2008 Project Abstract
For the Period Ending June 30, 2010

PROJECT TITLE: Pyrolysis Pilot Project

Project Manager: Roger Ruan
Affiliation: University of Minnesota – Department of Bioproducts/ Biosystems Engineering and Center for Biorefining
Mailing Address: Room 206, BAE Bldg., 1390 Eckles Ave.
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Web Page address: biorefining.cfans.umn.edu
FUNDING SOURCE: Environment and Natural Resources Trust Fund")
Legal Citation: ML 2007, [Chap.____], Sec.[__2__], Subd.__5___.

Appropriation Amount: $500,000.

Overall Project Outcome and Results

Diversified perennial plants throughout watersheds in rural areas of Minnesota are a source of biomass feedstock which can be converted biofuels while also producing ecosystem and water quality benefits. The nature of sporadic production of this biomass in lands away from power and convenient water supply requires conversion technologies to be mobile, portable, self energy sufficient, and water free. The goal of our project was to develop, build, and demonstrate a mobile microwave assisted pyrolysis system which can be operated on biomass production sites. The two specific aims of the project were: (1) developing water free microwave assisted pyrolysis (MAP) system for conversion of cellulosic feedstocks to biofuels, and (2) demonstrating the technology through outreach and communication. We first optimized the processes which we developed from our previous research. Based on the optimized processes, we designed and constructed our first generation pilot system. We then conducted a series of pilot scale experiments and identified technical and engineering problems. Finally we designed and built the mobile demo system. Our pilot scale system has been demonstrated to more than 300 people including university researchers, government officials, private interests, biomass feedstock producers, bioenergy producers, students, and investors. The mobile system has been tested on the manufacture site and further testing will occur in Minnesota at the University of Minnesota's UMore Park. The technology developed was presented to a broader audience through more than 15 outreach events. Nine (9) peer-reviewed papers have been published and over 30 presentations and reports were made to the public. Our co-PI's company Rural Advantages also developed and offered numerous educational outreach and demonstration events totaling over 78 events with 285 speakers and reaching at least 5,410 attendees.

Project Results Use and Dissemination

Information obtained from the project was disseminated through demonstration of the static pilot scale system, outreach and educational events, and peer-reviewed

publications. The results have successfully reached a wide range of audience including university researchers, government officials, private investigators, biomass feedstock producers, bioenergy producers, students, and investors. A number of publications have aroused strong interests from investors. The project also led to efforts to seek additional funding to support work which will employ the new technology and system developed through this project.

2007 LCCMR Work Program Final Report

I. PROJECT TITLE: Pyrolysis Pilot Project

Project Manager: Roger Ruan
Affiliation: University of Minnesota – Department of Bioproducts/ Biosystems Engineering and Center for Biorefining
Mailing Address: Room 206, BBE South Bldg., 1390 Eckles Ave.
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FAX Number: 612-624-3005
Web Page address: biorefining.cfans.umn.edu

Location: St. Paul, Minnesota

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$500,000**
	Minus Amount Spent:	**$500,000**
	Equal Balance:	**$0**

Legal Citation: ML 2007, [Chap.____], Sec.[__2__], Subd.__5___.

Appropriation Language: $500,000 is from the trust fund to the University of Minnesota in cooperation with Rural Advantage to demonstrate a water-free pyrolysis technology for converting biomass feedstock to biofuels. This appropriation is available until June 30, 2010, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II and III. FINAL PROJECT SUMMARY:

Diversified perennial watershed and other coverage plants in Minnesota rural areas are a source of biomass feedstock which can be converted biofuels while also producing ecosystem and water quality benefits. The nature of sporadic production of this biomass in lands away from power and convenient water supply requires conversion technologies to be mobile, portable, self energy sufficient, and water free. The goal of our project was to develop, build, and demonstrate a mobile microwave assisted pyrolysis system which can be operated on biomass production sites. The two specific aims of the project were: (1) developing water free microwave assisted pyrolysis (MAP) system for conversion of cellulosic feedstocks to biofuels, and (2) demonstrating the technology through outreach and communication. We first optimized the processes which we developed from our previous research; based on the optimized processes, we designed and constructed our first generation pilot system; we conducted a series of pilot scale experiments and identified technical and engineering problems; and finally we designed and built the mobile demo system. Our pilot scale system has been demonstrated to more than 300 people who were university researchers, government officials, private investigators, biomass feedstock producers, bioenergy producers, students, and investors. The mobile system is being tested

