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Golisano Institute for Sustainability
ROCHESTER INSTITUTE OF TECHNOLOGY

Biochar as a sustainable food waste management strategy

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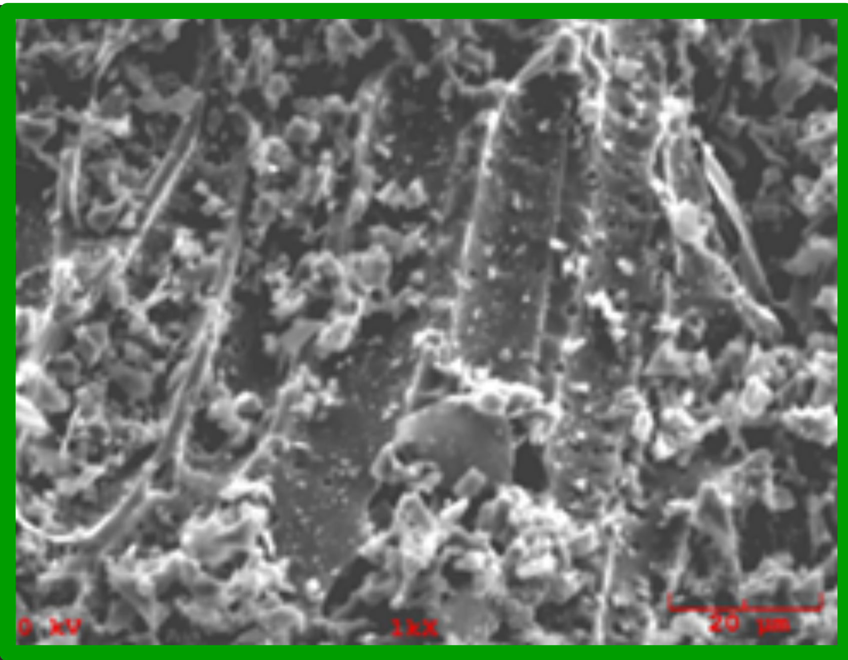
Biochar 2018
Wilmington, Delaware
August 22, 2018



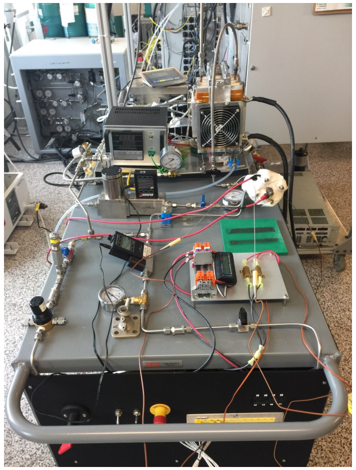
Golisano Institute for Sustainability (GIS)

Inter-disciplinary graduate program:

- M.S. Sustainable Systems
- Master of Architecture
- Ph.D. Sustainability

- System-level research:
  - Sustainable energy
  - Sustainable mobility
  - Sustainable manufacturing

Focusing on alternative food waste management technologies combined with sustainable energy systems (e.g., hydrogen fuel cells)



Food waste: a national and global problem

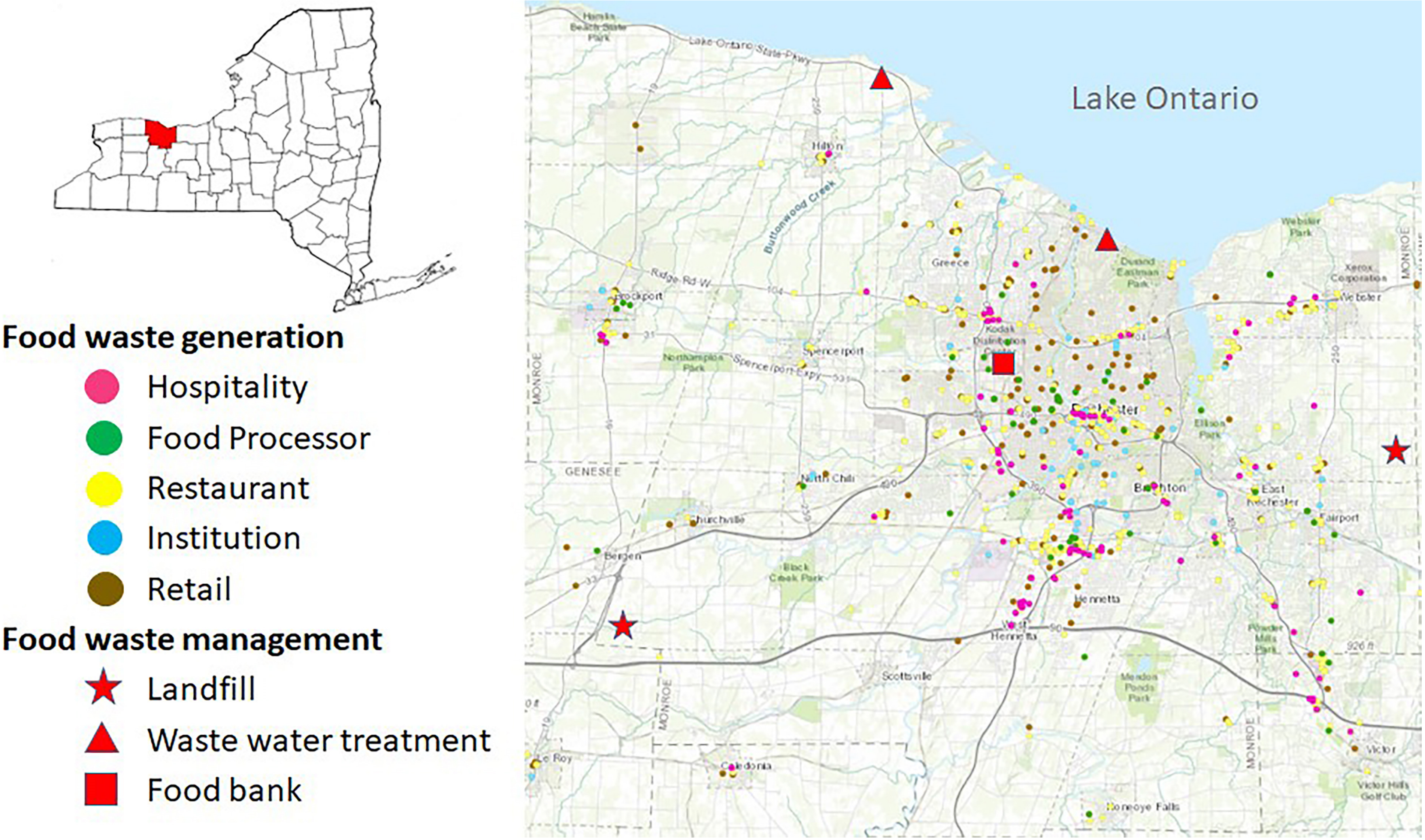
	Agriculture	Food Processing	Consumer-Facing Businesses	Households
Food waste (million tons)	10	1	25	27
% of total waste	16	2	40	43
Cost of waste (billion $)	15	2	57	144
% of total cost	7	1	26	66

Increasing heterogeneity and dispersion

ReFED, Rethink Food Waste through Economics and Data, 2016. *A Roadmap to Reduce U.S. Food Waste by 20 Percent*.

