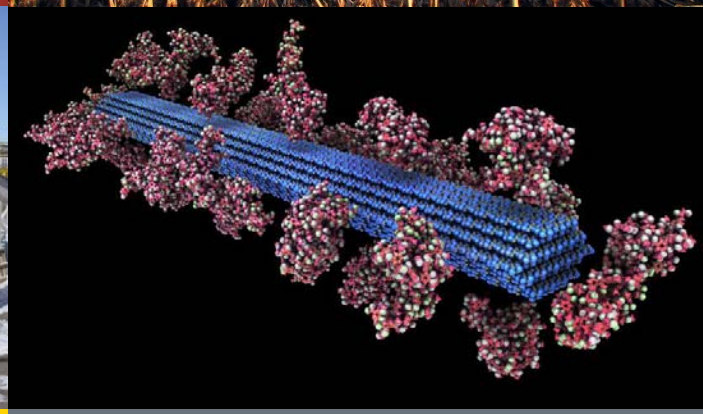
U.S. DEPARTMENT OF ENERGY
BIOENERGY TECHNOLOGIES OFFICE

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





Project Peer Review
TC Bio-oil Pathways R&D

May 20-24, 2013

Melissa Klembara
Technology Manager

Programmatic Strategic Goals and Legislative Drivers

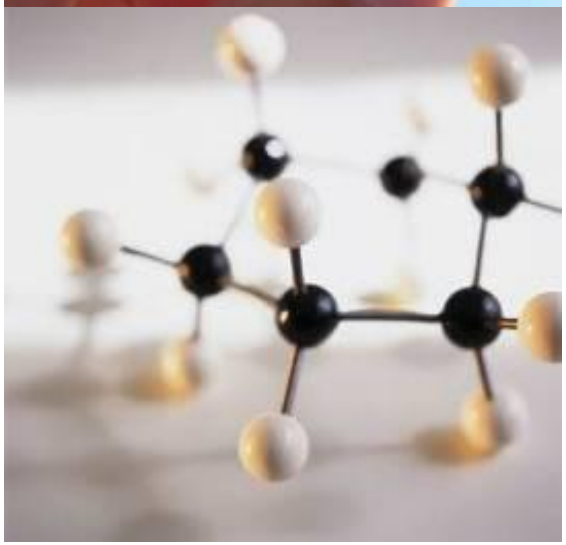
2001

Timeline

TODAY

- 2001: Program sets $1.07/gal cost target for cellulosic ethanol
- 2005's Energy Policy Act – Section 932: directed the Office to build 6 commercial-scale IBRs;
- 2007's Energy Independence and Security Act (EISA) of 2007 sets aggressive initial goals in RFS;
- 2009: ARRA funding of $800 million directed to Program
- 2009: Cost target for cellulosic ethanol adjusted to $1.76/gal based on updates to the Biochemical and Thermochemical Gasification design cases; **TC Fast Pyrolysis Design Case published**
- **2011: Program sets $3/gge cost target and makes a decision to de-emphasize gasification.**
- 2012: BETO hits cellulosic ethanol R&D cost targets in support of Biochemical and Thermochemical design cases (nth plant modeled cost projections).
- **2013: New design cases are being developed for TC Bio-oil Pathways to gasoline, diesel, and jet fuel that also support the $3/gge programmatic cost target.**

Goals and Objectives
Conversion R&D Goal



By 2022, achieve the overall program performance cost goal of $3 per gallon of gasoline equivalent ($2011) based on data at the integrated pilot scale.

Bio-oils R&D Goal Based on Fast Pyrolysis

2012 State of Technology currently at $3.95/gge, conversion cost with the biggest cost barrier in catalytic upgrading. The 2012 SOT Minimum Gasoline/Diesel Selling Price (Conversion + Feedstock Costs) is $5.23/gge and $5.29/gge for gasoline and diesel, respectively.

2017 Cost Target is $1.73/gge, conversion cost. The 2017 Minimum Gasoline/Diesel Selling Price is $2.59/gge for gasoline and diesel.

