Final Report

Sections 1-3 Administrative Data

DOE Award#: DE-FG02-07ER46373
Institution: The University of Maine, Orono, ME
Title: Thermochemical Conversion of Woody Biomass to Fuels and Chemicals
Principal Investigator: Dr. Hemant P. Pendse
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Section 4-DOE Laboratories and Collaborators
Brookhaven National Laboratory – Dr. Ping Liu
Oak Ridge National Laboratory – Dr. Yuri Menichenco, Dr. Souleymane Omar Diallo

Section 5-Abstract (Project Goals and Objectives)

Maine and its industries identified more efficient utilization of biomass as a critical economic development issue. In Phase I of this implementation project, a research team was assembled, research equipment was implemented and expertise was demonstrated in pyrolysis, hydrodeoxygenation of pyrolysis oils, catalyst synthesis and characterization, and reaction engineering. Phase II built upon the infrastructure to innovate reaction pathways and process engineering, and integrate new approaches for fuels and chemical production within pulp and paper and other industries within the state. This research cluster brought together chemists, engineers, physicists and students from the University of Maine, Bates College, and Bowdoin College. The project developed collaborations with Oak Ridge National Laboratory and Brookhaven National Laboratory. The specific research projects within this proposal were of critical interest to the DoE - in particular the biomass program within EERE and the catalysis/chemical transformations program within BES.

Scientific and Technical Merit highlights of this project included: (1) synthesis and physical characterization of novel size-selective catalyst/supports using engineered mesoporous (1-10 nm diameter pores) materials, (2) advances in fundamental knowledge of novel support/ metal catalyst systems tailored for pyrolysis oil upgrading, (3) a microcalorimetric sensing technique, (4) improved methods for pyrolysis oil characterization, (5) production and characterization of woody biomass-derived pyrolysis oils, (6) development of two new patented bio oil pathways: thermal deoxygenation (TDO) and formate assisted pyrolysis (FASP), and (7) technoeconomics of pyrolysis of Maine forest biomass.

This research cluster has provided fundamental knowledge to enable and assess pathways to thermally convert biomass to hydrocarbon fuels and chemicals. In particular, we focused on a conversion scheme that involves pyrolysis and hydrodeoxygenation (HDO) as shown generally in Figure 1.

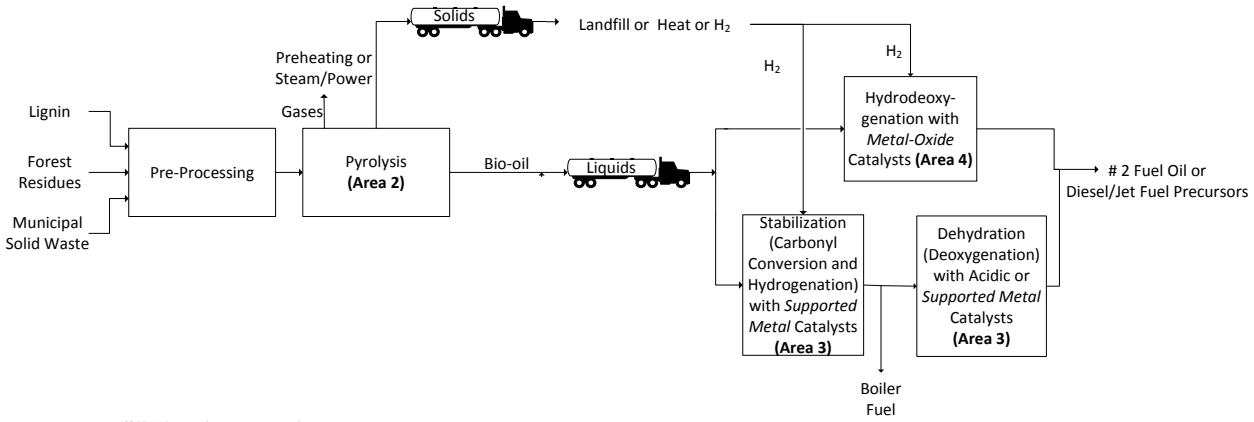

Figure 1. Thermal conversion of biomass pathways to various products integrating Cluster research Areas.

In Figure 1, low density feedstocks such as forest residues and municipal solid wastes are processed to appropriate size and water content. These products are then further upgraded to reduce oxygen content and achieve fuel-specific properties. A recent PNNL report presented a summary of fifteen research and development needs to achieve the potential for producing hydrocarbon fuels from biomass.[1] Our research addressed seven of these needs, specifically:

- Understand pyrolysis economics for Maine forest biomass.
- Improve the quality and consistency of bio-oil.
- Determine detailed characterization of upgraded oil and products.
- Conduct catalyst life studies for the pyrolysis oil upgrading catalysts.
- Pyrolysis including *in-situ* catalysis.
- Post pyrolysis processing to improve product bio-oil properties.
- Post-process separations and subsequent treatment to produce improved products.

[1] Jones, S. B.; Valkenburg, C.; Walton, C. W.; Elliott, D. C.; Holladay, J. E.; Stevens, D. J.; Kinchin, C.; Czernik, S., Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case. U. S. Department of Energy, P. N. N. L., Ed. 2009; pp 1-76.

Section 6-Accomplishments

Techno-Economic Analyses (TEA)

- The techno-economics for producing liquid fuels from Maine forest residues were determined from a combination of: (1) laboratory experiments at USDA-ARS's Eastern Regional Research Center using hog fuel from a pulp mill biomass boiler to establish product yields and composition, and (2) Aspen Plus® process simulation for a feed rate of 2000 dry metric tons per day to estimate energy requirements and equipment sizes. The simulated plant includes feedstock sizing and drying, pyrolysis, hydrogen production and hydrotreatment of pyrolysis oils. The biomass is converted into bio-oil (61% yield), char (24%) and gases (15%) in the pyrolysis reactor, with an energy demand of 17%.The bio-oil is then hydrotreated to produce hydrocarbon fuels. The final mass yield of gasoline/diesel hydrocarbons is 16% by mass with a 40% energy yield based on the dry biomass fed. A unique aspect to the simulation is that pyrolysis char and gases are used as sources for both thermal energy and hydrogen. The total capital investment for a grass-roots plant was estimated to be US$268 MM with an annual cost of manufacturing of US$130 MM. With a 20 year project life, a minimum fuel selling price was determined to be US$5.08 per gallon. The economic concerns are related to low pyrolysis yields and short hydrotreating catalyst lifetimes.
- Technoeconomics were also evaluated for a 2000 dry metric ton per day Formate Assisted Pyrolysis Plant. The model included feedstock sizing and drying, pyrolysis, hydrogen production and hydrotreatment of FAsP oils, and recycle of calcium. Char and pyrolysis gases were used to provide process heat and hydrogen. The process yields were 18 wt% gasoline/diesel and 42% energy yield based on the dry biomass fed. The total capital investment for a grass-roots plant was estimated to be US$276 million with an annual cost of manufacturing of US$171 million. With a 20 year project life, a minimum selling price for hydrocarbon fuel was determine to be US#3.91 per gallon with a 15% return on investment.

Fast Pyrolysis of Maine-based Feedstocks

- A study on the effects of processing conditions on the stability of fast pyrolysis oils was conducted. Instability of pyrolysis oil during aging is a significant issue for commercialization of pyrolysis technologies on an industrial scale. Hot gas filtration of pyrolysis vapors before condensation has been shown to dramatically improve the stability of pyrolysis oils. Detailed chemical analysis of oils produced under various hot gas filter temperatures and vapor residence times shows that the chemical composition of pyrolysis oil changes significantly when hot gas filtration is employed. Compounds which are known to cause instability are eliminated and more stable compounds are formed. This information provides insight into the mechanisms responsible for the stabilization of pyrolysis oils when hot gas filtration is employed.
- A study was conducted on the effects of various calcium salts (calcium hydroxide, calcium formate, calcium carbonate and calcium sulfate) had on pyrolysis when used as feed pretreatment. Pretreated pine sawdust was pyrolyzed in a fluidized bed pyrolysis reactor at 500 °C. The catalytic action of the calcium compounds varied depending on the anion. Analysis of pyrolysis gas, liquid and char yields and compositions demonstrated that calcium sulfate is inert during pyrolysis while calcium formate, carbonate, hydroxide and oxide show

significant deoxygenation activity. In addition to deoxygenation, the oils were more stable. Of the salts which showed deoxygenation activity, calcium formate had the highest relative yield. This effect is likely attributable to the activity of calcium formate as a hydrogen donor at the pyrolysis temperature. These properties allow for milder upgrading to remove the remaining oxygen, thus decreasing the mass loss and economic penalty associated with hydrotreating.

