Global Food Ventures MnDRIVE Mid-term Grant Reports

Due: January 29, 2016

Submit to: Linda Valeri (valer024@umn.edu)

Title of Grant: **WASTE NOT: CLOSING THE LOOP ON ORGANICS WASTES**

Principal Investigator(s): Larry Baker, Steve Kelley, William Lazarus, Roger Ruan, Carl Rosen, Gerald Shurson, and Tim Smith. External collaborator: Dr. Sara Hughes, University of Toronto.

1. Progress Towards Grant Objectives

A. Feasibility of converting various types of food waste to animal feed.

The objective of the Food Analysis Group is to collect and analyze the chemical composition and nutritional value of organic wastes that could potentially be converted to feedstocks for swine nutrition. Two motivations for this research are (1) increasing prices for conventional swine feed; and (2) a growing societal movement toward recycling food wastes (to be discussed below). In year 1, we collected and analyzed 150 samples from major food waste production facilities and developed a methodology for collecting, drying, grinding, and analyzing these wastes. In year 2, we expanded collection of food waste to source separated organics (SSO) from three drop-off sites in the city of Minneapolis. SSOs are important because Minneapolis is moving toward full-scale implementation of household SSO collection and St. Paul is planning to start in 2017. Samples were collected during winter and summer of 2015. We also increased our collaboration with the for-profit Russick Group, a start up food waste processor, to determine the nutritional composition of another food waste stream (which cannot be disclosed at this time) not included in our original sampling. Briefly, we observed that food waste from the Russick Group had greater crude protein and ether extract (fat) content than any of the food waste streams collected previously **(Table 1)**. In particular, note that the caloric content of most food wastes analyzed compare favorably with the most commonly used feeds (corn and soybean meal), although the SSO waste has somewhat lower caloric content that the other sources, and also has less

protein. The Russick food waste, on the other hand, compares favorably with other sources on the basis of calories, and is the richest in protein.

The last line of Table 1 shows the "shadow pricing" for each source. This is a modeled value based on the nutrient content of the dried product. The shadow prices for the food waste-derived products range from $200/ton (SSO waste) to $300/ton (supermarket waste); these values generally compare well with soybean products, indicating that they would be competitive.

Table 1. Simplified nutrient composition of organic waste sources, units/ dry matter basis.

Item	Supermarket Organic Waste	University Dinning Hall Waste	Hennepin County Transfer Station SSO	Russick	Corn	SBM
Dry matter – DM, %	91.7	93.0	90.0	73.23	88.31	89.98
Energy						
Metabolizable energy - ME, kcal/kg[1]	4832	4188	3198	4304	3395	3294
Crude protein - CP, %	25.5	18.9	17.7	52.9	8.24	47.73
Neutral detergent fiber - NDF, %	16.0	7.9	25.5	1.5	9.11	8.21
Ether extract - EE, %	34.1	12.0	9.7	40.6	3.48	1.52
Total amino acids, %						
Lys	1.82	0.77	0.67	3.67	0.25	2.96
Thr	1.07	0.60	0.47	2.05	0.28	1.86
Met	0.53	0.31	0.22	1.30	0.18	0.66
Trp	0.27	0.20	0.13	0.44	0.06	0.66
Minerals						
Calcium - Ca, %	0.98	0.25	1.02	2.91	0.02	0.33
Phosphorus - P, %	0.64	0.30	0.46	2.01	0.26	0.71
Shadow price, $/ton[2]	**300**	**240**	**200**	**280**	.	.

[1]Calculated using NRC (2012): ME = 4,194 – 9.2 × Ash + 1.0 × CP + 4.1 × EE – 3.5 × NDF.

[2]Assume prices of corn ($163/ton), soybean meal ($355/ton), soybean oil ($635/ton), and monocalcium phosphate ($510/ton).

B. Conversion of organic wastes to biofuels

(1) Analysis of food wastes from Fast Microwave Assisted Pyrolysis (fMAP) and Fast Microwave Assisted Gasification (fMAG). These analyses are useful for indicating the potential for creation of liquid and gaseous productions from food wastes. **Tables 2** and **3** show results for food wastes collected at Baily Hall of the University of Minnesota, Hennepin Co. Transfer Station, Lund's/Byerly and 3 Residential organics drop-off sites (Audubon, Armatage and Pearl Park). Food wastes from different sampling times were used and compared since the components of food wastes greatly vary for different collections.

The fMAP of food wastes was conducted at the temperature of 550 ^{o}C. The results show that the product yields and bio-oil components determined by GC/MS greatly varied for samples collected from different sites (**Table 2**) However, the main compounds detected in the bio-oil are important organic solvents and reagents, and can be also used as intermediates or precursors to other chemicals.

The fMAG of food wastes was conducted at the temperature of 900 ^{o}C and 60-70 wt.% of gas could be obtained for different samples. The contents of H_2, CO and CH_4 in the gas product were 25-35%, 15-21% and 8.5-10%, respectively for different samples. Note that for some samples, the H_2 to CO ratio in the gas product could reach above 2, which is much higher than that from other solid wastes, and almost perfect mixture for the syngas reforming (**Table 3**).

(2) Effect of catalysts on fMAP. To achieve higher conversion rates needed for commercial production, catalysts are needed. We experimented with various ratios of CaO and HZSM-5 zeolite for catalysis to evaluate yields at 550 ^{o}C. The catalysts decreased oil yield in the pyrolysis compared with the control, probably because pyrolysis vapors had to pass through the catalyst particles, which increasing the gas residence time. Increasing the ratio of HZSM-5: CaO generally increased the bio-oil yield (**Figure 1**) and changed the composition of the products (results not shown).

(3) Design of a continuous microwave based system for waste conversion. A third objective of the biofuel research was to build a continuous microwave-based system. A prototype capacity of digesting 15 kg/hr of food waste was constructed during this project period and will tested soon.

(4) Conversion of sewage scrum to biofuel. Earlier experiments showed that biofuel could be generated from the "skimmer sludge" that forms at the surface of sedimentation basins at the Metropolitan Wastewater Treatment Plant at St. Paul, MN. This is a particularly disgusting organic waste, one that would not be suitable for other uses, even compost. In this period, we focused on preparation of oil from scum for biodiesel production to determine an optimal processing condition for

best yield and energy efficiency and to improve both the oil preparation and biodiesel making processes so that the products will meet ASTM standards.

