10th International Conference on Sustainable Solid Waste Management
CHANIA 2023

HYDROTHERMAL CARBONIZATION OF FOOD WASTE: INFLUENCE OF FOOD WASTE COMPOSITION AND CARBONIZATION CONDITIONS ON HYDROCHAR FOR APPLICATION IN SOILS

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UAM Universidad Autónoma de Madrid | WASTE 2 VALUE | UNIVERSITY OF SOUTH CAROLINA | IQUAM Departamento de Ingeniería Química Universidad Autónoma de Madrid

Technology development → **Growth of population** → **Social problems**



Waste management

Landfilling

Incineration

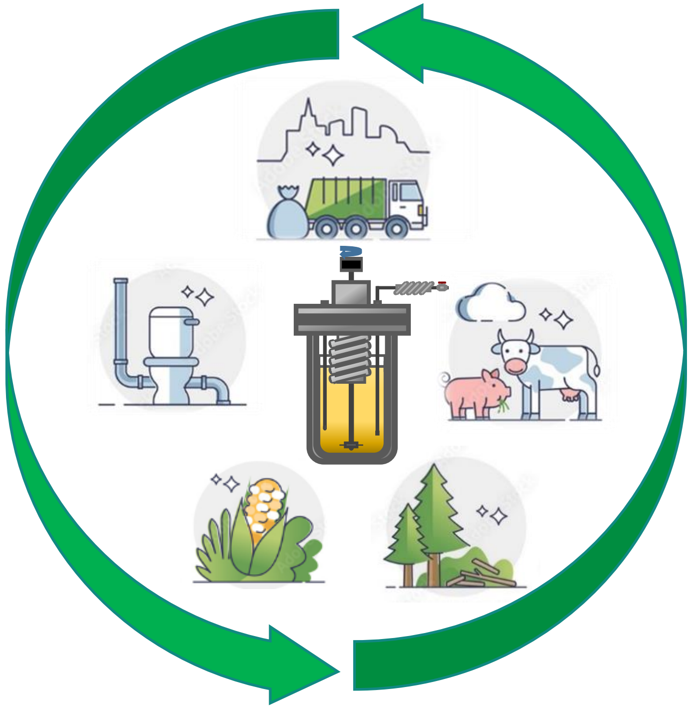
Compost

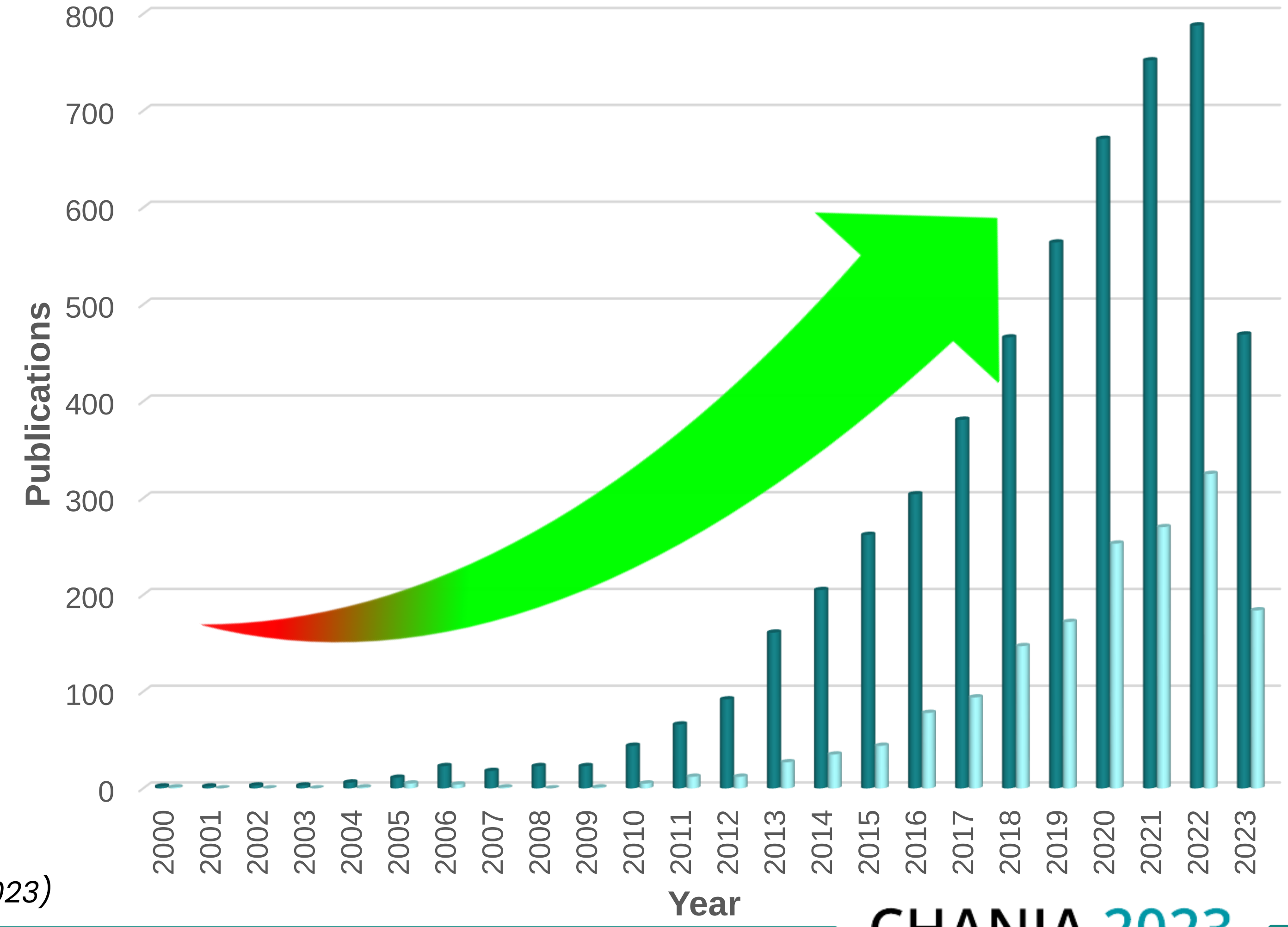
HYDROTHERMAL CARBONIZATION (HTC) OF BIOMASS WASTE

EVOLUTION OF PUBLICATIONS ON THE TOPIC

Hydrothermal Carbonization ***TOTAL: 4,870***

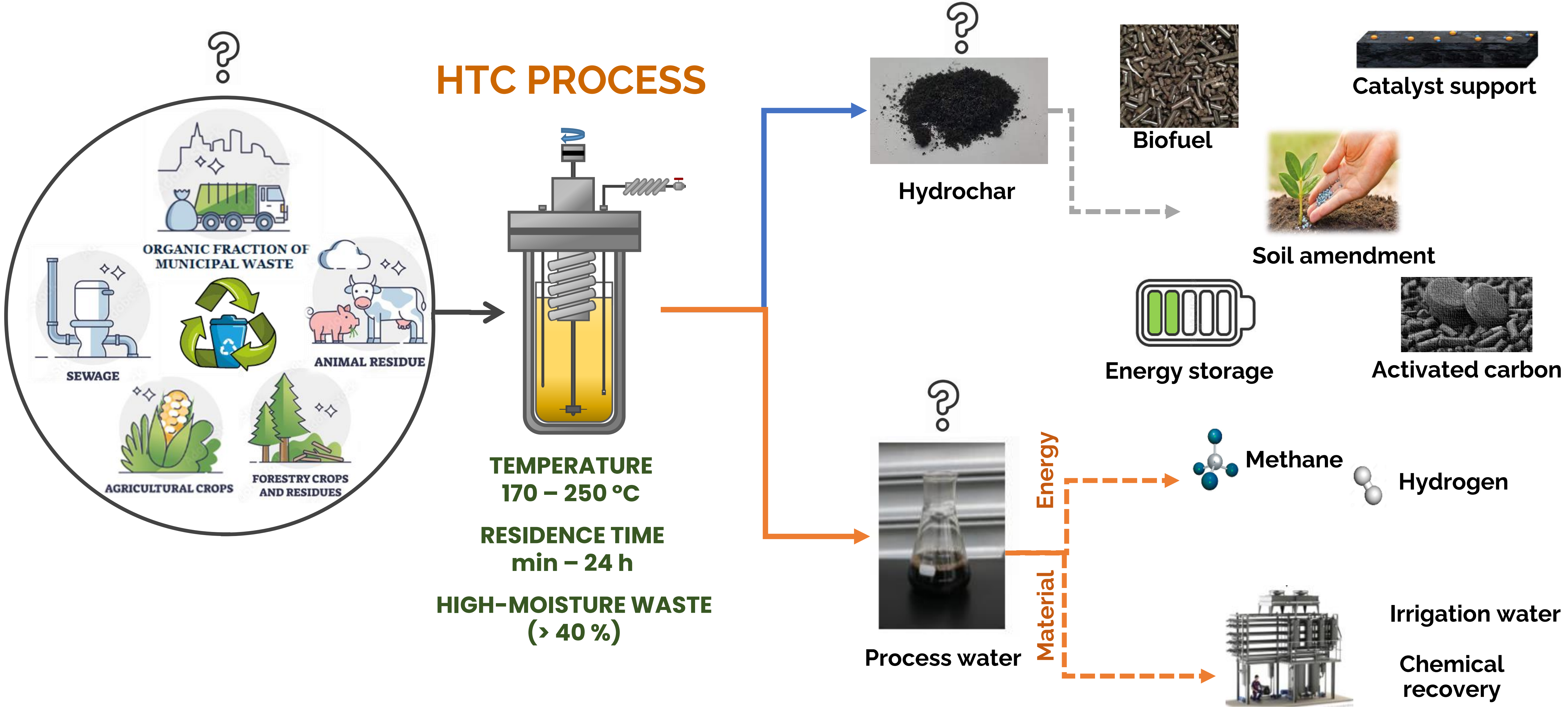
Hydrothermal Carbonization and Wastes ***TOTAL: 1,578***





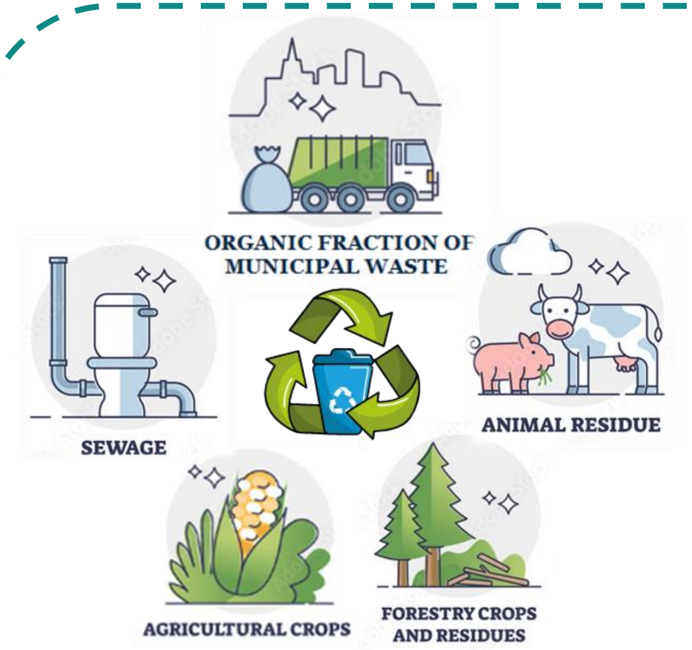
Source: Scopus (08/06/2023)

HYDROTHERMAL CARBONIZATION (HTC) OF BIOMASS WASTE

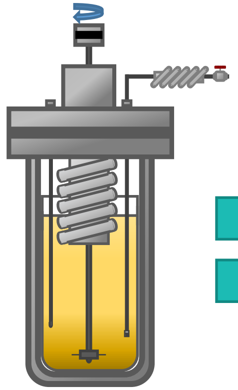


Project Motivation

- What feedstock properties are needed to achieve desirable products?



Critical feedstock properties



Critical process conditions

Critical product properties

Possible successful application area

Carbonization product market and usability is critical for HTC commercialization and/or routine HTC use

Goals and Objectives

- ***<u>Overall Goal</u>***

  Identify the feedstock properties and carbonization conditions that are critical in determining appropriate hydrochar use

- ***<u>Objectives</u>***

  1. To conduct carbonization experiments on food waste components over different carbonization conditions.
  2. To build statistical models using laboratory data.
  3. To identify the feedstock properties and carbonization conditions that most significantly impact hydrochar use.