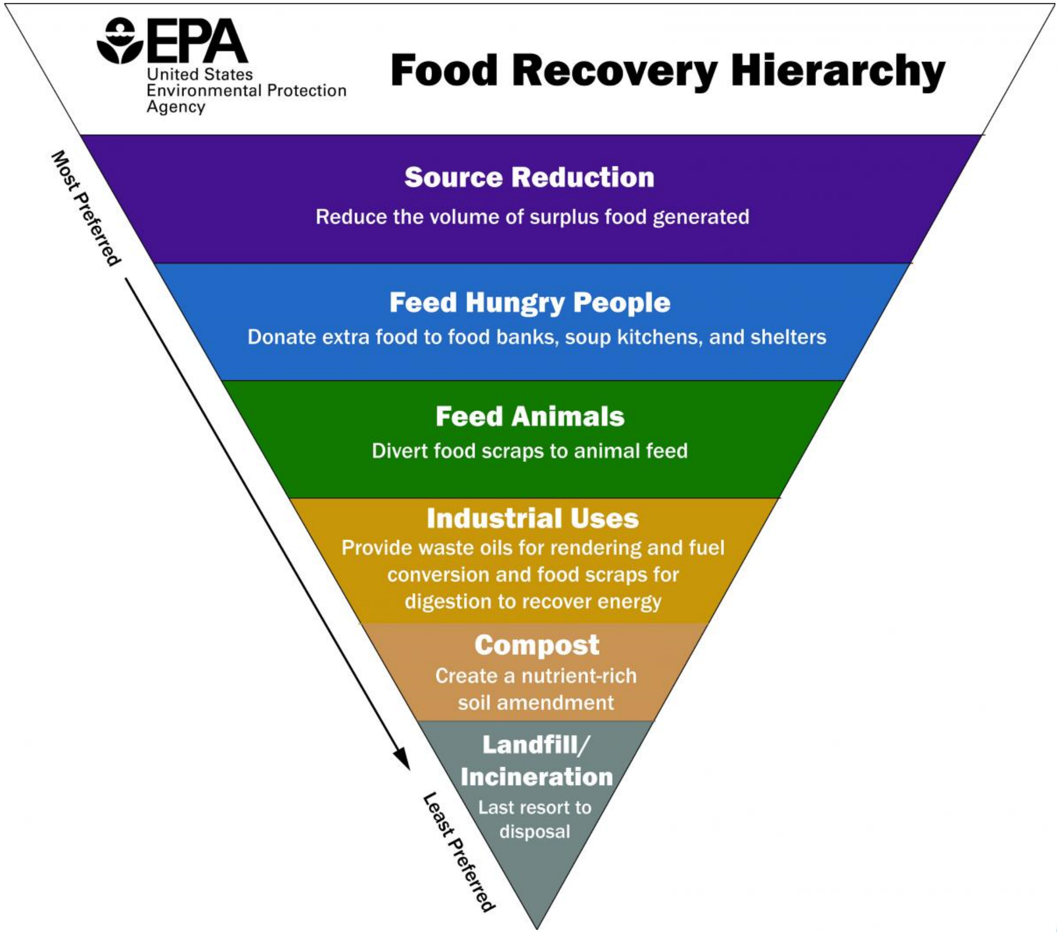
Shifting the paradigm in New York State

To make food “waste” a “resource”, we first need to know where waste is generated, how much is available, and its physical and chemical properties



Data from Organic Resource Locator, https://www.rit.edu/affiliate/nysp2i/food/organic-resource-locator

Alternatives to landfills



EPA United States Environmental Protection Agency

Food Recovery Hierarchy

Most Preferred

Least Preferred

Source Reduction

Reduce the volume of surplus food generated

Feed Hungry People

Donate extra food to food banks, soup kitchens, and shelters

Feed Animals

Divert food scraps to animal feed

Industrial Uses

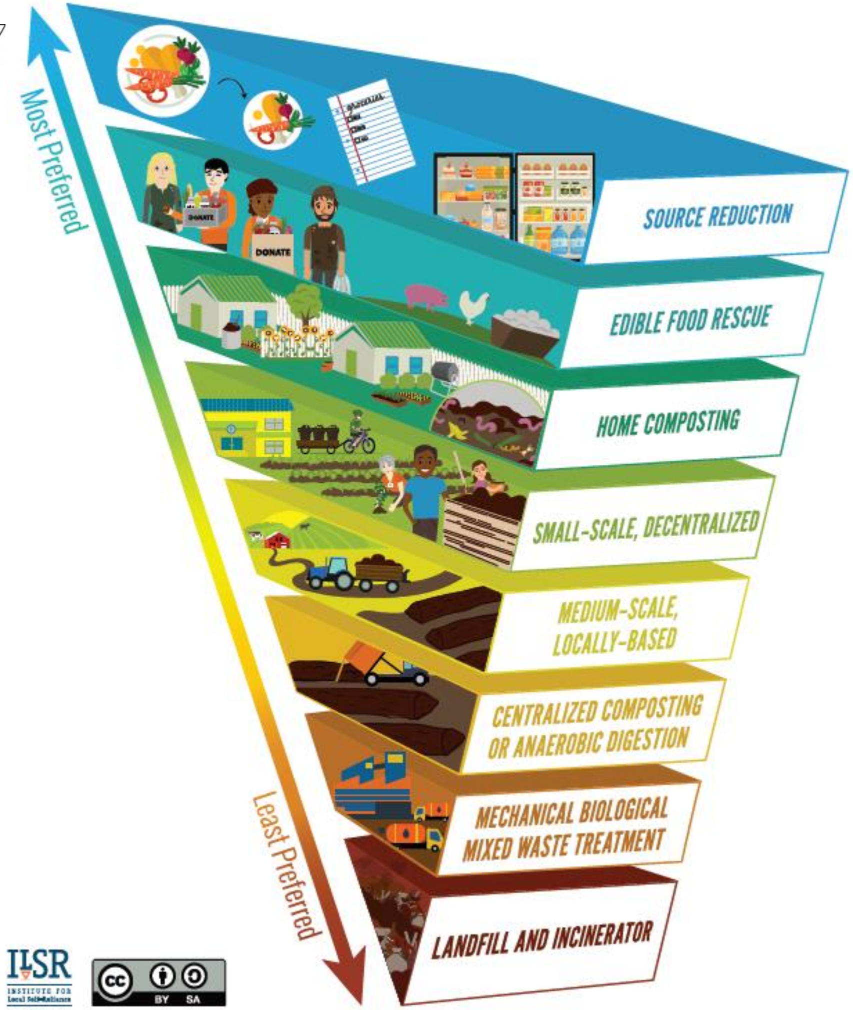
Provide waste oils for rendering and fuel conversion and food scraps for digestion to recover energy

Compost

Create a nutrient-rich soil amendment

Landfill/ Incineration

Last resort to disposal



Is thermochemical conversion an option?

Advantages

- Unlike biological processes, residence time is short and thus the physical size of a commercial-scale system can be relatively small
- Process stability much less dependent on feedstock characteristics, and co-processing with other materials (e.g., packaging) is possible
- Significant volume/mass reduction of solid product simplifies post-processing and transportation logistics
- Biochar and other co-products have many potential uses
- Carbon sequestration

Disadvantages

- May not be suitable for high moisture content wastes
- Relative value of different co-products (biochar, syngas, bio-oil, heat) is not well understood and their market potential is unclear
- Policymakers often confuse with combustion/incineration and thus in many regions has not been given serious consideration as a technology option

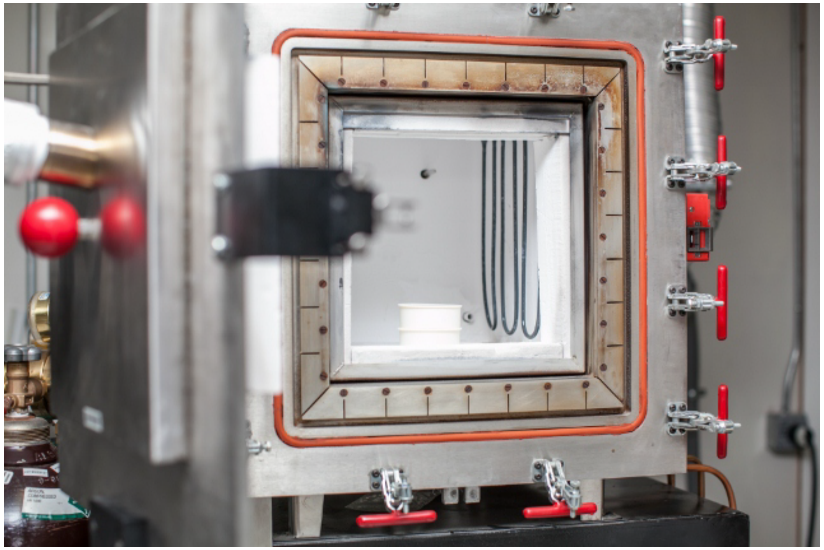
Research approach

1. Conduct lab-scale (batch) experiments in an oxygen-free environment to produce biochar from a wide array of food waste feedstocks, under different temperature and residence time conditions.
2. Conduct commercial-scale (continuous) experiments to produce biochar from mixed food waste under different temperature, residence time, oxygen concentration conditions.
3. Assess options for integrating thermochemical technology with other food waste valorization methods in different biorefinery architectures.
4. Conduct greenhouse plant trials to quantify the benefits of raw and "enriched" biochar as soil amendments.
5. Identify potential non-agricultural applications of biochar not suitable for soil amendment.