on the manufacture site. The technology developed was presented to a broader audience through more than 15 outreach events. Nine (9) peer-reviewed papers have been published and over 30 presentations and reports were made to the public. Our co-PI's company Rural Advantages also developed and offered numerous educational outreach and demonstration events totaling over 78 events with 285 speakers and reaching at least 5,410 attendees. The project successfully moved the lab-developed processes to the next level on the way towards transfer of the technology to the commercial sectors. The project also led to efforts to seek additional funding to support work which will employ the new technology and system developed through this project.

IV. OUTLINE OF PROJECT RESULTS*:*

Objectives: We will demonstrate and evaluate pyrolysis of diversified perennials to produce high-value, bio-based products and renewable energy while also producing ecosystem and water quality benefits. This project will support rural socio-economic development as proposed for the Madelia Energy Shed Initiative. Conversion and production of biomass, for a variety of products, will need to meet increasingly stringent environmental and water use standards while remaining profitable for farmers. A key component of this work will be the demonstration of a portable pyrolysis unit which uses a water free process to convert diverse biomass feedstocks to liquid fuels. This project will provide a practical demonstration of the integration of the production and processing of perennial crops for liquid fuel. The project will: 1) implement and demonstrate a portable pyrolysis unit that will convert cellulosic feedstocks to liquid fuels using a water free process; and 2) support educational outreach, promote established third crop plantings, and develop and implement a statewide **communication strategy** that will advance third crop adoption.

Result 1: Water free technology for conversion of cellulosic feedstocks to biofuels.

Description:

To demonstrate an innovative water-free **microwave assisted pyrolysis** technology that addresses the water energy nexus. This technology can convert feedstock produced from the field scale plantings to bio-oil, syngas and char. We will: 1) Develop an energy self-sufficient portable demonstration system that is capable of handling multiple harvested crops. The pyrolytic syngas is used to generate electricity for the operation of the system. The bio-oil produced can be used as home heating oil or blend into diesel fuel. The char residues mainly consisted of carbon and minerals can be used as fertilizer. The system, which does not require water or produce water contaminants, will be mounted on a trailer, and could be towed to different crop production sites. Depending on needs, the system can also be optimized to produce more bio-oil or syngas. 2) Conduct on-site and field testing and demonstration and report results. And 3) Evaluate product properties and energy and material balance for different feedstock applications and report results.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$**446,000
	Amount Spent:	**$446,000**
	Balance:	**$0**

	Deliverable	**Completion Date**	**Budget**	**Status**
1.	Initial prototype pyrolysis system	June 30, 2008	212,000	complete

2. Improved mobile pyrolysis system	June 30, 2009	132,000	complete
3. On-site and field test, demonstration	June 30, 2010	102,000	complete & on-going
4. Product evaluation	June 30, 2010		complete
5. Report	June 30, 2010		complete

Completion Date: *June 30, 2010*

Final Report Summary:

Preparatory R&D Work to Optimize the Processes

We conducted systematic experiments using batch microwave reactors to test catalysts and optimize processes to ensure the processes are energy efficient and the products meet the technical expectations. This part of work involved (1) catalytic pyrolysis to improve bio-oil yield and quality, and (2) catalytic upgrading of the bio-oil produced.

Fourteen catalysts either to assist heating rate or change chemical degradation have been selected, and are being tested. Some of the catalysts increased the liquid yield by 15-20%. It was also observed visually that the appearance of the resultant bio-oils varied with some catalysts, suggesting that these catalysts changed the chemical degradation pathways under pyrolytic conditions. Instrumental analysis of the bio-oils including GC-MS is planned. The analytical results are used as feedback to optimize the processes.