- An additional study was conducted in collaboration with the Technology Development Unit in Concepcion Chile. Pyrolysis of untreated and pre-treated tannins obtained from *Pinus radiata* bark was studied and the resulting products were analyzed. Tannins present unique challenges for fast pyrolysis because their thermophysical properties cause agglomeration issues during feeding. Pretreatment of tannins with calcium hydroxide and calcium formate enabled continuous feeding and allowed for the quantification of product yields at the bench scale. In addition, the pretreatment changed the chemical composition of the liquid product. This bench-scale work demonstrates the viability of producing renewable chemicals from tannin feedstocks.
- The effect of calcium pretreatment on pyrolysis of individual lignocellulosic compounds was studied to elucidate possible chemical pathways to producing a deoxygenated bio-oil. Previous work has demonstrated that the incorporation of calcium compounds with the feedstock prior to pyrolysis has a significant effect on the oxygen content and stability of the resulting oil. The aim of this work was to further explore the chemistry of calcium-catalyzed pyrolysis. Bench-scale pyrolyis of biomass constituents, including lignin, cellulose and xylan was performed and compared to the oils produced from pyrolysis of the same components after calcium pretreatment. The resulting oils were analyzed by quantitative GC-MS and SEC. These analyses, together with data collected from previous work provide evidence which was used to develop proposed reaction pathways for pyrolysis of calcium-pretreatment biomass.

Pyrolysis Oil Aging and Product Characterization

- Pyrolysis oils are viscous, unstable and need to be upgraded to use as transportation fuels. Previous studies of bio oil stability show that polymerization occurs, and a few of the chemical compounds that react during aging are known, but the classes of reactive compounds, types of reactions and products are not known. Understanding the reactions that cause aging is crucial to prevent aging processes. Our chemical analysis identified aldehydes, trihydroxy benzenes and guaiacols with conjugated propylene side chains that react during accelerated aging. We suggest that an acid catalyzed oligomerization mechanism, through a quinone methide pathway, leads to the reactivity of conjugated aromatic molecules.
- As an approach to stabilize bio-oil, methanol addition has proven to increase the stability of the bio-oil. But very little is known about the reaction of bio-oil components with methanol. We employed isotope labeling to study the reactions using NMR, gas chromatography/mass spectrometry (GC/MS) and gel permeation chromatography (GPC). Labeling studies provide direct evidence of esterification and acetal formation.
- The identification and quantitation of organic compounds in complex mixtures by GC/MS is adversely affected by co-elution, column bleed and ionizer contaminants. Manual deconvolution, to purify mass spectra, is very labor intensive, but necessary to correctly identify compounds. The Automated Mass Deconvolution and Identification System (AMDIS) associates peaks in extracted ion chromatograms to create “components,” whose mass spectra can be matched in a library search. However, many compounds have similar

mass spectra and aren't uniquely identified. We created a library of mass spectra and retention indices (RI) for standards and evaluated AMDIS for identifying compounds in pyrolysis oils. Although a high match factor criterion (>80) avoids false positives, the false negative rate is significant. We propose that, by lowering the mass spectral match criterion and imposing a statistically-based RI window, the rate of false positives and negatives can be decreased and simultaneously increase the rates of true positives and negatives.

Thermal DeOxygenation

- Thermal Deoxygenation (TDO) refers to a simple, non-catalytic, process which produces deoxygenated crude oils from biomass feedstock. The primary reaction is a single-step decomposition which converts calcium-neutralized biomass hydrolyzate to crude hydrocarbons at 450°C under an inert atmosphere at ambient pressure. The TDO reaction was applied to calcium-neutralized hydrolyzate produced by the Biofine® process consisting of levulinic acid (82 wt. %), formic acid (1.4 wt. %), ash (1.9 wt. %) and water. Molar ratios of formic acid to levulinic acids were modified from 0.042:1 to 1:1 to compare process yields and oil chemistry. The crude feedstock was found to be suitable for TDO processing which yielded shelf-stable crude hydrocarbons with very low water miscibility (<1.0 wt. %) and oxygen content (<2 wt %). Total acid number of the oils were low (<1.32 g KOH/kg oil) and had a boiling point distribution according to High Temperature SIMDIS between 75° and 585°C. A reagent crude oil of 1:1 molar ratio formate to levulinate was subsequently characterized for combustion and emission properties as a 50/50 vol. % blend with ultra-low sulfur diesel. The resulting fuel blend required intake air heating to 100°C to achieve high combustion efficiency. Emission and combustion behavior is consistent with low cetane fuels.
- The chemistry and upgrading potential of TDO oils derived from calcium and magnesium neutralized levulinate/formate mixtures was explored. Crude TDO oils were prepared using a 50 liter semi-batch reactor and analyzed for component chemistry and physicochemical properties. The TDO oils contain a broad distribution of mono- and poly-aromatic hydrocarbons with a H:C ratio of 1:1. Crude oils were hydrotreated in a vertical down flow tubular reactor using commercially-available Ni/SiO_2-Al_2O_3 catalyst. Sustained yields of 90+ wt. % were achieved over 700 hours operating without catalyst regeneration. Products were identified by GC-MS to contain primarily naphthenes, mono-aromatics, partially saturated poly-aromatics and only trace oxygenates. Hydrotreated oils were distilled into naphtha, jet, kerosene, diesel and residual fractions and analyzed using ASTM methods for fuel properties. Results indicate that upgraded TDO oils are suitable as blend stocks for reformulated fuels.
- Oxidation of soda-anthraquinone black liquor was investigated to determine if a lower-molecular weight starting material would be desirable for thermal deoxygenation and/or fast pyrolysis. It was determined that the organic yield was negatively affected and would no longer be investigated. Fast pyrolysis experiments using soda-anthraquinone black liquor were conducted and it was shown that the organic yield could be improved when sodium formate was added to the feedstock while maintaining a similar product distribution. DOE funding was used to purchase materials and supplies for these experiments.

Metal Based Hydrodeoxygenation Catalysts in Mesoporous Supports

- Substituted phenols are the most recalcitrant oxygenates in conventional pyrolysis oils and the dominant oxygenates in lower-oxygen content, formate-assisted pyrolysis oils (FAsP). Ru

catalysts with a wide range of dispersion on carbon, silica, alumina, and titania supports were synthesized, characterized and evaluated for hydrodeoxygenation (HDO) activity using phenol as a model compound. Metal con-tent, phase, and particle size were determined with ICP-OES, EXAFS/XANES, and CO pulse chemisorption, respectively. High dispersion of ruthenium on the supports converts more phenol to products. The majority of catalysts predominantly catalyze the hydrogenation (HYD) route typical of noble metal catalysts. A highly dispersed Ru/TiO2catalyst shows unusually high selectivity toward direct deoxygenation (DDO) and outstanding activity. We initially suggested that the DDO pathway on titania involves a bifunctional catalyst, where hydrogen creates reduced titania sites, created by hydrogen spillover, that interact strongly with the phenol hydroxyl group. Follow up work, however, that utilized isotopically-labeled substrates and co-solvents, coupled with a new collaboration with a computational chemical engineer (Professor Lars Grabow, University of Houston), lead to the development of a new hypothesis that was well-supported by both experimental and computational work. We now propose that catalysts comprised of highly dispersed Ru particles on TiO_2 effectively catalyze the direct deoxygenation of phenol by a mechanism in which the heterolytic splitting of hydrogen is assisted by a basic surface hydroxyl on titanium. The heterolytically-split hydrogen effectively forms a metal hydride on ruthenium that directly displaces the hydroxyl on phenol. That hydroxyl is made a better leaving group by protonation from the acidic water on titanium that was also formed from the heterolytic splitting of hydrogen. Calculations show that this mechanism, which preferentially occurs in aqueous environments, is the lowest energy pathway of all pathways calculated. These results suggest that it is the amphoteric nature of TiO_2 coupled with ruthenium's proclivity to react with hydrogen that contribute to making these catalysts so selective. The work has clear implications for the scale of up catalytic HDO.