Two different conversion processes were designed and evaluated. The first is based on a process based on acid catalyzed esterification, which operates at moderate temperature but involves methanol and water separation which can be energy intensive; the second, which uses glycerolysis, needs use higher temperature, but the steps are less and process is easier to operate. After some experimentation, second option was chosen for the further system design. Using this approach, the total biodiesel yield from the dried and filtered scum oil was about 70% which was equivalent to about 1.24 ton per day biodiesel production or about 134,000 gallon biodiesel per year for the Metro Plant. One potential problem we encountered that needs to be resolved is the high is high sulfur content in the final biodiesel product, which would not meet the ASTM limit for S. Several processes are being evaluated to solve this problem, including fractional distillation, catalyzed glycerolysis, solvent extraction, etc. More results will be reported later on.

Design a full scale system. **Figure 2** illustrates a full-scale system design that could treat all scum produced by the Metro Plant. The system design is based on 30 hr/batch with a process capacity of 2,577 gallon/batch. After screw presser, scum will be transferred to the first tank and subjected to acid wash and solvent extraction. In the second reactor, solvent recycle, glycerolysis and transesterification will be carried out. Then the separated raw biodiesel will go through distillation tower and be refined. In the 3rd reactor, water wash with vacuum drying will clean up the final biodiesel product to meet ASTM B100 standard.

Economic analysis._We developed a basic material balance and analysis of the economic feasibility of the proposed process and system (**Table 4**). The total biodiesel production is estimated at about 134, 000 gallon per year, with the tax credit and RIN value, the total revenue will add up to $595,389/year. The estimated capital cost is about $1.2M; the operation cost is about $198,613/year. *Based on the calculation the payback time for the system is about 2.75 year, which indicates a very promising technology for commercialization.*

Table 2. Fast microwave-assisted pyrolysis (fMAP) of food wastes collected from different sites.

Sampling site	Baily Hall	Hennepin Co. Transfer Station	Lund's/Byerly	Audubon	Armatage	Pearl Park
Product yield (wt.%)						
Bio-oil	22.4	17.5	29.6	23.4	14.62	25.82
Bio-char	35.8	54.8	43.8	35.32	31.17	36.45
Gas	41.8	27.7	26.6	41.28	54.21	37.73
Main compounds in the bio-oil	Furfural	2-Propanone, 1-hydroxy-	Furfural	Pyridine	1,2-Ethanediol, diacetate	Pyridine
	Acetic acid, methyl ester	2-Furanmethanol	2-Furancarboxaldehyde, 5-methyl-	2-Cyclopenten-1-one	Butyrolactone	2-Cyclopenten-1-one
	2(5H)-Furanone	Butyrolactone	2-Propanone, 1-hydroxy-	Butyrolactone	2-Furancarboxaldehyde, 5-methyl-	1,2-Ethanediol, diacetate
	2-Furancarboxaldehyde, 5-methyl-	2-Pyrimidinamine	Propanoic acid, 2-oxo-, methyl ester	2-Furancarboxaldehyde, 5-methyl-	Phenol	Butyrolactone
	1,2-Ethanediol, diacetate	3-Butyn-2-ol	2,4(1H,3H)-Pyrimidinedione, 5-hydroxy-	Phenol	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	2-Furancarboxaldehyde, 5-methyl-

Table 3. Fast microwave-assisted gasification (fMAG) of food wastes collected from different sites.

Sampling site	Baily Hall	Hennepin Co. Transfer Station	Lund's/Byerly	Audubon	Armatage	Pearl Park
Gas yield (wt.%)	61.1	58.5	68.6	55.8	54.74	59.04
			Gas composition (%)			
H_2	34.8	25.1	27	27.3	27.89	26.3
CO	17	15.4	21.3	13.22	17.84	13.89
CH_4	9.7	9.8	8.5	3.5	6.22	4.78
CO_2	15.3	19.1	14.6	24.68	24.17	24.2

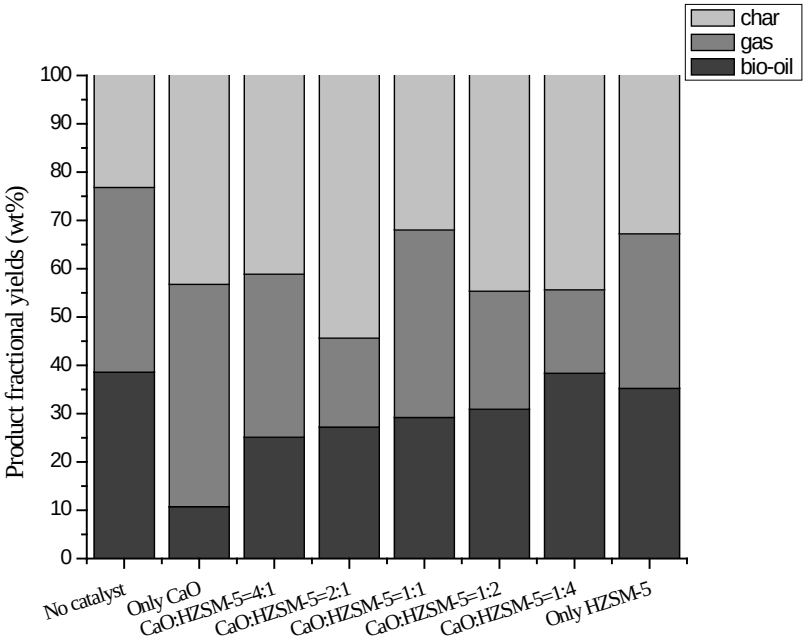

Fig. 1. The effect of CaO/HZSM-5 ratio on pyrolysis product fractional yields; T = 550 °C.