Figure 1 shows that pretreatment of biomass feedstock prior to microwave assisted pyrolysis changed the chemical profiles of pyrolytic oils. Alkaline pretreatments (A and B) seem to increase the phenolics slightly while the acid pretreatments greatly increased the furan compounds, resulting in a jump in product selectivity, compared with the control sample (C). This is a very important finding because this indicates that bio-oils with simple composition are possible with simple pretreatments. However we do not understand how this works. We would like to know whether the increased product selectivity is due to change in the physiochemical properties of the feedstock prior to the pyrolysis or because the acids present in the feedstock indeed function as catalysts during the pyrolysis. We would also like to know if it is possible to control the product variety by using different pretreatments.

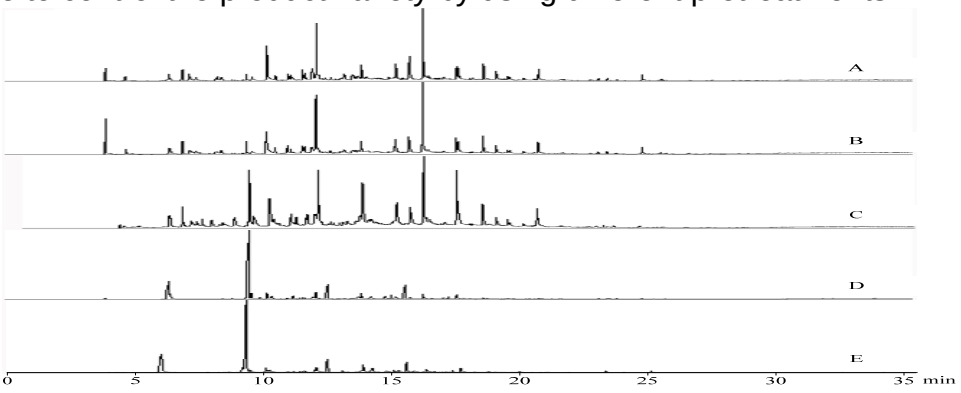

Figure 1. Effect of types of inorganic on bio-oil composition from pyrolysis of aspen: (A) 2%Na_2CO_3, (B) 2%NaOH, (C) Control, (D) 2%H_3PO_4, and (E) 2%H_2SO_4.

Figure 2 shows that catalysts ($MgCl_2 \cdot 6H_2O$, $ZnCl_2 \cdot 2H_2O$, and $Mg(ClO_4)_2$.) mixed with corn stover produced GC spectra of bio-oils with a large dominant peak. This result points to a great potential of simplifying bio-oil chemical profiles using appropriate catalysts. Bio-oils with simplified chemical profiles may require less or no post-conversion processing (upgrading) before they are used as liquid fuels, or the dominant chemical compounds may be separated as a high value product or as chemical stock for synthesis of other chemicals. Research is needed to understand how these and other catalysts work. We need to understand what happens on the biomass surface, particularly the interfaces between biomass and catalysts in molecular scale. Do the catalysts participate in the thermal degrading of the cellular constituents or do they catalyze the reforming of evolved organic volatiles generated after the thermal degradation of cellular constituents? We need to gain insight into the dynamics of the catalytic activities as a function of processing conditions. We also need to screen a range of catalysts for product selectivity data so that we can control the conversion products.