HTC EXPERIMENTS

Food waste

160 mL HTC reactor

Slurry

Vacuum filtration

Hydrochar

Process water

Hydrochar analyzed for:

- Elemental composition
- Energy content

Process water is analyzed for:

- Typical water quality parameters: pH, conductivity, TOC, COD
- Primary nutrients: Total nitrogen, ammonia, phosphorus, potassium

Operating conditions

- Reaction times: 4, 8, 16, 24 h
- Reaction temperatures: 200^{o}C, 225^{o}C, 250 ^{o}C

Food waste *Heating* *Products*

Individual Components Comprising Typical Food Waste

Food waste

- Meat (MT)

- Vegetables (VG)

- Fruits (FT)

- Grain derived (GD) foods

- Daily commodities (DC)

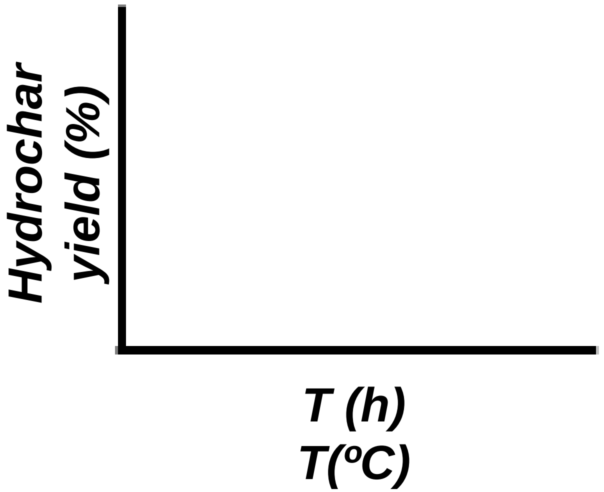
Properties of the Individual Components Comprising Typical Food Waste

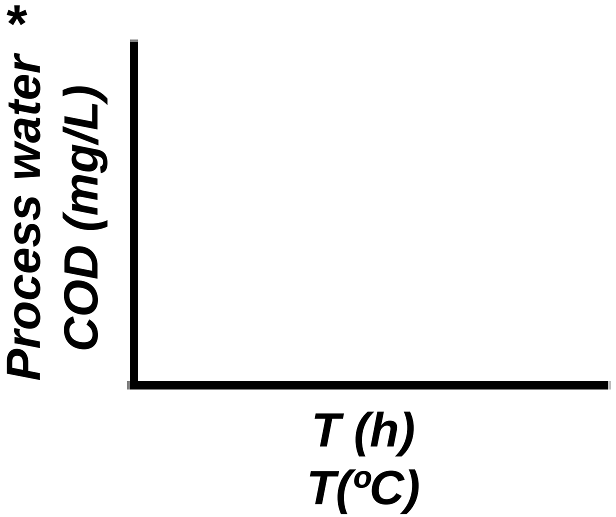
Food Waste	Moisture (%)	Component	%
Meat	72.6	Poultry	50
		Beef	25
		Pork	25
Vegetables	90.4	Potato	19
		Lettuce	17
		Onion	14
		Tomato	14
		Pumpkin	12
		Cole	9
		Carrot	8
		Pepper	7
Grain derived	34.8	Bread/ Flour	88
		Rice	9
		Oat	3

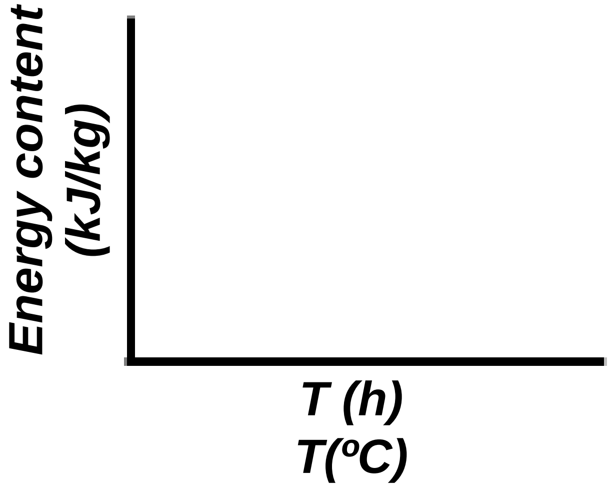
Food Waste	Moisture (%)	Component	%
Fruit	81.3	Banana	31
		Apple	20
		Orange	15
		Grape	9
		Avocado	9
		Pineapple	8
		Strawberry	8
Daily commodities	27.7	Cheese	70
		Chocolate	19
		Butter	11

General Carbonization Trends

- More than 120 products obtained.
- General trends associated with products generated for each food waste component are as expected:

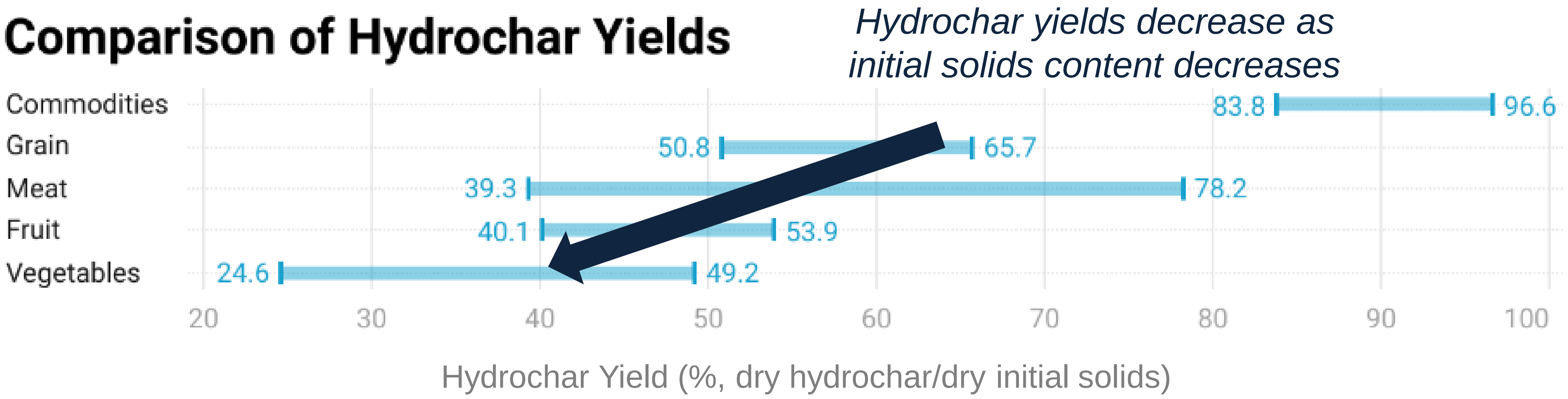






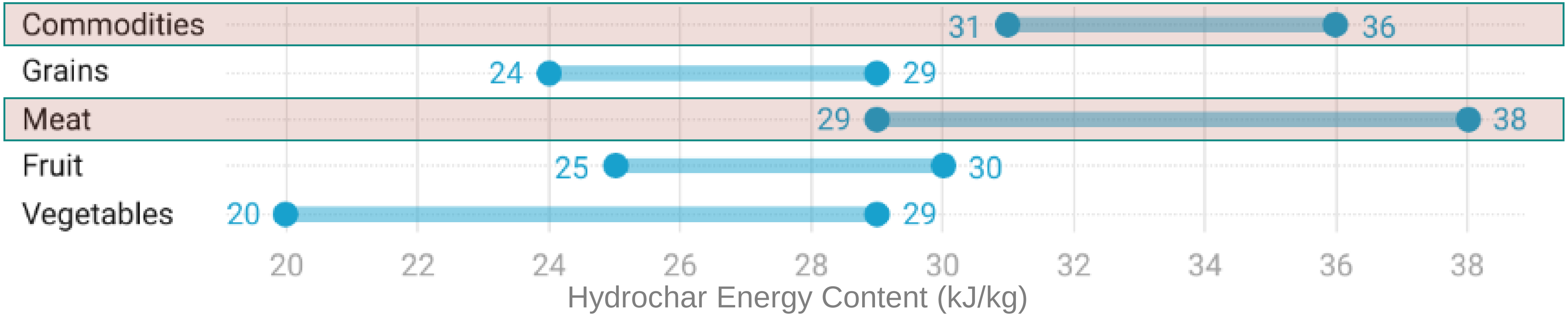
* *Drainable process water was not always obtained with the grain derived foods and daily commodities*