Reducible Metal Oxide based HDO Catalysis

- Reduced tungsten oxide bronzes, H_xWO_{3-z}, are a new class of heterogeneous catalysts for hydrodeoxygenation of bio-fuels. In the proposed mechanism, both Brønsted and Lewis acid sites are involved. The Brønsted and Lewis acidity of tungsten oxide bronzes as a function of reduction temperatures was investigated by Diffuse Reflectance Infrared Fourier Transform Spectroscopy (DRIFTS). During hydrogen reduction to form the bronze, electrons from both dissociative hydrogen adsorption and reduction of the oxide occupy the conduction band making the bronze semi-metallic and opaque, which limits the utility of transmission FTIR spectroscopy. Using high surface area porous tungsten oxide materials and DRIFTS, we overcame this limitation and used pyridine adsorption to probe the surface acidity for bronzes prepared at temperatures up to 300 °C. Our results showed low Brønsted acidity for WO_3 before reduction and WO_3 reduced at low temperatures. The Brønsted to Lewis acidity ratio increases continuously as a function of reduction temperature.
- Previous studies have shown that reduced tungsten oxide hydrogen bronze catalysts showed high activity in the conversion of acrolein to allyl alcohol, propene, propanol, and propanal in a packed bed reactor at atmospheric pressure. We reported the effect of the activation temperature on conversion of guaiacol in hydrocarbon solvents over reduced tungsten oxide catalysts in a trickle bed reactor. The activity depends strongly on the temperature of activation in hydrogen. Tungsten oxide presented high guaiacol conversion with phenol as the main product, with lesser amounts of toluene, methanol, benzene, cyclohexene and cyclohexane.

Section 7-Publications in Which DOE is Acknowledged

Peer Reviewed Articles (reverse chronological order)

1. Ryan Nelson, Byeongjin Baek, Pamela Ruiz, Ben Goundie, Ashley Brooks, M. Clayton Wheeler, Brian G. Frederick, Lars C. Grabow, and Rachel Narehood Austin, "Experimental and Theoretical Insights into the Hydrogen-Efficient Direct Hydrodeoxygenation Mechanism of Phenol over Ru/TiO_2," ACS Catalysis, 2015, http://dx.doi.org/10.1021/acscatal.5b01554.
2. Scott J. Eaton , Sedat H. Beis , Sampath A. Karunarathne , Hemant P. Pendse , and M. Clayton Wheeler; "Hydroprocessing of Biorenewable Thermal Deoxygenation Oils," Energy Fuels, 2015, 29 (5), pp 3224–3232.
3. P.A. Case, M.C. Wheeler, and W.J. DeSisto, "Formate assisted pyrolysis of pine sawdust for in-situ oxygen removal and stabilization of bio-oil," Bioresource Technology 09/2014; **173**:177–184.
4. Case, P.A.; Wheeler, M.C.; and DeSisto, W.J.; Effect of residence time and hot gas filtration on the physical and chemical properties of pyrolysis oil, *Energy & Fuels*, **28**, 3964-3969, (2014).
5. Case, P.A.; Bizama, C.; Segura, C.; Wheeler, M.C.; Berg, A.; and DeSisto, W.J.; Pyrolysis of pre-treated tannins obtained from radiata pine bark, *Journal of Analytical and Applied Pyrolysis*, **107**, 250-255 (2014).
6. C. Newman, X. Zhou, B. Goundie, I.T. Ghampson, R.A. Pollock, Z. Ross, M.C. Wheeler, R.W. Meulenberg, R.N. Austin, B.G. Frederick, "Effects of support identity and metal dispersion in heterogeneous ruthenium hydrodeoxygenation catalysts," Appl. Catal. A-General, 477 (2014), 64-74.
7. S.J. Eaton, S.H. Beis, B.G. Bunting, S.W. Fitzpatrick, G.P. van Walsum, H.P. Pendse, and M.C. Wheeler, "Characterization and Combustion of Crude Thermal Deoxygenation Oils Derived From Hydrolyzed Woody Biomass," Energy & Fuels, **27** (9), 5246-5252 (2013).
8. N. Hammer, A. Boateng, C. Mullen, and M. C. Wheeler, "Aspen Plus and Economic Modeling of Equine Waste Utilization for Localized Hot Water Heating via Fast Pyrolysis," J. Env. Mgmt., 128, 594-601 (2013).
9. R. A. Pollock, G. Y. Gor, B. R. Walsh, J. Fry, I. T. Ghampson, Y. B. Melnichencko, H. Kaiser, W. J. DeSisto, M. C. Wheeler, and B. G. Frederick; "Role of Liquid vs Vapor Water in the Hydrothermal Degradation of SBA-15," J. Phys. Chem. C, 116, 22802-22814 (2012).
10. I.T. Ghampson, C. Sepulveda, R. Garcia, J. L. Fierro, N. Escalona, W. J. DeSisto; "Comparison of alumina- and SBA-15-supported molybdenum nitride catalysts for hydrodeoxygenation of guaiacol," Appl. Catal. A, 435, 51-60 (2012).
11. I.T. Ghampson, C. Sepulveda, R. Garcia, L.R. Radovic, J. L. Fierro, W. J. DeSisto, N. Escalona; "Hydrodeoxygenation of guaiacol over carbon-supported molybdenum nitride catalysts: Effects of nitriding methods and support properties," Appl. Catal. A, 439, 111-124 (2012).
12. P. Ruiz, B. G. Frederick, W. J. DeSisto, R. N. Austin, L.R. Radovic, K. Leiva, R. Garcia, N. Escalona, and M. C. Wheeler; "Guaiacol hydrodeoxygenation on MoS_2 catalysts: Influence of activated carbon supports," Catal. Commun., 27, 44-48 (2012).
13. I. T. Ghampson, C. Sepúlveda, R. Garcia, B. G. Frederick, M. C. Wheeler, N. Escalona, and W. J. DeSisto; "Guaiacol transformation over unsupported molybdenum-based nitride catalysts," Appl. Catal. A, 413, 78-84 (2012).

14. S. Mukkamala, M.C. Wheeler, A.R.P. van Heiningen and W.J. DeSisto, Formate-Assisted Fast Pyrolysis of Lignin, Energy Fuels, 26 (2), pp 1380–1384 (2012).
15. P.A. Case, A.R.P. van Heiningen and M.C. Wheeler, "Liquid hydrocarbon fuels from cellulosic feedstocks via thermal deoxygenation of levulinic acid and formic acid salt mixtures," Green Chem. 14 (1), 85 – 89 (2012).
16. C. Sepúlveda, K. Leiva, R. García, L.R. Radovic, I. Ghampson, W. DeSisto, J. L. García Fierro, N. Escalona, "Hydrodeoxygenation of 2- methoxyphenol over activated carbon supported Mo_2N catalysts," Catalysis Today, 172 (2011) 232-239.
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24. Thibodeau, T. J.; Canney, A. S.; DeSisto, W. J.; Wheeler, M. C.; Amar, F. G.; Frederick, B. G., Composition of Tungsten Oxide Bronzes Active for Hydrodeoxygenation. Appl. Catal.A, 388 (2010) 86-95.
25. I.T. Ghampson, C. Newman, L. Kong, E. Pier, K. D. Hurley, R. A. Pollock, B. R.Walsh, B. Goundi, J. Wright, M. C. Wheeler, R. Meulenberg, W.J. DeSisto, B. G. Frederick, R.N. Austin, "Effects of pore diameter on particle size, phase, and turnover frequency in mesoporous silica supported cobalt Fischer-Tropsch catalysts," Appl. Catal.A 388 (2010) 57-67.
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27. D. R. Moberg, T. J. Thibodeau, F. G. Amar, B. G. Frederick, "Mechanism of Hydrodeoxygenation of Acrolein on a Cluster Model of MoO3", J. Phys. Chem. C, 114 (2010), 13782-13795.

Patents

1. U.S. patent 8,362,306 (2013) “Energy densification of biomass-derived organic acids”, M. C. Wheeler, G.P. Van Walsum, T.J. Schwartz, and A.R.P. van Heiningen.
2. U.S. patent 8,981,168 (2015) “Formate Assisted Pyrolysis,” W.J. DeSisto, M.C. Wheeler, and A.R.P. van Heiningen.
3. U.S. patent 9,120,712 (2015) "Process for improving the energy density of feedstocks using formate salts," M.C. Wheeler, A.R.P. van Heiningen, and P.A. Case. (International patents pending)

Manuscripts in preparation:

1. T. J. Thibodeau, C. M. Goodwin, F. G. Amar, B. G. Frederick, “Mechanism of Hydrodeoxygenation of Acrolein on a Cluster Model of WO_3.”
2. T. J. Thibodeau, F. Wang, C. Di Valentin, G. Pacchioni, A. Vidal Sandrea, P. Liu, F. G. Amar, B. G. Frederick, “DFT Methods for Chemical Reaction Thermodynamics of Tungsten Oxides.”
3. R. A. Pollock, P. Landry, A. Hicks, S. Omar Diallo, J. R. Lareese, and B.G. Frederick “Diffusion of Methane in SBA-15 using Quasi Elastic Neutron Scattering.”
4. J. Carrasco, C.A. Mullen, A.A. Boateng, B.G. Frederick, W.J. DeSisto, R.N. Austin, and M.C. Wheeler, “Economic model for fast pyrolysis of forest biomass and pyrolysis oil upgrading.”
5. J. Joseph, J. Fecteau, M. Rasmussen, B.L. Jensen, R.N. Austin, E.A. Stemmler, B.G. Frederick, “Identification of Reactions during Pyrolysis Oil Aging,” Energy Fuels.
6. Md. Chowdhury, J. Joseph, E.A. Stemmler, B.G. Frederick, “Probing the Reactions that Stabilize Bio-oil with Methanol,” Energy Fuels.

