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.
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.
• 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

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

The CTAB workshop identified barriers that apply to these pathways
Pyrolysis and Liquefaction Technologies
Accomplishments and Current Efforts

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

<table>
<thead>
<tr>
<th>Thermochemical Bio-Oils</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Don Stevens</strong>*</td>
</tr>
<tr>
<td><strong>Paul Bryan</strong></td>
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<tr>
<td><strong>Caroline Burgess Clifford</strong></td>
</tr>
<tr>
<td><strong>Dean Draemel</strong></td>
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<tr>
<td><strong>Thomas Phillips</strong></td>
</tr>
</tbody>
</table>

* 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

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

   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
<table>
<thead>
<tr>
<th>Start Time</th>
<th>WBS #</th>
<th>Project Title</th>
<th>Performing Organization</th>
<th>Principal Investigator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00 PM</td>
<td></td>
<td>Introduction to the review</td>
<td>BETO</td>
<td>Melissa Klembara</td>
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<tr>
<td>1:15 PM</td>
<td>3.2.2.21, 3.2.2.22, &amp; 3.2.2.23</td>
<td>New Bullated Bed Technology for Hydroprocessing Bio-oils to Produce Gasoline, Diesel and Jet Fuels</td>
<td>W.R Grace &amp; Co (with PNNL and ORNL subs)</td>
<td>Steve Schmidt</td>
</tr>
<tr>
<td>1:45 PM</td>
<td>3.2.2.24</td>
<td>Upgrading of Biomass Fast Pyrolysis Oil (Bio-oil)</td>
<td>PNNL (with UOP, Grace, and TUM)</td>
<td>Corinne Valkenburg</td>
</tr>
<tr>
<td>2:15 PM</td>
<td>3.3.1.15, 3.3.1.25, &amp; 3.3.1.26</td>
<td>Optimizing Co-Processing of Bio-Oil in Refinery Unit Operations Using a Davison Circulating Riser (DCR)</td>
<td>PNNL (with W.R. Grace, ORNL, and LANL subs)</td>
<td>Alan Zacher, John Holladay</td>
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<td>2:45 PM</td>
<td>3.3.1.18</td>
<td>Pt-based Bi-metallic Monolith Catalysts for Partial Upgrading of Microalgae Oil</td>
<td>Stevens Institute of Technology</td>
<td>Adeniyi Lawal</td>
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<tr>
<td>3:15 PM</td>
<td></td>
<td>Break</td>
<td>All</td>
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<tr>
<td>3:30 PM</td>
<td>3.3.1.21 &amp; 3.3.1.24</td>
<td>Stabilization of Bio-Oil Fractions for Insertion into Petroleum Refineries</td>
<td>Iowa State University (with PNNL sub)</td>
<td>Robert Brown</td>
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<td>4:00 PM</td>
<td>3.2.2.25</td>
<td>Demonstration of Pyrolysis Based Biorefinery Concept for Biopower, Biomaterials and Biochar</td>
<td>Avello</td>
<td>Dennis Banasiak</td>
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<tr>
<td>4:30 PM</td>
<td>7.7.4.8</td>
<td>Mississippi State University Sustainable Energy Center</td>
<td>Mississippi State University</td>
<td>Fei Yu</td>
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<tr>
<td>Start Time</td>
<td>WBS #</td>
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<td>Principal Investigator</td>
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<tr>
<td>7:30 AM</td>
<td>Breakfast</td>
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<td>All</td>
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<tr>
<td>8:30 AM</td>
<td>8:30 AM</td>
<td>Introductory Period - Core R&amp;D: Conventional Fast Pyrolysis and Catalytic Upgrading (with end of day focus on HHO)</td>
<td>BETO</td>
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<tr>
<td>8:35 AM</td>
<td>3.6.1.1, 3.6.1.3, 3.5.1.3, &amp; 3.1.2.4</td>
<td>Thermochem Platform Analysis - Fast Pyrolysis Design Case and Sustainability Interface</td>
<td>NREL &amp; PNNL</td>
<td>Abhijit Dutta, Sue Jones, and Lesley Snowden-Swan</td>
</tr>
<tr>
<td>9:05 AM</td>
<td>Break</td>
<td></td>
<td>All</td>
<td></td>
</tr>
<tr>
<td>9:20 AM</td>
<td>3.1.2.3, 3.7.1.3, 3.1.2.1, &amp; 3.1.2.2</td>
<td>Feedstock Interface &amp; Feedstock/Thermochemical Interface Equipment</td>
<td>INL/NREL/PNNL</td>
<td>Dave Muth, lead presenter Tyler Westover, Daniel Carpenter, &amp; Dan Howe</td>
</tr>
<tr>
<td>10:05 AM</td>
<td>Break</td>
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<td>All</td>
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<td>10:10 AM</td>
<td>3.2.2.4, 3.2.2.32, 3.7.1.2 &amp; former 3.2.2.5</td>
<td>Pyrolysis Oil R&amp;D, Hydrotreating of Physically Stabilized Pyrolysis Oil &amp; CapEx</td>
<td>PNNL/NREL</td>
<td>Alan Zacher and Kristiina lisa</td>
</tr>
<tr>
<td>10:55 AM</td>
<td>3.2.2.26</td>
<td>PNNL/VTT Production and Upgrade of Infrastructure Compatible Bio-Oil</td>
<td>PNNL</td>
<td>Douglas Elliott</td>
</tr>
<tr>
<td>11:25 AM</td>
<td>6.5.9.1 &amp; 6.5.9.2</td>
<td>CA-02 Pyrolysis and Upgrading Collaboration with Canada</td>
<td>NREL &amp; PNNL</td>
<td>Kristiina lisa &amp; Alan Zacher</td>
</tr>
<tr>
<td>11:45 AM</td>
<td>6.3.2.25</td>
<td>IEA Task 34 Fast Pyrolysis</td>
<td>PNNL</td>
<td>Douglas Elliott</td>
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<td>12:05 PM</td>
<td>Lunch</td>
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### DAY 2 – Tuesday May 21, 2013: Afternoon

