Ethanol from Cellulose *Faster*

J .W. Walkinshaw, PhD, P.E.- MA
University of Massachusetts Lowell
S.E. Poniatowski, MBA
TerraSonics LLC

Biofuel Goals

- Replace 30% of current gasoline consumption with ethanol (60 billion gallons) by 2030. (1.43 gallons of ethanol = 1 gallon of gasoline),
- Produce ethanol from non-food sources.
- Reduce conversion cost of cellulose to ethanol to $1.07/gallon by 2012.

Why Ethanol?

- Mature fermentation technology.
- Fermentation can be economically sound at current oil prices.

Why Not Corn?

Corn Based Ethanol Feasibilty

	2007 Actual Production	2030 Production Goals
Ethanol (gallons)	6.5 billion	60 billion
Feed Source	Corn	Corn
Feed Source Required	2,353,000 bushels (18 % of 2007 corn crop)	21,720,000 bushels (1.66 times 2007 corn crop)
Land Mass Required	15.6 million acres	144.8 million acres
U.S. Arable Land	465 million acres	465 million acres
% U.S. Arable Land	3.4 %	31.1 %

Cellulose from Discards

	Cellulose Feedstock from Solid Waste Streams					Potential Glucose[1]	Potential Xylose[1]	Estimated Ethanol Production[1]	EPA Reported Municipal Discards for 2006[2]	USDA Industrial/Agricultural Discards Estimates for 2005[3]	Estimated National Potential Ethanol from MSW	Estimated National Potential Ethanol from Industrial Discards
	Cellulose	Hemi-cellulose	Lignin	Extractives	Ash							
	weight percent (dry material basis)					kg per 100 kg dry feed stream		Gallons per ton dry feed stream	Thousands of tons	Thousands of tons	Millions of gallons	Millions of gallons
Hardwoods[4]	40-50	17-35	18-25	1-5	0.4-0.8	39-49	12-25	85	7,170[5]	10,000	616	850
Short Rotation Hardwoods[6]	50	23	22	5		49	16	91				
Softwoods[7]	45-50	25-35	25-35	3-8	0.2-0.5	44-49	18-25	95	1,800[8]	10,000	170	950
Wood Bark[9]	20-30					19-29		36		10,000		360
Stalk Fibers, Grasses[10]	33-38	15-18	17-19	37-32	6-8	32-37	10-13	49				
Grasses, Lawn Clippings[11]	45	30	15		10	44	21	89	12,300[12]		1,096	
Agricultural Residues[13]	38	32	17		13	37	22	62	15,065[14]	113,000	934	7,000
Orchard Grass[15]	32	40	4.7			21	28	62				
Leaves[16]	15.3	10.5	43.8			15	7	30	--[17]		--[17]	
Textile Waste – Cotton[18]	98	0	0		2	96		145	850[19]		124	
Food Wastes[20]	46.1	6.2	8.3		39.5	45	4	72				
Mixed Office Waste (MOW)	80	1	1		18[21]	85	6	135	12,190[22]		1,650 - 1,712[23]	
Old Corrugated Containers (OCC)[24]	57.3	9.9	20.8		12	56	7	92	8,800		812	
Old Newspaper (ONP)[24]	48.5	9	23.9	18.6		47	6	78	2,040[25]		158	
Post-Consumer Coated Papers (CP)[24]	42.3	9.4	15	33.3		41	7	56	1,530[26]		85	
Post-Consumer Sanitary Towels[27]	75	5	0	0		73	4	115	3,430[28]		394	
Total Estimate											6,039	9,160

