

# Thermochemical Platform

## Introduction

The size of the U.S. bioindustry will, to a large degree, be determined by the cost, quality and quantity of biomass available. Equally important are the conversion technologies available to process these varying types of biomass. The Thermochemical Conversion (TC) platform is developing technologies that can fully utilize a wide range of biomass which may not be amenable to alcohol fermentation to produce fungible transportation fuels.

Our initial focus is on the available biomass as identified in the “Billion Ton Study” that will produce an alcohol fuel. Beginning in FY 2008, the platform has broadened its efforts to develop technology that can utilize the same wide range of feedstocks to produce hydrocarbon transportation fuels (e.g. gasoline, diesel, jet).

## Platform Performance Goal

To reduce the estimated mature technology processing cost for converting cellulosic feedstocks to ethanol from \$1.21 in 2005 to \$0.82 per gallon by 2012 and \$0.60 per gallon by 2017 (2007\$), based on data at the bench scale.

## Objectives

- By 2012, validate integrated production of ethanol from mixed alcohols produced from syngas at pilot scale, using agricultural residues and woody and energy crops (lignin or biomass) as feedstocks.
- By 2012, validate integrated production of biomass to gasoline and diesel via pyrolysis routes at pilot plant scale for woody biomass.

## FY 2007 Accomplishments

- Completed TC design case
  - Industry validated (Feb)
  - Current ethanol cost goal is \$1.33 per gallon
  - Low process water use: 1.9 gal water per gal ethanol
- Success in gasification
  - Developed correlations for tar yields from components of various types of biomass
- Success in gas clean-up/conditioning
  - Identified catalyst deactivation mechanism and metal-substrate interactions
  - Improved tar-cracking catalyst activity by 2.5 times (2010 target)
  - 2007 syngas clean-up solicitation issued
- Success in mixed alcohol catalyst to meet 2012 goals
  - Achieved space-time yield goal in mixed alcohol catalyst
  - Reached agreement in principal for DOW to supply their “Best In Class” mixed alcohol catalyst (key to meeting 2012 goal)
- Success in pyrolysis
  - Achieved 70 gal/ton (for gas/diesel fuel)
  - Obtained data for design case (due in FY 2008)
- Success in collaboration with government and industry
  - Co-lead (with NSF) to examine R&D needed for next generation of biofuels
  - Program peer (industry/university) review in July

## Budget

The President's FY 2007 and 2008 budget requests include large funding increases for Thermochemical Conversion R&D from \$4,723,000 in 2006 to \$14,145,000 in 2007 and \$17,537,000 in 2008.

## 2008 Plans

- 2008 Planned Solicitations
  - Pyrolysis oil to fuels (\$1,000,000 in FY 2008 & \$4,000,000 in out years)
  - Lab call for new ideas (\$1,000,000)
    - Biomass substrate deconstruction and fuels synthesis
  - University call (\$1,035,000)
    - Pyrolysis oil production and upgrading
    - Biorefinery residue gasification to fuels
    - Alcohol fuel synthesis catalysis
- FY 2008 End of Year (EOY) Joule Target
  - Modeled ethanol price of \$1.92/gal from gasification
- FY 2008 Quarterly Milestones
  - By December 15, improve productivity of catalysts for mixed alcohol production from syngas (space-time yield = 800 g/l/hr).
  - By March 31, prepare and characterize two 75 kg charges of tar-reforming catalyst (pilot development unit).
  - By June 30, demonstrate 15 cumulative hours of thermochemical pilot operation

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## Thermochemical Platform Support

### Thermochemical Platform Analysis

Andy Aden, National Renewable Energy Laboratory

Principal Investigator:	Andy Aden	Funding Partners:	N/A
HQ Technology Manager:	Paul Grabowski	Sub-contractors:	N/A
PMC Project Officer:	John Scahill		

**Goals and Objectives:** The primary objective of thermochemical analyses is to accurately quantify the costs and benefits of thermochemical technologies in support of meeting the 2012 Minimum Ethanol Selling Price (MESP) of \$1.07 per gallon and the 2030 renewable fuel production volume goals outlined in the 30x30 vision. In general, these targets will be met through improved feedstock-to-syngas conversion (i.e. tar reforming to yield more and cleaner syngas), process intensification (combining unit operations into a single operation) resulting in lower capital costs, and improved syngas-to-fuels productivity resulting in both lower capital costs and operating costs while increasing ethanol yields.

This task supports thermochemical research areas including tar reforming, gas cleanup, and mixed alcohol synthesis. Its goals are:

- 1) Identify task level targets that will contribute to the overall critical project targets,
- 2) Track and report on progress to the goal of \$1.07 per gallon ethanol in annual State of Technology assessments,
- 3) Evaluate alternative processes and scenarios that might improve economics, feasibilities, or other factors such as environmental impacts (e.g. water usage),
- 4) Integration with other groups' activities including
  - a) Strategic analysis of biorefineries and the bioindustry
  - b) Systems Integration activities
  - c) OBP program activities including planning and reviews
  - d) Biochemical platform analysis
- 5) Technical Targets (i.e. cost, yield): Analysis is primarily focused on helping to demonstrate \$1.07/gal ethanol by 2012.

**Project Description:** The goal of analysis is to help set technical and cost targets for the thermochemical platform and guide the research towards meeting these targets. Conceptual process designs are developed based on input from researchers and other engineers for converting biomass feedstocks into liquid fuels. These designs are modeled using software such as Aspen Plus to develop mass and energy balance information that is subsequently used in economic analyses. Many times, a discounted cash flow rate of return economic analysis is used to calculate the minimum ethanol selling price (MESP) need to meet a certain hurdle rate, 10% IRR in most cases for a net present value of zero.

However, the appropriate level of engineering rigor is used for each project. For example, if a project is in a very early stage of development, a simplified cash flow analysis may be all that is needed.

Using these models, analysts can also track research progress towards the goals through what are known as "State of Technology" assessments, where data achieved at the laboratory or pilot scale is used in the model to predict what the economics might look like at the commercial scale. As the science and research advances technically, these advancements can be quantified economically as progress towards a cost goal.

**Accomplishments (FY05-current):** Since FY05, the thermochemical platform has changed focus. While a syngas intermediate used to be the focus (with hydrogen as a model product), it has shifted instead to a focus on the end fuel product, where ethanol is now being targeted. As a result of an extensive literature search, a fixed bed MoS<sub>2</sub>-based fuel synthesis catalyst was chosen for this process because of its potential for high ethanol selectivities. Initial process designs and economics for the production of mixed

alcohols from biomass gasification were developed, but these initial designs suffered from low ethanol yields and relatively poor economics.