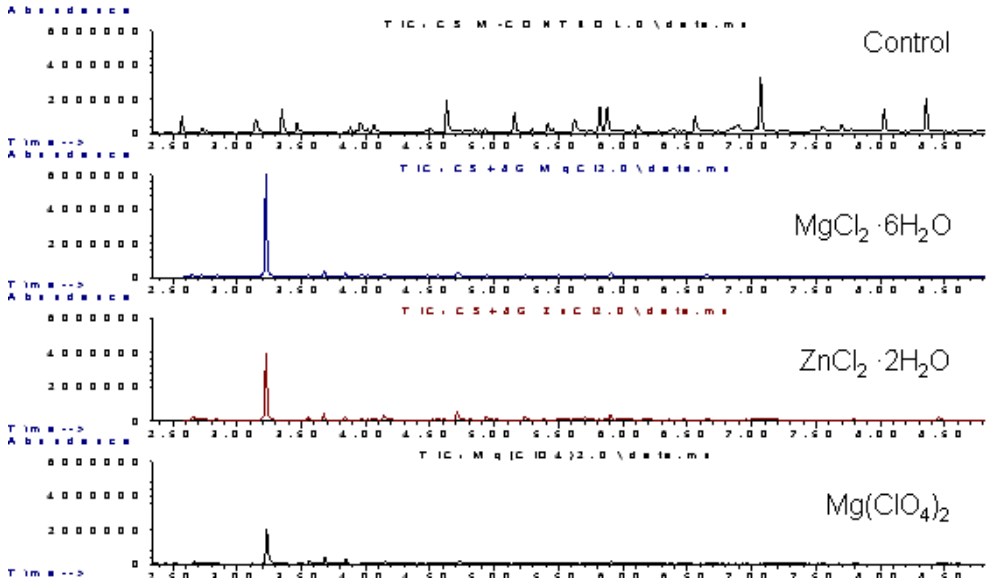

Figure 2. GC spectra of bio-oils from microwave assisted pyrolysis of corn stover: (1) control, (2) $MgCl_2 \cdot 6H_2O$, (3) $ZnCl_2 \cdot 2H_2O$, and (4) $Mg(ClO_4)_2$.

More biomass feedstocks were evaluated. Metal oxides, salts, and acids including $K_2Cr_2O_7$, Al_2O_3, KAc, H_3BO_3, Na_2HPO_4, $MgCl_2$, $AlCl_3$, $CoCl_2$, and $ZnCl_2$ were pre-mixed with corn stover or aspen wood pellets prior to pyrolysis using microwave heating. The thermal process produced three product fractions, namely bio-oil, gas, and charcoal. The best results were obtained from $MgCl_2$ treatment. At 8g $MgCl_2$ per 100 biomass level, the GC-MS total ion chromatograms of the bio-oils from the treated corn stover or aspen show only one major furfural peak accounting for about 80% of the area under the spectrum. We conclude that some catalysts improve bio-oil yields, and chloride salts in particular simplify the chemical compositions of the resultant bio-oils and therefore improve the product selectivity of the pyrolysis process.

<u>Product characterization and improvement</u>

In an effort to explore the uses of the bio-oils, fractionation of different bio-oils were carried out. Light oil and heavy oil phases were obtained. The physical and chemical properties of the two phases were determined. The light oil phase can readily be used as combustion fuel while the heavy oil can be used as heating oil with further refining and cleaning. We also tested the use of the bio-oils for making polyurethane foams.

Figure 3. Large pilot microwave assisted pyrolysis system installed at the Center for Biorefining, University of Minnesota.

Development of a Continuous Pilot System (first generation)

Microwave assisted pyrolysis (MAP) is a rather new technology and no commercial systems are available to date. In order to obtain first hand knowledge of a continuous MAP system, we developed a pilot system to be run in the laboratory conditions. Figure 3 shows the first generation pilot system installed in the Center for Biorefining.

The system has two microwave heating sections. The first one is for microwave assisted pyrolysis of fresh biomass feedstock and the second is for microwave assisted gasification of chars with potential of running water shift reactions to produce syngas. However, our experiments showed that the gasification stage doesn't work well in its original design. We decided to leave this out in our next mobile system.

Biomass feedstock enters the system from the feeder on top of the first microwave heating chamber. Inside the microwave heating chambers, feedstock is moved forward by an auger. The volatiles generated move through the pipes to a water scraper where ash particles are removed from the volatiles. The washed volatiles are cooled with tubular condensers (Figure 4) and the condensable volatiles flow to a bio-oil container while the non-condensable volatiles go into a gas turbine to generate electricity or are flared off.

Figure 4. Condenser of the stationary pilot scale microwave pyrolysis system

After a few test runs, we conducted experiments using the conditions we developed with batch MAP systems with and without catalysts. We were able to validate and improve the processes. During the course of pilot system operation, we met with many reaction and engineering problems. We studied these problems and developed solutions.

This has proven to be very beneficial to the design of our next generation system – the mobile demo system.