Theses

1. Scott Eaton, Ph.D., Chemical Engineering, University of Maine, August 2015: Thermal Deoxygenation of Levulinated and Formate Salts for the Production of Transportation Fuels.
2. Jamie St. Pierre, Ph.D., Chemical Engineering, University of Maine, August 2015: Thermochemical Conversion of Spent Pulping Liquor into Value-added Products.
3. James R. Clark, “Computational Investigation of Brønsted and Lewis Acid Properties of Tungsten Oxide Clusters”, B.S. Chemistry, Univ. of Maine, June 2015.
4. Paige Case, Ph.D., Chemical Engineeering, University of Maine, May 2015: fundamentals of Pyrolysis of Pretreated Biomass
5. Sean Moran, A.B. (Honors), Chemistry, Bowdoin College, May 2015: A Study of Reactions Responsible for Instability in Pyrolysis Oils.
6. Hamad AlMohamadi, M.S., Chemical Engineering, University of Maine, December 2014: Techno-Economic Analysis of Formate Assisted Pyrolysis
7. Md. Emtias Chowdhury, M.S., Chemistry, University of Maine, December 2014: Evaluation of AMDIS to Determine Bio-Oil’s Composition and Analysis of Lignin Fast Pyrolysis Oil
8. Jincy Joseph, Chemical Composition, Aging Reactions and Stabilization of Bio-Oils, Ph.D., Chemistry, Univ. of Maine, August 2014.
9. Xiaobo Zhou, M.S., Chemistry, University of Maine, August 2014: Hydrodeoxygenation (HDO) Upgrading of Whole Pyrolysis Oil by using Ru Supported Catalyst.

10. Sally Kim, A.B. (Honors), Biochemistry, Bowdoin College, May 2014:High-Resolution Mass Analysis of Wood-Derived Bio-Oils: Using Exact Mass Measurements to Assess Compositional Changes.
11. Matthew J. Rasmussen, A.B. (Honors), Chemistry, Bowdoin College, May 2014: Pyrolyis Oil Aging Reactions: A Mass Spectrometric Investigation of Reaction Components and Reaction Products.
12. Katelyn A. Tracy, "Identification of Sugars in Fast Pyrolysis Oil", B.S. Chemistry, Univ. of Maine, May 2014. (Use of GC/MS, materials & supplies)
13. Jordan Trasko, "Kinetic Study of Tetraethoxysilane Hydrolysis in Sol-Gel Solutions Using 1H Nuclear Magnetic Resonance Spectroscopy," B.S. Chemistry, Univ. of Maine, May 2014. (Used NMR in chemistry, a few materials & supplies)
14. T. Thibodeau, Ph.D., Chemistry, 2012: Development and Mechanisms of Hydrodeoxygenation Catalsysts for Upgrading Pyrolysis Oil.
15. J. P. Fecteau, B.S. Chemistry, 2012: Pyrolysis Oil Stability: Chemical Investigation of Polymerization Reactions.
16. C. Goodwin, B.S., Chemistry, 2012: Theoretical Cluster Studies: Hydrodeoxygenation of a Cluster Model of a WO_3 Catalyst and Coalescence of Gold Nanoclusters.
17. S. Mukkamala, M.S. Chemical Engineering, 2012: Fast Pyrolysis of Lignin Biomass in Fluidized Bed Reactor.
18. R. Pollock, Ph.D., Physics, 2012: Neutron scattering studies of structure, hydrothermal stability and transport in porous silica catalyst supports.
19. R. Chen, M.S. Chemical Engineering, 2012: A study of thin film behavior using nanocalorimetry and exploration of potential application.
20. I.T. Ghampson, Ph.D. Chemical Engineering, 2011: Synthesis and characterization of catalysts for the selective transformation of biomass-derived materials.
21. Cody Newman, B. S. Chemistry (Honors) 2011: Evaluating Ruthenium Catalysts for the Hydrodeoxygenation of Fast Pyrolysis Oil
22. Daniel R. Moberg, B.S. Honors (Chemistry) May 2010: DFT Study of Molybdenum Trioxide Defect Formation and Acrolein Hydrodeoxygenation
23. Brenna Walsh, B.S. Honors (Chemistry) May 2010: Neutron Scattering to Characterize Micropore Structure in Mesoporous Silica SBA-15
24. T. Schwartz, B.S. Chemical Engineering (Honors), 2010: Energy Densification of Cellulosic Biomass by Thermal Deoxygenation.

Presentations:

1. A.Mahdavi-Shakib, J. R. Clark, F. G. Amar, B. G. Frederick, Mechanistic Studies of Reducible Metal Oxides as Hydrodeoxygenation Catalysts, ACS Summer School on Green Chemistry & Sustainable Energy, Colorado School of Mines, Golden, CO, Jun 17-24, 2015.
2. A. Mahdavi-Shakib, J. R. Clark, F. G. Amar, B. G. Frederick, "Surface Acidity of Tungsten Oxide Bronzes in the Hydrodeoxygenation Mechanism", 40th Northeast Regional Meeting of the American Chemical Society, Ithaca College, Ithaca, NY, Jun. 10-13, 2015.
3. James R. Clark, Francois G. Amar, Brian G. Frederick, "Computational Investigation of Bronsted and Lewis Acid Properties of Tungsten Oxide Clusters," 6th Annual Undergraduate Research & Creative Activities Academic Showcase, UMaine, Apr. 14, 2015
4. A. Mahdavi-Shakib, B. G. Frederick, Mechanistic Mechanistic Studies of Reducible Metal Oxides as Hydrodeoxygenation Catalysts, GradExpo, Univ. of Maine, Apr. 2-3, 2015. Awarded 3rd place, Physical Sciences & Technology Oral Competition.
5. Clayton Wheeler, UMaine Forest Bioproducts Research Institute: Transportation Biofuels, University of New Mexico Department of Chemical and Nuclear Engineering, May 1, 2015.
6. William Barclay, M. Clayton Wheeler, and G. Peter van Walsum, Hydrolysis of Biomass Using a-Hydroxysulfonic Acids, 15AIChE Spring Meeting, Austin, TX, April 28, 2015.
7. Scott Eaton and M. Clayton Wheeler, Levulinate and Formate Salt Reactions during Thermal Deoxygenation (TDO), 14AIChE Annual Meeting, Atlanta, GA, November 19, 2014.
8. Hamad AlMohamadi, William J. DeSisto and Clayton Wheeler, Techno-Economics of Formate Assisted Pyrolysis, 14AIChE Annual Meeting, Atlanta, GA, November 18, 2014.
9. Clayton Wheeler, Hydrocarbon Fuels from Biomass, Meeting of the UMaine Student Chapter of the National Society of Black Engineers, October 8, 2014.
10. B. G. Frederick, "Catalysis for bio-oil hydrodeoxygenation," Dept. of Chem. & Biological Eng., Lehigh University, Bethlehem, PA Oct. 1, 2014. (Invited talk)Clayton Wheeler, University of Maine's Forest Bioproducts Research Institute: Biofuels for Transportation, Instituto de Catalysis y Petroleoquimica, Madrid, Spain, July 9, 2014
11. S.J. Eaton, P.A. Case, W.J. DeSisto, and M.C. Wheeler, Decomposition Pathways during Pyrolysis of Hydrolyzate Salts, tcs2014: Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products, Denver, CO, September 2-4, 2014.
12. P.A. Case, M.C. Wheeler, and W.J. DeSisto, Proposed Mechanisms for Pyrolysis of Calcium Pretreated Pine, tcs2014: Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products, Denver, CO, September 2-4, 2014
13. M.C. Wheeler, H.P. Pendse, and A. Luce,UMaine Research in Drop-In Fuel from Lignocellulosics, Biomass 2014: Growing the Future Bioeconomy, Washington, DC, July 29, 2014
14. F. G. Amar, B. G. Frederick, K. York, R. A. Pollock, "Modeling the Filling of Methane in Heterogeneous Pore Networks," 248th National Meeting of the American Chemical Society, San Francisco, CA, Aug. 13, 2014. Rasiah Symposium