TC - Integration of Feedback from Peer Review 2011

- Require TEA's and LCA of all projects (including assumptions and uncertainties)
- Include by-products in design cases/TEAs/LCAs (i.e. chemicals, hydrogen, and bio-heat/power)
- Develop additional cost projection models for other pathways.
- Use Design Case cost projects as a "score card" for all projects to track their SOT and to make comparisons *(still a work in progress)*
- Enable hybrid and "new alternative" approaches
  - Lignin Utilization (w/Biochemical)
  - Algae and other HTL approaches
- Understand bio-oil quality and potential motor fuel end use and refinery integration

Research Approach: TC Bio-oil Pathways

Pathway	Description	Key Challenges & Barriers
Fast Pyrolysis (FP) with Liquid Phase Upgrading	FP followed by a separate liquid phase upgrading step, then multi-stage hydrotreating	• Feeding wet and dry biomass • Catalyst and catalytic process comprehension • Hydroprocessing and hydrogen considerations • Separation systems and selective fractionation • Sensors and controls • Liquefaction of biomass and bio-oil stabilization • Fuel synthesis and upgrading • Utilizing Organics in Waste Streams (Aqueous Phase and Off Gases) • Bio-oil pathway process integration • Refinery Integration
FP with Ex-Situ Vapor Phase Upgrading	FP followed by a separate vapor phase upgrading step, then one or two stages of hydrotreating	
FP with In-Situ Vapor Phase Upgrading	FP in the same reactor as upgrading catalyst, followed by one or two stages of hydrotreating	
Hydrothermal Liquefaction (HTL) or Solvent Liquefaction (SL)	Direct liquefaction in water (HTL) or solvent medium (SL), followed by catalytic upgrading. Used with high moisture feedstocks, such as algae	
Hydropyrolysis	FP in the presence of hydrogen and catalysts, followed by one stage of hydrotreating	

The CTAB workshop identified barriers that apply to these pathways

Pyrolysis and Liquefaction Technologies Accomplishments and Current Efforts

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CHASE Bio-Oils Pathways – 2013 ($12M, closes Feb 20, 2013)

- **Goal**: Use fundamental knowledge to inform R&D breakthroughs in carbon, hydrogen, and separation efficiencies in pyrolysis and liquefaction technologies to make gasoline, diesel, and jet fuels
- **Awards**: Summer 2013

Bio-oil Stabilization and Commoditization – 2012 ($11.4M)

- **Goal**: Work with the petroleum refinery industry on R&D to make bio-oils an acceptable feedstock and defining those specification for use in refineries, thus leveraging capital and economies of scale.
- **Awards**: Stevens Institute of Technology, Southern Research Institute, Sapphire Energy, University of Georgia Research Foundation, Iowa State University, IN, PNNL, Gas Technology Institute

Thermochemical Intermediates Upgrading – 2011 ($12M)

- **Goal**: Demonstrate the ability to produce intermediate-hydrocarbon process, or the ability to produce transportation fuel from any intermediate.
- **Awards**: LanzaTech, Virent Energy Systems, Inc., Research Triangle Institute

Bio-Oil Upgrading – 2010 ($7M)

- **Goal**: Demonstrate ability to produce hydrocarbon transportation fuel that can be blended at up to 30 wt% or an upgraded bio-oil compatible with existing petroleum refining unit operations
- **Awards**: W.R. Grace & Company, PNNL, GTI, Battelle Memorial Institute

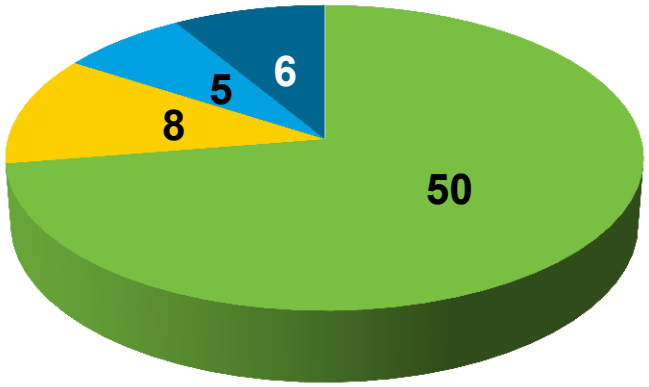
Pyrolysis Oil Stabilization – 2008 ($7M)