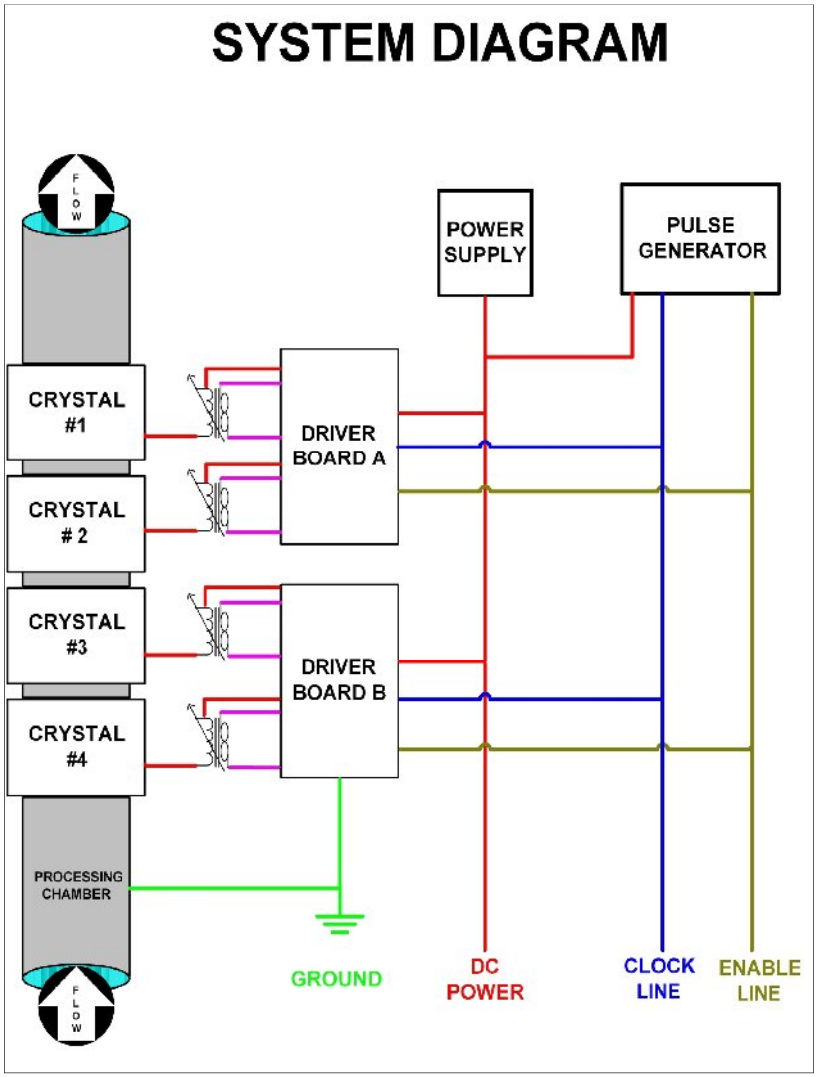
Cellulose Issues

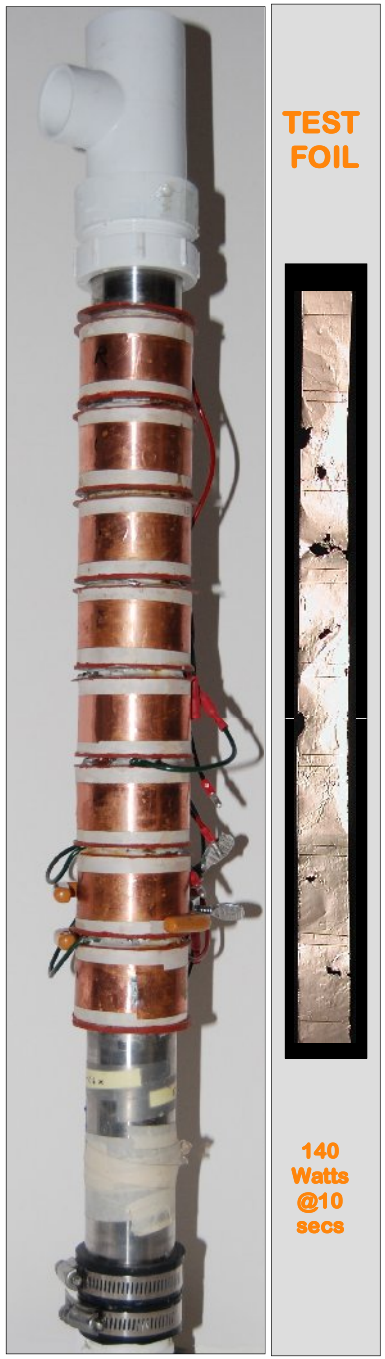
- **Cellulose is a component of complex physical structures (e.g. fibers containing cellulose, hemi-cellulose, lignin).**
- **Processing fiber is challenging:**
  Dewatering, clumping, balling, hanging,
  Expensive to mix or pump.
- **Crystalline cellulose regions within the fiber inhibit enzyme penetration.**

Enzyme Issues

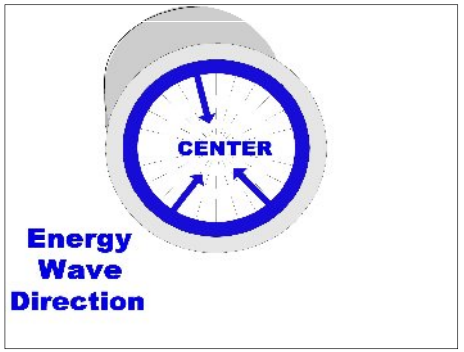
- **Feedstock structures inhibit enzyme activity.**
- **Products produced by enzyme activity can inhibit further enzyme activity.**
- **Low saccrification reaction rates.**
- **Enzymes activity cannot always be accelerated by increasing process temperatures as enzymes can sometimes be denatured by high temperatures.**