15. Jamie St. Pierre, Sedat Beis, Adriaan van Heiningen, "Fast Pyrolysis of a Hardwood Soda-Anthraquinone Spent Pulping Liquor," 2014 International Chemical Recovery Conference, June 12, 2014, Tampere, Finland. (Oral Presentation)
16. M. Rasmussen, J. Joseph, B. G. Frederick, E. A. Stemmler, 62nd ASMS Conference on Mass Spectrometry: An LC/MS/MS investigation of chemical reactions causing instability in wood-derived pyrolysis bio-oils, Baltimore, MD, June 15-19, 2014. Undergraduate poster award recipient.
17. M.C. Wheeler, "Recent Progress at University of Maine's forest Bioproducts Research Institute with a Focus on Biofuels for Transporation," University of Concepcion Faculty of Chemical Science, March 7, 2014, Concepcion, Chile (invited).
18. S.J. Eaton and M.C. Wheeler, "Production and Characterization of Straight-Run Thermal Deoxygenation (TDO) Fuels," AIChE Annual Meeting, November 3-8, 2013, San Francisco, CA.
19. P.A. Case, E. Stemmler, W.J. DeSisto, and M.C. Wheeler, Pyrolysis of Alkali Pre-Treated Biomass and Biomass Constituents," AIChE Annual Meeting, November 3-8, 2013, San Francisco, CA.
20. K. A. Tracy, J. Joseph, B. J. W. Cole, E. A. Stemmler, Identification of Sugars in Fast Pyrolysis Oil," 39th Northeast Regional Meeting of the American Chemical Society, New Haven, CT, Oct. 23-26, 2013. (Poster presentation)
21. J. Joseph, J. Fecteau, M. Rasmussen, E. A. Stemmler, B. L. Jensen, B. G. Frederick, "Chemical Reactions Causing Instability of Bio-oils", 39th Northeast Regional Meeting of the American Chemical Society, New Haven, CT, Oct. 23-26, 2013. (Oral presentation)
22. P. Ruiz, N. Escalona, W. J. DeSisto, M. C. Wheeler, B. G. Frederick, "Effect of H_2 activation on reduced tungsten oxide bronze catalysts for hydrodeoxygenation of guaiacol," 39th Northeast Regional Meeting of the American Chemical Society, New Haven, CT, Oct. 23-26, 2013. (Oral presentation)
23. Md. Emtias Chowdhury, J. Joseph, E. A. Stemmler, B. G. Frederick, "Automated identification of Compounds in Bio-oil with GC/MS," 39th Northeast Regional Meeting of the American Chemical Society, New Haven, CT, Oct. 23-26, 2013. (Poster presentation)
24. A. Mahdavi Shakib, B. G. Frederick, "Surface Acidity of Tungsten Oxide Bronze Catalysts," 39th Northeast Regional Meeting of the American Chemical Society, New Haven, CT, Oct. 23-26, 2013. (Poster presentation)
25. S. Kim; H. Lee; E. A. Stemmler, "Analysis of Simple and Complex Sugars in Fast Pyrolysis Oils Using Liquid Chromatography-Mass Spectrometry (LC-MS) Techniques", NERM 2013, New Haven, CT, Oct. 23-26, 2013.
26. M.J. Rasmussen; J. Joseph; B.G. Frederick; E. A. Stemmler, "Pyrolysis oil aging reactions: An LC/MS/MS investigation of reactive components and reaction products", NERM 2013, New Haven, CT, Oct. 23-26, 2013.
27. X. Zhou, C. Newman, B. Goundie, R. A. Pollock, M. C. Wheeler, R. W. Meulenberg, R. N. Austin, B. G. Frederick, Hydrodeoxygenation of Pyrolysis Oils with Ruthenium Catalysts"Symposium on Alternative Energy and Fuel Chemistry, 38th Northeast Regional Meeting of the American Chemical Society, Rochester NY, Oct. 1-3, 2012. (Oral Presentation)
28. W.J. DeSisto, Formate-Assisted Pyrolysis of Woody Biomass, University of Massachusetts, Amherst, Department of Chemical Engineering Seminar Series, October 2013, Amherst, MA (invited).

29. P.A. Case, S. Mukkamala, E.A. Stemmler, W.J. DeSisto, and M.C. Wheeler, "Formate-Assisted Pyrolysis of Biomass," tcbiomass2013 the International Conference on Thermochemical Conversion Science, September 3-5, 2013, Chicago, IL (poster).
30. Francois G. Amar, Brian G. Frederick, Timothy J. Thibodeau, Christopher Goodwin, Daniel Moberg, "Theoretical investigation of tungsten oxide bronzes as hydrodeoxygenation catalysts", 246th American Chemical Society National Meeting, Indianapolis, IN, Sept. 8-12, 2013.
31. S.J. Eaton, S.H. Beis, G.P. van Walsum, H.P. Pendse, and M.C. Wheeler, "Thermal DeOxygenation of Woody Biomass Hydrolyzate," tcbiomass2013, the International Conference on Thermochemical Conversion Science, September 3-6, 2013, Chicago, IL (poster).
32. Jamie L. St Pierre and Adriaan R.P. van Heiningen, "Dry Distillation of Soda-AQ Black Liquor: Effect of Pretreatment," The 17th International Symposium on Wood, Fibre and Pulping Chemistry, June 13-14, 2013, Vancouver, BC. (Poster Presentation)
33. E. A. Stemmler; M. J. Rasmussen; H. D.Rone; N.D.Ricke, "The Application of GC/MS and nanoESI-LC/MS/MS to the Characterization of Pine Fast Pyrolysis Bio-oils", 61st ASMS Conference on Mass Spectrometry, Minneapolis, MN, June 9-13, 2013.
34. W.J. DeSisto and M.C.Wheeler, "Formate Assisted Pyrolysis of Woody Biomass," Pacific Northwest National Laboratory, June 2013, Richland, WA (invited).
35. W.J. DeSisto and M.C.Wheeler, "Thermal Conversion of Woody Biomass to Fuels and Chemicals," Latin American Congress on Biorefineries, Pucon Chile, November 2012.
36. S.H. Beis, A. Hayden, H.P. Pendse, P. van Walsum, D.L. Smith, and M.C. Wheeler, "Performance Characterization of Crude Oil Produced by Thermal Deoxygenation," 2012 Annual Meeting of the American Institute of Chemical Engineers, November 1, 2012, Pittsburgh, PA.
37. S. Eaton, B.G. Bunting, P. van Walsum, M.C. Wheeler, "Engine Performance of Biohydrocarbons Produced by Thermal Deoxygenation of Biomass Derived Organic Acids," 2012 Annual Meeting of the American Institute of Chemical Engineers, November 1, 2012, Pittsburgh, PA.
38. N.L. Hammer, A.A. Boateng, C.A. Mullen, M.C. Wheeler, and J.L. Carrasco, "Aspen PLUS Modeling of the Utilization of Equine Waste for Localized Heating Via Fast Pyrolysis," 2012 Annual Meeting of the American Institute of Chemical Engineers, November 1, 2012, Pittsburgh, PA.
39. S. Mukkamala, W.J. DeSisto, M.C. Wheeler, and A. van Heiningen, "Thermal Conversion of Lignin to Transportation Fuels and Chemicals Through Formate Assisted Fast Pyrolysis," 2012 Annual Meeting of the American Institute of Chemical Engineers, October 29, 2012, Pittsburgh, PA.
40. J.L. Carrasco, N.L. Hammer, A. McAloon, A.A. Boateng, W.J. DeSisto, and M.C. Wheeler, "Technoeconomic Analysis of Pyrolysis of Forest Residues," 2012 Annual Meeting of the American Institute of Chemical Engineers, October 29, 2012, Pittsburgh, PA.
41. James P. Fecteau, Jincy Joseph, David Labrecque, Bruce L. Jensen, Brian G. Frederick, "Polymerization Reactions during Pyrolysis Oil Aging," Symposium on Alternative Energy and Fuel Chemistry, 38th Northeast Regional Meeting of the American Chemical Society, Rochester NY, Oct. 1-3, 2012. (Undergraduate Poster presentation)
42. B.G. Frederick, T.J. Thibodeau, D. Moberg, C. Goodwin, F.G. Amar, "Fast Pyrolysis of Biomass and Hydrodeoxygenation using Metal Oxide Bronzes," 38th Northeast Regional Meeting of the American Chemical Society, Rochester, NY, October 3, 2012.