- **Goal**: Develop processes or techniques that stabilize fast pyrolysis bio oils generated from woody biomass
- **Awards**: Honeywell's UOP, Virginia Tech, Iowa State University, Research Triangle Institute, University of Massachusetts – Amherst

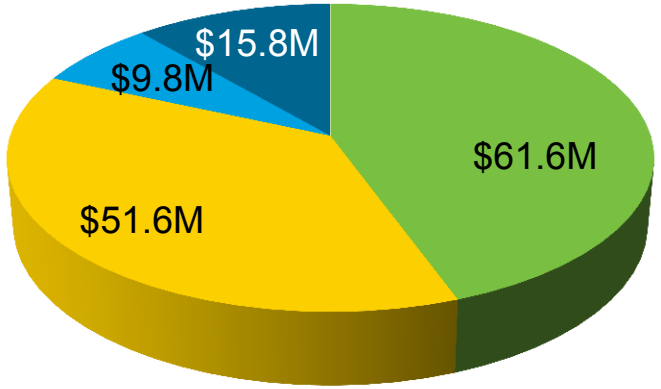
Thermochemical Bio-Oil Conversion Project Portfolio

The Thermochemical Bio-Oil Technology Area will be reviewing 69 performers in 44 project presentations this week

Bio-Oils: Portfolio Performers Reviewed



Bio-Oils: Total DOE Funding



Goals and Objectives: TC Bio-oil Pathways R&D

Performance milestones in MYPP:

- By 2014, establish out-year conversion cost projections and technical targets for achieving a minimum fuel selling price of $3/GGE based on completed TEAs for two additional bio-oils pathways (i.e. *Ex situ* and *In situ* Catalytic Fast Pyrolysis).
- By 2015, evaluate bench scale, semi-integrated pyrolysis or liquefaction conversion and upgrading processes on formatted biomass to produce gasoline and diesel fuels. This data informs a decision on which bio-oil pathway will be selected for pilot-scale operation to demonstrate the 2017 design case projections for a minimum fuel selling price of $3/GGE.
- By 2017, demonstrate integrated pilot-scale operations on formatted biomass using pyrolysis or liquefaction conversion with upgrading to produce gasoline, diesel, or jet finished fuels to meet the 2017 design case projections for a minimum fuel selling price of $3/GGE.

Long Term Goal:

- Continue to develop and demonstrate new thermochemical bio-oil R&D pathway technologies to convert biomass to hydrocarbon fuels, achieving an nth plant modeled minimum fuel selling price of $3/GGE by 2022.

Conversion Reviewers

Thermochemical
Bio-Oils

Don Stevens*	Cascade Science and Technology Research
Paul Bryan	Consultant, formerly with Chevron
Caroline Burgess Clifford	Penn State University
Dean Draemel	UC Berkeley. Formerly with ExxonMobile
Thomas Phillips	Intellection, LLC, Refinery Engineering Consultant

**** Lead Reviewer***

Review Expectations

- Individual PI Project Reviews
  - Presentations are public on website now
  - Final Report with reviewer comments publically available
- TC Goals and Portfolio
  - Appropriate goals that are clearly articulated
  - Organized R&D to address the goal
  - Portfolio Balance (Funding Level and Prioritization)
  - Balance of Lab Core R&D and Competitive
  - R&D Gaps or Overlaps
  - Tracking progress clearly and appropriately in through project TEAs/LCAs, publically available SOT/Design Cases

Schedule: Monday-Thursday

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Day 1: Fast Pyrolysis/Upgrading of Liquid Bio-oil

Competitively Awarded Projects

Day 2: Fast Pyrolysis/Upgrading of Liquid Bio-oil (continue)

Lab Core R&D Projects
Related International Collaborations
Home heating oil applications

Day 3: National Advanced Biofuels Consortium Joint Review BC/TC
Catalytic Fast Pyrolysis (ex situ or in situ) with upgrading