Test Unit





Process Tube
5GS-1.6x



Experimental Procedure: Set-Up

Equipment: Without Ultrasonics – 2 liter beaker with heating & agitation
With Ultrasonics – Process Tube 5GS-1.6x (as shown)

Paper stock: 500 ml of thick stock
(100 grams waste office papers paper per 3.0 liters water)

Additives: 2-ml Antibiotic to retard bacteria growth
(25 mg of chloramphenicol dissolved in 1 ml 95% ethanol)

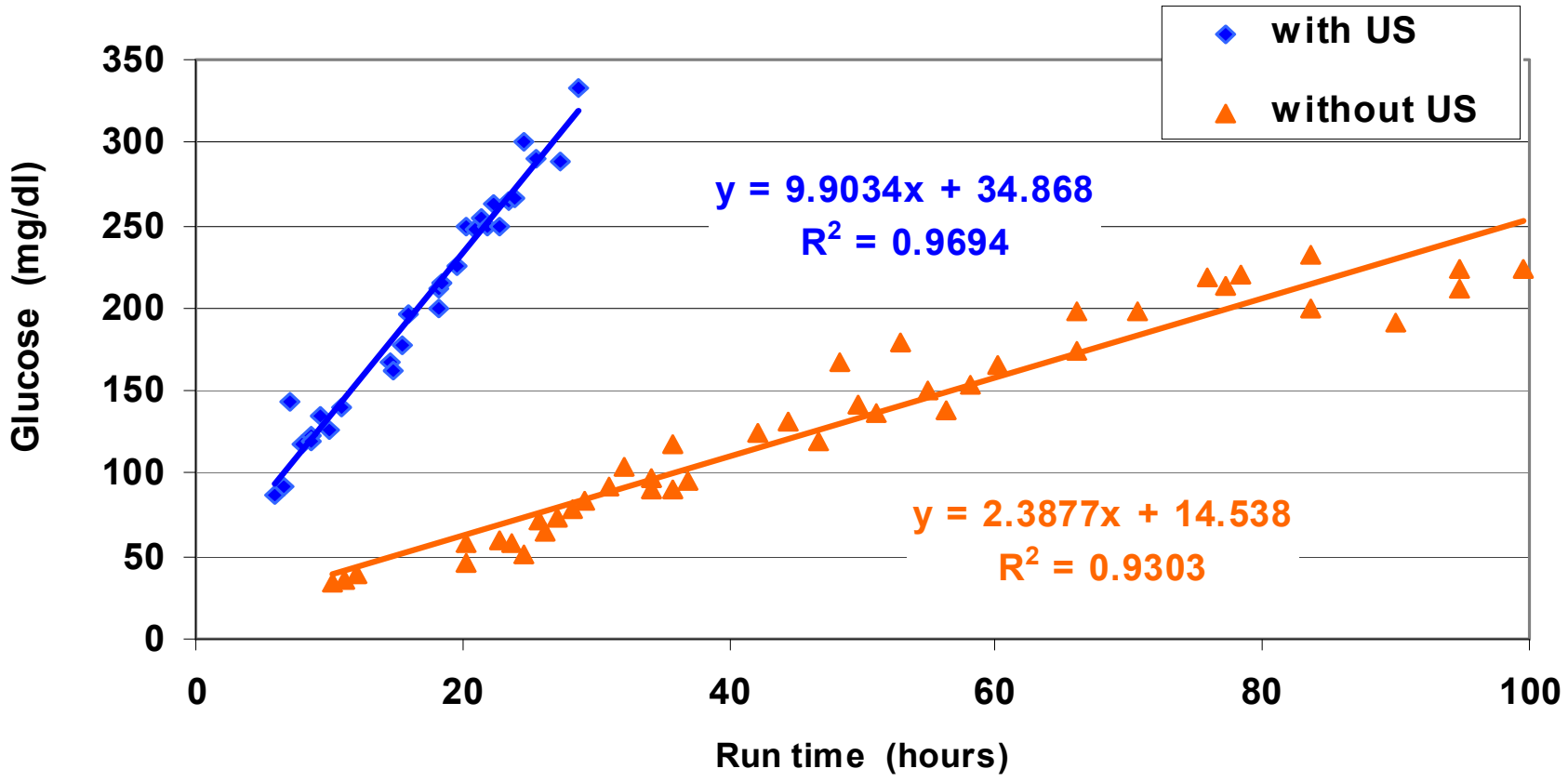
5 ml of buffer solution
(0.1 M citric acid solution in water)