It soon became clear that a detailed design report was necessary for several reasons. First of all, the biochemical platform had used such a report as a successful means of establishing a benchmark against which all process improvements could be quantified. A detailed design report represents one technology package that can meet the cost objectives. It by no means is meant to be considered the “optimal” design, but simply establishes a baseline. In addition to documenting a sound basis behind quantifiable targets, it also functions as a means of establishing better collaboration with industrial and academic partners.

In a short period (approximately 4 months), a design report was generated to document the process for converting wood chips into fuel ethanol via indirect gasification and mixed alcohols synthesis. Several steps for cleanup and conditioning were used, including tar reforming (with catalyst regeneration), quench, syngas compression, and acid gas scrubbing. In addition to detailed documentation of the process design assumptions and economic parameters used, a set of process flow diagrams were also developed. This report described where the research parameters needed to be to achieve “economic” ethanol; it did not reflect where state of the technology was at present. The initial report was extensively reviewed during the thermochemical platform workshop held in Washington, DC in January, 2007.

The gasifier in the model was based on the Battelle Columbus Labs (BCL) design and data from their 9 ton/day gasifier from which correlations were built. The syngas tar reforming conversions used in the model did not reflect what had actually been achieved at pilot scale, but rather were conversion targets to achieve. Syngas cleanup requirements were based on the catalyst system chosen with advice and support from Nexant Inc. The mixed alcohol fuel synthesis data was also a depiction of necessary targets for CO conversion, selectivity, and productivity. Liquid alcohols were condensed from the reactor outlet, and purified into two products: fuel grade ethanol and a “higher alcohol” co-product made predominantly of C3- and C4- linear alcohols. Methanol was recovered and recycled back to the synthesis reactor to increase the yields of ethanol and higher alcohols. Unconverted syngas was primarily recycled back to the tar reformer.

An MESP of \$1.01/gallon was shown for a 2000 dry metric tonnes per day facility with a yield of 80 gal/dry ton of ethanol. The overall project investment was on the order of \$190MM. The overall energy efficiency of the process on an LHV basis was 46%. Overall, the economics clearly showed that the cleanup and conditioning section of the process was one of the most expensive, and therefore should be targeted for research. Sensitivity analyses were also conducted in order to show which process variables had significant economic impact.

Two primary design considerations implemented during this period were: energy self-sufficiency and water usage minimization. The design used a small slipstream of “dirty” unreformed syngas to provide the heat needed to run the process. While this allowed for the requirement of no external fuel (i.e. natural gas), it did come with a price; a small loss of alcohol yield. Realizing that water sustainability is a key consideration in today’s ethanol industry, engineers implemented several design changes to minimize the water needed for cooling. For example, forced air cooling was used in place of cooling water heat exchangers where appropriate. The resulting water demand for the process was 1.9 gallons per gallon of ethanol produced.

#### **Schedule**

Project Initiation Date: October 1, 2002  
Planned Completion Date: September 30, 2012

## Gasification

### Gasification Process Modeling and Optimization Task

David Dayton, National Renewable Energy Laboratory

Principal Investigator:	David Dayton	Funding Partners:	N/A
HQ Technology Manager:	Paul Grabowski	Sub-contractors:	N/A
PMC Project Officer:	John Scahill		

**Goals and Objectives:** Mixed alcohol production from biomass-derived syngas is the leading thermochemical technology option for meeting the Advanced Energy Initiative's goal of producing ethanol for \$1.07/gal by 2012. Thermochemical gasification technology is essential to fully exploit the diverse biomass resource base available for biofuels production. This is because the performance of thermochemical conversion technologies is relatively insensitive (compared to biochemical conversion) to the carbohydrate composition of biomass feedstocks and as such can utilize a wide variety of regionally specific materials exhibiting a broad range of chemical and physical properties. Biomass feedstock types being specifically targeted for thermochemical conversion are those not suitable for biochemically-based ethanol production. Ultimately lignin-rich residues from the biological conversion of lignocellulosic feedstocks will be used as thermochemical feedstocks to maximize biofuel production in integrated biorefineries.

Using wood as a model feedstock, the goal of the gasification fundamentals task is advance our understanding of thermochemical conversion mechanisms, particularly how processing conditions influence reaction behavior. In FY07, we performed detailed studies of lignin devolatilization kinetics using lignin model compounds. The objective of these studies is to identify reactor independent reaction mechanisms that can be used to model the formation and evolution of tars and heteroatom impurities in syngas. The kinetic models will then be used to explore and define process parameters that minimize tar formation (thermally or catalytically) as well as sulfur, chlorine, and nitrogen release during biomass gasification. The models will be tested/validated using a range of biomass feedstocks spanning woody and herbaceous types as well as biochemical process residues over a statistically robust set of gasification conditions to evaluate the effect of feedstock type (particularly ash content and composition) on product gas composition.

The ability to control the biomass gasification step to reduce the levels of syngas tars and other impurities offers the potential to significantly lower the cost of downstream cleanup and conditioning process steps. This approach is ultimately expected to increase overall conversion efficiency and decrease capital and operating costs for an integrated process.

#### Technical Targets (i.e. cost, yield):

- Validate the technical and economic feasibility of generating syngas from low carbohydrate feedstocks
- Quantify the impact of feedstock composition on the cost of thermochemical ethanol production
- Develop a chemical mechanistic understanding of thermochemical biomass conversion

Biomass Gasification Targets for pilot-scale demonstration of 2012 cost-competitive ("\$1.07") TC Ethanol Technology:

- 78% syngas efficiency
- H<sub>2</sub>/CO = 1.0
- CH<sub>4</sub> ≤ 5vol%
- Tars ≤ 1 g/Nm<sup>3</sup>
- benzene ≤ 0.04 vol%
- H<sub>2</sub>S ≤ 20 ppm
- NH<sub>3</sub> and HCl to be determined

**Project Description:** The goal of this project is to develop tools to understand fundamental mechanisms and reaction kinetics that can be applied to developing thermochemical biorefinery technologies. The focus is on fundamental chemical kinetic measurements of trace product formation in biomass thermochemical processes including tar formation and destruction, transformation of S, N, Cl, and alkali metal release rates. The thermochemical conversion of model compounds of relevance to biomass pyrolysis and gasification will also be investigated. Some candidates for detailed study are furans, guaiacols, phenols, anisole, and levoglucosan. These are all important compounds in the pyrolysis of lignocellulosic materials. The thermal conversion rates of model tar compounds (benzene, naphthalene, phenol, toluene, etc) will also be measured under relevant gasification atmospheres. Tar formation and conversion will be investigated as a function of temperature and gasification atmosphere (steam and partial oxidation). Fundamental kinetic rates for the thermal decomposition, steam reforming, and partial oxidation of these models compounds will be determined and compared to literature values when available. Extrapolation of results obtained from these bench-scale experiments to larger scale systems will be facilitated.