43. James P. Fecteau, Jincy Joseph, David Labrecque, Bruce L. Jensen, Brian G. Frederick, "Polymerization Reactions during Pyrolysis Oil Aging," Symposium on Alternative Energy and Fuel Chemistry, 38th Northeast Regional Meeting of the American Chemical Society, Rochester NY, Oct. 1-3, 2012. (Undergraduate Poster presentation)
44. Brian G. Frederick, Timothy J. Thibodeau, Daniel Moberg, Christopher Goodwin, Francois G. Amar, "Fast Pyrolysis of Biomass and Hydrodeoxygenation using Metal Oxide Bronzes", Symposium on Alternative Energy and Fuel Chemistry, 38th Northeast Regional Meeting of the American Chemical Society, Rochester NY, Oct. 1-3, 2012. (Oral Presentation)
45. Jincy Joseph, David Labrecque, Diane Smith, Bruce L. Jensen, Brian G. Frederick, " Probing the reactions that stabilize bio-oil with methanol", Symposium on Alternative Energy and Fuel Chemistry, 38th Northeast Regional Meeting of the American Chemical Society, Rochester NY, Oct. 1-3, 2012. (Oral Presentation)
46. P. Ruiz, Brian G. Frederick, M. Clayton Wheeler, W. DeSisto, "Activity and Selectivity over a tungsten oxide catalyst", Symposium on Alternative Energy and Fuel Chemistry, 38th Northeast Regional Meeting of the American Chemical Society, Rochester NY, Oct. 1-3, 2012. (Poster presentation)
47. X. Zhou, C. Newman, B. Goundie, R. A. Pollock, M. C. Wheeler, R. W. Meulenberg, R. N. Austin, B. G. Frederick, Hydrodeoxygenation of Pyrolysis Oils with Ruthenium Catalysts"Symposium on Alternative Energy and Fuel Chemistry, 38th Northeast Regional Meeting of the American Chemical Society, Rochester NY, Oct. 1-3, 2012. (Oral Presentation)
48. Rachel A. Pollock, Francois G. Amar, Brian G Frederick, "Modeling diffusion of Methane in polydisperse pore systems", 2012 American Conference on Neutron Scatttering, Washington, D.C., June 24-28, 2012.
49. Rachel A. Pollock, Gennady Yu. Gor, Brenna R. Walsh, Jason A Fry, I. Tyrone Ghampson, Yuri B Melnichenko, Helmet Kaiser, Brian G. Frederick, "Probing the Spatial Distribution of Pores during Hydrothermal Degradation of SBA-15," 2012 American Conference on Neutron Scatttering, Washington, D.C., June 24-28, 2012.
50. M.C. Wheeler, "Production of Drop-in fuels from Waste Biomass by Thermal Deoxygenation," Northern Regional Meeting of the National Council for Air and Stream Improvement, May 9, 2012.
51. M.C. Wheeler, P.A. Case, S.J. Eaton, A.R.P. van Heiningen, and W.J. DeSisto, "Atmospheric, Non-catalytic Method for Hydrocarbon Fuels from Cellulosic Biomass by Pyrolysis of Organic Acid Salts," tcbiomass2011, September 27-30, 2011, Chicago, Illinois.
52. M. C. Wheeler (invited), W. J. DeSisto, B.G. Frederick, A.R.P. van Heiningen, G. P. van Walsum, H. P. Pendse, R.N. Austin, N. Escalona B., and S. H. Beis, "Biomass Thermal Conversion Research within the University of Maine's Forest Bioproducts Research Institute (FBRI)," XXV Interamerican Congress of Chemical Engineering, November 14-17, 2011, Santiago, Chile.
53. W.J. DeSisto, S. Mukkamala, A. van Heiningen, and M.C. Wheeler, Thermal deoxygenation of woody biomass feedstocks: a potential wood-to-drop-in-fuel process with a focus on lignin, XXV Interamerican Congress on Chemical Engineering and XVIII Chilean Congress on Chemical Engineering, November 14-17, 2011.
54. M.C. Wheeler (invited), "Biomass to Transportation Fuels Research at the University of Maine," University of Concepción, November 22, 2011, Concepción, Chile.

55. M.C. Wheeler (invited), Hydrocarbons via thermal deoxygenation of biomass hydrolyzates, USDA-ARS Teleseminar Series on Chemical Conversion Technologies, http://www.ars.usda.gov/research/programs/programs.htm?np_code=213&docid=21205 , January 3, 2012
56. B. G. Frederick, T. J. Thibodeau, C. Goodwin, F. G. Amar, "Reduced tungsten oxide bronze catalysts for hydrodeoxygenation of bio-oils," 243rd National American Chemical Society Meeting, San Diego, CA, March 25-29, 2012.
57. T. J. Thibodeau, F. Wang, C. Di Valentin, G. Pacchioni, A. Vidal Sandrea, P. Liu, F. G. Amar, B. G. Frederick, Theoretical Modeling of Reduced Tungsten Oxides and Bronze Hydrodeoxygenation Catalysts," 243rd National American Chemical Society Meeting, San Diego, CA, March 25-29, 2012.
58. H. P. Pendse, M.C. Wheeler and W.J. DeSisto, Biomass to hydrocarbons via formate-assisted pyrolysis, Spring Meeting of the American Institute of Chemical Engineers, April 3, 2012, Houston, TX.
59. J. Fecteau, "Pyrolysis Oil Stability: A Study of Polymerization Chemistry in Wood-Based Bio-Oil", CUGR Undergraduate Research & Academic Showcase, UMaine, April 11, 2012, Orono, ME. (Advised by J. Joseph, B. L. Jensen, B. G. Frederick)
60. T. J. Schwartz, P. A. Case, A. R.P. van Heiningen, G. P. van Walsum, M. C. Wheeler (invited), "Thermal Deoxygenation of Levulinic Acid," 241st ACS National Meeting & Exposition, March 27-31, 2011, Anaheim, California.
61. F. G. Amar, "Mechanism of Hydrodeoxygenation of Model Biofuel Feedstocks over Metal Oxide Catalysts," invited seminar at the Department of Chemistry, University of New Hampshire, Durham, NH, March 3, 2011.
62. R.A. Pollock, B.R. Walsh, J.A. Fry, I.T. Ghampson, H. Kaiser, R. Pynn, M.C. Wheeler, W.J. DeSisto, B.G. Frederick, "Structure and adsorption in secondary pore network of mesoporous silica", 2010 American Conference on Neutron Scattering, Ottowa, CN, June 27 – July 2, 2010.
63. M. Bhatia, A. van Heiningen, G. P. van Walsum and M. C. Wheeler, "Kinetics and Mechanism for Acetone Hydrogenation by Ru/Carbon," AIChE Annual Meeting Conference Proceedings on CD, New York, NY (2010).
64. T. J. Schwartz, P. Case, A. van Heiningen, G. P. van Walsum and M. C. Wheeler, "Thermal Deoxygenation of Levulinic Acid," AIChE Annual Meeting Conference Proceedings on CD, New York, NY (2010).
65. B. G. Frederick, F. G. Amar, T. J. Thibodeau, and D. Moberg, "Hydrodeoxygenation (HDO) of Acrolein on Reduced Molybdenum and Tungsten Oxide Bronze Catalysts: Mechanism for Upgrading of Biomass Derived Feedstocks," Center for Functional Nanomaterials, Brookhaven National Laboratory, Upton, NY, July 13, 2010.
66. A. van Heiningen, "Overview of Forest Biorefinery Concept; Opportunities and Challenges", Bioenergy Boosting Forest Industry, PulPaper 2010 Conf., 1-3 June 2010, Helsinki, Finland.
67. F. G. Amar, D. R. Moberg, T. J. Thibodeau, M.C. Wheeler, W. J. DeSisto, B. G. Frederick, "Hydrodeoxygenation of Acrolein on Reducible Oxide Catalysts: Mechanism for Upgrading of Biomass Derived Feedstock," 2010 Spring National Meeting of the American Chemical Society, San Francisco, CA, Mar. 21-25, 2010.
68. B. G. Frederick, "Catalyst Development for Thermochemical Conversion of Woody Biomass to Fuels and Chemicals", Nov. 21, 2009, Dept. of Physics, Univ. of Maine.
69. S. H. Beis, N. Hill, S. Mukkamala, H. Lehtonen, A. van Heiningen, B. G. Frederick, M. C. Wheeler, W. J. DeSisto, "Fast Pyrolysis of Pine Wood: The Influence of Process

Parameters On the Quality and the Quantity of the Pyrolysis Oil," AIChE Annual Meeting Conference Proceedings on CD, New York, NY (2009).