Final step: Add water to dilute to 1500 ml

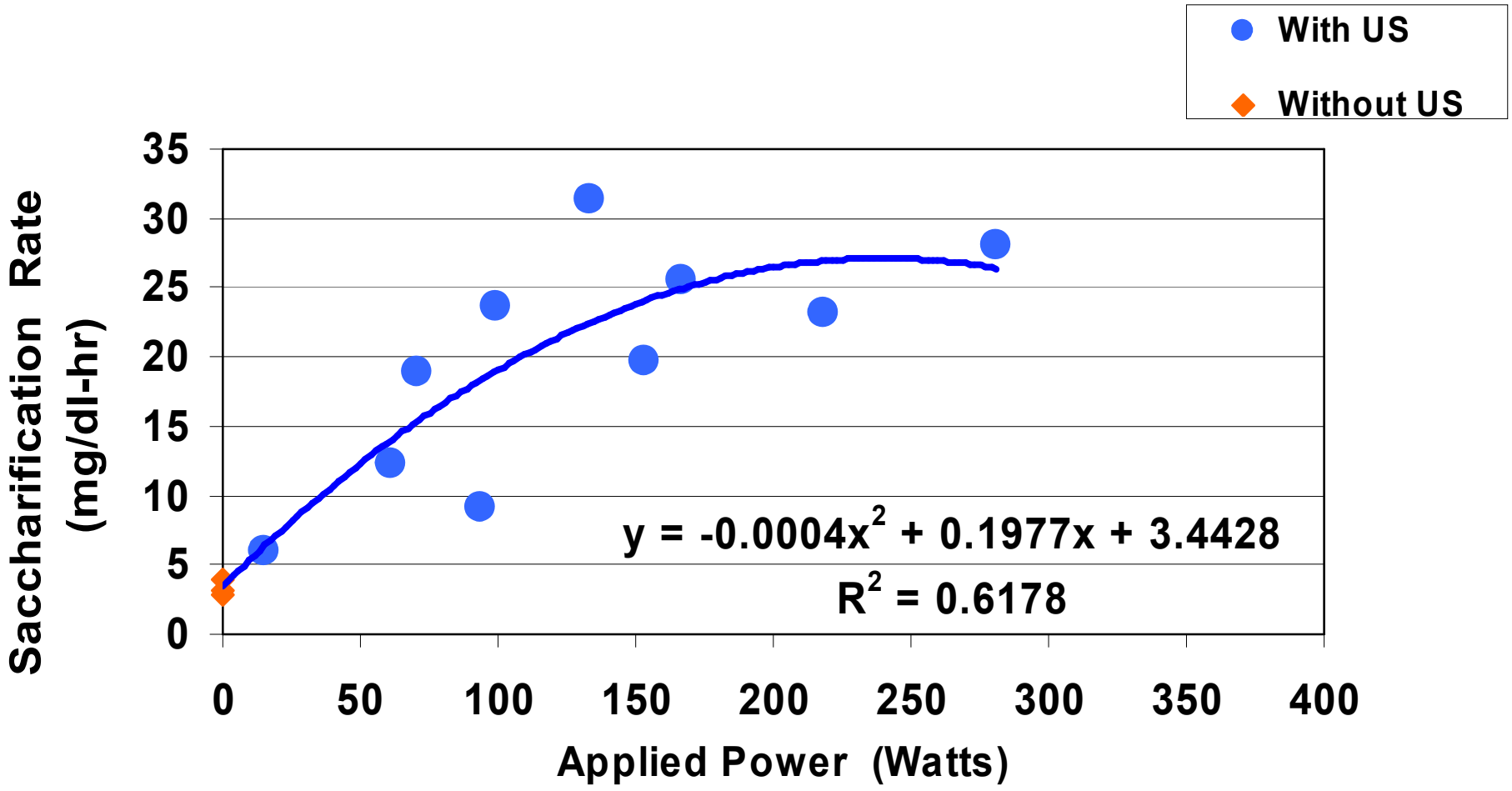
Experimental Procedure: Trial

- Procedure: Add diluted stock to beaker/tube. Start circulating pump, ultrasonic generator (23.6 $\pm$ 0.1 kHz), adjust power level.
- Allow temperature to rise, or provide heat to circulation loop, until a temperature of 92^{o}F is reached. Maintain temperature at 95 $\pm$ 4 ^{o}F.
- Add 5 ml enzyme solution Cellulase from *Trichoderma reesei* ATCC 26921start run clock. Additional 1-ml quantities of enzymes added at 2-hour time intervals.
- Check glucose, power level temperature at timed intervals.