Lab Core R&D Projects
Competitively Awarded Projects

Day 4: Catalytic Fast Pyrolysis (continue) & Hydropyrolysis
Hydrothermal and Solvent Liquefaction

Lab Core R&D Projects
Competitively Awarded Projects

DAY 1 – Monday May 20, 2013: Afternoon

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Start Time	WBS #	Project Title	Performing Organization	Principal Investigator
1:00 PM		Introduction to the review	BETO	Melissa Klembara
1:15 PM	3.2.2.21, 3.2.2.22, & 3.2.2.23	New Ebullated Bed Technology for Hydroprocessing Bio-oils to Produce Gasoline, Diesel and Jet Fuels	W.R Grace & Co (with PNNL and ORNL subs)	Steve Schmidt
1:45 PM	3.2.2.24	Upgrading of Biomass Fast Pyrolysis Oil (Bio-oil)	PNNL (with UOP, Grace, and TUM)	Corinne Valkenburg
2:15 PM	3.3.1.15, 3.3.1.25, & 3.3.1.26	Optimizing Co-Processing of Bio-Oil in Refinery Unit Operations Using a Davison Circulating Riser (DCR)	PNNL (with W.R. Grace, ORNL, and LANL subs)	Alan Zacher, John Holladay
2:45 PM	3.3.1.18	Pt-based Bi-metallic Monolith Catalysts for Partial Upgrading of Microalgae Oil	Stevens Institute of Technology	Adeniyi Lawal
3:15 PM		**Break**	**All**	
3:30 PM	3.3.1.21 & 3.3.1.24	Stabilization of Bio-Oil Fractions for Insertion into Petroleum Refineries	Iowa State University (with PNNL sub)	Robert Brown
4:00 PM	3.2.2.25	Demonstration of Pyrolysis Based Biorefinery Concept for Biopower, Biomaterials and Biochar	Avello	Dennis Banasiak
4:30 PM	7.7.4.8	Mississippi State University Sustainable Energy Center	Mississippi State University	Fei Yu

DAY 2 – Tuesday May 21, 2013: Morning

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

Start Time	WBS #	Project Title	Performing Organization	Principal Investigator
7:30 AM		**Breakfast**	**All**	
8:30 AM		Introductory Period - Core R&D: Conventional Fast Pyrolysis and Catalytic Upgrading (with end of day focus on HHO)	BETO	
8:35 AM	3.6.1.1, 3.6.1.3, 3.5.1.3, & 3.1.2.4	Thermochem Platform Analysis - Fast Pyrolysis Design Case and Sustainability Interface	NREL & PNNL	Abhijit Dutta, Sue Jones, and Lesley Snowden-Swan
9:05 AM		**Break**	**All**	
9:20 AM	3.1.2.3, 3.7.1.3, 3.1.2.1, & 3.1.2.2	Feedstock Interface & Feedstock/Thermochemical Interface Equipment	INL/NREL/PNNL	Dave Muth, lead presenter Tyler Westover, Daniel Carpenter, & Dan Howe
10:05 AM		**Break**	**All**	
10:10 AM	3.2.2.4, 3.2.2.32, 3.7.1.2 & former 3.2.2.5	Pyrolysis Oil R&D, Hydrotreating of Physically Stabilized Pyrolysis Oil & CapEx	PNNL/NREL	Alan Zacher and Kristiina Iisa
10:55 AM	3.2.2.26	PNNL/VTT Production and Upgrade of Infrastructure Compatible Bio-Oil	PNNL	Douglas Elliott
11:25 AM	6.5.9.1 & 6.5.9.2	CA-02 Pyrolysis and Upgrading Collaboration with Canada	NREL & PNNL	Kristiina Iisa & Alan Zacher
11:45 AM	6.3.2.25	IEA Task 34 Fast Pyrolysis	PNNL	Douglas Elliott
12:05 PM		**Lunch**	**All**	