**Accomplishments (FY05-current):**

Title of task, subtask or milestone	Status of Progress in Task or Milestone	Approved Updated Completion Date	Task or Milestone Completion Criteria (to include cost and performance metrics)
Pilot-scale parametric gasification of wood, lignin-rich residues, switchgrass, and wheat straw to develop correlations for input in process models.	On schedule, progress positive or work completed	9/30/07	Biorefinery residues - Indirect (atm) gasification : corn stover; switchgrass; wheat straw; lignin - 78% syngas efficiency: H <sub>2</sub> /CO = 1.0-1.5; CH <sub>4</sub> ≤ 15vol%; Tars ≤ 30 g/Nm <sup>3</sup> ; benzene ≤ 1vol%; H <sub>2</sub> S = 50-600 ppm; NH <sub>3</sub> and HCl to be determined

The work in this project will be conducted in 3 related subtasks that explore the range of syngas compositions produced from various feedstocks including biorefinery and agricultural residues and future energy crops. Pilot-scale parametric gasification studies will provide the basis for developing correlations between feedstock composition and fundamental process parameters such as temperature and steam: biomass ratio that can be used as input for biomass gasification to mixed alcohols process simulations. Combining the pilot-scale experimental results with thermochemical analysis will be used to update techno-economic analyses for thermochemical ethanol scenarios developed for the near term \$1.07/gallon 2012 cost target and longer-term 30x30 vision.

The three tasks associated with this project are as follows:

- 1) Lignin Production – In collaboration with NREL’s Targeted Conversion Research task, a sufficient amount of biochemically-derived lignin rich residues will be produced to satisfy the feedstock requirements for bench-scale and pilot-scale gasification and catalyst testing studies.
- 2) Parametric Gasification Studies – Process variables in NREL’s TCPDU will be varied according to a statistical design to measure syngas composition, tar concentrations, and impurity levels (H<sub>2</sub>S, and NH<sub>3</sub>) with selected feedstocks; including lignin-rich residues, wheat straw, and switchgrass as a function of process conditions. These pilot-scale experiments will provide the data needed to develop correlations for use in Thermochemical Process Analysis.
- 3) Fundamental Thermochemical Conversion Kinetics – This task will conduct fundamental kinetics measurements in a bench-scale, variable temperature laminar entrained flow reactor (LEFR). These measurements will help validate chemical kinetics mechanisms that can be used for reactor designs by gasification developers.

**Technical Feasibility and Risks:** A Benchmark thermochemical process designed for achieving \$1.07/gal ethanol by 2012

Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass (NREL-TP-510-41168) <http://www.nrel.gov/docs/fy07osti/41168.pdf> was completed and used to develop specific, quantitative R&D targets for overcoming identified technical barriers to successful technology demonstration. This project is to provide the technical feasibility needed to advance, demonstrate, and validate gasification performance of appropriate feedstocks meeting process design targets.

The benchmark process design also quantifies the relative capital and operating costs associated with process unit operations highlighting the economic benefit of overcoming specific technical barrier areas to help guide R&D efforts to maximize the economic impact of research by optimizing performance and identifying process integration opportunities. Integrating unit operations provides opportunities for process consolidation to improve technical and economic feasibility and brings about a systems-level approach to identify relative importance of identified technical barriers.

All of these R&D activities are focused on process improvements at the scale of projected biomass systems, roughly 2000 tpd as benchmarked in the Mixed Alcohol Design Study. At this scale there are limited cost-reductions from increased economy of scale and costs associated with feedstock collection, processing and handling are significant.

The challenges directly associated with this project are to 1) develop laboratory-scale correlations that apply to larger-scale systems, 2) incorporate detailed chemical kinetic mechanistic modeling to explore biomass thermochemical conversion, and 3) develop computationally-tractable CFD models of thermochemical biomass conversion systems.

#### **Schedule**

Project Initiation Date: October 01, 2002  
Planned Completion Date: September 30, 2011



## Catalytic Hydrothermal Gasification for Eastman Kingsport Chemical

Chris Lindsey, Antares Group Incorporated

Principal Investigator:	Ed Gray	Funding Partners:	Eastman Chemical
HQ Technology Manager:	Paul Grabowski	Sub-contractors:	N/A
PMC Project Officer:	John Scahill		

**Goals and Objectives:** The objective of the project team's Phase-I research and development effort is to advance a low-temperature catalytic gasification concept for use with wet biomass feedstocks, such as biosludges. The effort will leverage efforts already undertaken by PNNL in developing LTCHG and verify reactivity and treatability for various key byproducts. The endpoint of this Phase is a design for the first commercial application for the LTCHG process. This work is expected to lead to the first chemical synthesis application for a broad class of biomass resources with very high moisture contents including biosludges and stillage from ethanol production.

**Technical Targets (i.e. cost, yield):** This project contributes to the technical targets for the Corn Stover to Ethanol process, as LTCHG can be used to treat wet residue streams from the biorefinery. In particular, the lignin by-product of lignocellulosic ethanol production can be converted into a high value fuel gas which can then be used to generate energy. As LTCHG does not require the energy-intensive drying step necessary for combustion or air-blown gasification, it will be the technology of choice for converting wet byproducts to energy in and integrated Biorefinery.

**Project Description:** Substantial amounts of biomass are available in high-moisture or slurry waste streams generated Biorefineries and municipalities and industrial facilities. These include cellulose and hemicellulose hydrolysis byproducts, animal manures (especially dairy and swine), pulp mill sludges, food processing sludges, and municipal wastewater sludges. The high moisture content of these streams makes them problematic for conventional thermochemical conversion since water removal (either mechanical or thermal drying) puts a significant strain on project economics. Using the raw byproducts as a boiler fuel is a frequently used disposal application that has no energy benefit for the process. As a result, there is substantial industry interest in thermochemical technologies to convert waste streams into added-value products.

Low-Temperature Catalytic Hydrothermal Gasification (LTCHG) offers the potential to access the carbon trapped in these streams using a less energy intensive process that works with, rather than against the high moisture contents of these resources. The process is a thermocatalytic gasification concept, which converts wet organic residues to a medium-Btu gas. The system is operated as a liquid-phase, heterogeneously catalyzed process at nominally 350°C and 20 MPa to produce a methane/carbon dioxide product gas from the water solutions or slurries of organics. The LTCHG system operates with streams containing as little as a few percent dry solids by weight. In contrast, conventional gasification systems are generally inoperable with feedstocks containing more than 50 weight % moisture.