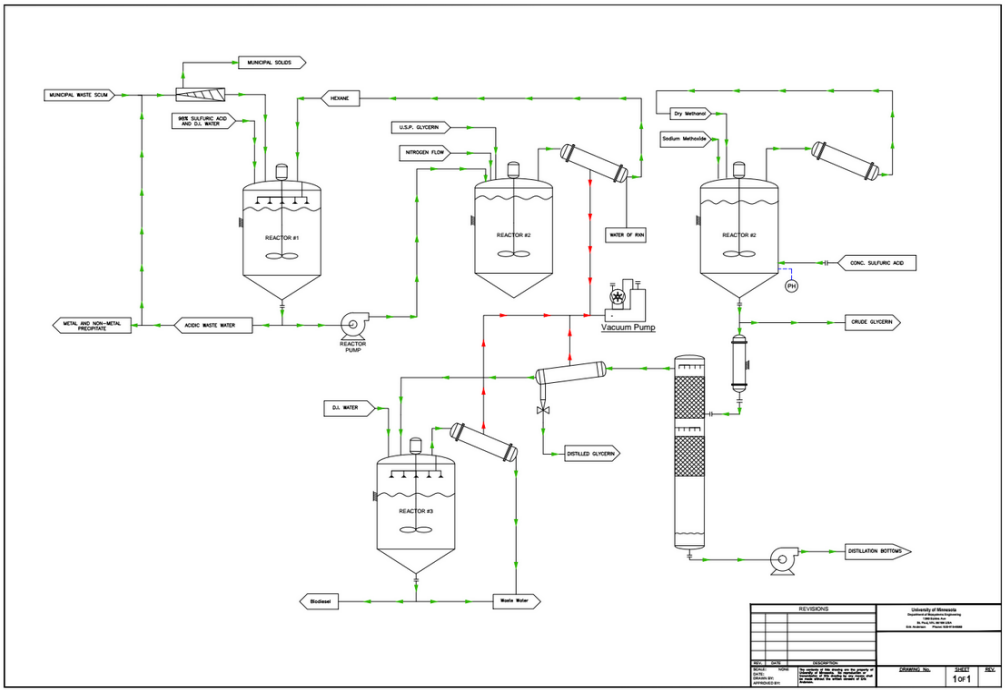

Figure 2. A batch-wise 3-tank system design diagram.

Table 4. Economic analysis of the proposed process and system.

Item	value	Unit
Plant Capacity	134000	Gallons/year
Plant Operations	1,560	Hours/year
Biodiesel Produced	2,577	gallons/week
Biodiesel Yield from Scum Oil	70	%
Cost		
Estimated capital Cost	1,200,000	$
Operation Cost	198,613	$/year
Revenue		
Biodiesel production	472,109	$/year
RINs and Tax credited	123,280	$/year
Total revenue	**595,389**	$/year
Payback Period, Years	**2.75**	year
Cost of biodiesel	1.482	$/gallon

C. Spatially distributed supply and demand for food wastes

A second major thrust of Waste Not research is to spatially understand, describe and eventually model sources of organic wastes and demand for waste-derived products in the Twin Cities region. While our work on biosolids from wastewater treatment facilities has begun to connect the dots between supply and demand (see section D, below), food waste is more complex. There are multiple sources of food waste (grocery stores, households, restaurants, and food processing plants) as well as multiple uses (compost, animal feed, and bioenergy). The optimal use depends on the waste composition and economics, with the economics largely being driven by spatial location of supply, demand, and transport. Despite its complexity, the importance of food waste is significant. The life cycle greenhouse gas emissions embedded in the Twin Cities' food waste is over a billion kg/CO2e a year (Venkat, 2011). These emissions represent a significant opportunity for emission mitigation in that no consumption needs to be curbed to achieve these GHG reductions.

In working to describe, model, and provide solutions to this multifaceted problem of food waste production, we have been breaking down the sources of food waste in the Twin Cities using national estimates for food waste. Given these estimates, Twin Cities households generate about 495,000,000 lbs. of food waste a year. Closely following this is waste from grocery stores at about 415,000,000 lbs. Food waste from restaurants tops out at about 370,000,000, with about 40% of coming from quick service restaurants (Cascadia, 2006; BSR, 2012; Buzby et al., 2014). While households are widely dispersed across the metro area, grocery stores and restaurants provide a more concentrated source for food waste (**Figure 3**) and together make up almost 800,000,000 lbs of food waste annually. This amount of food waste has the potential to annually feed over one million hogs (Pork Checkoff, 2015). However, the nuances of waste composition significantly affect these numbers. We are working to describe and then model these sources and their reasonable variations so we can then connect the dots for food waste as we have done for biosolids.

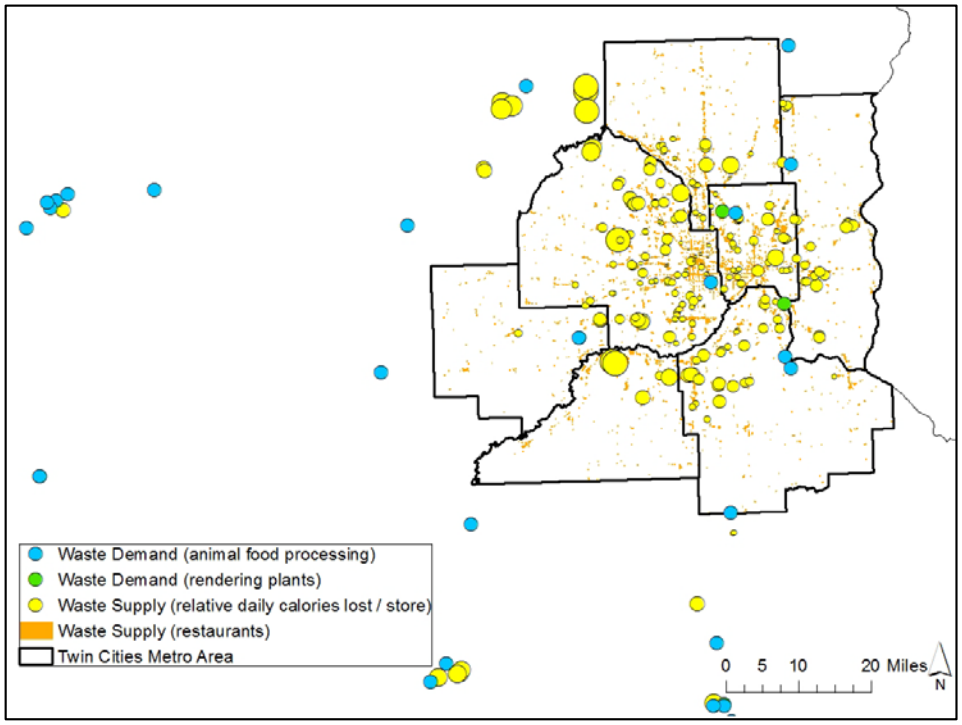

Figure 3: Supply and Demand for Food Waste in the Twin Cities, Minnesota.