Lab-scale: biochar from cafeteria food waste

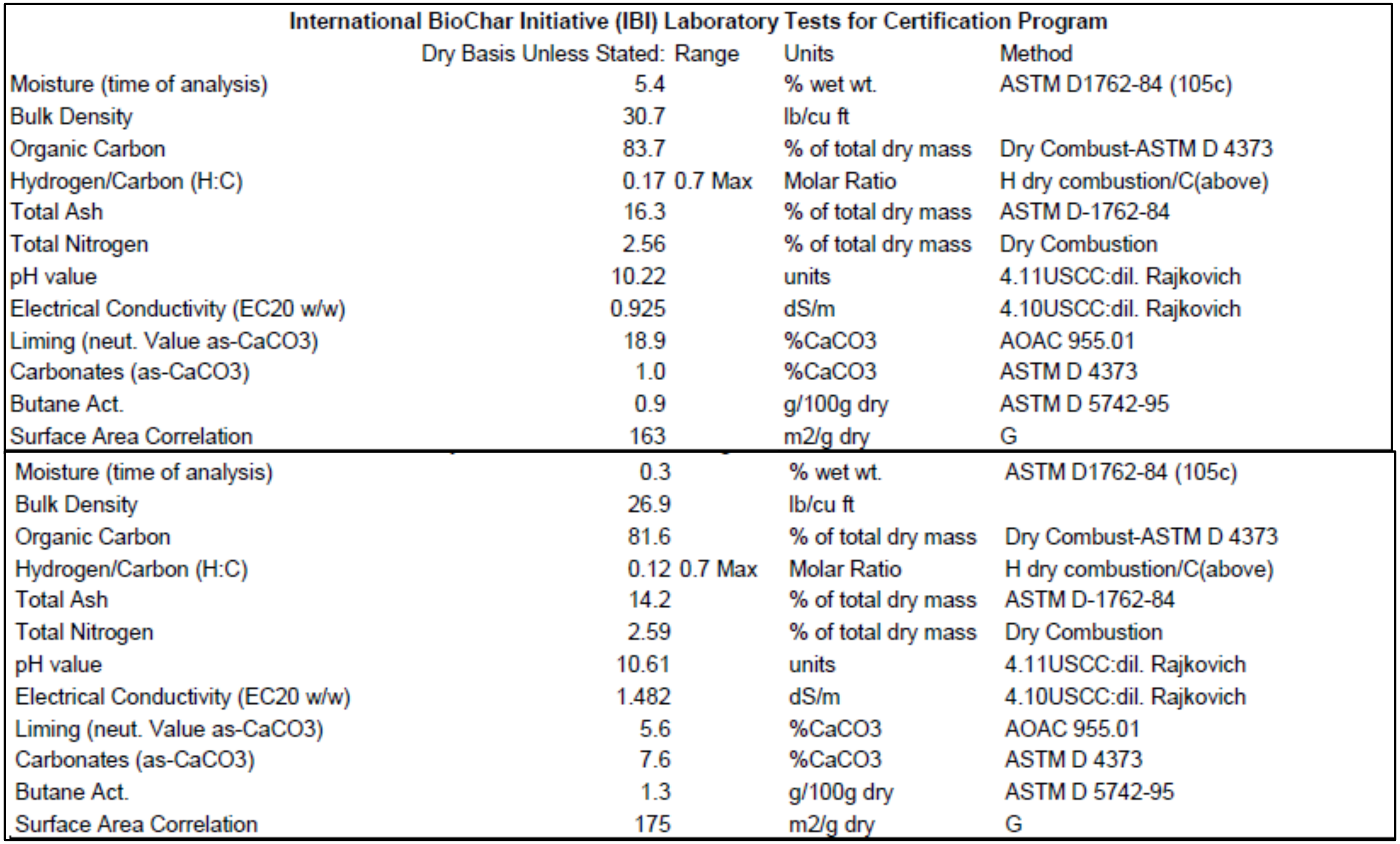
Partnered with local school district to monitor cafeteria waste over ~ 2 months. Material not recycled was comprised of 87% food and 13% plastic film, foam and food-soiled paper plates, plastic utensils, etc.

What happens if food waste only and mixed waste are pyrolyzed in an N_2 environment at 1000^oC for 30 minutes?



Lab-scale: biochar results

Control Laboratories
42 Hangar Way
Watsonville, CA 95076
www.biocharlab.com
Tel: 831 724-5422
Fax: 831 724-3188



International BioChar Initiative (IBI) Laboratory Tests for Certification Program

Pure food waste

	Dry Basis Unless Stated:	Range	Units	Method
Moisture (time of analysis)	5.4		% wet wt.	ASTM D1762-84 (105c)
Bulk Density	30.7		lb/cu ft	
Organic Carbon	83.7		% of total dry mass	Dry Combust-ASTM D 4373
Hydrogen/Carbon (H:C)	0.17	0.7 Max	Molar Ratio	H dry combustion/C(above)
Total Ash	16.3		% of total dry mass	ASTM D-1762-84
Total Nitrogen	2.56		% of total dry mass	Dry Combustion
pH value	10.22		units	4.11USCC:dil. Rajkovich
Electrical Conductivity (EC20 w/w)	0.925		dS/m	4.10USCC:dil. Rajkovich
Liming (neut. Value as-CaCO3)	18.9		%CaCO3	AOAC 955.01
Carbonates (as-CaCO3)	1.0		%CaCO3	ASTM D 4373
Butane Act.	0.9		g/100g dry	ASTM D 5742-95
Surface Area Correlation	163		m2/g dry	G

Mixed waste

Moisture (time of analysis)	0.3		% wet wt.	ASTM D1762-84 (105c)
Bulk Density	26.9		lb/cu ft	
Organic Carbon	81.6		% of total dry mass	Dry Combust-ASTM D 4373
Hydrogen/Carbon (H:C)	0.12	0.7 Max	Molar Ratio	H dry combustion/C(above)
Total Ash	14.2		% of total dry mass	ASTM D-1762-84
Total Nitrogen	2.59		% of total dry mass	Dry Combustion
pH value	10.61		units	4.11USCC:dil. Rajkovich
Electrical Conductivity (EC20 w/w)	1.482		dS/m	4.10USCC:dil. Rajkovich
Liming (neut. Value as-CaCO3)	5.6		%CaCO3	AOAC 955.01
Carbonates (as-CaCO3)	7.6		%CaCO3	ASTM D 4373
Butane Act.	1.3		g/100g dry	ASTM D 5742-95
Surface Area Correlation	175		m2/g dry	G