Kinetics of *T. reesei* Enzymes with and without Ultrasonic Treatment

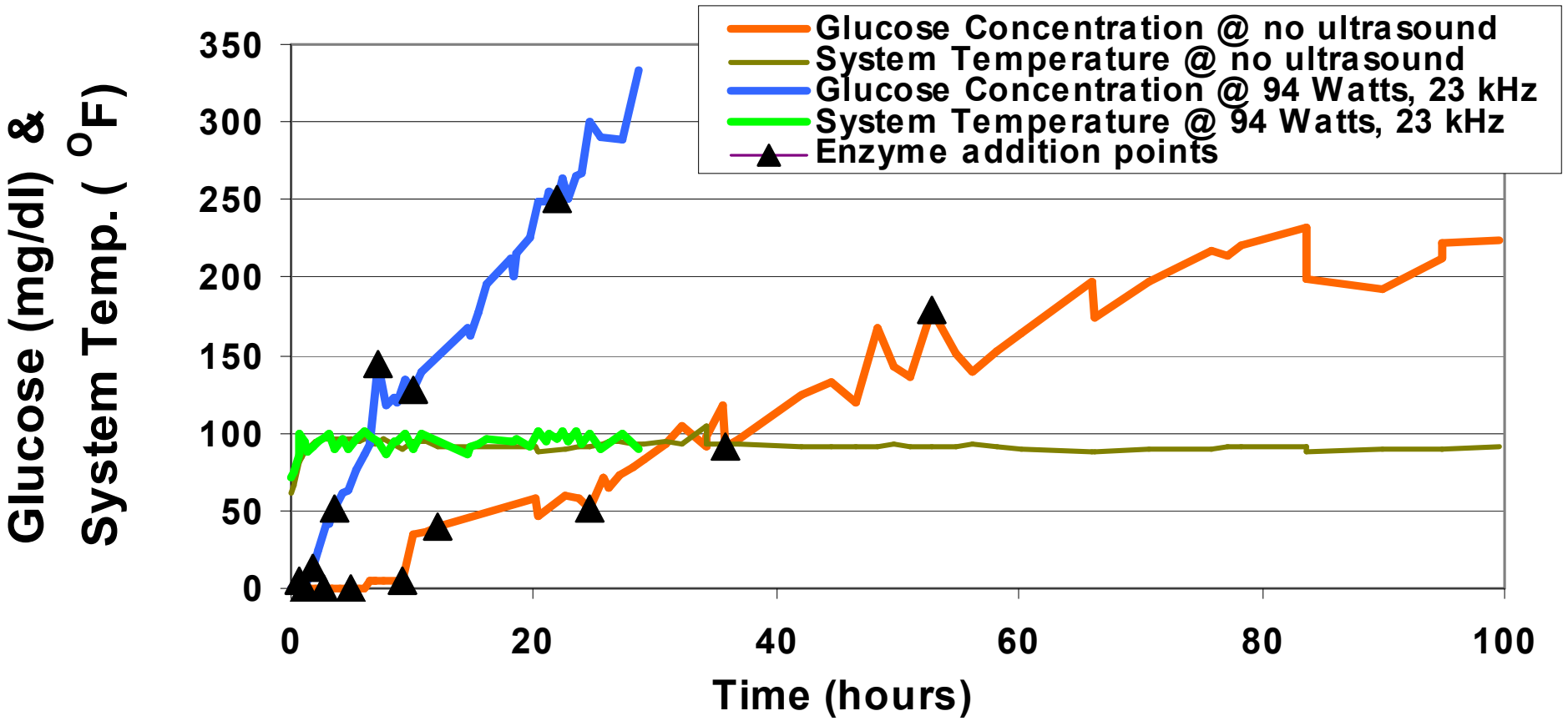


Accelerating Saccharification With Ultrasound @ 23.5 kHz



(Applied Power = Total Power - 'No Load' Power)

Saccrafication of Paper with and without Ultrasonic Treatment



Conclusions

- Conversion of cellulose to glucose is **FOUR times** faster when ultrasonic energy is applied.

- Substituting ethanol (made by fermenting cellulose) for gasoline is one way for reducing U.S. dependence on gasoline for transportation; other technologies and fuels are needed.

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For Further Information

Ms. Susan Poniatowski
TerraSonics, LLC
978-692-3274
email: Suponiatow@aol.com

Dr. John Walkinshaw
University of Massachusetts Lowell
978-934-3159
email: John_Walkinshaw@uml.edu