D. Spatial optimization of biosolids (sewage sludge) on cropland

There is considerable value in using biosolids (sewage sludge) on cropland. Wet and d~~D~~ried biosolids provide not only nutrients (nitrogen, phosphorus, and potassium), but also increase~~s~~ the organic content of the soil, which generally improves a soil's structure and water holding capacity. When biosolids are incinerated, as occurs at the large Metro Plant, phosphorus and potassium are concentrated, and the weight is reduced, making distribution easier, but the ash does not contribute organic matter and nitrogen because these are lost during incineration. In addition to the fertilizer value of biosolids, landfill "tipping fees" and transportation to landfills are avoided, but cost of transporting biosolids to farms now enters into the equation.

To address this question, a linear programming spreadsheet model was developed to optimize the geographic distribution of wastewater treatment plant partially dried biosolids and biosolids ash from the four large plants in the Twin Cities area to the surrounding townships that contain cropland. Data includes material from each of four metro plants (Blue Lake, Empire, Seneca, and Metro sludge and incinerator ash), distances from each of the four metro plants to each township in the state that is less than 50 miles from at least one of the four plants, and acres of corn, soybeans, and alfalfa hay by township.

We assumed that the sludge and ash would be spread on corn, soybeans or alfalfa in nearby townships. Two fertilizer rates for N and P2O5 are considered. The U of M recommended rates for N assume that the mineralization of soil organic matter contributes some N to the crop, so less fertilizer needs to be applied than is actually measured in the harvested crop. The recommended rates are intended to be rates at which there is a maximum economic return, not maximum physical yield. Above those rates, there may still be some added yield but not enough to pay for the additional fertilizer.

However, where surplus N is available at no cost, such as in a large livestock operation, the Minnesota Pollution Control Agency allows use of higher rates referred to as "crop removal rates" (Minnesota Pollution Control Agency 2010). At these rates, in theory, all of the N will be taken up by the crop and none will enter the environment and cause pollution. Likewise, the U of M recommended P2O5 rates are higher than the allowed crop removal P rates.

In this analysis, land application of the sludge and ash provides two sources of value: 1) the avoided cost of the commercial fertilizer N, P2O5, and K2O that doesn't need to be purchased because they are provided by the sludge or ash, and 2) the avoided sludge or ash disposal cost. These values are partially offset by the sludge or ash hauling and application cost. There are 340 townships that fit the criterion of being less than 50 miles from at least one of the plants. There are five sources of biosolids (the four plants and both sludge and ash from Metro), yielding 5 x 340 or 1700 decision variables. The decision variables are wet tons of biosolids applied from each plant to the land in each township.

Figure 4 shows maps of optimized P and N application rates; the maps on the right show optimized distribution of wet tons of biosolids for two of the plants. The spatially optimized model reveals the following cost savings: reduced P_2O_5 fertilizer ($820,785), reduced N fertilizer ($414,440), reduced K_2O_5 fertilizer ($122,532), the difference between savings from avoiding of tipping fees and the transportation cost of biosolids to farms, $1,435,487, for a net savings of **$2.87 million**. This would reduce the total operating expense of Met Council Environmental Services ($122 million) by about 2.3%, but recycling biosolids has the additional values of reducing environmental impacts of landfill disposal and the benefit of enriching farm soils with organic matter (for the un-incinerated biosolids)

Comment [r1]: Our rates for corn currently do not directly account for organic matter. The rate is based on soli productivity which may or may not be related to organic matter. See:

http://www.extension.umn.edu/agriculture/nutrient-management/nutrient-lime-guidelines/fertilizer-recommendations-for-agronomic-crops-in-minnesota/corn/

Comment [r2]: This is not true. Manure and biosolids applications rates are based on N recommendations. This will result in an excess of P in most cases.

Comment [r3]: I do not think your modeling is appropriate for ash.

Comment [r4]: With ash the 50 mile distance is not really applicable because you are not hauling water and the P concentration is much higher.

Cost minimization model results – Total N and P2O5 applications/township from the four large metro WWTP, and wet tons applied from the Blue Lake and Seneca plants (Metro and Empire plant tons not shown)

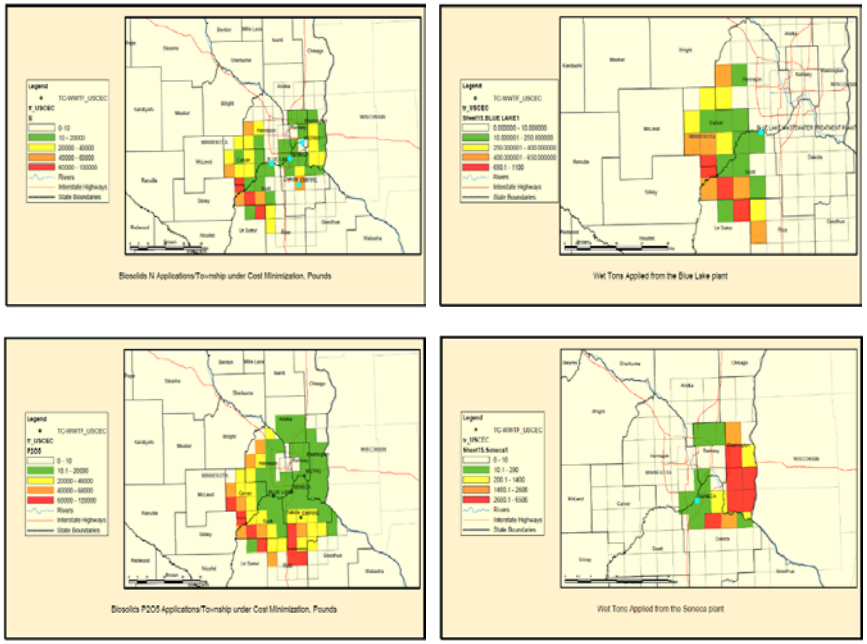

Figure 4. Maps showing optimized distribution of N and P (left side) and biosolids mass from two wastewater plants (right side).