70. S. H. Beis, S. Mukkamala, N. Hill, T.-H. Ong, A. Van Heiningen, B. G. Frederick, M. Clayton Wheeler, E. Stemmler and W. J. DeSisto, "Fast Pyrolysis of Wood Lignin: Towards A Continuous Process", AIChE Annual Meeting Conference Proceedings on CD, New York, NY (2009).
71. M. Bhatia, K. D. Hurley, G. P. van Walsum and M. C. Wheeler, "Thermal Conversion of Carboxylate Salts (Biomass-to-Mixed Alcohols)," AIChE Annual Meeting Conference Proceedings on CD, New York, NY (2009).
72. I.T. Ghampson, K. Hurley, R. Pollock, B. Walsh, B. Frederick, E. Pier, R.N. Austin, C. Wheeler, A. van Heiningen, and W.J. DeSisto, "Pre- and Post-Reaction Measurement of Catalyst Properties for Silica Supported Cobalt Catalysts with Variable Pore Size," AIChE Annual Meeting Conference Proceedings on CD, New York, NY (2009).
73. P. Ruiz, K. D. Hurley, B. G. Frederick, W. J. DeSisto, L. R. Radovic, N. Escalona, and M. C. Wheeler, "Hydrodeoxygenation of guaiacol as a model compound for pyrolysis oil," AIChE Annual Meeting Conference Proceedings on CD, New York, NY (2009).
74. K. D. Hurley, R. Chen, D. Bragg, T. Kirkmann, B. J. Frederick, S. MacKay, W. J. DeSisto, and M. C. Wheeler, "High-throughput screening of hydrodeoxygenation catalysts," AIChE Annual Meeting Conference Proceedings on CD, New York, NY (2009).
75. R. A. Pollock, B. R. Walsh, J. A. Fry, I. T. Ghampson, T. Steinbach, H. Kaiser, R. Pynn, Y. Melnichencko, M. C. Wheeler, W. J. DeSisto, B. G. Frederick, "Mild Pressure Liquid Water Modification of Mesoporous Silica," 36th Northeast Regional Meeting of the American Chemical Society, Hartford, CT, Oct. 7-10, 2009.
76. 11. D. R. Moberg, T. J. Thibodeau, F. G. Amar, M. C. Wheeler, W. J. DeSisto, B. G. Frederick, "Density Functional Theory Study of Oxygen Vacancy Formation on Cluster Models of the MoO3(010) Surface," 36th Northeast Regional Meeting of the American Chemical Society, Hartford, CT, Oct. 7-10, 2009.
77. K.D. Hurley, R. Chen, R. Nelson, B.G. Frederick, W.J. DeSisto, and M.C. Wheeler, "Catalyst screening using micromachined calorimeters," 238th National Meeting of the American Chemical Society, Washington, DC, Aug. 16-20, 2009.
78. T. J. Thibodeau, B. G. Frederick, M. C. Wheeler, W. J. DeSisto, D. R. Moberg, F. G. Amar, "Hydrodeoxygenation of acrolein and allyl alcohol: Model compounds for upgrading of biomass derived feedstocks", 238th National Meeting of the American Chemical Society, Washington, DC, Aug. 17-20, 2009.
79. 8. R. A. Pollock, B. R. Walsh, J. A. Fry, I. Tyrone Ghampson, T. Steinbach, H. Kaiser, R. Pynn, Y. Melnichenko, M. C. Wheeler, W. J. DeSisto, B. G. Frederick, "Mild Pressure Liquid Water Modification of Mesoporous Silica", DOE EPSCOR National Meeting, Brookhaven National Laboratory, July 2009.
80. D. Cassidy, S. Higgins and W. J. DeSisto, Atomic layer deposition as a tool to modify inorganic membranes, Proceedings of the Electrochemical Society Meeting, Honolulu, HI 2008.
81. W.J. DeSisto, Atomic layer deposition as a tool to modify inorganic membranes, Electrochemical Society Meeting, Honolulu, HI, October 2008 (Invited presentation).
82. R. Nelson, W. J. DeSisto, B. G. Frederick, A. van Heiningen, M. C. Wheeler, High Throughput Microcalorimetry for Catalyst Discovery, AIChE Annual Meeting Conference Proceedings on CD, New York, NY (2008).

83. H. P. Pendse, M. C. Wheeler, W. J. DeSisto, B. G. Frederick, A. van Heiningen, "Thermochemical Conversion of Woody Biomass to Fuels and Chemicals", Maine EPSCOR Conference, Sept. 29-30, 2008.
84. H. P. Pendse, M. C. Wheeler, W. J. DeSisto, B. G. Frederick, A. van Heiningen, "Thermochemical Conversion of Woody Biomass to Fuels and Chemicals", First Annual Conference on Cellulosic Biofuels, Sept. 19, 2008, TIMBER, Univ. of Massachusetts Amherst.
85. H. P. Pendse, M. C. Wheeler, W. J. DeSisto, B. G. Frederick, A. van Heiningen, "Thermochemical Conversion of Woody BIomass to Fuels and Chemicals", DOE EPSCoR Annual Program Review and Workshop 2008, July 22-24, 2008, Oak Ridge National Laboratory.
86. I. T. Ghampson, B. Walsh, M. C. Wheeler, W. J. DeSisto, B. G. Frederick, A. van Heiningen, Infrastructure development for rapid screening of potential catalysts for the thermal conversion of woody biomass to fuels and chemicals, Gordon Research Conference: Nanoporous Materials, Waterville, ME 2008.

Section 8 -Personnel

Table 2. Postdoctoral and Senior Research Associates

Name	Institution/ Department	Primary Focus	% Support by Grant
Dr. Catherine Sepulveda	UMaine/ Chem Eng	Hydrogenation of glycerol and XPS of reduced metallic catalysts	100
Dr. Nestor Escalona	UMaine/ Chem Eng	Fundamental catalysis and upgrading on pretreated oils	100
Dr. Sedat Beis Sr. Res. Assoc.	UMaine/ Chem Eng	Pyrolysis and pyrolysis oil upgrading	75
Barbara Frederick	UMaine/ Chem Eng	Part time laboratory chemist	100

Table 3. Graduate Students

Name	Institution/ Department	Project Title	% Support by Grant
Isaac Ghampson, Ph.D.(graduated)	UMaine/ Chem Eng	Mesoporous catalyst synthesis and characterization	100
Tim Thibodeau, Ph.D. (graduated)	UMaine/ Chemistry	Hydrodeoxygenation mechanisms using model compounds & in-situ spectroscopy	100
Rachel Pollock, Ph.D. (graduated)	UMaine/ Physics	Characterization of mesoporous supports by neutron scattering	100
Rongkai Chen, M.S. (graduated)	UMaine/ Chem Eng	Nanocalorimetry of reducible metal oxide catalysts	100
Saikrishna Mukkamala, M.S. (graduated)	UMaine/ Chem Eng	Pyrolysis of fractionated wood components	100
Jose Carrasco M.S. (graduated)	UMaine/ Chem Eng	Pyrolysis Techno-Economic Analysis	100
Xiaobo Zhou M.S. (graduated)	UMaine/ Chemistry	Hydrodeoxygenation of pyrolysis oils using supported metal catalysts	100
Jincy Joseph Ph.D. (graduated)	UMaine/ Chemistry	Methods for stability of and analysis of pyrolysis oils	100
Emtias Chowdhury M.S. (graduated)	UMaine/ Chemistry	Stability of pyrolysis oil	100
Paige Case Ph.D. (graduated)	UMaine/ Chem Eng	Formate Assisted Pyrolysis	100
Pamela Ruiz ** (Ph.D. candidate)	UMaine/ Chemistry	Hydrodeoxygenation of guaiacol using carbon-supported catalysts	100
Akbar Mahdavi (Ph.D. candidate)	UMaine/ Chemistry	Characterization of metal oxide HDO catalysts	100
Jamie St. Pierre (Ph.D candidate)	UMaine/ Chem Eng	Thermal deoxygenation of black liquor	25
Scott Eaton Ph.D. (graduated)	UMaine/ Chem Eng	Thermal Deoxygenation of Levulinate and Formate Salts for the Production of Transportation Fuels	25