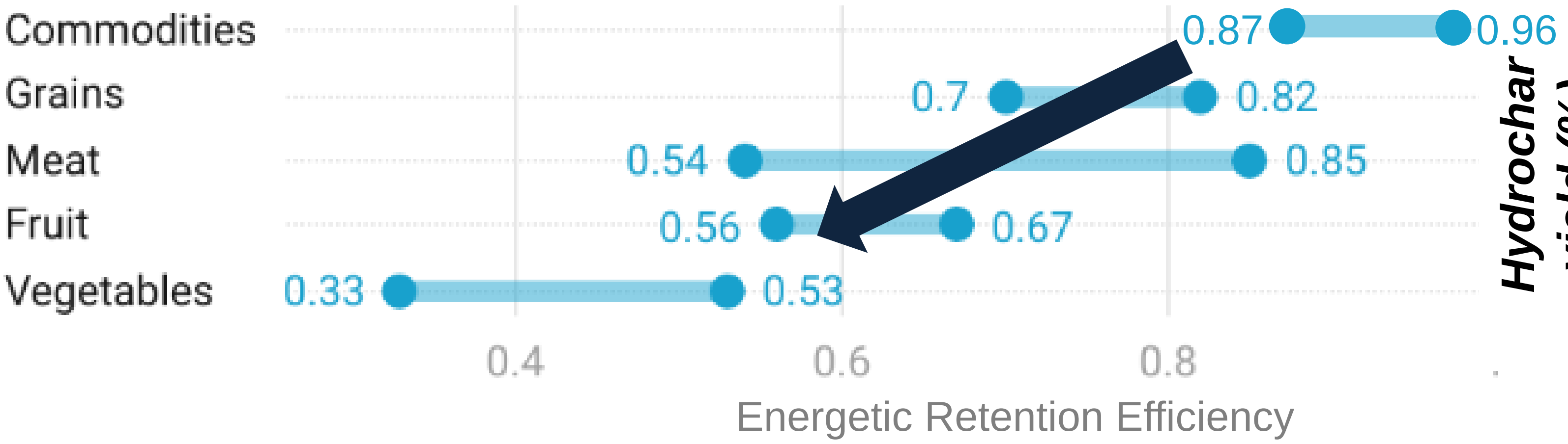
Hydrochar Yield

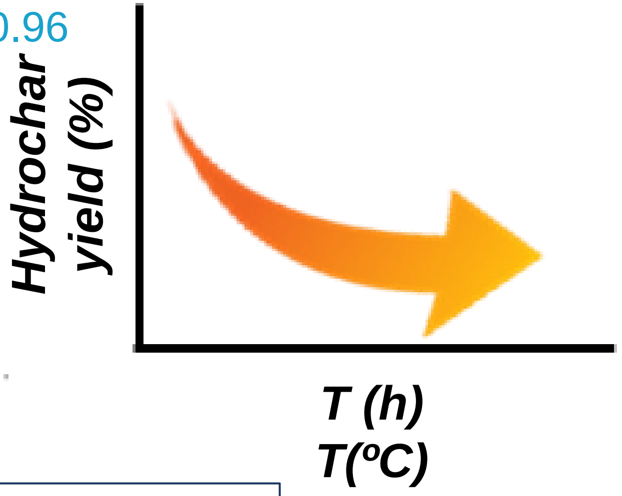


- Yields influences hydrochar use
- Interesting hydrochar characteristics:
  - Daily commodities & Meat: more of a tar