E. Analysis of social and policy drivers

The Waste Not *Policy and Social Science Team* continues to investigate the key policy and social drivers behind waste management and, specifically, source-separated organics (SSO) recycling in the Twin Cities metro area. After completing a successful SSO household survey and 15 policy actor interviews in the first half of 2015, the policy team is now analyzing the data and interpreting the results. The intent of the policy and social science research is to demonstrate the complex political dynamics in which decisions about waste management, recycling, and environmental policy are determined. Interview and survey data have been analyzed in order to make evidence-based policy recommendations and produce original academic research on organics recycling policy in the Twin Cities. To these ends, the policy team is currently writing 1) a white paper report on the design and findings of the SSO household survey and 2) an article for publication in a peer-reviewed journal. The journal article focuses on the role of private industry and private-public collaboration in advancing organics recycling policy in the Twin Cities metro area. Findings and analysis will also be presented at the 46th Urban Affairs Association conference (San Diego, March 2016) and the Annual Canadian Political Science Association conference (Calgary, May 2016). Additional conference presentations will be made as time and funding allow. Finally, the policy team is also beginning research on a second peer-reviewed article, to be completed by the end of 2016. This second publication will draw on both the survey and interview results to assess the role of pilot projects in public sector policy innovations, such as organics recycling.

F. Community Engagement

We are starting to engage Minnesota's businesses in a number of ways. First, we have worked closely with the start-up Russick Group to begin the commercialization of processing various food wastes to feedstocks for animal feed; we then wrote a letter of support for the Russick Group's proposal to EPA's Small Business Innovation Research (SBIR) Program, now in review; and we hope to benefit from this project because it would support a "feed trial" in which food waste-derived feed would be fed to growing swine to assess metabolic efficiency.

Second, one of our Roger Ruan's Ph.D. students, Erik Anderson, intends to start a new biofuel processing business upon completion of his Ph.D., leveraging his 15 years of experience in the biofuels industry with new research that he is completing as part of the MNDrive Waste Not project.

Third, with some interesting and important findings now in hand, we are actively disseminating findings from Waste Not to local businesses and industry groups and have made about 15 presentations in various local settings. We have also participated (or are slated to participate) in 8 in national/international forums, for a total of 23 engagement events, ranging from small group presentations to international conferences and workshops.

Finally, we continue to work with our Technical Advisory Group (TAG). In year 2, we have agreed to hold joint meetings (MNDrive/Waste Not researchers + TAG) every other month (rather than every month), interspersed with monthly research team meetings.

2. How has your grant addressed the following MnDRIVE goals?

A. Advances Minnesota's economy.

The central theme of this project is that because of the abundance of urban organic wastes and the need for nutrients for crops in Minnesota, recycling organic urban wastes can benefit both our cities and farms, both economically and environmentally.

Some examples to date:

- Data from the Life Cycle and Economic Analysis group of the Waste Not project, along with nutritional characterization of the food waste, suggests that about 15% of the pig population in Minnesota could be fed with food waste nutrients recycled into feed. The total economic value of this application is about $70 million.
- Spatial optimization of biosolids application indicates that the net benefit from land application of all biosolids would be about $2.8 million, plus the added benefit of avoiding landfilling.
- Preliminary economic analysis of converting sewage scum from one wastewater treatment plant (Metro Plant) to biofuel has a payback period of only 2.75 years.
- We have learned from our households SSO survey that the barrier to adoption is rather low and could be made lower (by using responses from participants to inform educational programs for non-participants); and that there is consensus among policy actors that more efficient routing of food waste haulers is needed to efficiently recycle food wastes. Although we have done yet done an overall analysis of food waste recycling, we have been told, by Dr. David Meek (per comm., National Renders Association) that if we could bring food wastes to central locations, renderers as far as Wisconsin would likely pick it up.

B. Seizes opportunities to leverage MN's strengths and comparative advantages.

Waste Not has developed an academic team that combines core expertise in animal nutrition, crop science, sustainable business, applied economics, law, and engineering to work on the problem of food waste, anticipating the food waste would become a growing concern. This has turned out to be truer than we originally thought. Some new drivers for this research that have arisen ***since we started Waste Not in 2014*** include:

- The EPA and USDA launched a national Food Waste Challenge in September 2015, calling for a 50% reduction in food waste going to landfills by 2030. USDA and EPA are developing a plan to reach that goal, which we hope will include a strong research component.
- The National Science Foundation has started a new $78 research initiative, Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS); we are altering our course in Waste Not a bit in order to prepare for next year's competition (early 2016).
- The City of Minneapolis started rolling out its citywide Source Separated Organics (SSO) Program; St. Paul is planning to follow suit in 2017. These will create a large new supply of organic wastes, potentially opening up new markets to utilize organic wastes for their "highest and best use".
- The State of Minnesota passed a law requiring (115A) mandating 75% recycling of total waste generation in metropolitan counties; achieving this goal will require substantial food recycling.

In order to "seize the opportunity" our MnDrive/Waste Not project team has written several proposals to seeking additional research support:

1. Shurson (PI). New opportunity for the U.S. rendering industry in sustainable food production, submitted to the Fats and Proteins Research Foundation 9/14/15. $219,000 requested; not funded.
2. Ruan (PI). Biorefining of organic wastes, submitted to EREF 7/15/15. $500,000 requested; not funded.
3. Hikaru (PI), with J. Schmidtt. Food Waste Serendipity Grant, submitted to the OVPR 1/22/16, pending.
4. Collaboration with the Russick SBIR proposal, also pending.

Moreover, in the near future (1 year):

1. We are currently planning to submit a proposal to Minnesota's LCCMR program in late spring 2016, guiding by Waste Not co-PI Steve Kelley, a former state senator.
2. Co-PI Shurson will meet soon with Minnesota's Agricultural Utilization Research Institute to discuss new research.
3. Co-PI Tim Smith will meet with staff from the Environmental Defense Fund in the near future to discuss research opportunities.
4. We are shaping our research analysis to develop a strong proposal to NSF's new program Innovation at the Nexus of Food, Energy, and Water in 2017, to be led by Baker.

C. Improves Minnesotans' health and quality of life

Processing food waste into animal feed is a high priority in the EPA hierarchy of high value uses of food waste and prevents lower value uses such as incineration and disposal in landfills, which have negative environmental and land use implications. The same is true for biosolids, especially incinerated ash (which is always landfilled to date). In the future, we may look back on discarding organic wastes to landfills with the same distain that older Americans felt for the widespread practice of burning garbage in open dumps prior to the 1970s.