Development of Mobile Demo System

Based on the understanding of the MAP processes and experience and knowledge gained during the testing of our first generation pilot system, we designed the mobile demo system. The system, with a processing capacity of 100 kg/hr, is mounted on a 5 ft x 15 ft trailer. The feeding and conveying devices have been much improved. A new cooling approach which involves a two-stage quench is incorporated into the system. The new cooling device enables rapid cooling of volatiles from the reactors and hence improves the yield and quality of bio-oils. A gas turbine is built in the mobile system to provide the needed electricity from the syngas produced from the pyrolysis process. Figure 5 shows the mobile demon system.

Figure 5. Mobile microwave pyrolysis demo system.

Result 2: Demonstration, Outreach, and Communication

Description:

We will do demonstration and educational outreach by a variety of methods to support the pyrolysis technology developed in Result 1 and third crops across the state. We will secure perennial feedstocks for testing and demonstrating the pyrolysis technology. A communication strategy for the advancement of third crops will be developed and implemented across the state.

Summary Budget Information for Result 2: **Trust Fund Budget:** $54,000.00
Rural Advantage Amount Spent: $39,079.91
UMN Amount Spent: $14,920.09
Balance: $0

Deliverable	Completion Date	Budget	Status
1. Communication Strategy Development And Implementation	June 30, 2010	$20,000	complete
2. 3rd Crop Outreach and Demonstration	June 30, 2010	$29,000	complete & on-going
3. Feedstock Procurement for Pyrolysis Demonstrations	June 30, 2010	$ 5,000	complete

Completion Date: *June 30, 2010*
Final Report Summary

Communication Strategy Development

We developed a communication strategy to disseminate 3rd crop stories to a statewide audience by developing stories about a variety of 3rd crop farmers in Minnesota with geographic diversity. We utilized our existing contacts plus information from our partners to identify successful farmers who would portray a positive story. We contracted with a local writer to contact the farmer[s] and write the story at a rate of about one per month. This resulted in 23 stories being written and published. We developed a dissemination system of all of the newspapers in Minnesota, several regional publications such as The Land and the Agri-News papers and Farm Journal type magazines. Each story was formatted as a press release the same way each time they were sent out. We received positive feedback from the publishers who used our news releases. Many contacted us to do a more in-depth story, especially when it was someone in their area. We found this to be an effective method to elevate the awareness of 3rd crops and increase adoption. The following is a list of the stories.

Title	Date	Person
Land Stewardship: Straub Style	7/9/2008	Straub
Livestock Grazing: For Love and Money	8/11/2008	Hall
Answer to High Gas Prices Might Come From Trees	9/16/2008	Gibson
Growing Your Own: Sustaining Farm, Family & Environment	10/27/2008	Morlock
A Green Island Paradise	11/18/2008	Scheer
Grass Powers Growth	12/8/2008	Kreidermacher
Hazelnuts Work for Environment and Income	12/17/2008	Cerling
Making Deposits in a Different Kind of Bank	2/17/2009	Raney
Experiments in Alternative Energy	3/18/2009	Erickson
Not Your Typical Online Auction	4/13/2009	Domeier
Sowing Seeds of Biomass	4/28/2009	Vogt
Small Crop Gets Big Celebration	6/22/2009	Ford
A Berry Good Idea	9/14/2009	Altrichter
Powering up on Canola	10/20/2009	Dahl
Poultry Only Part of Free-Range Model	11/23/2009	Haslet-Marroquin
Out of a Jam	12/7/2009	Kuhlers
Bees: Honey of a Crop Alternative	1/5/2010	Harris Tinklenberg
Sustainable Ag: Balance Brings Benefits	1/25/2010	Jim Van der Pol
Decorative Woody Florals: Beautiful and Sustainable	2/23/2010	Chad Kingstrom
Strawberries: A Sweet Crop in more ways than One	3/25/2010	Tony Carter
Seeing a Market for the Trees	4/21/2010	Curt Kreklau
Sweetness Flows for Farmer	5/18/2010	Janna Goerdt
Are Hazelnuts the New Soybean?	6/3/2010	Norman Penner

3rd Crop Outreach and Demonstration

Throughout the project we were able to develop and offer numerous educational outreach and demonstration events totaling over 78 events with 285 speakers and reaching at least 5,410 attendees. The core of these events is our annual 3rd Crop Winter Series meetings and our summer Walk N Talks. In addition, we were able to collaborate for the annual corn and soybean meeting in Martin County and assisted with the development and delivery of eight biomass "Biobaler" harvest demonstrations across the state in the fall of 2009 and 4 prairie grass harvest demonstrations across the western edge of MN. We were also able to collaborate with our partners on additional learning activities around perennial feedstocks for bioenergy and 3rd crops.