Lab-scale: biochar results

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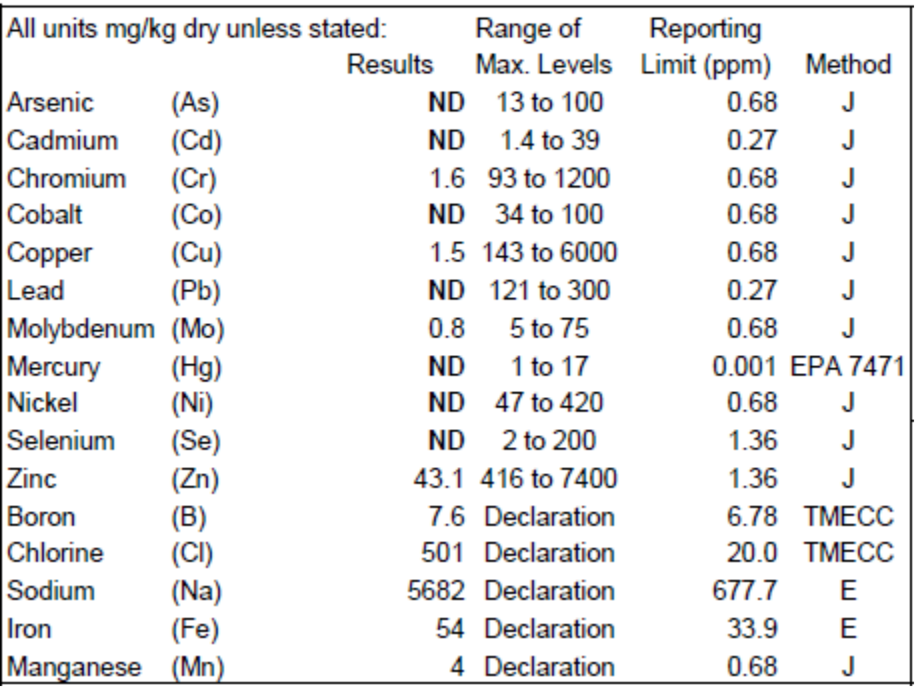
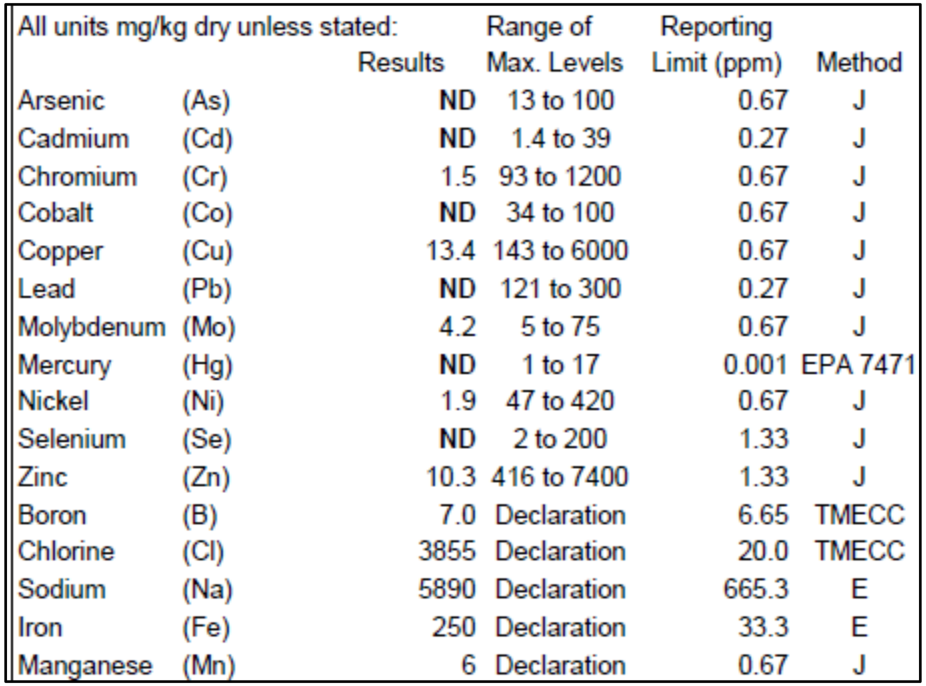


All units mg/kg dry unless stated:		Results	Range of Max. Levels	Reporting Limit (ppm)	Method
Arsenic	(As)	ND	13 to 100	0.68	J
Cadmium	(Cd)	ND	1.4 to 39	0.27	J
Chromium	(Cr)	1.6	93 to 1200	0.68	J
Cobalt	(Co)	ND	34 to 100	0.68	J
Copper	(Cu)	1.5	143 to 6000	0.68	J
Lead	(Pb)	ND	121 to 300	0.27	J
Molybdenum	(Mo)	0.8	5 to 75	0.68	J
Mercury	(Hg)	ND	1 to 17	0.001	EPA 7471
Nickel	(Ni)	ND	47 to 420	0.68	J
Selenium	(Se)	ND	2 to 200	1.36	J
Zinc	(Zn)	43.1	416 to 7400	1.36	J
Boron	(B)	7.6	Declaration	6.78	TMECC
Chlorine	(Cl)	501	Declaration	20.0	TMECC
Sodium	(Na)	5682	Declaration	677.7	E
Iron	(Fe)	54	Declaration	33.9	E
Manganese	(Mn)	4	Declaration	0.68	J

Mixed waste



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Copper	(Cu)	13.4	143 to 6000	0.67	J
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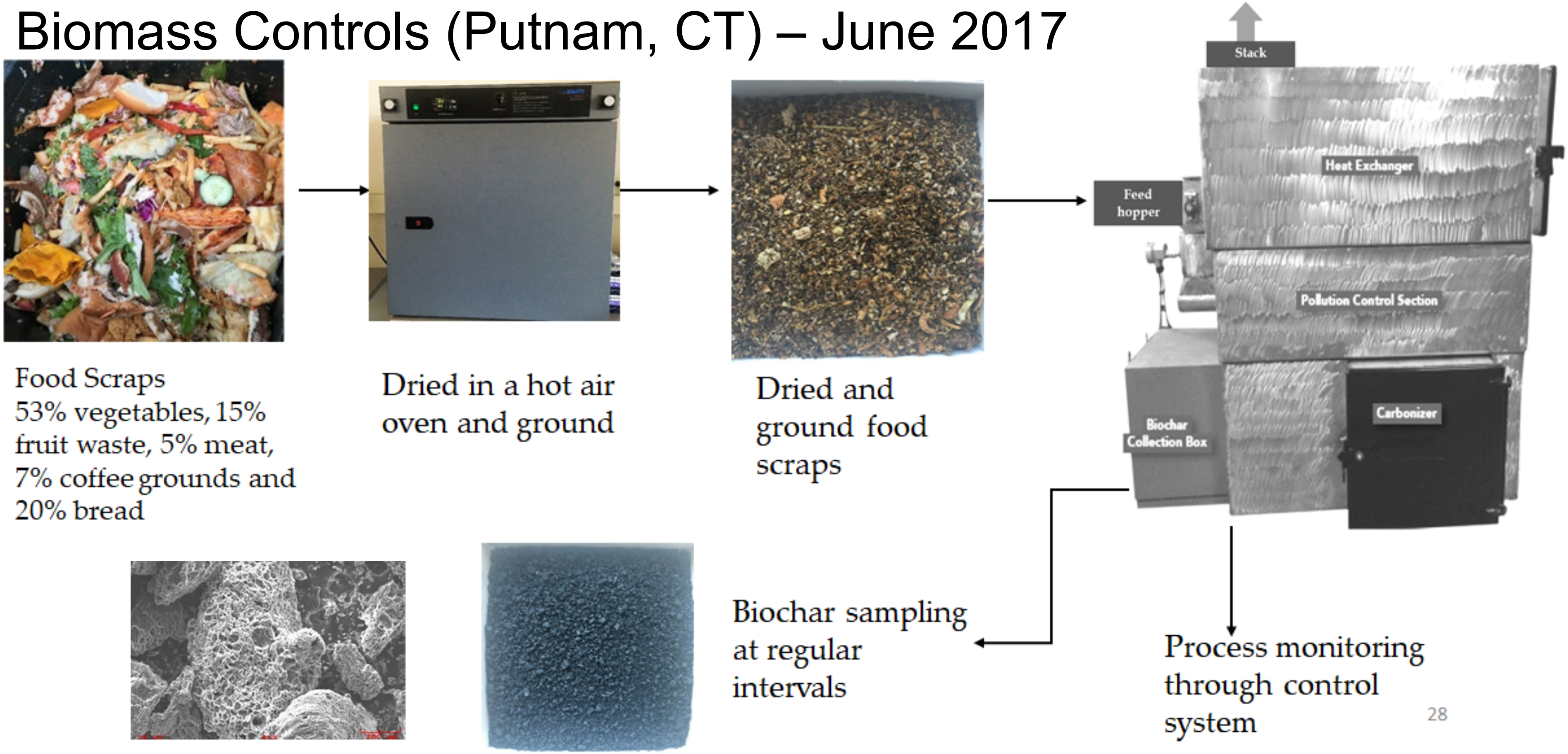
Molybdenum	(Mo)	4.2	5 to 75	0.67	J
Mercury	(Hg)	ND	1 to 17	0.001	EPA 7471
Nickel	(Ni)	1.9	47 to 420	0.67	J
Selenium	(Se)	ND	2 to 200	1.33	J
Zinc	(Zn)	10.3	416 to 7400	1.33	J
Boron	(B)	7.0	Declaration	6.65	TMECC
Chlorine	(Cl)	3855	Declaration	20.0	TMECC
Sodium	(Na)	5890	Declaration	665.3	E
Iron	(Fe)	250	Declaration	33.3	E
Manganese	(Mn)	6	Declaration	0.67	J