The development efforts undertaken to date have included characterization of numerous feedstocks, including recent work characterizing waste biosludge streams at Eastman's Kingsport Chemical Plant and materials from existing dry corn ethanol mills. Characterizations have included detailed chemical analyses as well as process tests in batch reactors, bench scale continuous flow processing evaluations, and finally testing in a continuous flow reactor in a mobile Process Development Unit (PDU). With the knowledge gained in the PDU testing of the Eastman biosludges Antares is proposing to restructure the industrial arrangements focusing on Biorefinery partners whose byproducts of hydrolysis better fit the range of treatability. Antares intends to work with several partners providing confidential results to each company on the treatability of the byproducts. Partners with strong interest in the technology and high byproduct treatability will be selected as the basis for completing a conceptual pilot plant design.

**Accomplishments (FY05-current):** The development efforts undertaken to date have included analysis and characterization of waste biosludge streams at Eastman's Kingsport Chemical Plant. Characterizations have included detailed chemical analyses as well as process tests in batch reactors, bench scale continuous flow processing evaluations, and finally testing in a continuous flow reactor in a mobile Process Development Unit (PDU). A summary of the accomplishments to date by task is given below.

Task A: Biosludge Analysis and Assessment: PNNL completed chemical analyses of Eastman biosludge samples collected approximately monthly for more than a year. A deliverable report was issued on January 19, 2005. The analyses show the expected levels of the various elemental components and confirm the similarity of composition of the biosludge with other biomass feedstocks. This similarity also suggests the broader applicability of the pretreatment technology being developed in this project to other wet biomass feedstocks, including biorefinery residues. While the basic organic components of the biosludge were very consistent the results indicated highly variable concentrations of key contaminants including sulfur.

Task B: Batch and Continuous Flow Reactor Testing: PNNL completed a set of process tests with the biosludge samples in its batch reactor to evaluate catalyst activity and reaction conditions. The effect of different catalysts and solids concentration of the feed streams were evaluated. Tests confirmed the expected high activity of the catalyst with this feedstock, particularly for the ruthenium on carbon catalyst. From the results it was determined that Eastman wastes can be gasified in the catalytic gasification system at levels equivalent to or better than other wet biomasses. PNNL also tested Eastman feedstock in a bench-scale continuous reactor process, which confirmed the expected high activity of the catalyst and the high-pressure feeding of the biosludge at up to 5 wt% dry solids. Optimization of the mineral capture system operation was evaluated, and the sulfur capture system was expanded to include both reduced sulfur and sulfate separation.

The scaled-up reactor system (or Process Development Unit – PDU) was modified to include biosludge feeding, mineral matter separation and recovery, and sulfur removal (both sulfate and sulfide) to protect the catalyst bed. Several process tests were performed in the PDU, which confirmed the high-pressure feeding of the biosludge at up to 5 wt% dry solids. A high level of gasification was accomplished in the catalyst bed. Plugging in the heat-up portion of the system was overcome by a pressure stabilization modification to the reactor system. Subsequent operations confirmed significant losses of carbon in the solids separation step.

Task C: Process Modeling and Economic Analysis: Antares developed a detailed mass balance spreadsheet which tracks the relevant composition and properties (temperature, pressure) through each process element. This model was used to determine equipment requirements and sizes, and to estimate the end products of the process. PNNL analysis results were used for the initial composition of the biosludge and post-reactor gas composition. Estimates of equipment costs were gathered from vendor quotes and cost-estimating software. Antares generated a pro forma preliminary economic analysis based on the Eastman process and a switch from a negative or neutral value boiler fuel disposal option to a positive value high BTU methane production option. Sensitivity analyses were performed for the key factors in the process, including capital cost, catalyst lifetime and LHSV. Significant capital and O&M costs were included for sulfur and mineral treatment for the Eastman feedstock. These costs were shown to have a large impact on the project economics. A preliminary evaluation of the process using feedstocks with minimal sulfur loading indicates very favorable economics.

Task D: Conceptual Pilot Plant Design: The project team determined that a biosludge composition with approximately 5 wt% solids is preferred for Eastman feedstock, based on economic and pumping considerations. The project team made preliminary decisions about equipment type, size, and materials from economic and technical analysis. Several possible pumping systems were identified, including screw, reciprocating, and syringe pumps. Screw pumps are currently the favored option. Due to the importance of effective sulfur removal before the catalyst, the project team has incorporated a pre-process sulfur trap, to remove the bulk of sulfur.

**Technical Feasibility and Risks:** LTCHG has the ability to turn industrial process liabilities (low or negative value byproducts) into assets – a clean medium-Btu fuel gas. While much attention is being poured into partial oxidation gasification, particularly on the gas clean-up side of the equation, limited effort in the US has focused on gasification in an aqueous medium – hydrothermal catalytic gasification. Although there are advantages to both gasification approaches, the benefits particular to LTCHG include:

- Alkali metals at concentrations typically found in biomass pass through the reactor in aqueous solution;
- Tars are efficiently converted to gasification products over the reactor bed;
- Wastewater cleanup of organic byproducts is not an issue;
- Reactor effluents are not airborne but are in solution making it relatively easy to separate out the clean product gasses;
- Chlorine is in dilute ionic form and passes through the reactor without problem;
- The medium-BTU gas comes available at high pressure (around 3000 psi), which facilitates (semi) selective removal of CO<sub>2</sub> resulting in a high-BTU fuel gas and separate CO<sub>2</sub> product stream.

These advantages combined with the very active hydrothermal environment aids the pretreatment of feedstocks and the post-treatment of byproducts. As this technology can be applied to a wide range byproducts from industrial and municipal customers (ethanol Biorefineries, pulp & paper mills, municipal or industrial WWT), it ensures that there will be a place for LTCHG even if markets shift.

The primary challenge for hydrothermal gasification is to adequately clean the feedstock prior to the catalyst bed in the gasifier reactor. As feedstock contaminants (such as sulfur and minerals) are detrimental to catalyst life, the feedstock composition is a key to project success. In addition to selecting feedstocks based on compositional requirements, effective low cost pretreatment options and polishing steps for sulfur and mineral removal need to be developed. Carbon losses (with mineral precipitation) also need to be minimized.

#### **Schedule**

Project Initiation Date: October 01, 2004

Planned Completion Date: March 31, 2008

**Mississippi State University Sustainable Energy Center**

Mark Bricka, Mississippi State University

No Project Summary Provided.