DAY 2 – Tuesday May 21, 2013: Afternoon

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

Start Time	WBS #	Project Title	Performing Organization	Principal Investigator
1:05 PM	6.5.1.1	Brazil Bilateral – Petrobras– NREL CRADA	NREL	Helena Chum & Rich Bain
1:25 PM	6.5.2.2	U.S.-China Collaboration - Thermochemical Conversion of Biomass	PNNL	Jonathan Male & Huamin Wang
1:45 PM	3.2.2.28 & 3.2.2.29	Bio-oil Upgrading with Novel Low Cost Catalysts and the synergistic Evaluation of Novel Catalytic Metals for bio-oil Upgrading	ORNL/PNNL	Jae-Soon Choi and Alan Zacher
2:15 PM	3.3.1.11	Selective Deoxygenation Catalysts / Prevention of Deactivation of Supportive Metal Catalysts	ANL	Jeffrey Elam & Joseph Libera
2:35 PM	3.2.2.34, 3.2.2.30, and 3.2.2.33	Characterization and Treatment of Aqueous Products from Direct Liquefaction Processes, Conversion of Direct Liquefaction Process Aqueous Phase Organic Products into Liquid HC fuels, and Steam Reforming of Aqueous Fraction from Bio-oil to produce H2	PNNL	Daniel Howe, Mark Gerber and Karl Albrecht, Robert Dagle
3:20 PM		**Break**	**All**	
3:45 PM	3.2.5.16, 3.2.2.26 (Task E) & 3.6.1.5	HHO Related R&D activities	PNNL/INL/BNL/ORNL	Richard Boardman, Corrine Valkenburg, Jonathan Male & Thomas Butcher, James Keiser

DAY 3 – Wednesday May 22, 2013: Morning

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

Start Time	WBS #	Project Title	Performing Organization	Principal Investigator
7:30 AM		**Breakfast**	**All**	
8:30 AM		Opening Plenary Session - Pathways Analysis	BETO	Alicia Lindauer
9:15 AM	3.3.1.1 (BC-Plenary)	National Advanced Biofuels Consortium (NABC) (Presented in conjunction with Thermochem technology area)	Alliance for Sustainable Energy, LLC	Tom Foust
10:15 AM		**Break**	**All**	
10:30 AM		Introductory Period	BETO	
10:35 AM	3.6.1.1, 3.6.1.3, & 3.5.1.3	Thermochem Platform Analysis - *Ex-Situ* and *In-Situ TEAs*	NREL & PNNL	Abhijit Dutta & Sue Jones
11:05 AM	3.6.1.8, 3.6.1.11	Computational Pyrolysis Consortium	ORNL, INL, NREL, ANL, PNNL, and University of Delaware	Stuart Daw
11:35 AM	3.6.1.6	Catalytic Pyrolysis Science	NREL	Mark Nimlos
12:05 PM		**Lunch**	**All (Reviewer lunch together, public on their own)**	

DAY 3 – Wednesday May 22, 2013: Afternoon

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

Start Time	WBS #	Project Title	Performing Organization	Principal Investigator
1:05 PM	3.3.1.14	Catalyst Development/Testing: Deconstruction	NREL	Kim Magrini
1:35 PM	3.3.1.12	Catalytic Upgrading of Pyrolysis Products	NREL	Jesse Hensley
2:05 PM	3.3.1.13 & 3.7.1.1	Integration and Scale up	NREL	Mark Davis or Esther Wilcox
2:35 PM	3.2.2.16	Biomass Derived Pyrolysis Oils Corrosion Studies	ORNL	James Keiser & Mike Kass
3:05 PM		**Break**	**All**	
3:20 PM	3.2.2.27	TAN Control of Bio-oil	ANL	Yupo J. Lin and Seth W. Snyder
3:40 PM	3.2.2.7	A low-cost high-yield process for the direct production of high energy density liquid fuel from biomass	Purdue University	Fabio Ribeiro
4:10 PM	3.2.2.19 & 3.2.2.20	Upgrading of Intermediate Bio-Oil Produced by Catalytic Pyrolysis	Battelle Memorial Insititute (with PNNL sub)	Zia Abdullah
4:40 PM	3.3.1.9	Catalytic Upgrading of Thermochemical Intermediates to Hydrocarbons	Research Triangle Institute	Dave Dayton