- Both pure food and mixed wastes had high organic carbon, low H:C, pH > 10 and [Na] > 5600 ppm
- Significant differences were observed in chlorine (501 vs. 3855 ppm) and iron (54 vs. 250 ppm)
- Need simultaneous syngas analysis to determine fate of non-food constituents in co-pyrolysis of “real” post-consumer waste

Commercial-scale: biochar from mixed food waste

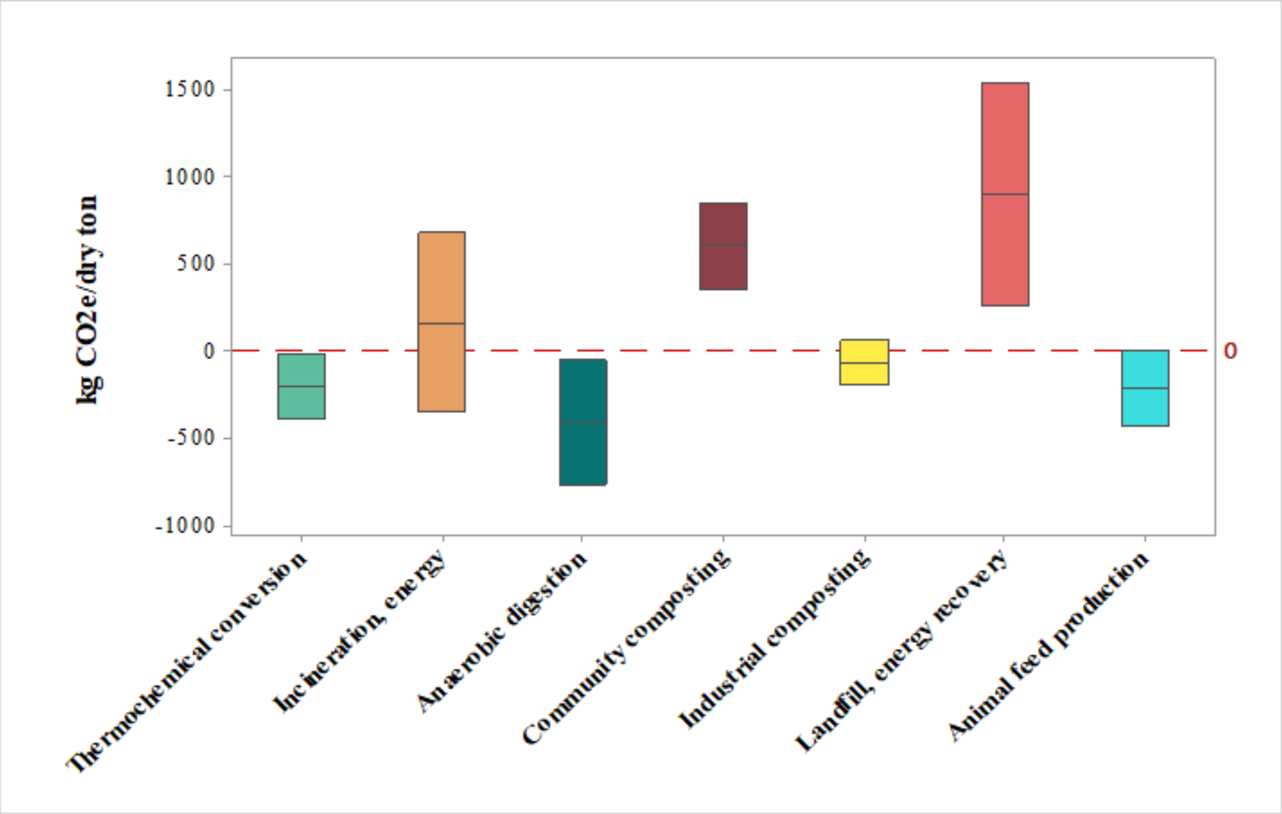
Biomass Controls (Putnam, CT) – June 2017



- Initial trials with $T_{avg} = 797^{o}C$, feed flow rate up to 10 kg/hr and average biochar yield = 7.8%
- Relatively low organic carbon (60-70%) and high H:C (0.3-0.5) compared to lab experiments → need T and O_2 profiles

Commercial-scale: balancing yield & efficiency

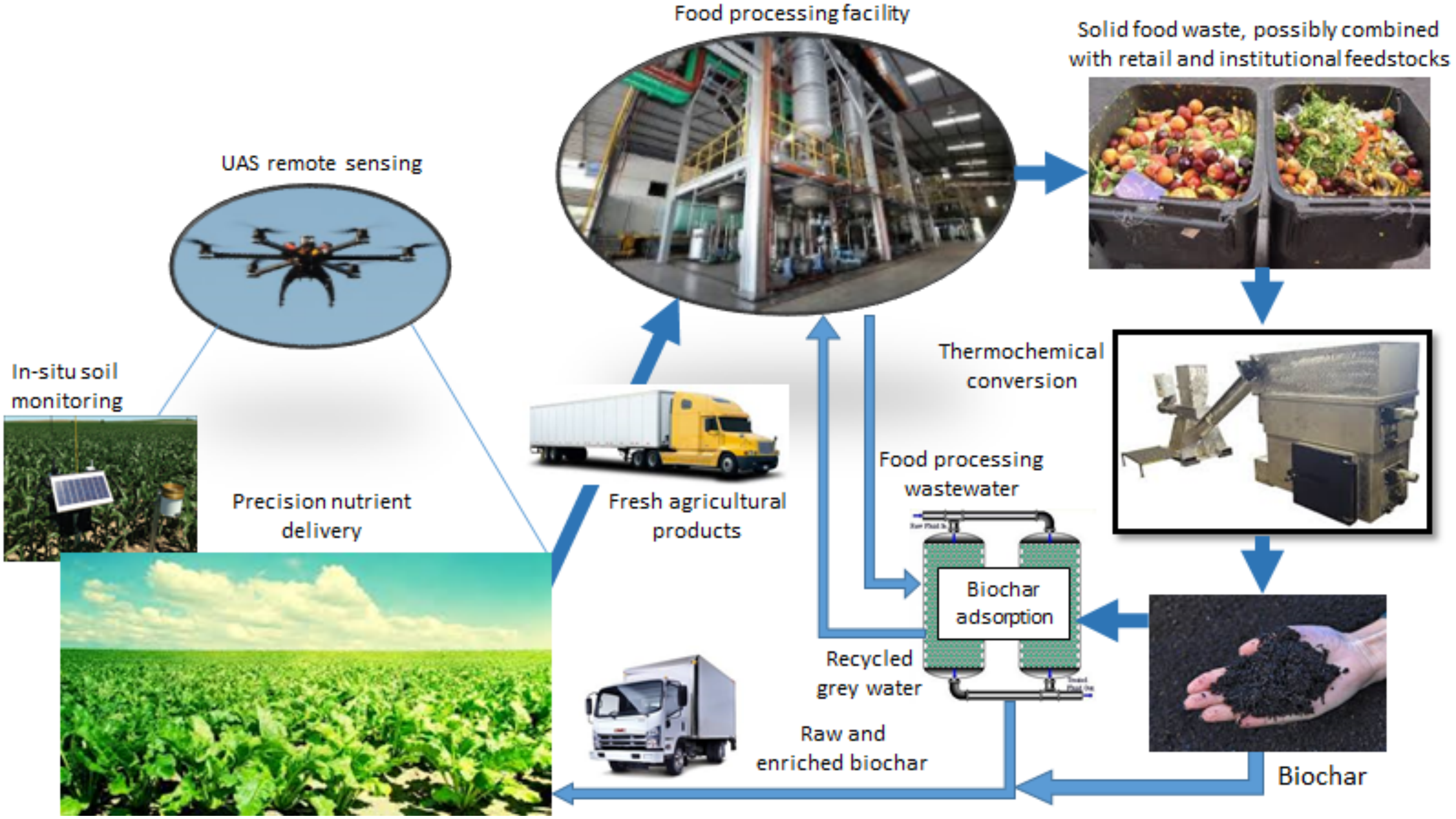
Greenhouse gas emissions can be competitive with other technologies, but may not be achieved at conditions that maximize biochar yield → need modeling of biochar benefits from soil health, carbon sequestration, minimizing eutrophication, etc.