**Fuel Chemistry and Bed Performance in a Black Liquor Steam Reformer Project**

Kevin Whitty, University of Utah

No Project Summary Provided.

## **Clean-Up and Conditioning**

**Biomass Gas Cleanup Using a Therminator**  
Santosh Gangwal, RTI International

No Project Summary Provided.

## Engineering New Catalysts for In-Process Elimination of Tars

Larry Felix, Gas Technology Institute

Principal Investigator:	Rachid B. Slimane	Funding Partners:	Alfred University; Ohio State University; NexTech Materials, Ltd.
HQ Technology Manager:	Paul Grabowski		
PMC Project Officer:	John Scahill	Sub-contractors:	N/A

**Goals and Objectives:** The primary goal of this project is to develop a new and more efficient method for engineering and economically producing optimized catalysts for the reduction or elimination of tars in biomass gasification. A second project goal is to determine if waste materials of little (or negative) value that contain potential catalysts can be converted into attrition-resistant refractory catalyst substrates and tar-cracking catalysts. All work will be performed by GTI and our partners on this project (NexTech Materials, Alfred University, and Ohio State University).

**Accomplishments (FY05-current):** In FY2007, work will first focus on assessing the information gained from intensive studies by Ohio State University (OSU) of new Ni-based tar-cracking catalytic materials produced on this project and samples of these catalysts that have been exposed to surrogate biomass tars both by GTI in its Catalyst Test Facility in Des Plaines, IL and by Dr. David Dayton in his catalyst testing facilities at NREL in Golden, CO. Samples of Ni-based catalysts developed at NREL will also be evaluated by OSU to compare with the catalytic materials developed on this project elucidate the underlying mechanisms that these catalysts share. GTI and NREL will also conduct exposure tests of new catalytic material made on this project with syngas made by gasifying corn stover and biorefinery wastes supplied by NREL. Samples of materials tested at GTI and NREL will be forwarded to OSU for in-depth analysis and characterization.

As part of its techno-economic analysis of catalysts, NexTech Materials is determining the costs for producing these materials by two routes: first, by taking the process used at GTI to a commercial scale, and second, by determining the costs associated with producing these catalysts in a submerged combustion melter. In this work, NexTech will produce small amounts of the types of catalysts that have been produced at GTI, but with commercial equipment to establish basis for cost. GTI will provide economic cost information for incorporating submerged combustion melting. Alfred University will investigate formulating high-temperature glasses that exhibit catalytic activity.

Title of task, subtask or milestone	Approved Updated Completion Date
Concept Feasibility	14-Oct-05
Performance Optimization	15-Mar-07
Develop waste-based catalyst	1-Jun-07
Techno-economic analysis	31-Dec-07
Large-Scale Test	1-Dec-07
Large-scale test of baseline catalytic bed materials	4-Nov-05
Evaluate existing materials	4-Nov-05
Produce new catalytic materials	1-Jul-07
Evaluate new Catalysts	1-Dec-07
Demonstrate feasibility of concept	14-Oct-05

### Schedule

Project Initiation Date: October 1, 2004  
Planned Completion Date: December 28, 20-07

## Catalyst Fundamentals

Dave Dayton, National Renewable Energy Laboratory

Principal Investigator:	Kim Magrini	Funding Partners:	N/A
HQ Technology Manager:	Paul Grabowski	Sub-contractors:	N/A
PMC Project Officer:	John Scahill		

**Goals and Objectives:** Technoeconomic analysis has shown that cleanup and conditioning of biomass-derived syngas to remove chemical contaminants such as tar, ammonia, chlorine, sulfur, alkali metals, and particulates has the greatest impact on the cost of clean syngas. To date, gas cleanup and conditioning technologies and systems are unproven in integrated biorefinery applications. Catalytic steam reforming of tars produced during biorefinery residues gasification will be investigated in bench-scale reactors. Surface analysis and fundamental catalyst screening studies using Micro-Activity Test Systems (MATS) will be used to assess the impact of sulfur release from biorefinery residue gasification on the long-term activity and regenerability of developing tar reforming catalysts. The collective catalyst activity and lifetime measurements from these experimental investigations and ongoing catalyst deactivation kinetic determinations will be used to aid in the preliminary design of a regenerating catalytic tar reforming reactor that can be implemented in thermochemical conversion processes that are integrated into current and developing biorefinery process concepts.

**Accomplishments (FY05-current):** Developing an optimized fluidizable tar reforming catalyst for gas cleanup and conditioning in a biomass gasification/mixed alcohol synthesis process has been the focus of these efforts. Correlating bench-scale results from micro-activity test systems with pilot-scale catalyst performance has led to improved catalyst regeneration procedures and better catalyst formulations. The methods and protocols developed should benefit catalyst manufacturers in the future as these catalysts become commercial.

Additional improvements in catalyst performance could be realized by taking a much more fundamental approach to developing improved catalyst formulations and optimized regeneration protocols to maintain high tar reforming activity for long periods of time. The three tasks below will increase the core knowledge of tar/catalyst interactions.

- 1) Catalyst Surface Science – A detailed, fundamental understanding of catalyst surface chemistry as it impacts initial catalyst deactivation and long term catalyst activity will be developed. Utilizing the capabilities in NREL's Biomass Surface Characterization Laboratory (BSCL). Correlating catalyst surface analysis with metal dispersion, elemental composition, crystal growth, active site poisoning, etc. is the goal of this effort. Alternatively, we will collaborate with Argonne National Laboratory to explore the effectiveness of using existing in-situ catalyst reactor cells and on-line analysis equipment available in ANL's Advanced Photon Laboratory to perform TPR, EXAFS, and XANES. This work should provide quantitative of nickel species during preparation and reaction and insight to catalyst morphology changes with composition, sulfur adsorption, and deactivation.
- 2) Bench-scale catalyst testing – The micro-activity test systems and slipstream 2" fluidized bed catalyst reactor will continue to be utilized to evaluate the performance of developing catalysts. Catalysts will include new formulations on alternative supports plus catalysts being developed in other Biomass Program projects.
- 3) Computational Catalysis – Computational methods will be developed and applied to guide catalyst design and related experimental work to explore/validate basic molecular interactions occurring on metallic and metal oxide surfaces. Ni-based tar reforming catalysts are the basis for developing initial computational methods. First principles methods will be used to comparatively investigate and rank the catalytic activity of different metals, metal-alloys and nano-structured catalyst systems. The experimental capabilities for catalyst activity screening and catalyst evaluation developed in this will be used to test and validate key computational results.