DAY 4 – Thursday May 23, 2013: Morning

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

Start Time	WBS #	Project Title	Performing Organization	Principal Investigator
7:30 AM		**Breakfast**	**All**	
8:30 AM		Opening Plenary Session - Billion Ton Update	BETO	
9:15 AM		**Break**	**All**	
9:25 AM		Introductory Period	BETO	
9:30 AM	7.5.7.3	Southern Pine Based Biorefinery Center	Georgia Institute of Technology	Arthur Ragauskas
10:00 AM	7.3.4.1	University of Oklahoma Biofuels Refining	University of Oklahoma	Steven Crossley
10:30 AM	3.2.2.18	Long Term Processing in the Production of Gasoline and Diesel from Biomass using Integrated Hydropyrolysis Plus Hydroconversion Process (IH2 Process)	Gas Technology Institute	Terry Marker
11:00 AM	3.3.1.16	Refinery Upgrading of Hydropyrolysis Oil from Biomass	Gas Technology Institute	Terry Marker
11:30 AM	3.2.2.17	Advanced Biomass to Gasoline Process	Exelus, Inc	Mitrajit Mukherjee
12:00 PM		**Lunch**	**All (Reviewer lunch together, public on their own)**	

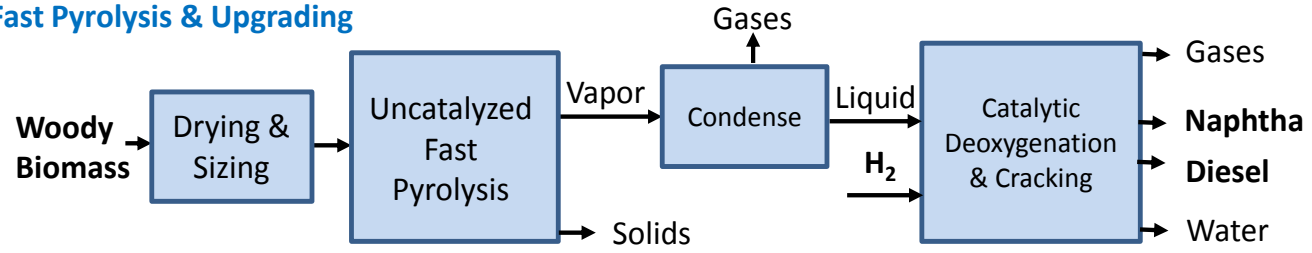
DAY 4 – Thursday May 23, 2013: Afternoon

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

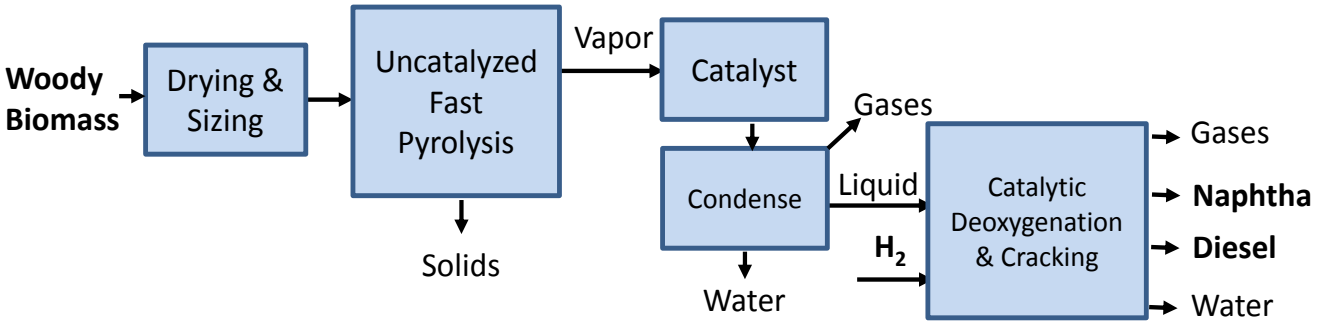
Start Time	WBS #	Project Title	Performing Organization	Principal Investigator
1:00 PM	3.6.1.3, 3.6.1.1 & 3.5.1.3	Thermochem Platform Analysis - HTL TEA	NREL & PNNL	Abhijit Dutta & Sue Jones
1:30 PM	3.2.2.31	Improved Hydrothermal Liquefaction Bio-oil Production	PNNL	Richard Hallen
2:00 PM	3.3.1.20	Optimized Co-processing of Algal Bio-Crude through a Petroleum Refinery	Sapphire Energy	Benjamin Saydah
2:30 PM	3.3.1.22	Development of bio-oil commodity fuel as a refinery feedstock from high impact algae biomass	University of GA Research Foundation	James Kastner
3:00 PM		**Break**	**All**	
3:15 PM	3.3.1.19	Bio-Oil Separation and Stabilization by Supercritical Fluid Fractionation	INL	Daniel Ginosar
3:45 PM	3.3.1.23	Liquefaction of Agricultural and Forest Biomass to "Drop-In" Hydrocarbon Biofuels	Iowa State University	Robert Brown
4:15 PM	3.3.1.10	Catalytic Upgrading of Thermochemical Intermediates to Hydrocarbons: Conversion of Lignocellulosic Feedstocks to Aromatic Fuels and High Value Chemicals	Virent Energy Systems, Inc.	Randy Cortright
4:45 PM	3.3.1.17	Mild Biomass Liquefaction Process for Economic Production of Stabilized Refinery-Ready Bio-Oils	Southern Research Institute	Santosh Gangwal