D. Advances the capacity and competitiveness of Minnesota industries.

Treating "wastes" as "garbage" is becoming economically unsustainable. We are systematically working to close the loop on organics wastes, in particular, looking for *higher and better uses* for utlilization of food wastes. As seen in part 2(a), utilizing food waste and biosolids may yield significant economic benefit, and we have only just started our economic analysis.

Some of this new knowledge will be used directly by existing companies, but our research will also support the development of entrepreneurs seeking to start businesses in various organics waste niche. These start-ups are especially receptive to new research findings, illustrated by our interaction with the Russick Group; we also create young entrepreneurs – perhaps Ph.D. student Erik Anderson?

E. Positions our state as a national leader.

- *MNDrive/Waste Not has developed a national caliper organics waste research team at precisely the moment when interest in organic wastes, especially food waste, has exploded on the national scene*.
- Our research team has extraordinary interdisciplinary capacity, with expertise that includes animal nutrition, mechanical engineering, political science, applied economics, soil and crop science, law and science policy, and environmental engineering.
- Our successful conference "Future of Organics Wastes in Minnesota", held June 2, 2015 has made our project very visible to the state organics waste community and to some extent, the national community, mainly by invite talks from representatives of the National Resource Defense Council (JoAnne Berkenkamp), Walmart (Kate Worley), the U.S. Congress (Keith Ellison), the National Rendering Association (Dr. David Meeker), and the City of San Jose (Stephanie Molloy).
- MNDrive/Waste Not researchers have (or will soon have) participated in 22 forums, ranging from presentations at business meetings to presentations and workshops at international conferences (see 3b).
- We have established a Waste Not website and have started posting products, including research tools (our SSO surveys) for others to use.
- Taken together, Minnesota has long embraced research in support of policy development. In the past few decades, some hallmarks these synergies have yielded some of the most advanced policies on water pollution, mercury contamination, and wetland policy in the country. MNDrive/Waste Not may continue this tradition of environmental leadership; the Legislature has just passed one of most advanced recycling laws while MnDrive/Waste Not pursues research to find better uses for organic wastes.

3. Publications, Presentations, Patents, And Intellectual Property Associated With Your Grant.

A. Publications. Because some publications and presentations are "partly" MNDrive products, we have assigned a percentage contribution from MNDrive.

1. Anderson, E., M. Addy, Qinglong Xie, Huan Ma, Yuhuan Liu, Yanling Cheng, Nonso Onuma, Paul Chen, Roger Ruan, Glycerin esterification of scum derived free fatty acids for biodiesel production, Bioresource Technology, Volume 200, January 2016, Pages 153-160, ISSN 0960-8524, http://dx.doi.org/10.1016/j.biortech.2015.10.018. 10%
2. Chong-hao Bi, Min Min, Yong Nie, Qing-long Xie, Qian Lu, Xiang-yuan Deng, Erik Anderson, Dong Li, Paul Chen, Roger Ruan, Process development for scum to biodiesel conversion, Bioresource Technology, Volume 185, June 2015, Pages 185-193, ISSN 0960-8524, http://dx.doi.org/10.1016/j.biortech.2015.01.081. 10%
3. Liu, S., Xie, Q., Zhang, B., Cheng, Y., Liu, Y., Chen, P., & Ruan, R. (2016). Fast microwave-assisted catalytic co-pyrolysis of corn stover and scum for bio-oil production with CaO and HZSM-5 as the catalyst. *Bioresource Technology*, *204*, 164-170. 20%
4. Mayer, B., L. Baker, T. Boyer, P. Dreshsel, M. Gifford, M. Hanjfra, P. Parameswaran, P. Westershoff, and B. Rittman. In revision. Total value of phosphorus recovery. 10%

5. Peterson, J., S. Hughes, L. Baker. Forthcoming (March 2016) Source-Separated Organics Survey: Survey design, methods and findings. White paper, to be posted on our wastenot.umn.edu website. 100%.
6. Peterson, J., S. Hughes. White paper report on the design and findings of the *Policy and Social Science Team*'s Source-Separated Organics (SS) household survey, which was conducted in the Hiawatha community in Spring 2015. 100%
7. Peterson, J., and S. Hughes. *Incentivizing Environmental Policy Change in Private Service Delivery Systems.* In prep. 100%
8. Zhang, Bo, Zhaoping Zhong, Min Min, Kuan Ding, Qinglong Xie, Roger Ruan, Catalytic fast co-pyrolysis of biomass and food waste to produce aromatics: Analytical Py–GC/MS study, Bioresource Technology, Volume 189, August 2015, Pages 30-35, ISSN 0960-8524, http://dx.doi.org/10.1016/j.biortech.2015.03.092. 20%

B. Presentations (22 total)

(1) National/International Presentations and Workshops

1. Baker, L. (invited) NSF Chemistry Division Workshop: P Sustainability Research for INFEWS, May 18-19, 2015, Washington, DC.
2. Baker, L. (Invited) Workshop on Food, Energy, and Water, A multi-disciplinary workshop sponsored by the University of Nebraska-Lincoln, Georgia Tech, the Ohio State University and industry partners, to be held Feb. 22-24 at the University of Nebraska.
3. L. Baker was also invited to a workshop on P sustainability by John W. McGrath, Queen's University Belfast (Ireland), part of a plan to connect Waste Not with an Irish EPA project on recycling. The date has not been set but will probably be in 2017.
4. Peterson, J., and S. Hughes. Governing Garbage: How can local government advance environmental aims in sectors where service is privately delivered? To be presented at the, 46th Urban Affairs Association Conference, March 16-19, San Diego. 100%
5. Peterson, J., and S. Hughes. Advancing environmental reforms in waste management in Minnesota's Twin Cities metro area. To be presented at the 2016 Canadian Political Science Association (CPSA) Annual General Conference, May 16-19
6. Peterson, J., and S. Hughes. Panel Presentation at the CPSA Environmental Politics Workshop, Public Goals, Private Pick-up: Advancing environmental reforms in waste management in Minnesota's Twin Cities metro area.
7. Urriola, P. E. and G. C. Shurson. 2015. Swine Research Program at the University of Minnesota. October 2015. Seminar at Chinese Academy of Agriculture Science. Beijing China. 10% was Waste Not

(2) Regional presentations and meetings

The first four presentations were made at our MnDrive/Waste Not sponsored conference *The Future of Organics Wastes in Minnesota* held on June 2, 2015 at the Continuing Education Center on the St. Paul Campus:

1. Baker, L., D. Nidzgorski, J. Schmidt, and C. Rosen. Overview of Waste Not Research. Presented at The Future of Organic Wastes in Minnesota.
2. Shurson, G. Potential for Utilizing Food Waste for Animal Feed. Presented at The Future of Organic Wastes in Minnesota.