The arrangement of the various components in these multi-functional catalysts at the nano-scale may be critical. As postulated in the literature, at least two metal atoms (typically nickel) are needed to adsorb the hydrocarbon and break the C-C bond while the alumina support provides hydroxyl moieties to react with

the carbon to form hydrogen and oxides of carbon. Computationally, the arrangement, size, and orientation of these components could be modeled to develop a better understanding of how these catalysts work and guide the synthesis of new catalysts which could be tested to verify the approach.

**Schedule**

Project Initiation Date: August 1, 2001

Planned Completion Date: September 30, 2011



**Integrated Catalyst Testing**

Calvin Feik, National Renewable Energy Laboratory

No Project Summary Provided.

## Fuel Synthesis

### Thermochemical Conversion of Corn Stover

James L. Gaddy, Bioengineering Resources, Inc.

Principal Investigator:	James L. Gaddy	Funding Partners:	Bioengineering Resources, Inc.; Chippewa Valley Ethanol Company; Katzen International, Inc.; Burns & McDonnell Engineering Company, Inc.; University of Arkansas
HQ Technology Manager:	Paul Grabowski		
PMC Project Officer:	John Scahill		
		Sub-contractors:	N/A

**Goals and Objectives:** The overall objective of this project is to develop an economical gasification/fermentation process to produce ethanol from corn stover. Process variables will be optimized and a detailed cost projection prepared for the integration of a conventional grain alcohol plant with the stover and ethanol facilities.

**Technical Targets (i.e. cost, yield):** Gasification of corn stover and subsequent gas cleanup to provide a fermentable syngas. Fermentation productivity of at least 50 g/L/day is sought. An overall process ROI of 15 percent is targeted.

**Project Description:** The overall objective of this project is to develop an economic gasification / fermentation process to produce ethanol from corn stover. Process variables will be optimized and a detailed design and cost projection prepared for the integration of a conventional grain alcohol plant with the stover and ethanol facilities. Stover gasification experiments will be conducted in the BRI Gasifier where conditions to maximize the CO and H<sub>2</sub> concentrations in corn stover syngas will be sought to optimize ethanol production by fermentation. Syngas produced from stover gasification will be used in the gas fermentation. Fermentation subtasks include syngas clean-up, the fermentation experiments, emissions measurement and by-product utilization. Economic projections will be prepared, including a process design and economic analysis and a detailed energy balance.

#### **Accomplishments (FY05-current):**

Task A. Stover Gasification. The current method utilized by farmers is to bale the stover for alternative cattle feed. They use round bales and square bales. We have utilized round bales bound either with string or with wrap. The wrapped bales are easier to handle and are co-fed with wood chips into our grinder, which reduces the size and mixes the two feeds. This mixture has proven to flow without much difficulty through our feed conveyors and dryer.

The cost of delivered corn stover has been investigated by CVEC to be about \$35 to 40 per ton delivered within a 30 mile radius. Recently we have priced early summer square baled stover to be \$40 per ton before delivery costs.

Gasification in our pilot 1 ton per day gasifier (120 lbs/hr) works best with the stover after rough grinding. The grinding serves to reduce the variation in size to provide a more dense feed. Wood chips are being added at a ratio of 50 percent by weight. Stover availability seemed to be in short supply, so the chips extend the life of the stover without adding much volume. By volume, the stover to chip ratio is 3 to 1. The chips may also help alleviate bridging within the gasification bed. Experience with sugar cane bagasse required considerations for bridging and stover may also.

Therefore, at this time, the focus has been on long operating periods with the stover / wood chip mix to refine gasifier operating parameters to maintain high CO concentrations and to ferment the gas generated. Carbon monoxide concentrations of over 30 percent have been demonstrated during the last two month period.

This task is scheduled to be completed by September 2007.

Task B. Syngas Fermentation. Gas clean-up by water scrubbing has permitted successful fermentation of syngas generated from wood chips, sugar cane bagasse, corn stover and mixtures thereof. The focus of the fermentation has been to maintain a productivity of 40 g/L/day or higher and doing so over long periods of time to demonstrate the suitability of the gas, reaction to gas contaminants and changes in gas composition. Theoretical productivity of over 50 g/L/day has been demonstrated over the last two months.

This task is scheduled to be completed by April 2008.

Task C. Economic Projections. This task is being delayed until sufficient data from the pilot plant is available to pursue preliminary design and cost projections.

This task is scheduled to be completed by August 2008.

### **Technical Feasibility and Risks:**

#### Technical Risks

Dilute Syngas requires large downstream equipment. Air leakages into the gasifier cause syngas dilution due to the nitrogen in the air. Heat losses result in higher CO<sub>2</sub> concentrations and subsequently lower CO concentrations. These two causes can be alleviated by using oxygen enriched air and by the reduced surface to volume ratio in the larger units.

The fermentation process is continuous, therefore the gas supply must also be continuous. Downtime due to tar/soot deposition must be resolved or minimized. Mechanical failures of equipment must also be minimized.

The Fermentation productivity impacts the size of the fermentation vessels. The syngas must also be adequately scrubbed to remove materials toxic to the bacteria.

Process emissions must at a minimum, satisfy environmental regulations.

#### Business Risks

Raw Material cost and availability constraints require that the raw material be available and that the delivery cost be in an acceptable range. Alternative feedstocks will likely need to be considered due to uncertainty of annual availability.

The Scale-up uncertainties are centered around the gasifier and the fermenter. The gasifier has been in mechanical operation at the unit size envisioned (150 tons per day). The difference is that we will be operating the second stage with starved air (oxygen or oxygen-enriched air feed) to just crack the tars, not burning all the gas to completion. The fermenter scale-up will be a 10 to 1 scale-up based on reactor diameter. This is a normal scale-up ratio.

The Fuel Market needs to continue to support ethanol production. The potential market is 100 billion gpy to replace all imported liquid fuel. An ethanol price of \$2 per gallon will help ensure the financial success of the process.

### **Schedule**

Project Initiation Date: October 1, 2004  
Planned Completion Date: September 30, 2008

**Small Scale Biomass System (BioMax)**

Robb Walt, Community Power Corporation

No Project Summary Provided.

**Biomass-Derived Syngas Utilization for Fuels and Chemicals**

Santosh Gangwal, RTI International

No Project Summary Provided.

**Syngas Quality for Mixed Alcohols**

Jim White, PNNL

No Project Summary Provided.

## Pyrolysis

### Core Pyrolysis R&D

Doug Elliot, Pacific Northwest National Laboratory

Principal Investigator:	Douglas C. Elliott	Funding Partners:	collaboration with VTT (Finland) is under development
HQ Technology Manager:	Paul Grabowski	Sub-contractors:	N/A
PMC Project Officer:	John Scahill		

**Goals and Objectives:** Pyrolysis is an effective method for converting solid biomass or biomass-processing residues into liquid that can be directly used in stationary power generators, can be upgraded to gasoline-like fuel or can be used as feedstock for producing syngas by gasification. Each of these applications adds value and improves economics of the biomass to ethanol process by utilizing the whole biomass and not only the carbohydrate fraction.