TC Bio-oil Pathways

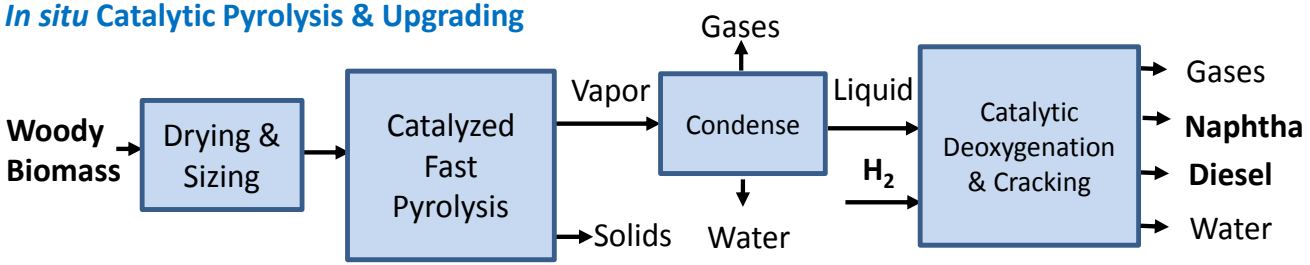
Fast Pyrolysis & Upgrading



***Ex situ* Catalytic Pyrolysis & Upgrading**

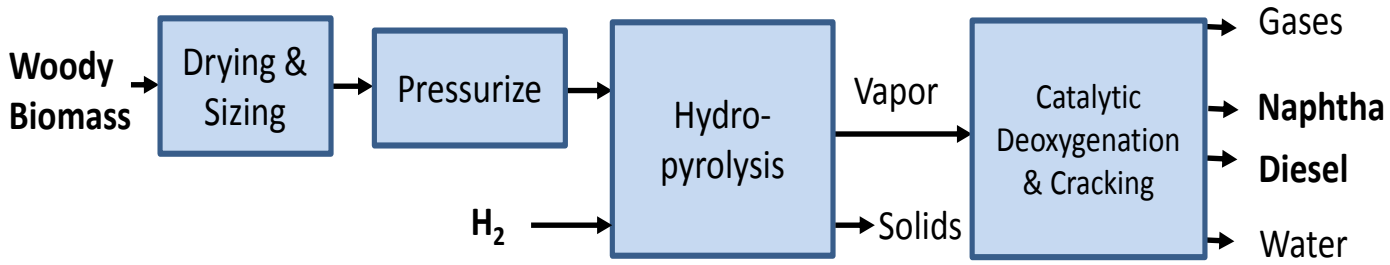


***In situ* Catalytic Pyrolysis & Upgrading**



TC Bio-oil Pathways (cont.)

Hydropyrolysis and Upgrading



Hydrothermal Liquefaction & Upgrading