System demonstration

UMN demonstrated the pilot system to more than 300 people from different sectors such as universities, research labs, biofuel companies, biomass producers, students, and investors.

Rural Advantage also collected and delivered a variety of feedstocks for utilization in test runs of the pyrolysis unit at the university. In addition, we have identified several cooperators, feedstock supply and sites for demonstrating the pyrolysis unit once it arrives. Examples of feedstock materials we have supplied or available include switchgrass, Indian grass, mixed prairie grass, hybrid poplar, short rotation willow, potato vines, miscanthus, corn stover, wheat straw, and big blue stem.

We tested the mobile demo system on the manufacture site. Additional minor improvements have just been made. The mobile demo system is expected to arrive in late August depending on shipping arrangement and customs clearance. The delay is mainly due to the continued inclusion of the additional process improvements. Nevertheless, we are glad that the "Pyrolysis Pilot Project" is a very successful program, thanks to LCCMR's support. We have leveraged a number of supports from DOE/USDA, DOT, and IREE, among others. With these supports, we conducted extensive research on microwave assisted pyrolysis process, catalytic reforming process, and pyrolytic product development and applications. We have been making significant progress in those areas, and built and tested two generations of pilot scale systems. We could have made the final mobile system earlier but we believe it would be a waste if we did not incorporate the new improvements into the final mobile system. We feel this is a more efficient way to use the tax payers' money.

Since we do have other related ongoing projects, we will continue to work with Rural Advantages to conduct field demonstration of the mobile system. In fact, we have done substantial outreach work on this project. We have published quite a few peer-review research journal articles (See publication list), and we have given many tours and interviews including the most recent article on the mobile microwave pyrolysis system in the *Popular Science* magazine (June, 2010), which generated tremendous interested in this technology and system. A patent has been filed to protect our invention of microwave assisted catalytic pyrolysis (See publication list).

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: $300,000

Staff: Pyrolysis: Research asst. (50% time/3 years) 96,000

& Post-Doctor (100% time/3 Yr) 150,000
Contract Services: Rural Advantage: 54,000
[Educational Outreach, Biomass Feedstocks, Travel, Signage, Comm. Strategy]

Laboratory Supplies: $50,000
Laboratory supplies, minor components, testing materials

Equipment: $ 150,000
Major system components 130,000
Other components and supplies 20,000

Development: $ (improvement to land or building)
Restoration: $ (how many acres)
Acquisition, including easements: $ (how many acres, also who will hold the title to the land)

TOTAL TRUST FUND PROJECT BUDGET: $500,000

Explanation of Capital Expenditures Greater Than $3,500:

The $200,000 budget will be used to develop, construct, and operate a mobile pyrolysis system that consists of a main reactor, gas turbine generator, condenser/distillation column, and other components. The system can be used for the demonstration of the technology and for evaluation of additional biomass feedstocks after the completion of this three years project.

Explanation of Actual Spending Variations:
We spent slightly more on personnel and less on equipment than originally budgeted because we obtained additional supports from other sources for equipment development, and therefore we put more LCCMR source on process improvement and optimization, the outcomes of which were incorporated into the final mobile system.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

Center for Integrated Natural Resources and Agricultural Management (UMN) 300,190
Department of Agronomy and Plant Genetics (UMN) 150,000
Dept of Bioproducts and Biosystems Engineering and Center for Biorefining (UMN) 446,000
Rural Advantage 120,250
Martin County SWCD 9,000