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<tbody>
<tr>
<td>1:05 PM</td>
<td>6.5.1.1</td>
<td>Brazil Bilateral – Petrobras– NREL CRADA</td>
<td>NREL</td>
<td>Helena Chum &amp; Rich Bain</td>
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<tr>
<td>1:25 PM</td>
<td>6.5.2.2</td>
<td>U.S.-China Collaboration - Thermochemical Conversion of Biomass</td>
<td>PNNL</td>
<td>Jonathan Male &amp; Huamin Wang</td>
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<td>1:45 PM</td>
<td>3.2.2.28 &amp; 3.2.2.29</td>
<td>Bio-oil Upgrading with Novel Low Cost Catalysts and the synergistic Evaluation of Novel Catalytic Metals for bio-oil Upgrading</td>
<td>ORNL/PNNL</td>
<td>Jae-Soon Choi and Alan Zacher</td>
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<td>2:15 PM</td>
<td>3.3.1.11</td>
<td>Selective Deoxygenation Catalysts / Prevention of Deactivation of Supportive Metal Catalysts</td>
<td>ANL</td>
<td>Jeffrey Elam &amp; Joseph Libera</td>
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<tr>
<td>2:35 PM</td>
<td>3.2.2.34, 3.2.2.30, and 3.2.2.33</td>
<td>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</td>
<td>PNNL</td>
<td>Daniel Howe, Mark Gerber and Karl Albrecht, Robert Dagle</td>
</tr>
<tr>
<td>3:20 PM</td>
<td>Break</td>
<td>All</td>
<td></td>
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<tr>
<td>3:45 PM</td>
<td>3.2.5.16, 3.2.2.26 (Task E) &amp; 3.6.1.5</td>
<td>HHO Related R&amp;D activities</td>
<td>PNNL/INL/BNL/ORNL</td>
<td>Richard Boardman, Corrine Valkenburg, Jonathan Male &amp; Thomas Butcher, James Keiser</td>
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</table>
## DAY 3 – Wednesday May 22, 2013: Morning