Hydrochar Energy Content



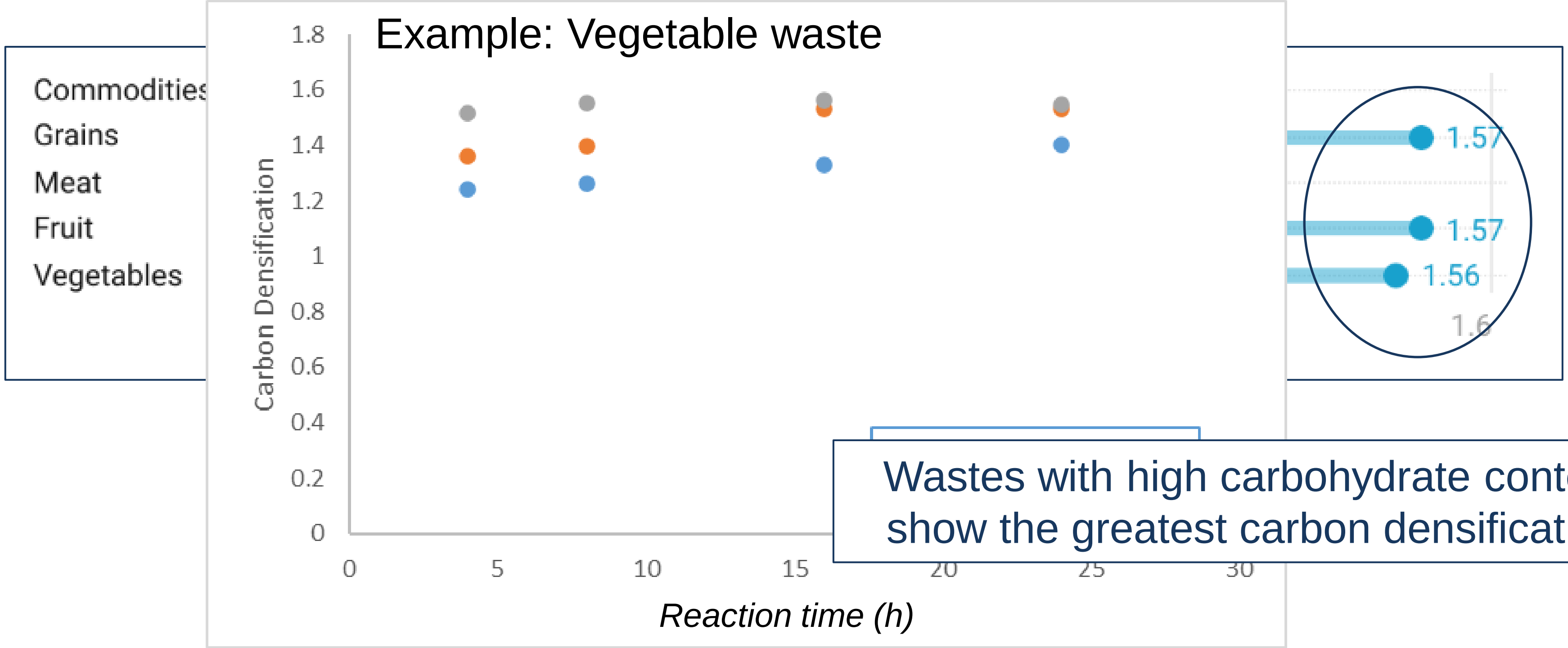




Hydrochar yields greatly influence recoverable energy

Hydrochar Nutrients

- <u>Carbon densification</u> increases with temperature and time:

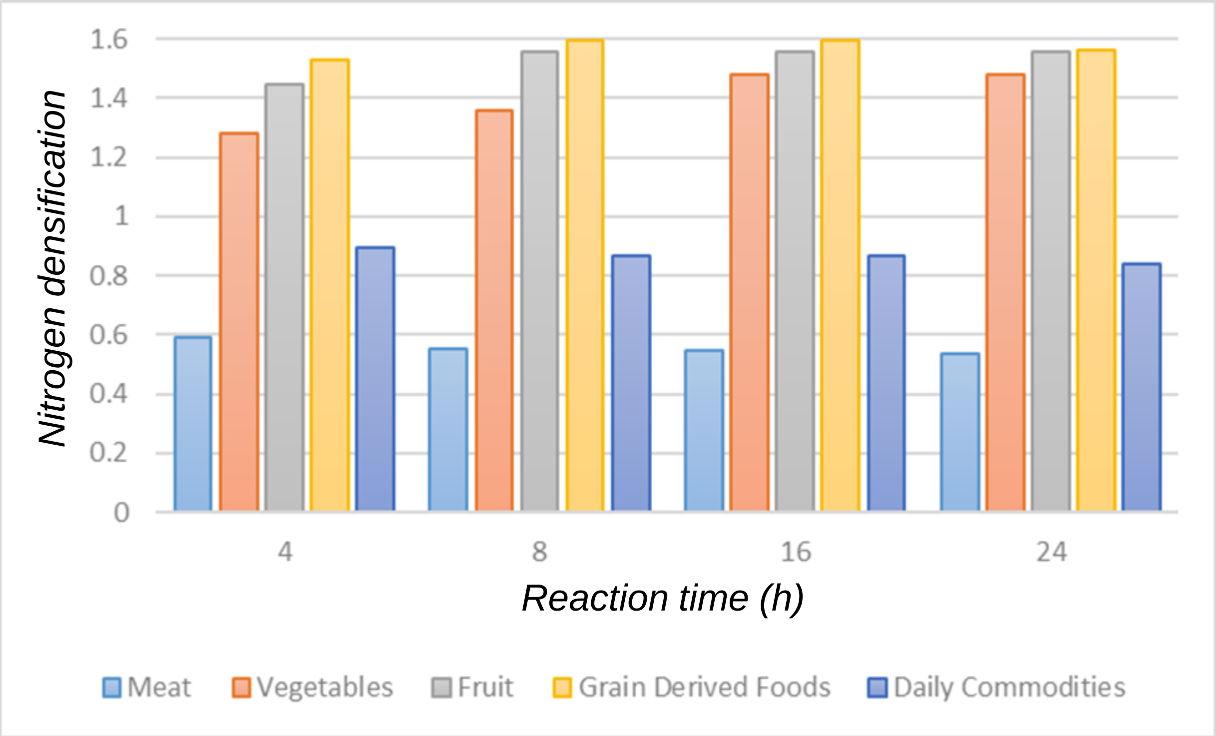


Wastes with high carbohydrate content show the greatest carbon densification

- *Carbon content is relevant for energy-related applications*
- *Carbon, Nitrogen, and Phosphorus are relevant when using as a fertilizer*

Hydrochar Nutrients

- Nitrogen densification trends vary based on food waste component



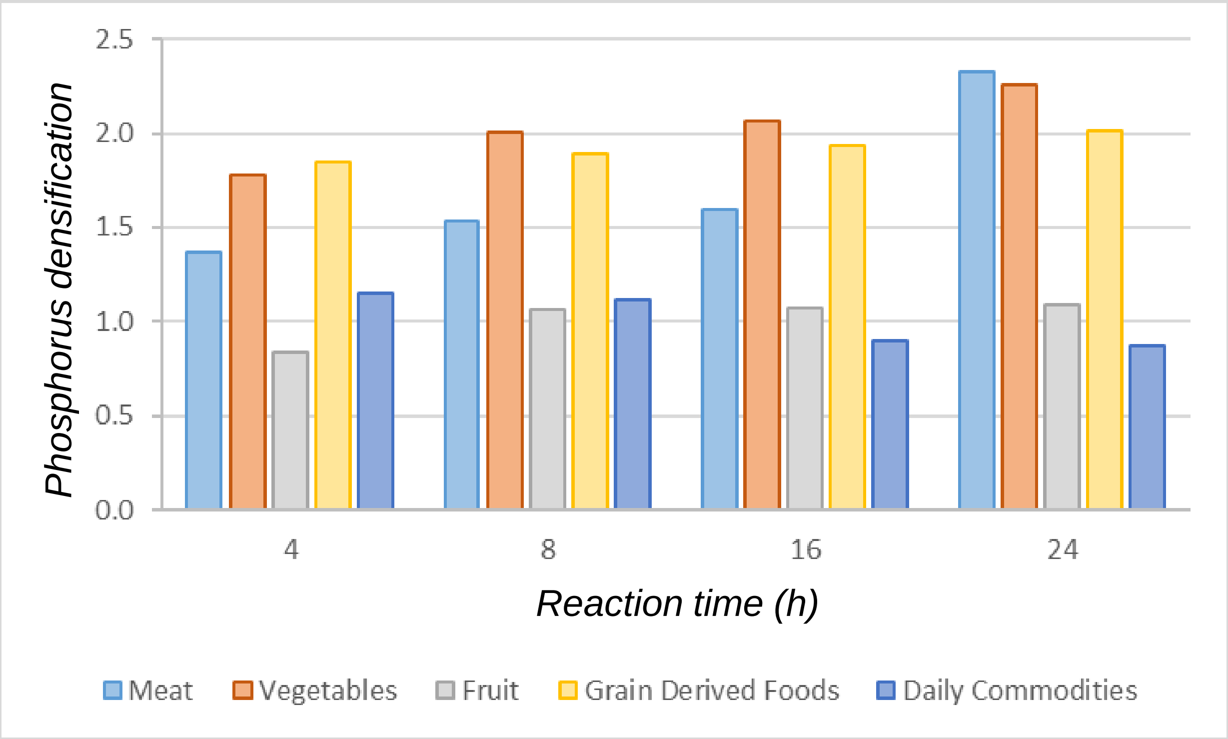
Example at 225^{o}C:

- Meat slightly decreases
- Daily commodities remain constant
- Vegetables, fruit, and grain derived foods slightly increase
- Trends depend on waste chemical composition

- *Carbon content is relevant for energy-related applications*
- *Carbon, Nitrogen, and Phosphorus are relevant when using as a fertilizer*

Hydrochar Nutrients

- Phosphorus densification usually increases with temperature and time



Example at 225ºC:

- Meat, vegetables, fruit, and grain derived foods slightly increase
- Daily commodities slightly decrease
- Trends depend on waste chemical composition

- *Carbon content is relevant for energy-related applications*
- *Carbon, Nitrogen, and Phosphorus are relevant when using as a fertilizer*

Potential Implications of Using as a Soil Amendment

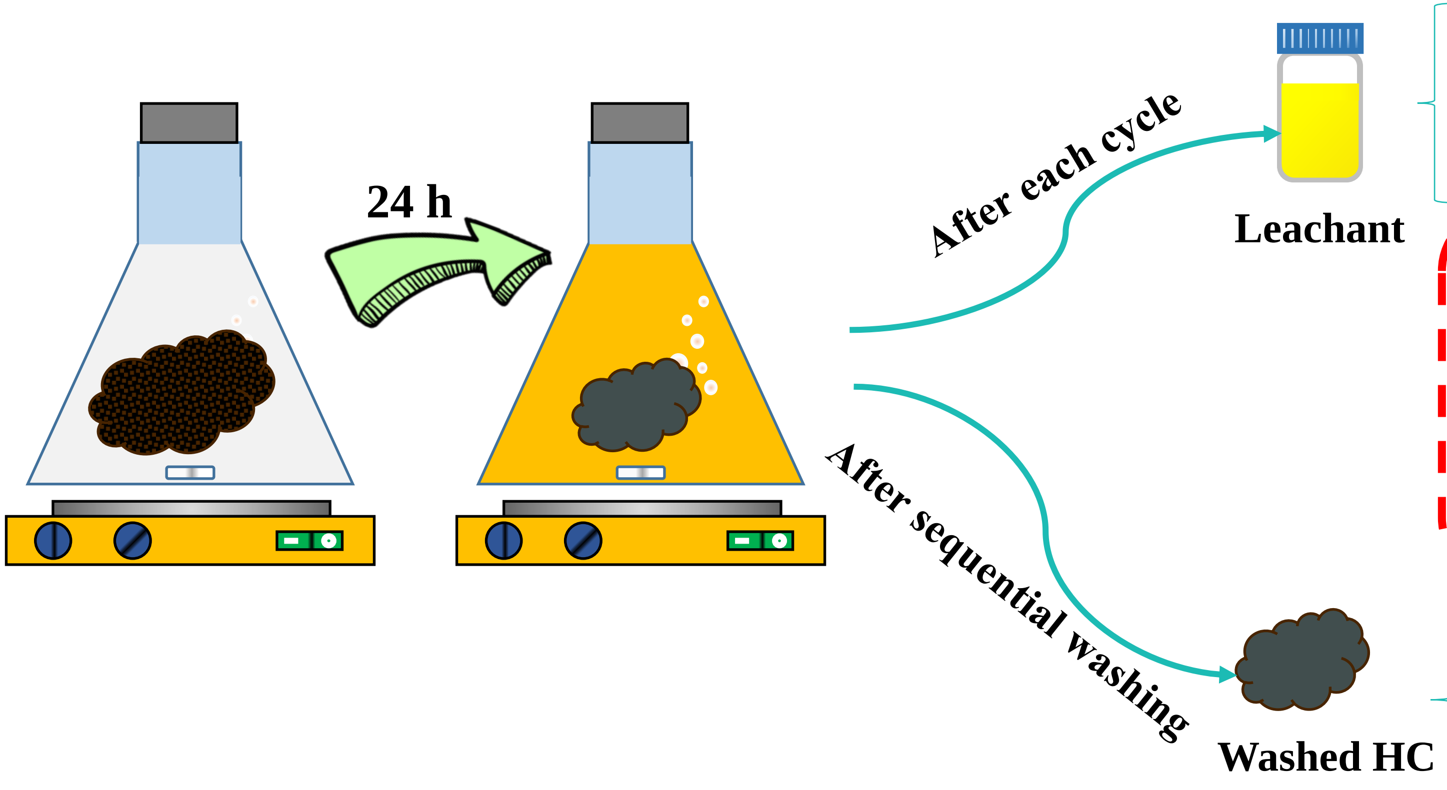
Hydrochar shows adequated characteristics to be used as a fertilizer/soil amendment

Different trends were found, with no clear understanding of what causes the differences

Sequential Water Washing of Hydrochar

Washing Process:

- 5 washing cycles
- 24 h/cycle
- Ratio water:HC = 6:1 (equivalent to a rainfall/irrigation event for soils with 1% hydrochar)



Analysis:

pH **COD** **^{1}H NMR** **Toxicity** **N, P, K**

Toxicity testing:

- Acute toxicity to E. *coli*
  - Toxi-Chromo Test (Environmental Bio-detection products, Inc.)
- Acute toxicity to V. *fischeri*
  - Microtox test (ISO 11348-3)