**Technical Targets (i.e. cost, yield):** This project is focused on fundamental research to support the main pyrolysis barrier to develop “new methods to control the pyrolytic pathways to bio-oil intermediates in order to increase product yield and recovery.” As this is a new area for research, the specific targets have not been instituted for pyrolysis and will be developed as part of the FY07 effort in this project.

**Project Description:** The objective of this work is to develop improved pyrolysis systems for production of liquid fuels from biomass. PNNL will evaluate the use of innovative catalysts and processing conditions for modifying bio-oil composition. The research will also examine products from bio-oil through modified pyrolysis techniques including in-situ catalysis. Research will also examine pyrolysis oil components which can be recovered in an aqueous phase.

The experimental work will use innovative catalysts and processing conditions to produce higher quality biocrude oils during biomass pyrolysis. The high oxygen content and reactivities of current technologies require significant stabilization and upgrading of the biocrude before it can be used as a refinery feedstock. Improved methods to create higher quality oil during the pyrolysis step would result in a product that could be fed directly to petroleum refineries with little or no stabilization or pretreatment.

The project includes tasks for development of a base-case design of pyrolysis to liquid fuels, experimental work in a bench-scale unit, participation in the IEA pyrolysis activity, and support for standards development.

**Accomplishments (FY05-current):** A base-case design study is underway and should be completed by the end of FY07. It will provide a basis for comparison with other biomass conversion systems and a means to assess the utility of this processing option and to evaluate the process options to allow a means to focus on parameters of importance.

A bench-scale fast pyrolysis reactor will be assembled at PNNL for production of modified bio-oils for analysis and evaluation for products recovery. The unit is currently under construction with final design of remaining elements to be completed shortly.

This project also includes participation in the IEA Bioenergy Pyrolysis Task. The semiannual meetings include the PI in workshops with European experts in the field. The PI is also the lead of an element on Biorefinery within the international collaboration. The Biorefinery effort includes preparation of techno-economic assessments of 4 scenarios for a pyrolysis-based biorefinery and organization of a lignin pyrolysis round-robin, which is underway.

In addition, the project includes a task to support the establishment of standards for bio-oil within the ASTM structure. The draft standard, produced by the industrial participant Dynamotive with input from the national labs and others, has been reviewed by ASTM and is being revised.

**Technical Feasibility and Risks:** Benchmarking Pyrolysis processes to produce hydrocarbon liquid fuels designed for achieving \$1.07/gal ethanol-equivalent by 2012 will be a goal using a basecase design study, which is being drafted. Through experimental work we hope to demonstrate and validate pyrolysis performance of appropriate feedstocks meeting process design targets.

Process integration options should provide opportunities for process consolidation to improve technical and economic feasibility. A systems approach will be used to identify relative importance of identified technical barriers.

Scalability of operation will be evaluated from 200 to 2000 tpd. Potential exists for cost reduction of biomass pyrolysis systems through economy of scale incorporating petroleum refinery infrastructure. Feedstock cost, handling, processing, and bio-oil cost, handling, processing elements will all play a role.

Specific to this project, bench-scale studies provide fundamental data for relatively low cost and low risk and can explore a wide range of experimental conditions in a reasonable time frame to focus process optimization of demonstration projects.

**Remaining challenges to be assessed include:**

- Variability of bio-oil composition,
- Inorganic impurities,
- Long-term catalyst performance.

**Schedule**

Project Initiation Date: October 01, 2006  
Planned Completion Date: September 30, 2010

## Core Pyrolysis R&D

Doug Elliot, PNL

Principal Investigator:	Stefan Czernik	Funding Partners:	N/A
HQ Technology Manager:	Paul Grabowski	Sub-contractors:	N/A
PMC Project Officer:	John Scahill		

**Goals and Objectives:** Pyrolysis is an effective method for converting solid biomass or biomass-processing residues into liquid that can be directly used in stationary power generators, can be upgraded to gasoline-like fuel or can be used as feedstock for producing syngas by gasification. Each of these applications adds value and improves economics of the biomass to ethanol process by utilizing the whole biomass and not only the carbohydrate fraction.

**Technical Targets (i.e. cost, yield):** Technical targets for pyrolysis R&D are being developed in collaboration by NREL and PNNL. A draft document proposes the following FY2007 targets for bio-oil: yield of 53%, oxygen content 35%, acid number 150, carbonyl content 5 mol/kg, and hydrocarbon fuel yield of 75 gal/ton biomass. For 2012 these targets are respectively: 67%, 15%, 25, 2 mol/kg, and 90 gal/ton biomass. Pyrolysis design case report to provide benchmark baseline technology for cost targets and R&D goals will be completed by the end of FY2007.

**Project Description:** The goal of this project is to improve the quality of biomass pyrolysis oil (bio-oil) that will result in more efficient converting biomass to gasoline-type fuel. The main barriers for using bio-oil in refineries (adaptation of hydrotreating process to bio-oil being developed by UOP) are its instability and high acid content. Therefore, at present, only the lignin-derived bio-oil fraction (1/3 of the whole bio-oil) is considered an acceptable refinery feedstock. This effort focuses on improving bio-oil properties that will make possible using the whole bio-oil in the hydrotreating process, which will produce more biomass-based gasoline.

The pH of bio-oils is about 3 and results from the presence of organic acids of which acetic acid is the most abundant. 1 kg of bio-oil includes 1.5-2 moles of carboxylic acid groups. The acidity implies corrosive behavior to mild steel and promotes unwanted reactions of polymerization and condensation that lead to increase in molecular weight and a consequent increase in viscosity on storage. The most abundant compounds in bio-oil are aldehydes and ketones, with 5-6 moles of carbonyl groups per 1 kg bio-oil. Those compounds readily react between themselves and with other bio-oil components, especially in the presence of acids, to form unwanted large molecules. The destruction of acidity and prevention of molecular weight growth is the goal of the proposed upgrading process. The idea is to react organic acids and aldehydes in bio-oil with small molecular weight alcohols (methanol, ethanol) and convert them respectively in esters and acetals. This will remove acidity and improve chemical stability by preventing further reactions between functional groups attached to larger molecules. The reaction of bio-oil with alcohols can be carried out both in liquid phase using condensed bio-oil and in vapor phase using pyrolysis vapors before condensation of bio-oil. The first approach is compatible with the existing pyrolysis processes (Ensyn, DynaMotive) and will require an additional reactor for upgrading bio-oils as currently produced. The second approach involves a modification to the pyrolysis system with a catalytic gas-phase reactor installed before the condensation train, which may be more challenging but more innovative and potentially more advantageous.