Table 4. Undergraduate Students

Name	Institution/ Department	Project Title	% Support by Grant
Ashley Brooks	Bates/ Chemistry	Synthesis and characterization of ruthenium based catalysts	Supported by Bates
Cody Newman	Bates/ Chemistry	Synthesis and characterization of ruthenium based catalysts	Supported by Bates
Eric Pier	Bates/ Chemistry	Functionalization of catalyst supports	100
Jasmin Hernadez	Bates/ Chemistry	Catalyst synthesis and characterization	Supported by Bates
Lina Kong	Bates/ Chemistry	Catalyst synthesis	100
Mary Lewis	Bates/ Chemistry	Reaction characterization of ruthenium based catalysts	Supported by Bates
Tessa Pals	Bates/ Chemistry	Catalyst synthesis	100
Zach Ross	Bates/ Environmental Chemistry	XRD on catalysts	Supported by Bates
Hassan Rone	Bowdoin/ Chemistry	Selective Derivatization and Subsequent Detection of Catechol Derivatives in Pyrolysis Oils	50
Hyunji Lee	Bowdoin/ Chemistry	Molecular Characterization of Pyrolysis Oils using LCMS/Q-TOF Analysis: Common Fragmentation Patterns for Carbohydrates	50
Matthew Kwan	Bowdoin/ Chemistry	Development of pyrolysis oil characterization methods	100
Matthew Rasmussen	Bowdoin/ Chemistry	Pyrolyis Oil Aging Reactions: A Mass Spectrometric Investigation of Reaction Components and Reaction Products	50
Nathan Ricke	Bowdoin/ Chemistry	The Chemical Characterization of Biomass-Derived Pyrolysis Oils: Application of Advanced Liquid Chromatography/Mass Spectrometry Techniques	50
Sally Kim	Bowdoin/ Chemistry	High-Resolution Mass Analysis of Wood-Derived Bio-Oils: Using Exact Mass Measurements to Assess Compositional Changes	50
Ta-Hsuan Ong	Bowdoin/ Chemistry	Development of pyrolysis oil characterization methods	100
Sean Morin	Bowdoin/ Chemistry	A Study of Reactions Responsible for Instability in Pyrolysis Oils	Supported by Bowdoin
Shehan Don Talagala	Colby/ Chemistry	Surface plasmon resonance and quartz crystal microbalance studies of binding to mesoporous thin film silica	100
Alex Canney	UMaine/ Chemical Eng	Mechanical design of micro reactor autosampling system	100
Marc Beauchemin	UMaine/ Chemical Eng	In-situ production of formate salts via oxidative biomass pretreatment	100
Paige Case	UMaine/ Chemical Eng	Thermal deoxygenation of aqueous pyrolysis oil fraction	100
Thomas Schwartz	UMaine/ Chemical Eng	Thermal deoxygenation of levulinic acid	100
Brenna Walsh	UMaine/	X-ray diffraction of mesoporous catalysts	100

	Chemistry	and reaction characterization	
Daniel Moberg	UMaine/ Chemistry	Characterization of catalyst supports, reactions, and products	100
James Fecteau	UMaine/ Chemistry	Polymerization chemistry in wood-based bio-oil	20
Jordan Trascko	UMaine/ Chemistry	Kinetic Study of Tetraethoxysilane Hydrolysis in Sol-Gel Solutions Using 1H Nuclear Magnetic Resonance Spectroscopy	50
Katelyn Tracy	UMaine/ Chemistry	Identification of Sugars in Fast Pyrolysis Oil	50
Paul Holyoke	UMaine/ Chemistry	Characterization of pyrolysis oils by NMR	100
James R. Clark	UMaine/ Chemistry	Computational Investigation of Brønsted and Lewis Acid Properties of Tungsten Oxide Clusters	UMaine
Nicholas Dunn	Union College/ Chemistry	Chemical composition of pyrolysis oil by Solid Phase Micro Extraction	FBRI REU

Table 5. Technicians

Name	**Institution/ Department**	**Project Title**	**% Support by Grant**
Elisha Cram	UMaine/ Chemical Eng	General technical support	10
Nick Hill	UMaine/ Chemical Eng	General technical support	100
Kenneth Hill	UMaine/ Chemical Eng	Part time laboratory assistant	100
George Bernhardt	UMaine/ LASST	Clean room support and training and materials characterization	12.5
David Frankel	UMaine/ LASST	XRD characterization of catalysts	4

Section 9-Other Support (Current and Pending)

Current

1. Pendse, Wheeler - SEP Integrated National Framework for Cellulosic Drop-in Fuels, National Science Foundation Sustainable Energy Pathways, $1,999,786, 9/1/2012-8/31/2016.
2. Pendse, Wheeler - Distributed On-Farm Bioenergy, Biofuels and Biochemicals (FarmBio3), U.S. Dept. of Agriculture BRDI, $299,76, 9/1/2012-8/31/2016. Woody feedstock development activities and testing of hydrodeoxygenation catalysts for the project being led by USDA – Agricultural Research Service (Lead Institution NIFA Award No. 2012-10008-20271, ARS Award No. 59-1935-3)
3. Pendse, Wheeler, Leahy, & Benjamin – SELF: Sustainable Energy Leaders of the Future – Connecting Rural Women to STEM Careers, $95,086, 09/02/2013 – 09/01/2016, USDA-NIFA Accession No. 1000535.
4. Pendse, Wheeler, Luce – Saving the Biomass Hydrolysis Pilot Plant in Old Town to help the Sustainable Forests & Forest-based Economy Cluster, Maine Technology Institute (MTI) CIP-180, 06/01/2015 – 04/30/2016.
5. Wheeler, DeSisto – Renewable Acid-hydrolysis Condensation Hydrotreating (REACH) Pilot Plant Project Phase: Budget Period 1B, U.S. Dept. of Energy subaward through Mercurius Biofuels, LLC under DE-FOA-000739, $148,122, 6/1/2015-12/31/2015. Provide laboratory data and process simulations for FEL1 engineering design.
6. Wheeler, DeSisto – DOT UTC, Marine Engine Testing and Evaluation Laboratory, $218,000, 1/1/2014-12/31/2015, produce TDO and FAsP oils for testing in marine diesel applications.
7. Austin - Lead interactions with metallothionein-3, National Science Foundation $302,886. March 2012-Feb 2015. A study to determine whether lead binds to Matallothionein-3 which is a small, brain-specific protein.
8. Amar - Maine Physical Sciences Curriculum Partnership: Research and Infrastructure for Ongoing Educational Improvement National Science Foundation MSP program $12,347,770; 7/1/2010 through 6/30/2015 A study of physical sciences curriculum renovation in rural Maine middle schools.
9. Amar – Brookhaven National Laboratory Proposal No. 33186 Brønsted and Lewis acidity of reduced tungsten oxide bronze catalysts for hydrodeoxygenation of bio-oils. Up to 100,000 CPU hours, May-August 2014.
10. Stemmler - "MRI Consortium: Acquisition of LC-MS/MS Instrumentation for Undergraduate Research and Education." NSF, $379,944 , 8/15/2011-7/31/2014
11. Stemmler (supporting personnel with P.S. Dickinson (PI), A.E. Christie (co-PI), NSF - Collaborative Research: RUI: Molecular mechanisms and physiological triggers underlying neuromodulator plasticity in a lobster pattern generator, $430,000, 2014-2017.
12. Stemmler, Beckman Scholar's Program Award, Arnold and Mabel Beckman Foundation, participating faculty mentor, $104,000, 2014-2017.

Pending

1. Austin, Grabow, Schwartz, Frederick, "Designing and characterizing highly selective heterogeneous catalysts for hydrodeoxygenating bio-oils," NSF, $472,793, 09/01/2016-08/31/2019.

Section 10 –Project Cost Status (Actual Expenditures)

DOE SHARE	Phase I	Phase II	Grand Total
Compensation	$ 889,097.09	$ 865,998.04	$ 1,755,095.13
Equipment Unit Cost < $5,000	$ 52,090.66	$ 58,112.30	$ 110,202.96
Equipment Unit Cost >= $5000	$ 178,033.68	$ 64,902.50	$ 242,936.18
Travel	$ 17,538.41	$ 55,463.03	$ 73,001.44
other	$ 298,896.16	$ 360,909.06	$ 659,805.22
TDC	$ 1,435,656.00	$ 1,405,384.93	$ 2,841,040.93
F&A	$ 514,344.00	$ 514,603.08	$ 1,028,947.08
TOTAL	**$ 1,950,000.00**	**$ 1,919,988.01**	**$ 3,869,988.01**
UMAINE SHARE	Phase I	Phase II	Grand Total
Compensation	$ 348,088.77	$ -	$ 348,088.77
Equipment Unit Cost < $5,000	$ 63,825.30	$ -	$ 63,825.30
Equipment Unit Cost >= $5000	$ 324,121.37	$ -	$ 324,121.37
Travel	$ 53,781.80	$ -	$ 53,781.80
other	$ 189,142.60	$ -	$ 189,142.60
TDC	$ 978,959.84	$ -	$ 978,959.84
F&A	$ -	$ -	$ -
TOTAL	**$ 978,959.84**	**$ -**	**$ 978,959.84**
PROJECT TOTAL	Phase I	Phase II	Grand Total
Total Compensation	$ 1,237,185.86	$ 865,998.04	$ 2,103,183.90
Equipment Unit Cost < $5,000	$ 115,915.96	$ 58,112.30	$ 174,028.26
Equipment Unit Cost >= $5000	$ 502,155.05	$ 64,902.50	$ 567,057.55
Travel	$ 71,320.21	$ 55,463.03	$ 126,783.24
other	$ 488,038.76	$ 360,909.06	$ 848,947.82
TDC	$ 2,414,615.84	$ 1,405,384.93	$ 3,820,000.77
F&A	$ 514,344.00	$ 514,603.08	$ 1,028,947.08
TOTAL	**$ 2,928,959.84**	**$ 1,919,988.01**	**$ 4,848,947.85**