S. Hegde, *Evaluation of Alternative Valorization Options for Institutional and Industrial Food Wastes*, Ph.D. dissertation, Rochester Institute of Technology (2018).

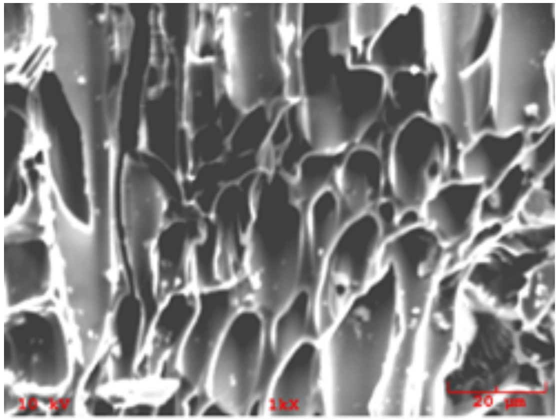
Biorefinery - Concept #1

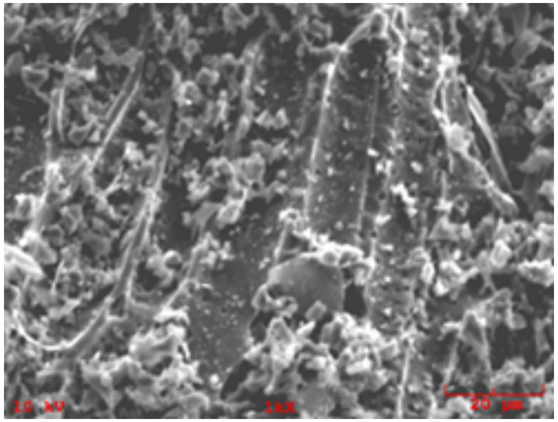
Use biochar to return nutrients in food waste to the farm