**Accomplishments (FY05-current):** This effort will focus on the effectiveness of reacting selected alcohols (methanol, ethanol, glycerol, etc.) with high temperature pyrolysis vapors to convert acids to esters. A review of the literature will validate this approach and identify other potential chemical reactions that can be targeted. In addition, supporting experiments will be conducted with molecular beam mass spectrometer systems in conjunction with variable, high temperature flow reactors. The goal is to evaluate the effect of pyrolysis temperature, reaction temperature, alcohol (methanol, ethanol, and glycerol) addition, and feedstock cellulose, lignin, poplar, and corn stover). One hypothesis that will be tested is whether the carbohydrate fraction of biomass pyrolysis vapors reacts with alcohols to make esters and whether or not the lignin-derived pyrolysis products are unreactive or inhibit the carbohydrate reactions.

Task 1. Literature Review to evaluate reactions of methanol, ethanol and glycerol. Explore other potential additives to concentrate species in modified bio-oil

Task 2. Preliminary scoping experiments with bench-scale flow reactors to determine the effects of high temperature alcohol addition on biomass pyrolysis products

Title of task, subtask or milestone	Status of Progress in Task or Milestone	Approved Updated Completion Date	Task or Milestone Completion Criteria (to include cost and performance metrics)
Opportunities for Biomass Pyrolysis - Scenario Analysis	On schedule, progress positive or work completed	30-Sep-07	Develop Quantitative Technical R&D Targets for Biomass Pyrolysis Technologies through 2012 - This analysis will provide the basis for developing R&D Targets for out-year milestones

The literature review was conducted to determine the existing state-of-the-art methodologies that are currently known for esterification and acetalization reactions. These reactions are expected to remove unwanted acidity and improve stability of bio-oil. Our experiments with a mixed hardwood bio-oil so far have shown that the acidity can be reduced by more than 60% during the simple azeotropic removal of water from the crude bio-oil, while over 30% of volatile carbonyl compounds were also removed from the oil. Treatment of the bio-oil with lower alcohols, *i.e.* methanol, ethanol and butanol, using acid catalysts such as *p*-toluenesulfonic acid (a homogeneous acid) or Amberlyst-15 (a solid acid resin) led to near-quantitative removal of the carboxylic acids, and also up to 70% reduction in free carbonyl compounds. While this clearly surpasses our initial goal, we decided to further expand our 'proof-of-concept' to the use of polyols such as glycerol and ethylene glycol. Preliminary experiments showed that these polyols not only promoted near-quantitative removal of the acidity of the bio-oils, but also removed up to 90% of the free carbonyl concentration. The use of glycerol is particularly interesting because this polyol is in need of large market outlets as it is an abundant by-product of the biodiesel industry. We are currently focusing on the analysis of the various distillates and oil residues in order to better understand the underlying chemistry of the reactive distillations.

#### Technical Feasibility and Risks:

At present, unknown is a potential impact of feedstock composition variability, especially of inorganic impurities on the pyrolysis yields and on the upgrading catalyst performances.

#### Schedule

Project Initiation Date: October 01, 2006  
 Planned Completion Date: September 30, 2007



## Pyrolysis Oil to Gasoline

Richard Marinangeli, UOP

Principal Investigator:	Richard L. Bain (NREL), Doug Elliott (PNNL), Richard Marinangeli (UOP)	Funding Partners:	N/A
HQ Technology Manager:	Paul Grabowski	Sub-contractors:	N/A
PMC Project Officer:	John Scahill		

**Goals and Objectives:** In the DOE report "Opportunities for Biorenewables in Oil Refineries," refined pyrolysis oils were shown to have the potential to replace a significant portion of transportation fuels. This thermal processing route can effectively utilize a vast majority of the 1 billion tons of biomass projected to be available in the United States, including those feedstocks unsuitable for fermentation. The pyrolysis pathway therefore provides the opportunity for increasing the impact of biofuels while leveraging existing processing and distribution systems. The short term option produces gasoline and refinery fuel, while longer term advanced thermal conversion configurations may have the potential to produce both gasoline and ethanol. The project supports the 30 x 30 goal of replacement of 30% of 2005 gasoline with renewable fuels by 2030 and supports the \$1.07 goal by investigating alternative higher value uses of lignin rich streams in a biochemical biorefinery.

### Thermochemical Pyrolysis (Gasoline) Targets:

- Pyrolysis Oil to biocrude (58 wt% conversion) (2009)
- Stabilization of Dry biomass by hydrotreating (TAN < 100)
- Upgrading to Finished Fuel 82 galHC/ton (2009)

**Project Description:** The objective of this project is to upgrade biomass pyrolysis oils to petroleum refinery feedstocks in a cost-effective manner. Pyrolysis-derived biooils are relatively inexpensive to produce, but there is little market for the resulting crude bio-oil. Selective hydroprocessing will be used generate a higher value biocrude and the biocrude will be converted to biofuels.

### Accomplishments (FY05-current):

- Bio Oil prepared from mixed wood and corn stover
- Four bio-oil feedstocks have been processed through hydrotreating and hydrocracking process steps to examine processing conditions and determine product yields and composition.
- Intermediate stabilized bio-oil has been recovered and analyzed
- A fungible fuel product has been made from lignocellulosic waste
- Data base developed for pyrolysis, hydrotreating, hydrocracking and fuel properties
- Detailed results from these tests provide the basis for assessment of the process concept and the determination of process costs.
- LCA in progress

### Technical Feasibility and Risks:

Potential Issue:	Mitigation
Yield loss to char and gas:	Improved T control, Metals removal, Catalyst development
Corrosion:	Stabilization of raw oil, Improved metallurgy
Unknown deactivation mechanism:	Analysis of deactivated catalyst during development stage
Poor fuel quality:	Use as feedstock to upgrading process

### Schedule

Project Initiation Date: April 01, 2006  
Planned Completion Date: Dec 31, 2007

**Developing Thermal Conversion Options for Biorefinery Residues**

Vann Bush, Gas Technology Institute

Combine with Previously Reviewed Project – Page XX.

**Mississippi State University Sustainable Energy Center (MS)**

Phil Steele, Mississippi State University

No Project Summary Provided.

**Applications of Thermo-Depolymerization Technology**

Thomas Butcher, Brookhaven National Laboratory

No Project Summary Provided.