellulosic biofuel	**60%**

Upgrading Pyrolysis Oil Makes Cellulosic Biofuels

Future Work

Remaining IBR Project Schedule



- **Complete IBR project by June 30, 2015 deadline**

PNNL Goal Statement

Pacific Northwest NATIONAL LABORATORY

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- **Goal: PNNL was tasked with developing Catalytic Hydrothermal Gasification (CHG) for use with aqueous streams within the biorefinery**
  - **Aqueous phase separated from the fast pyrolysis bio-oil**
  - **Aqueous byproduct streams formed in the hydroprocessing of the bio-oil to finished products**
  - **Other aqueous streams as identified as of interest within the biorefinery, (none were so identified)**
- **The development work progressed at two levels:**
  - **Initial tests in the laboratory in mini-reactor scale and bench-scale continuous-flow reactor systems**
  - **Validation in the scaled-up engineering development system**
- **Major Future Project Activities:**
  - **Mini-reactor tests of CHG of bio-oil hydrotreater aqueous byproduct and chemical models thereof**
  - **Tests in the updated mobile processing plan**
  - **Final report preparation**
  - **Publication drafting**

PNNL Project Overview

Pacific Northwest NATIONAL LABORATORY

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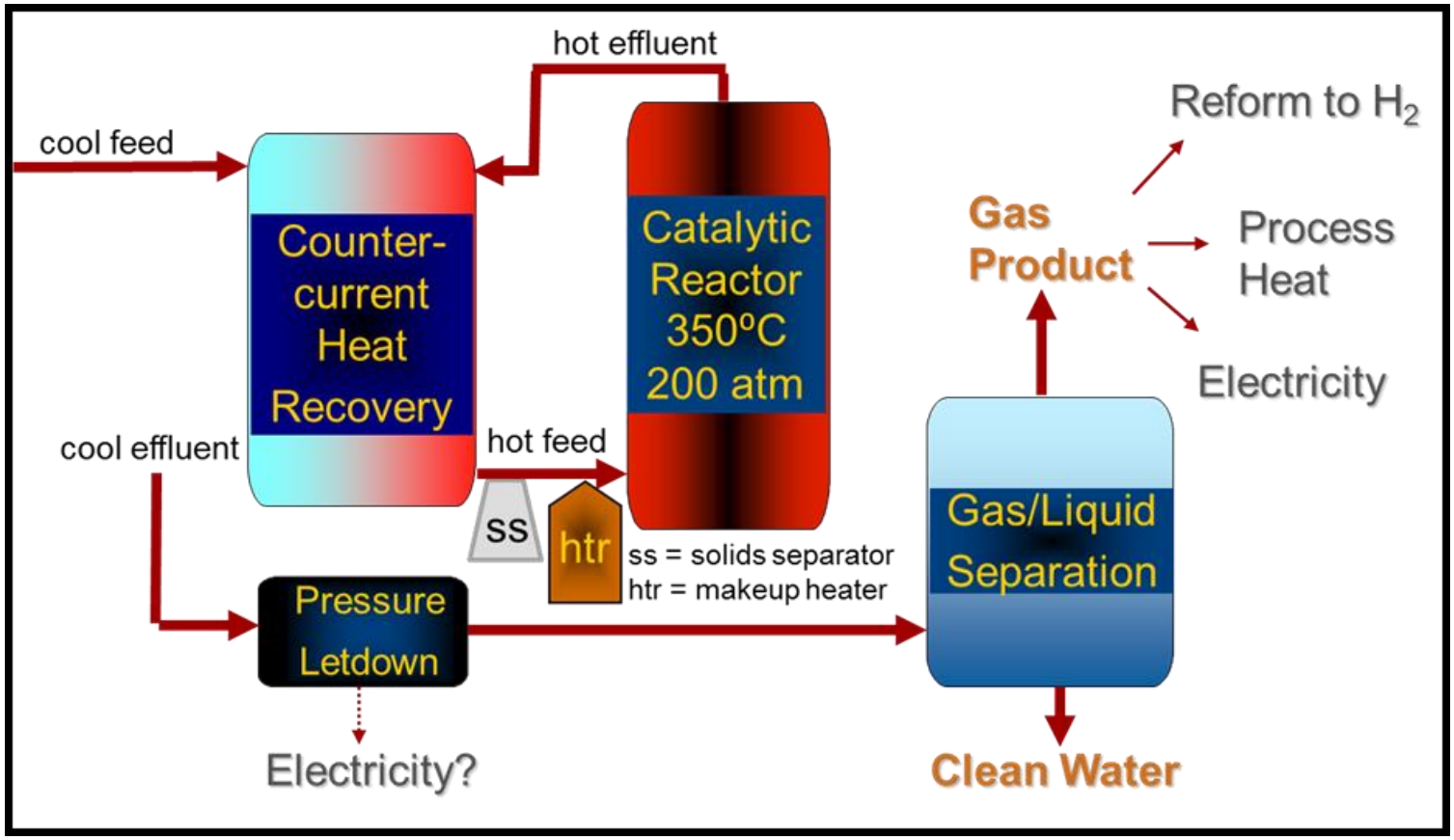
- **Catalytic Hydrothermal Gasification**
  - **Recover organic byproducts lost to aqueous byproduct**
  - **Allow hydrogen production from byproduct organics via gasification and reforming.**