3. Ruan, R., Q. Xie, Y. Cheng, S. Liu, P. Peng, B. Zhang, P. Chen, and L. Baker, Energy and Chemical Extraction from Waste.
4. Hughes, S. and J. Peterson. Policy and Politics of Urban Innovation: Minneapolis and Beyond.

5. Baker, L. Waste not: closing the loop on organic wastes. Presented to the Twin Cities Research Group, Wilder Center, St. Paul, Sept. 9, 2015. 100%
6. Schmitt, J. Food waste modeling. Presented to Hennepin County (Karen Nikolai, Alene Tchourumoff) and UMN (Anu Ramaswami, Mark Reiner, Frank Douma) 6/18/15. 100%.
7. Schmitt, J. Food waste recycling. Presented at Eureka Recycling (Kate Davenport), 6/22/15 & 11/16/15. 100%
8. Schmitt, J. Agricultural supply chains. Presented at Cargill, 7/27/15 . 10%
9. Schmitt, J. Agricultural Supply Chains. Presented at the Renewable Fuels Association (Geoff Cooper) and UMN (Pedro Urriola), 8/31/15. 10%
10. Schmitt, J. Food waste sourcing and processing. Presented to the Russick Group (David Russick), 9/17/15. 100%
11. Schmidtt, J.Agricultural supply chains and organic wastes. Presented at Land O' Lakes (Jessica Wingert, Tai Ullman, Keith Newhouse, Todd Peterson, Tanya Dowda, 9/24/15. 33%
12. Schmitt, J. Agricultural supply chains and food waste to feed. Presented to the National Pork Board (Allan Stokes) and UMN (Jerry Shurson and Tim Smith), 10/14/15. 33%
13. Schmitt, J. Agricultural supply chains and pork Production, Presented at the University of Arkansas (Marty Matlock and Greg Thoma), 10/29/15. 10%
14. Schmitt, J. Food systems. Presented at Forum for the Future (Georgia Rubenstein), 11/10/15. 50%
15. Schmitt, J., Twin Cities Food Waste, Presented at Hennepin County (John Jaimez and Donovan O Koxvold), 11/19/15. 100%

(3) Stock presentations. We have also prepared two "stock" presentations to share with colleagues and to post on our web site:

- Peterson, J., S. Hughes. Waste Not: Closing the Loop on Organic Waste: Social Science Team Report.
- Baker, L., G. Shurson, R. Ruan, T. Smith, S. Kelley, P. Urriola, J. Schmitt, S. Hughes, J. Peterson. Waste Not: Closing the Loop on Organics Wastes in the Twin Cities.

4. Did your project create any new programs, degree areas, or courses/seminars?
No.

5. Project Participants
A. Faculty
Larry Baker, Bioproducts and Biosystems Engineering (BBE), PI
Sarah Hughes, Political Science, University of Toronto
Steve Kelley, Humphrey School, co-PI
William Lazarus, co-PI, Applied Economics
Carl Rosen, co-PI, Soil, Water, and Climate

Roger Ruan, BBE, co-PI
Gerald Shurson, Animal Science, co-PI
Tim Smith, BBE, co-PI

B. Other faculty and post-docs
Dr. Pedro Uriola, Research Assistant Professor, Animal Science
Dr. Jennifer Schmitt, Research Associate, IonE
Dr. Paul Chen, Research Associate Professor, BBE
Min Addy, Post Doc, BBE.

C. Graduate students
Eric Anderson, Ph.D. student, BBE (originally an industry TAG member)
Jacqueline Peterson, Ph.D. student at the University of Toronto
Leonard Fung, M.S. student (started Waste Not as an undergraduate)
Shiyu Liu, BBE

C. Undergraduates
Ana Arango

6. External partners and specific resources/contributions they have made to the grant.
Our Technical Advisory Group (TAG) remains active. In the current project period we have agreed to meet every other month (rather than every month, as in year 1). The primary role of the TAG is advisory, but individual members have often helped us make arrangements for sampling (for example, Kellie Kish from the City of Minneapolis worked with us on our Household SSO survey and has coordinated pickup of SSO wastes at drop-off sights; Larry Rogacki from Met Council provide us with biosolids data from the Met Council wastewater treatment plants used in the spatial optimization study of biosolids (above); Erik Anderson, originally an industry representative, is now a Ph.D. student working with Roger Ruan. We added one new TAG member, Dr. Heidi Peterson (a former post-doc of LB), a research scientist at the Minnesota Department of Agriculture, to advise us on the agricultural side of the "closed loop".

Regarding commercial entities, as noted above, we are collaborating informally with David Russick (Russick Group) - david.russick@russickgroup.com and are collaborators his SBIR proposal (pending).

We have also held numerous meetings with various companies and industrial groups. For some of these we are utilizing Waste Not members of IonE's Northstar Initiative (Tim Smith and Jennifer Schmitt); note above that Jennifer has met with many of them.

Finally, we are also expanding food waste collaborations with other academic researchers. As noted above, one or more Waste Not researchers will be attending a workshop on organics recycling in Ireland, part of an Ireland EPA-funded project. The PI has recently been invited to a workshop on Food, Energy, and Water led by the University of Nebraska, which will likely lead to further collaborations (e.g.,

workshop publications; invitations to other conferences, etc.). In another workshop project, the PI is working with a subgroup to write a paper “transitions in phosphorus management”, exploring the emerging concept of transitions theory in the context of P governance (including food wastes).

7. Financial Summary

The starting budget was $220,116. So far we have spent $118,872.66; another $73,941.90 is encumbered, leaving $27,287.44 (**Table 5**). The majority of the remaining budget will go to lab analyses and travel. Thus, we are very much on track to spend down the budget by the end of the project period.

Table 5. Financial summary.