B. Other Funds Spent during the Project Period:

Office of Naval Research (ONR) & Luna Innovations - Biofuels production from non-edible biooils.
Phase I. 8/1/09 – 7/31/10. $37,000
USDA/DOE - Development of Scalable Biorefining Processes for Distributed Biomass Conversion.
01/01/2007 - 06/30/2012 $1,224,055

USDA FAS - 2008. Lartin American Biofuel Training Grant. 2008 $25,000
US DOT and Sun Grant Initiative - Develop sustainable renewable energy systems for practical utilization of bulky biomass. 9/1/07 – 8/31/11 $1,186,084
University of Minnesota IREE - Catalytic reforming of liquids and gases from thermochemical and biological conversion of biomass. 7/1/09 – 6/30/11 $250,000
EPA-MPCA - Assessing Potential of Watershed and Stream Channel Modifications on Suspended Sediment, Turbidity and Nutrients in the Blue Earth River Basin [UMN] 295,516
Bush Fnd. – Third Crop Init./ Conservation Agronomist [Rural Advantage] 254,000
Xcel Energy – Feasibility of Growing Miscanthus [Rural Advantage] 318,500
McKnight Foundation – Third Crop Initiative [Rural Advantage] 180,673
Clean Water Legacy– Conservation Agronomist [Rural Advantage via GBERBA] 80,000

C. Past Spending:

USDA-CSREES - Improving Water Quality and Enhancing Hydrologic Stability of the MN River through Agroforestry and Other Perennial Cropping Systems [UMN] 556,500
LCMR - 3rd Crops and Native Perennials for Water Quality [BERBI] 622,000
LCMR – 2005 3rd Crops For Water Quality Phase II [Rural Advantage] 500,000
EPA 319 – Innovative Easements, Cost Share, Coordination [BERBI] 671,250

D. Time:

VII. DISSEMINATION:

1. Wang, W, J Wu, F Yu, P Chen, and R Ruan. 2007. *Preparation of polyurethane foam from microwave pyrolytic bio-oils*, in *The 234th ACS National Meeting*. 2007: Boston, MA.
2. Wu, J, Y Wang, F Yu, Y Liu, P Chen, and R Ruan, *Preparation of Bio-polyesters and adhesives from Microwave Pyrolytic Oils*, in *ASABE Annual International Meeting*. 2007: Minneapolis MN.
3. Yu, F, S Deng, P Chen, Y Liu, Y Wan, A Olson, D Kittelson, and R Ruan. 2007. *Physical and chemical properties of bio-oils from microwave pyrolysis of corn stover.* Applied Biochemistry & Biotechnology, 2007. 137-140(1-12): p. 957-70.
4. Yu, F, K Hennessy, S Deng, P Chen, and R Ruan. 2007. *Biofuel production from corn residues by thermochemical conversion*, in *The 234th ACS National Meeting*. 2007: Boston, MA.
5. Yu, F, R Ruan, P Chen, and S Deng. 2007. *Characterization of char from the microwave pyrolysis of corn stover*, in *ASABE Annual International Meeting*. 2007: Minneapolis, MN.
6. Yu, F, R Ruan, S Deng, and P Chen, *Kinetics of thermal decomposition of corn stover studied by two-step consecutive reaction model*, in *ASABE Annual International Meeting*. 2007: Minneapolis, MN.
7. Moen, J, C Yang, B Zhang, K Hennessy, P Chen, and R Ruan, 2008. *Catalytic Microwave-Assisted Pyrolysis of High-diversity Grassland Perennials*, in *The 30th Biotech for chemicals and energy symposium*. 2008: New Orleans, LA.
8. Ruan, R and P Chen, *Bioenergy Industry Status and Prospects*, in *Industrial Crops and Uses*, B. Singh, Editor. 2008, CABI Oxfordshire, UK.
9. Yang, C, J Moen, B Zhang, K Hennessy, P Chen, and R Ruan. 2008. *Fractionation and characterization of bio-oil from biomass pyrolysis*, in *The 30th Biotech for chemicals and energy symposium*. 2008: New Orleans, LA.