Summary

- Demonstrate full pathway for cellulosic biomass feedstocks to transportation fuels using combination of new and existing equipment
- Complete commercial scale coprocessing trial to demonstrate viability of technology pathway
- Capitalize on integration of cellulosic biofuel with existing oil refining infrastructure to speed up path to market
- Demonstrate flexibility with types of biomass feedstocks to produce “drop-in” transportation fuels
- Create technology pathway to meet cellulosic fuel demand of RFS2 program

Acknowledgements

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  - The Honeywell - UOP Renewable Energy and Chemicals R&D group
  - The broad Honeywell-UOP technical community
  - the Honeywell-UOP Renewable Energy and Chemicals business group, Envergent Technologies, and Ensyn Corporation
  - The group of Dr. Doug Elliott at Pacific Northwest National Laboratories for past and ongoing collaborations on biomass pyrolysis oil upgrading and Catalytic Hydrothermal Gasification
  - The group of Prof. David Shonnard, Michigan Technological Univ., for ongoing LCA collaborations
- The material presented is based in-part upon work supported by the Department of Energy, Energy Efficiency & Renewable Energy, Biomass Program, under Award Number DE-EE0002879, Recovery Act - Pilot Scale BioRefinery: Sustainable Transport Fuels From Biomass And Algal Residue Via Integrated Pyrolysis And Catalytic Upgrading.

Additional Slides

Response to Past PEER Review Comments

Project Approach	UOP Response
UOP was in the process of debugging Upgrader 2 when it began constructions of the facility. They have not yet debugged Upgrader 2, and construction of RTP and Upgrader 1 are complete. According to the presenter, progressing with construction of the first upgrader was done earlier than UOP would have typically done. The loss of the hydrogen supply appears to be a very big issue.	
Having the unfortunate circumstance to have lost both its host and hydrogen supplier, UOP has some significant hurdles to overcome in order to meet its project goals.	Based on results of pilot plant testing of the UG2 process, UOP recommended to not proceed with design and construction of UG2 at Kapolei site
This is a well managed pyrolysis oil approach to achieving DOE's IBR goals.	Thank you
This project, although very interesting and relevant, has been plagued by technical and managerial issues. It is encouraging that the company recognizes the need to address those issues promptly and to shoulder the resulting financial responsibility for making the project successful. Producing such fuels from renewable biomass is very important.	UOP recognizes the importance of developing a pathway to commercialization for cellulosic biofuels in the transportation fuel market. The coprocessing solution presented as part of this project is a direct step to producing commercial volumes of cellulosic biofuel.

Response to Past PEER Review Comments

Project Approach	UOP Response
Unfortunately with the shutdown of the Tesoro refinery, this project appears to be a stranded asset at the current time. This reviewer suggests a strategic decision-making session among all stakeholders to decide the future course of this project.	The project was re-scoped to produce the most benefits from the technology and to find the fastest, most applicable solution to produce commercial volumes of cellulosic biofuels.
UOP is investing its own cash, indicating continued interest in this technology. Hurdles to achieve critical success factors are significant. Surprising miss on scale-up of Upgrader 2 given UOP's reputation in the industry.	As project proponent, UOP has committed over $14 million dollars to the success of creating cellulosic biofuels for the transportation market.

Presentations & Patents

Ten (10) US patent applications and four (4) Foreign applications have been submitted covering py-oil upgrading to hydrocarbon fuels covering both process designs and catalyst composition

- ***Integrated BioRefinery***, Mike Lunda, 2012 Asia Pacific Clean Energy Summit and Expo, August 13-15, 2012, Honolulu, Hawaii
- ***Solid Biomass Conversion to Transportation Fuels with UOP RTP™ Upgrading Technology*** , Jim Rekoske, Advanced Biofuels Leaders Conference, April 3, 2012, Washington, D.C.
- ***The UOP Integrated BioRefinery (IBR) project,*** Steve Lupton, IEA Pyrolysis Newsletter, December Issue, 2012
- ***Transportation Fuels From the Catalytic Hydrodeoxygenation of Biomass Pyrolysis Oil***, Lance Baird, 2013 AIChE Spring Meeting & 9th Global Congress on Process Safety, May 2, 2013
- ***Production of Renewable Fuels From Biomass by FCC Co-processing***, Ray Wissinger, Biomass 2014, July 30, 2014, Washington, D.C.