Summary by Chartstring - Rolled up

1/29/2016 9:39:41 AM

As of 1/28/2016 FY 2016 July to January

11032 Bioprod&Biosys Eng, Dept of

Chart string 1000-11032-MNF11- - -1105980 -

Fund: 1000 State Appr and Tuition
Program: MNF11 MnDrive Global Food Org Rsrch
Project: Varies
CF1: Varies
CF2: Varies
CF3: 1105980 Baker,Lawrence Alan

Account		Budget	Expense Year to Date	Encumbrance	Total Expense & Encumbr	
Carry Forward						BALANCE
900100	FYE Carryfwd	$0.00	$31,960.31	$0.00	$31,960.31	
Total		**$0.00**	**$31,960.31**	**$0.00**	**$31,960.31**	
Transfers In						
600200	Non-Mand Int Trsfr In O	$220,000.00	$188,156.00	$0.00	$188,156.00	
Total		**$220,000.00**	**$188,156.00**	**$0.00**	**$188,156.00**	
Transfers Out						
610200	Non-Mand Int Trsfr Out	$0.00	$0.00	$0.00	$0.00	
Total		**$0.00**	**$0.00**	**$0.00**	**$0.00**	
		$220,000.00			$220,116.31	
Expenses						
700100	Salaries-Faculty	$42,127.00	($25,311.19)	($17,980.27)	($43,291.46)	($1,164.46)
700200	Salaries-P/A/PoliceOnly	$26,168.00	($19,168.18)	($4,229.06)	($23,397.24)	$2,770.76
700300	Salaries-Grd/Pr w/Tuitn	$28,977.00	($14,335.88)	($15,090.40)	($29,426.28)	($449.28)
700400	Salaries-UG/Pro-in-Trng	$5,898.00	($4,198.50)	$0.00	($4,198.50)	$1,699.50
700500	Salaries-Civil Service	$0.00	($535.36)	$0.00	($535.36)	($535.36)
710100	Fringe - Faculty	$14,196.00	($8,529.86)	($6,058.97)	($14,588.83)	($392.83)

710200	Fringe-P/A/PoliceOnly		$8,819.00		($6,459.65)	($1,425.16)	($7,884.81)	$934.19
710300	Fringe-Grad/Pr-w/Tuitn		$30,687.00		($15,033.47)	($15,824.70)	($30,858.17)	($171.17)
710500	Fringe-Civil Service		$0.00		($42.29)	$0.00	($42.29)	($42.29)
	Total Personell	***$156,872.00***	***($93,614.38)***	***$0.00***	***($93,614.38)***	***($60,608.56)***	***($154,222.94)***	***$2,649.06***
720200	Lab/Med Supplies		$27,210.00		($14,792.54)	$0.00	($14,792.54)	$12,417.46
720300	Gen Oper Services		$0.00		($109.39)	$0.00	($109.39)	($109.39)
720400	Lab/Medical Svcs		$7,750.00		($177.83)	$0.00	($177.83)	$7,572.17
720500	Telecommunications		$0.00		($66.89)	$0.00	($66.89)	($66.89)
720600	Travel/Mileage/Mov		$5,850.00		($2,154.41)	$0.00	($2,154.41)	$3,695.59
730200	Professional Svcs		$20,000.00		($6,666.66)	($13,333.34)	($20,000.00)	$0.00
750100	NC Bldgs/Equip		$600.00		($300.00)	$0.00	($300.00)	$300.00
820200	Enterprs Assessmnt		$1,820.00		($990.56)	$0.00	($990.56)	$829.44
	Total Non-Personell	***$63,230.00***	***($25,258.28)***	***$0.00***	***($25,258.28)***	***($13,333.34)***	***($38,591.62)***	***$24,638.38***
Total			**$220,102.00**		**($118,872.66)**	**($73,941.90)**	**($192,814.56)**	**$27,287.44**

Appendix: Letter of Support for the Russick SBIR proposal.

UNIVERSITY OF MINNESOTA

Department of Bioproducts and Biosystems Engineering
College of Food, Agricultural and Natural Resource Sciences
College of Science and Engineering

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To: SBIR Program Reviewers

As the PI of a University of Minnesota research project "Waste Not: Closing the Loop on Organic Wastes" (wastenot.umn.edu) I am pleased to write a letter of support for David Russick's SBIR proposal on processing food waste to animal feed.

The U of M project is being funded through a legislative initiative called MNDrive, more specifically, a program within MNDrive called Food Ventures. One of the goals of Food Ventures is to "advance early to mid-stage existing projects that have a high probability of being launched in the private sector to a more fast track and intensive development"

Waste Not started in 2104 and will continue with funding from Food Ventures at least through June 2016, with the possibility of renewal. One vein of this research is to examine the potential for greatly expanded utilization of food waste, especially for use as a feedstock for animal feeds. As Mr. Russick has indicated in his proposal, our early work indicates that some types of food wastes have very strong potential for being used as feedstocks, especially with respect to contributing calories, protein, and phosphorus.

We are clearly at a stage to enter into collaborations with the private sector (e.g., Mr. Russick). My colleagues who are leading the food waste analysis (Drs. Jerry Shurson and Pedro Urriola) have met with David many times to plan the SBIR project, and David is on the external Technical Advisory Group for our larger Waste Not project. Hence, on a personal level, the initial collaboration is well developed.

On a technical note, the proposed SBIR proposal hits all the right notes. It is one thing to conclude that the nutrient content of a food waste makes it a good candidate for a feedstock; the larger step is to learn how to process the food waste to make it stable and safe (Mr. Russick's work) and to understand how pigs respond to the new feed from a nutritional standpoint (Drs. Shurson's and Urriola's work). Both of these elements are addressed in this proposal.

Findings from Mr. Russick's proposed SBIR project would be synergistic with broader findings from our Waste Not project. For example, we are examining social and political barriers to organics waste recovery, partnering a political science professor from the University of Toronto (Dr. Sara Hughes) and her Ph.D. student (Jacqueline Brown). Further, we are not working in academic isolation, but are advised by an outside Technical Advisory Group (of which David is a member) that includes representatives from municipal, county, and state governments as well as other industries. Hence, findings from the proposed SBIR would become an integral part of our Waste Not

project, which in turn is already shaping the future direction of food waste management in the region.

Finally, applied research to reduce and reuse food waste is especially timely and important to EPA in light of the recently announced EPA-USDA Food Waste Challenge, which calls for 50% reduction in food waste by 2030. We cannot wish that this goal will be accomplished; it will take a lot of research and hard work – projects like Mr. Russick's proposed SBIR project.

Sincerely,

Lawrence A. Baker, Ph.D.
Research Professor