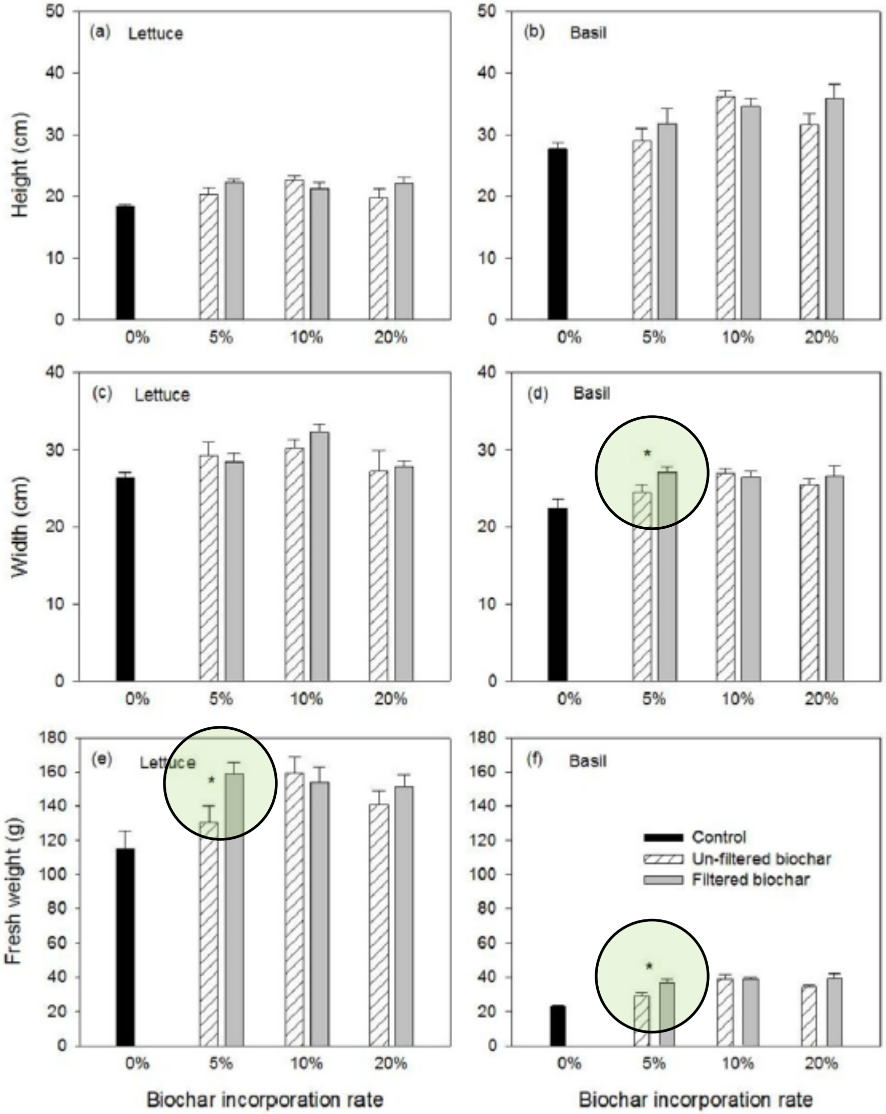


Potential benefits of “enriched” biochar

Raw maple wood biochar, and
“enriched” with tofu wastewater



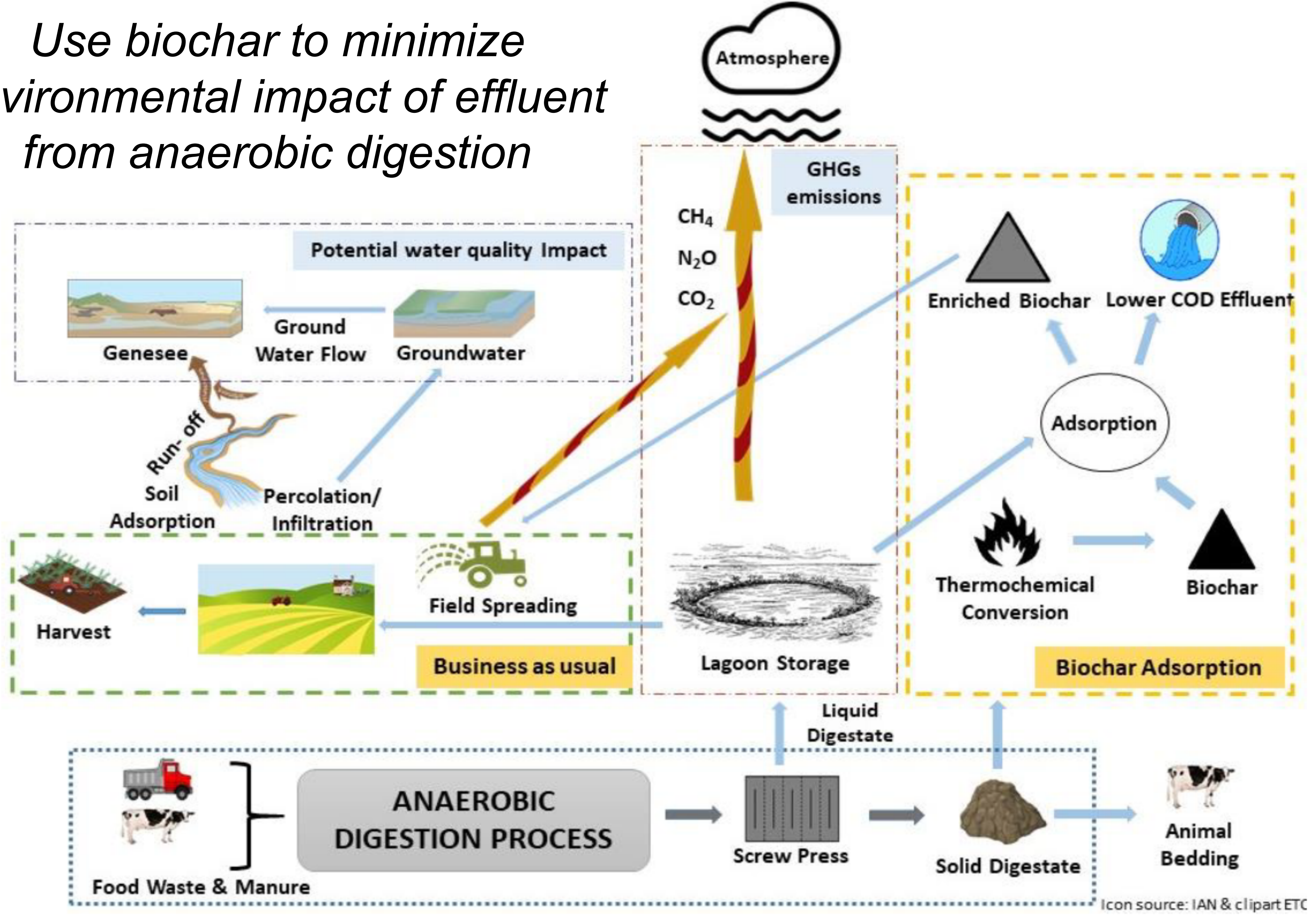




S. Barber, J. Yin, K. Draper and T.A. Trabold, “Closing nutrient cycles with biochar - from filtration to fertilizer,” *Journal of Cleaner Production*, Vol. 197, 1597-1606 (2018).

Biorefinery – Concept #2

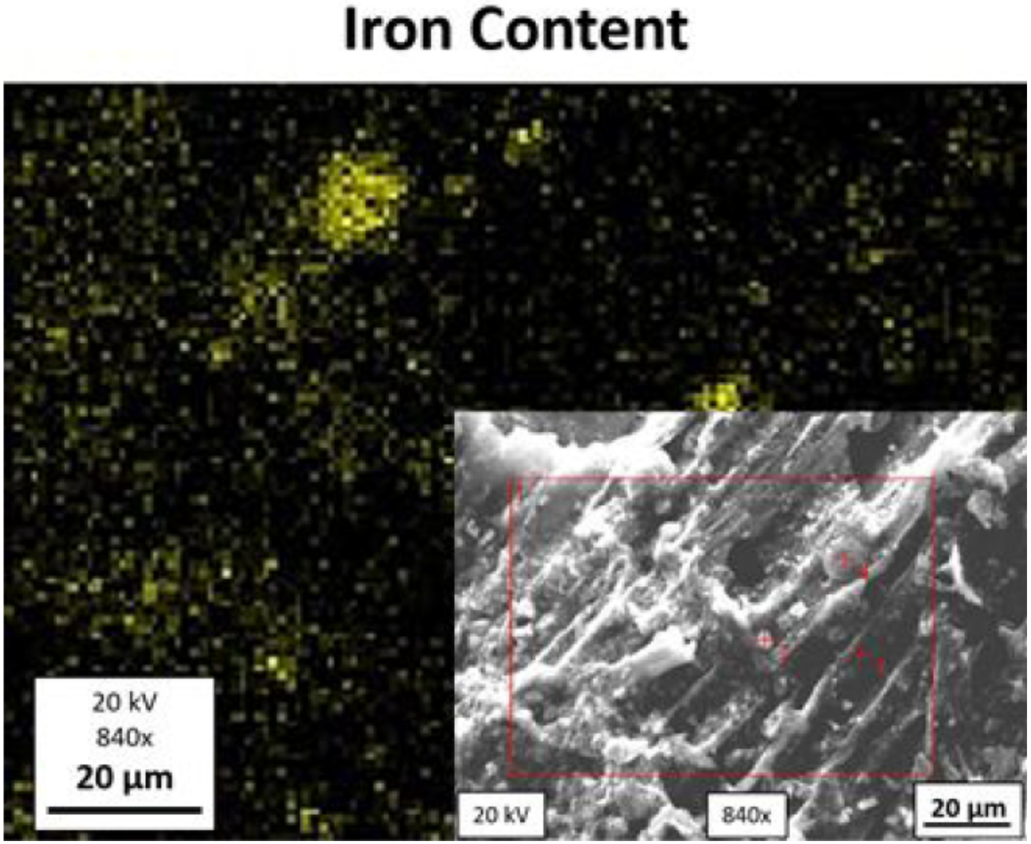
Use biochar to minimize environmental impact of effluent from anaerobic digestion



Icon source: IAN & clipart ETC

Non-agricultural applications: magnetic biochar

Unintended outcome resulted from two factors: high concentration of iron in digestate and Biomass Controls system architecture that enables controlled air flow



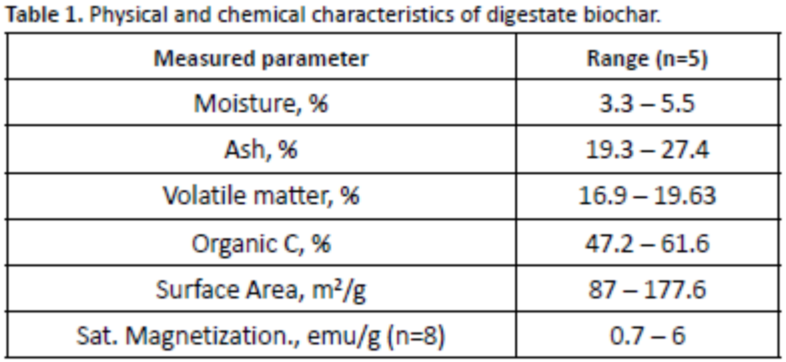


Table 1. Physical and chemical characteristics of digestate biochar.

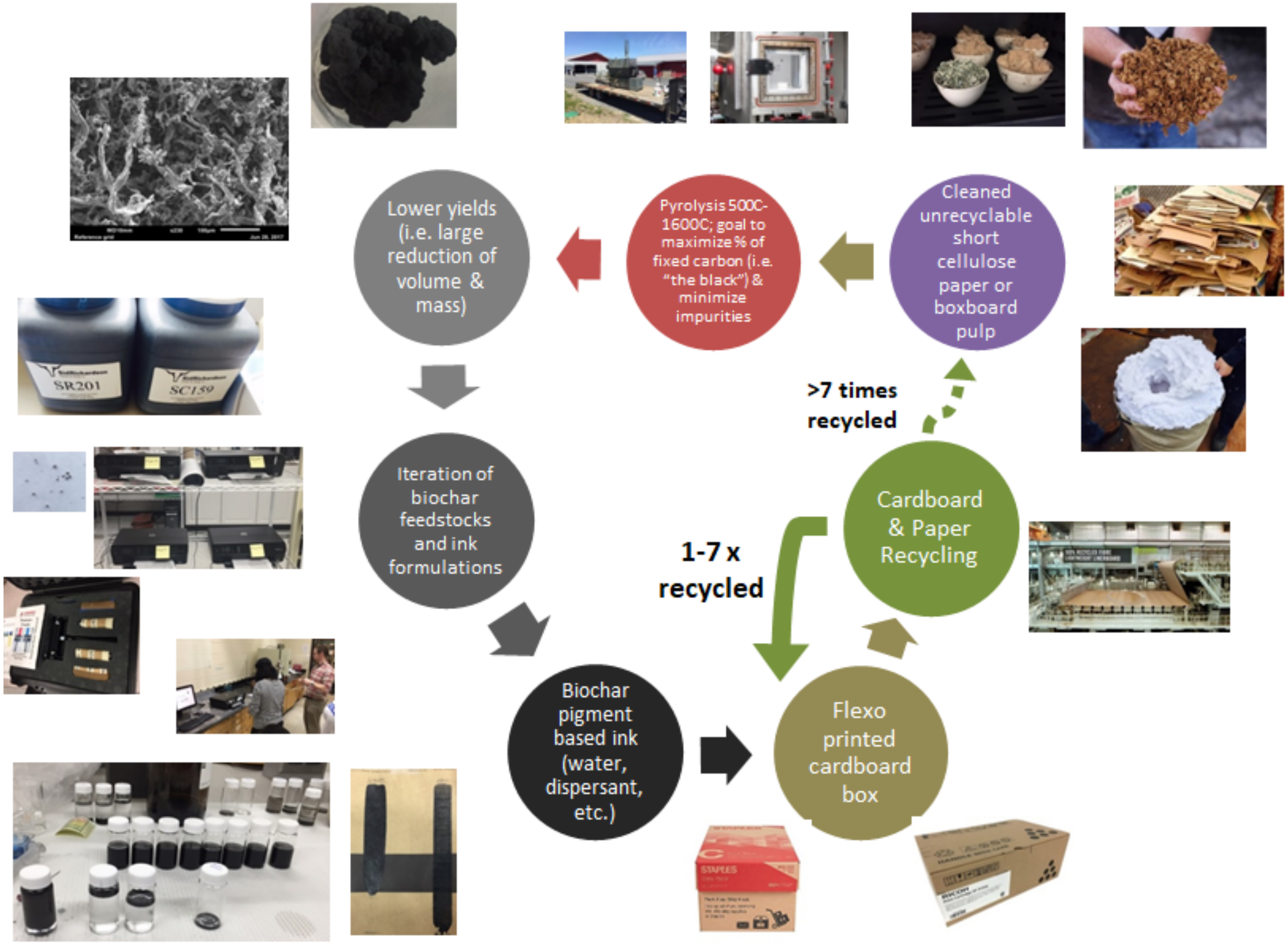
Measured parameter	Range (n=5)
Moisture, %	3.3 – 5.5
Ash, %	19.3 – 27.4
Volatile matter, %	16.9 – 19.63
Organic C, %	47.2 – 61.6
Surface Area, m^2/g	87 – 177.6
Sat. Magnetization., emu/g (n=8)	0.7 – 6