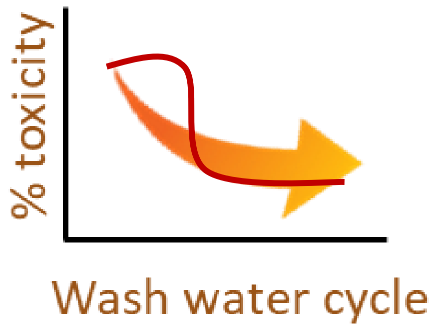
Elemental analysis

Proximate analysis

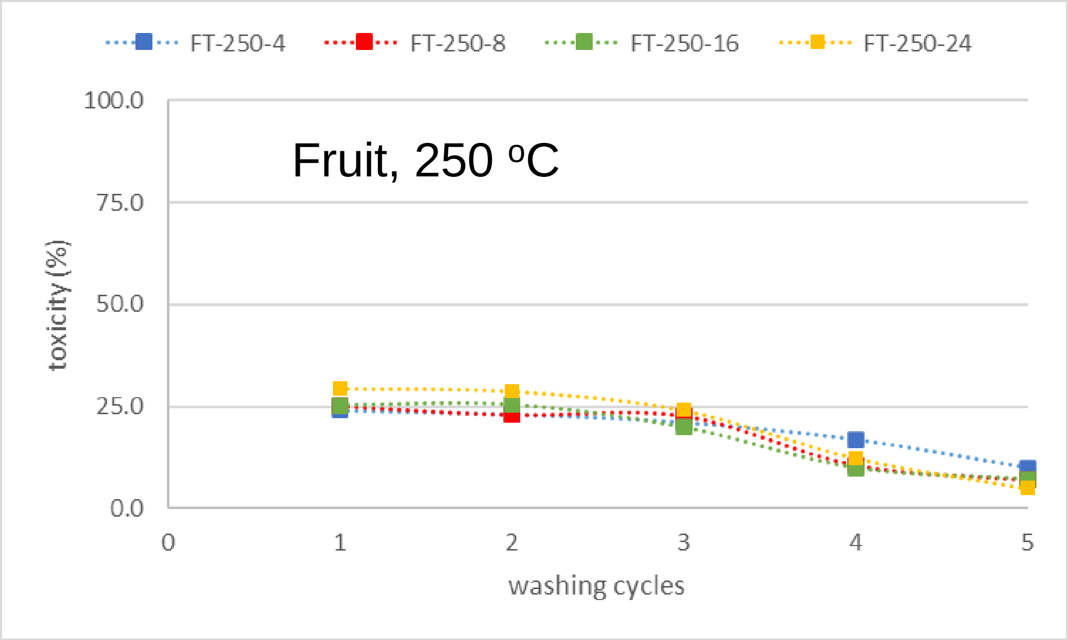
ICP

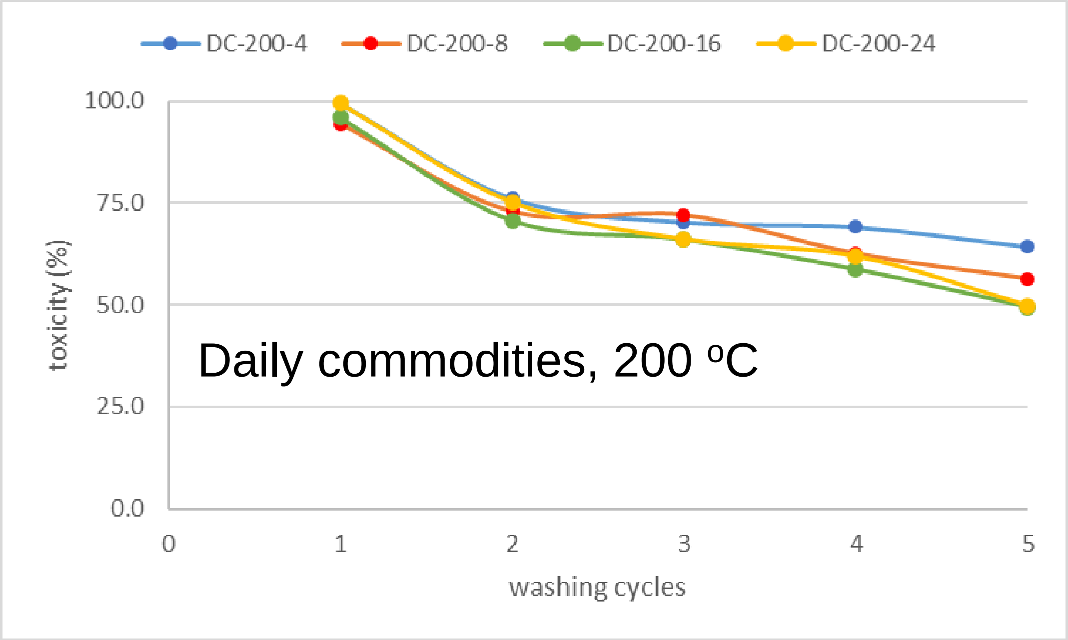
Wash Water Toxicity

- Acute ecotoxicity to E. *coli*



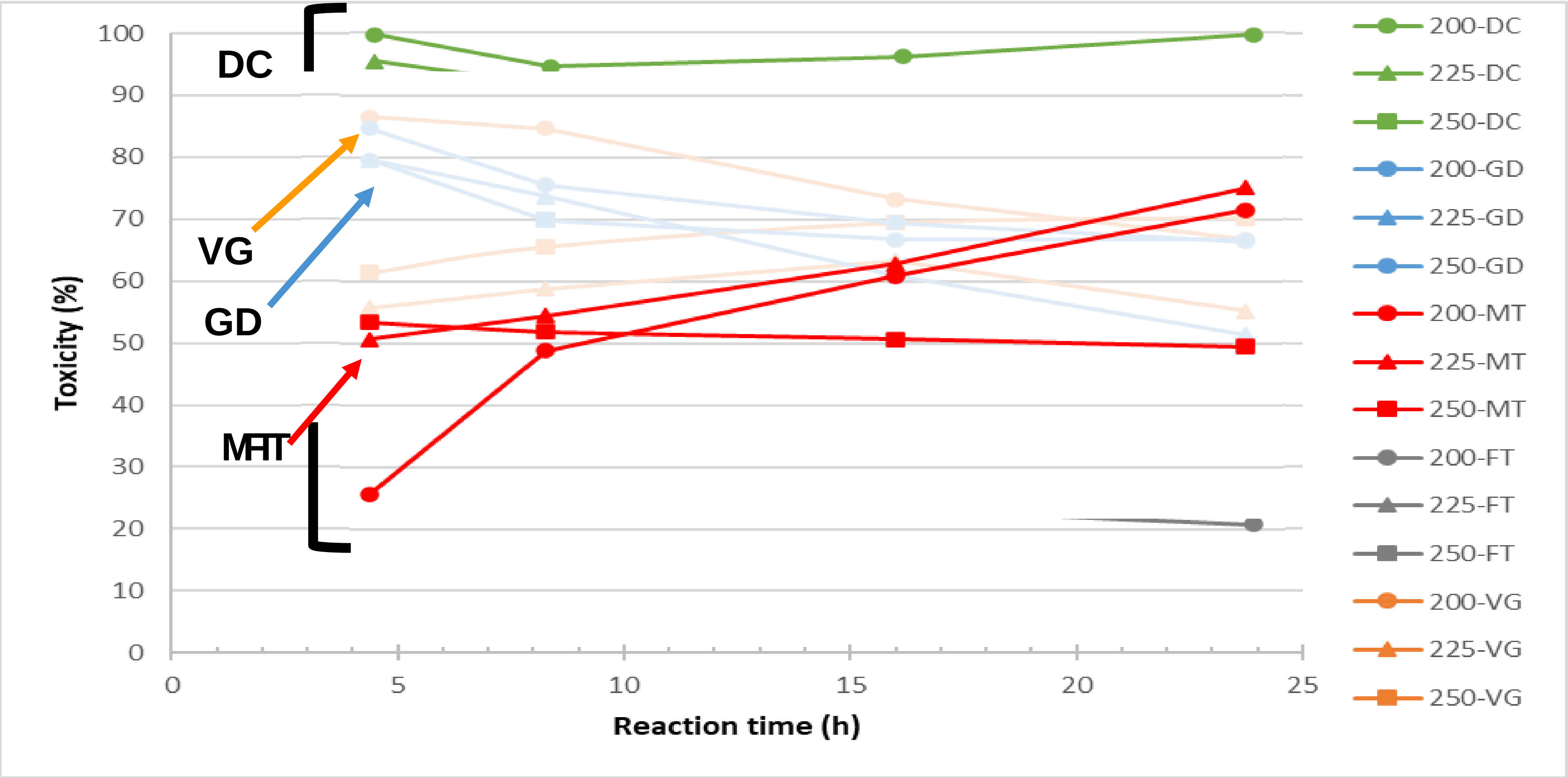
- Trends depend on feedstock and carbonization conditions
- Overall, toxicity decreases with washing