10. Yu, F, Z Le, P Chen, Y Liu, X Lin, and R Ruan. 2008 *Atmospheric pressure liquefaction of dried distillers grains (DDG) and making polyurethane foams from liquefied DDG.* Applied Biochemistry & Biotechnology, 2008, 148(1-3): p. 235-43.
11. Wan, Y., P Chen, B. Zhang, C. Yang, Y. Liu, X. Lin, and **R. Ruan.** 2009. Microwave assisted pyrolysis of corn stover pellets with catalysts for bio-oil production. *Journal of Analytical and Applied Pyrolysis* 86(1):161-167.
12. Y Wan, Y Liu, X Lin, C Yang, B Zhang, P Chen, H Lei, R Ruan. 2009. *Microwave assisted pyrolysis of corn stover pellets with catalysts for bio-oil production and its component*. Transactions of the Chinese Society of Agricultural Engineering, 2009. 25(4):190-195.
13. B Zhang, C Yang, M Johannes, Z Le, K Hennessy, Y Wan, Y Liu, H Lei, P Chen, R Ruan. 2009. *Catalytic Conversion of Microwave-Assisted Pyrolysis Vapors*. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, In press.
14. Moen, J., C. Yang, B. Zhang, H. Lei, K. Hennessy, Y. Wan, Z. Le, Y. Liu, P. Chen, **R. Ruan**. 2010. Catalytic microwave assisted pyrolysis of aspen. *International Journal of Agricultural and Biological Engineering* 2(4):70-75.
15. Wan, Y., J. Wu, Y. Qan, H. Lei, F. Yu, P. Chen, X. Lin, Y. Liu, **R. Ruan**. 2009. Liquefaction of corn stover using industrial biodiesel glycerol. *International Journal of Agricultural and Biological Engineering* 2(2): 32-40.
16. Roger Ruan, Yiqin Wan, Changyang Yang, Bo Zhang, Xiangyang Lin, Xiaoquan Wang, Zhiping Le, and Paul Chen. 2009. IMPROVED PROCESS FOR PREPARING BIO-OILS FROM BIOMASS, US Patent Application, PCT/US2009/057009

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted every six months. A final work program report and associated products will be submitted between June 30 and August 1, 2010 as requested by the LCCMR.

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: *Pyrolysis Pilot Project*

Project Manager Name: *Roger Ruan.*

Trust Fund Appropriation: $500,000

1) See list of non-eligible expenses, do not include any of these items in your budget sheet

2) Remove any budget item lines not applicable

2007 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 2 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 3 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	Water free technology for conversion of cellulosic feedstocks to biofuels			*Fill in your result title here.*			*Fill in your result title here.*				
BUDGET ITEM			0			0			0	0	0
PERSONNEL: wages and benefits	273,545	289,108	-15,563			0			0	273,545	-15,563
Contracts			0			0			0	0	0
Rural Advantage - Outreach, Demonstration, Feedstock Supply, Communication Strategy			0	54,000	45,079.91	8,920			0	54,000	8,920
Other contracts *(with whom?, for what?) list out: personnel, equipment, etc.*			0			0			0	0	0
Other direct operating costs *(for what? – be specific)*			0			0			0	0	0
Equipment / Tools *(mobile pyrolysis reactor and components)*	113,800	96,130	17,671			0			0	113,800	17,671
Office equipment & computers - NOT ALLOWED unless unique to the project			0			0			0	0	0
Other Capital equipment *(list specific items)*			0			0			0	0	0
Land acquisition			0			0			0	0	0
Land rights acquisition *(less than fee)*			0			0			0	0	0
Professional Services for Acq.			0			0			0	0	0
Printing			0			0			0	0	0
Other Supplies *(list specific categories)*	58,655	69,683	-11,028			0			0	58,655	-11,028
Travel expenses in Minnesota			0			0			0	0	0
Travel outside Minnesota *(where?)*			0			0			0	0	0
Construction *(for what?)*			0			0			0	0	0
Other land improvement *(for what?)*			0			0			0	0	0
Other *(Describe the activity and cost) be specific*			0			0			0	0	0
COLUMN TOTAL	**$446,000**	**$454,920**	**-$8,920**	**$54,000**	**$45,080**	**$8,920**	**$0**	**$0**	**$0**	**$500,000**	**$0**