No need for precursor such as $FeCl_3$ to achieve formation of magnetite (Fe_3O_4)

Applications in wastewater treatment & supercapacitors

D. Rodriguez Alberto, K.S. Repa , S. Hegde, C.W. Miller and T.A. Trabold, “Novel production of magnetite particles via thermochemical processing of digestate from manure and food waste,” submitted for publication in *Proceeding of Joint MMM-Intermag Conference*, Washington, D.C., January 2019.

Non-agricultural applications: printing ink



Cleaned unrecyclable short cellulose paper or boxboard pulp

Pyrolysis 500C-1600C; goal to maximize % of fixed carbon (i.e. "the black") & minimize impurities

Lower yields (i.e. large reduction of volume & mass)

Iteration of biochar feedstocks and ink formulations

Biochar pigment based ink (water, dispersant, etc.)

Flexo printed cardboard box

Cardboard & Paper Recycling

1-7 x recycled

>7 times recycled

S. Barber, S. Williams, T. Trabold, S. Lauro and Y. Goh, "Novel pigment replacement for commercial printing inks," Provisional U.S. Patent Application, filed April 12, 2018.

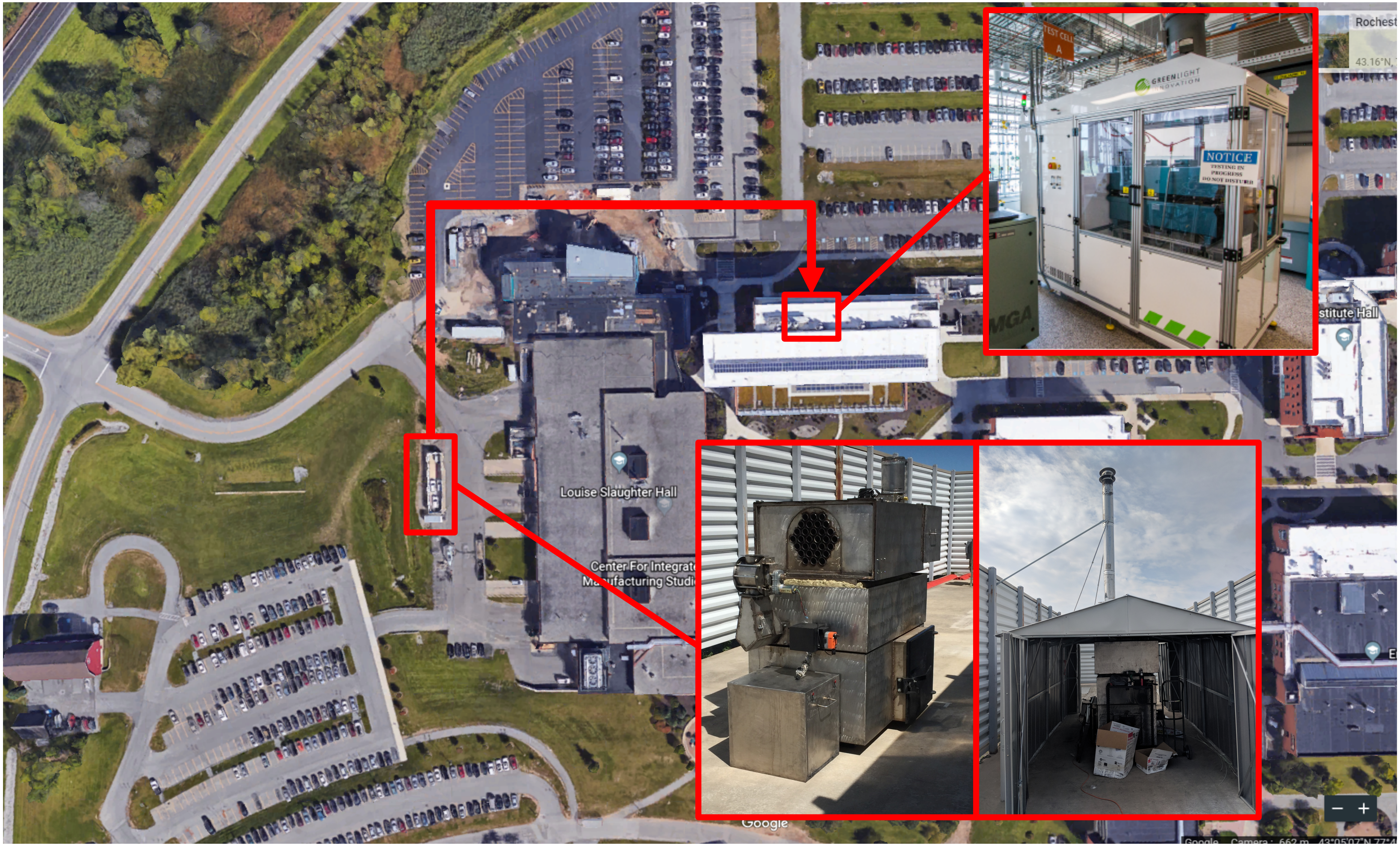
Conclusions and path forward

- Biochar is a potential valorization pathway for some types of food waste and is worthy of focused R&D
- Best opportunities are in mixed pre- and post-consumer wastes where limited valorization options exist (“free” feedstock!)
- Need demonstrations at scale, with optimized thermal integration to minimize impact of drying energy
- Must identify and develop non-agricultural applications to grow the biochar market
- Seek out opportunities for biorefinery deployment with other technologies like anaerobic digestion
- Consider all available biomass feedstocks, especially those where constraints to conventional disposal practices are on the horizon (e.g., WWTP biosolids, packaged food)
- Economic viability will be achievable only through consideration of all co-products

Think waste management + bio-products + sustainable energy

Integrating thermochemical & electrochemical systems

Solid oxide fuel cell test stand



Biogenic Refinery from Biomass Controls

Thanks for your attention!

Special thanks to:

- Ph.D. students @ RIT: Steve Barber, Swati Hegde, Diana Rodriguez Alberto and Jessica Peterson
- Kathleen Draper (Finger Lakes Biochar)
- Jeff Hallowell (Biomass Controls)
- Akio Enders (Cornell University)
- Dr. Jingjing Yin (Cornell University)
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