<table>
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<tr>
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<tr>
<td>7:30 AM</td>
<td></td>
<td>Breakfast</td>
<td>All</td>
<td></td>
</tr>
<tr>
<td>8:30 AM</td>
<td></td>
<td>Opening Plenary Session - Pathways Analysis</td>
<td>BETO</td>
<td>Alicia Lindauer</td>
</tr>
<tr>
<td>9:15 AM</td>
<td>3.3.1.1 (BC-Plenary)</td>
<td>National Advanced Biofuels Consortium (NABC) (Presented in conjunction with Thermochem technology area)</td>
<td>Alliance for Sustainable Energy, LLC</td>
<td>Tom Foust</td>
</tr>
<tr>
<td>10:15 AM</td>
<td></td>
<td>Break</td>
<td>All</td>
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<tr>
<td>10:30 AM</td>
<td></td>
<td>Introductory Period</td>
<td>BETO</td>
<td></td>
</tr>
<tr>
<td>10:35 AM</td>
<td>3.6.1.1, 3.6.1.3, &amp; 3.5.1.3</td>
<td>Thermochem Platform Analysis - <em>Ex-Situ</em> and <em>In-Situ</em> TEAs</td>
<td>NREL &amp; PNNL</td>
<td>Abhijit Dutta &amp; Sue Jones</td>
</tr>
<tr>
<td>11:05 AM</td>
<td>3.6.1.8, 3.6.1.11</td>
<td>Computational Pyrolysis Consortium</td>
<td>ORNL, INL, NREL, ANL, PNNL, and University of Delaware</td>
<td>Stuart Daw</td>
</tr>
<tr>
<td>11:35 AM</td>
<td>3.6.1.6</td>
<td>Catalytic Pyrolysis Science</td>
<td>NREL</td>
<td>Mark Nimlos</td>
</tr>
<tr>
<td>12:05 PM</td>
<td></td>
<td>Lunch</td>
<td>All (Reviewer lunch together, public on their own)</td>
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</tr>
<tr>
<td>Start Time</td>
<td>WBS #</td>
<td>Project Title</td>
<td>Performing Organization</td>
<td>Principal Investigator</td>
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<tr>
<td>1:05 PM</td>
<td>3.3.1.14</td>
<td>Catalyst Development/Testing: Deconstruction</td>
<td>NREL</td>
<td>Kim Magrini</td>
</tr>
<tr>
<td>1:35 PM</td>
<td>3.3.1.12</td>
<td>Catalytic Upgrading of Pyrolysis Products</td>
<td>NREL</td>
<td>Jesse Hensley</td>
</tr>
<tr>
<td>2:05 PM</td>
<td>3.3.1.13 &amp; 3.7.1.1</td>
<td>Integration and Scale up</td>
<td>NREL</td>
<td>Mark Davis or Esther Wilcox</td>
</tr>
<tr>
<td>2:35 PM</td>
<td>3.2.2.16</td>
<td>Biomass Derived Pyrolysis Oils Corrosion Studies</td>
<td>ORNL</td>
<td>James Keiser &amp; Mike Kass</td>
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<tr>
<td>3:05 PM</td>
<td>Break</td>
<td></td>
<td>All</td>
<td></td>
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<tr>
<td>3:20 PM</td>
<td>3.2.2.27</td>
<td>TAN Control of Bio-oil</td>
<td>ANL</td>
<td>Yupo J. Lin and Seth W. Snyder</td>
</tr>
<tr>
<td>3:40 PM</td>
<td>3.2.2.7</td>
<td>A low-cost high-yield process for the direct production of high energy density</td>
<td>Purdue University</td>
<td>Fabio Ribeiro</td>
</tr>
<tr>
<td></td>
<td></td>
<td>liquid fuel from biomass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4:10 PM</td>
<td>3.2.2.19 &amp; 3.2.2.20</td>
<td>Upgrading of Intermediate Bio-Oil Produced by Catalytic Pyrolysis</td>
<td>Battelle Memorial Institute (with PNNL sub)</td>
<td>Zia Abdullah</td>
</tr>
<tr>
<td>4:40 PM</td>
<td>3.3.1.9</td>
<td>Catalytic Upgrading of Thermochemical Intermediates to Hydrocarbons</td>
<td>Research Triangle Institute</td>
<td>Dave Dayton</td>
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## Day 4 – Thursday May 23, 2013: Morning

<table>
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<tr>
<td>7:30 AM</td>
<td></td>
<td>Breakfast</td>
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<td></td>
</tr>
<tr>
<td>8:30 AM</td>
<td></td>
<td>Opening Plenary Session - Billion Ton Update</td>
<td>BETO</td>
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</tr>
<tr>
<td>9:15 AM</td>
<td></td>
<td>Break</td>
<td>All</td>
<td></td>
</tr>
<tr>
<td>9:25 AM</td>
<td></td>
<td>Introductory Period</td>
<td>BETO</td>
<td></td>
</tr>
<tr>
<td>9:30 AM</td>
<td>7.5.7.3</td>
<td>Southern Pine Based Biorefinery Center</td>
<td>Georgia Institute of Technology</td>
<td>Arthur Ragauskas</td>
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<tr>
<td>10:00 AM</td>
<td>7.3.4.1</td>
<td>University of Oklahoma Biofuels Refining</td>
<td>University of Oklahoma</td>
<td>Steven Crossley</td>
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<tr>
<td>10:30 AM</td>
<td>3.2.2.18</td>
<td>Long Term Processing in the Production of Gasoline and Diesel from Biomass using Integrated Hydropyrolysis Plus Hydroconversion Process (IH2 Process)</td>
<td>Gas Technology Institute</td>
<td>Terry Marker</td>
</tr>
<tr>
<td>11:00 AM</td>
<td>3.3.1.16</td>
<td>Refinery Upgrading of Hydropyrolysis Oil from Biomass</td>
<td>Gas Technology Institute</td>
<td>Terry Marker</td>
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<tr>
<td>11:30 AM</td>
<td>3.2.2.17</td>
<td>Advanced Biomass to Gasoline Process</td>
<td>Exelus, Inc</td>
<td>Mitrajit Mukherjee</td>
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<tr>
<td>12:00 PM</td>
<td></td>
<td>Lunch</td>
<td>All (Reviewer lunch together, public on their own)</td>
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## DAY 4 – Thursday May 23, 2013: Afternoon

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

Woody Biomass → Drying & Sizing → Pressurize → Hydro-pyrolysis → Catalytic Deoxygenation & Cracking

H₂ → Vapor → Solids → Diesel → Water

Gases → Naphtha

Hydrothermal Liquefaction & Upgrading

Woody Biomass → Sizing & Slurry → Pressurize → Hydro-Thermal Liquefaction → Condense

Buffering Agent → Water → Solids

H₂ → Liquid → Catalytic Deoxygenation & Cracking

Gases → Naphtha → Diesel → Water