Wash Water Toxicity

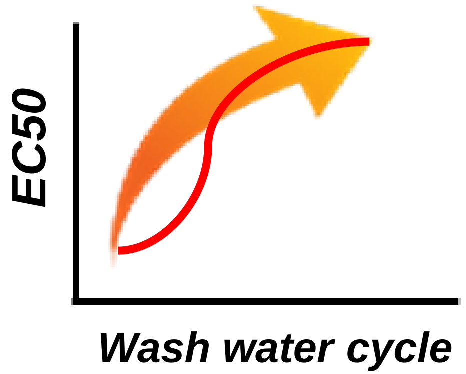
- Acute toxicity to E. *coli* – Day 1 washing



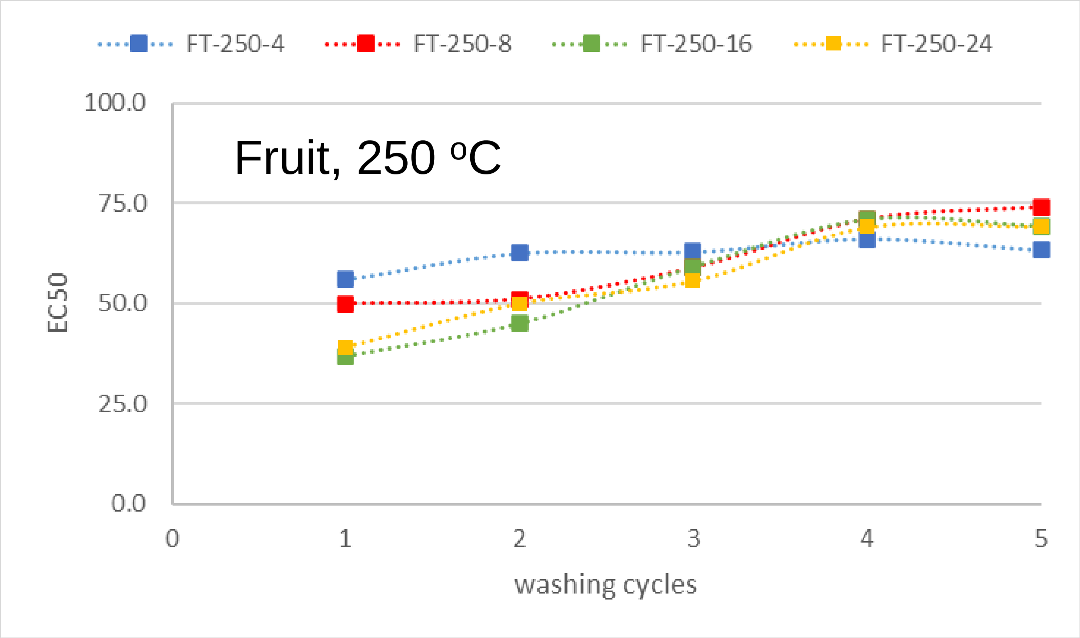
***Specific trends differ for each feedstock*

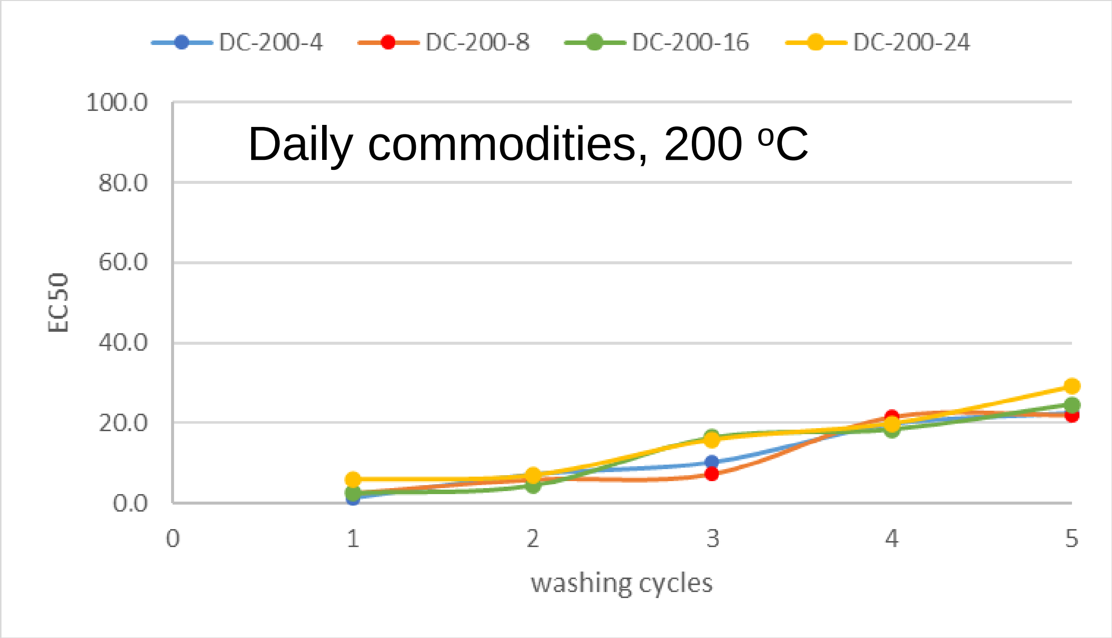
Wash Water Toxicity

- Acute toxicity to V. *fischeri* – Day 1 washing



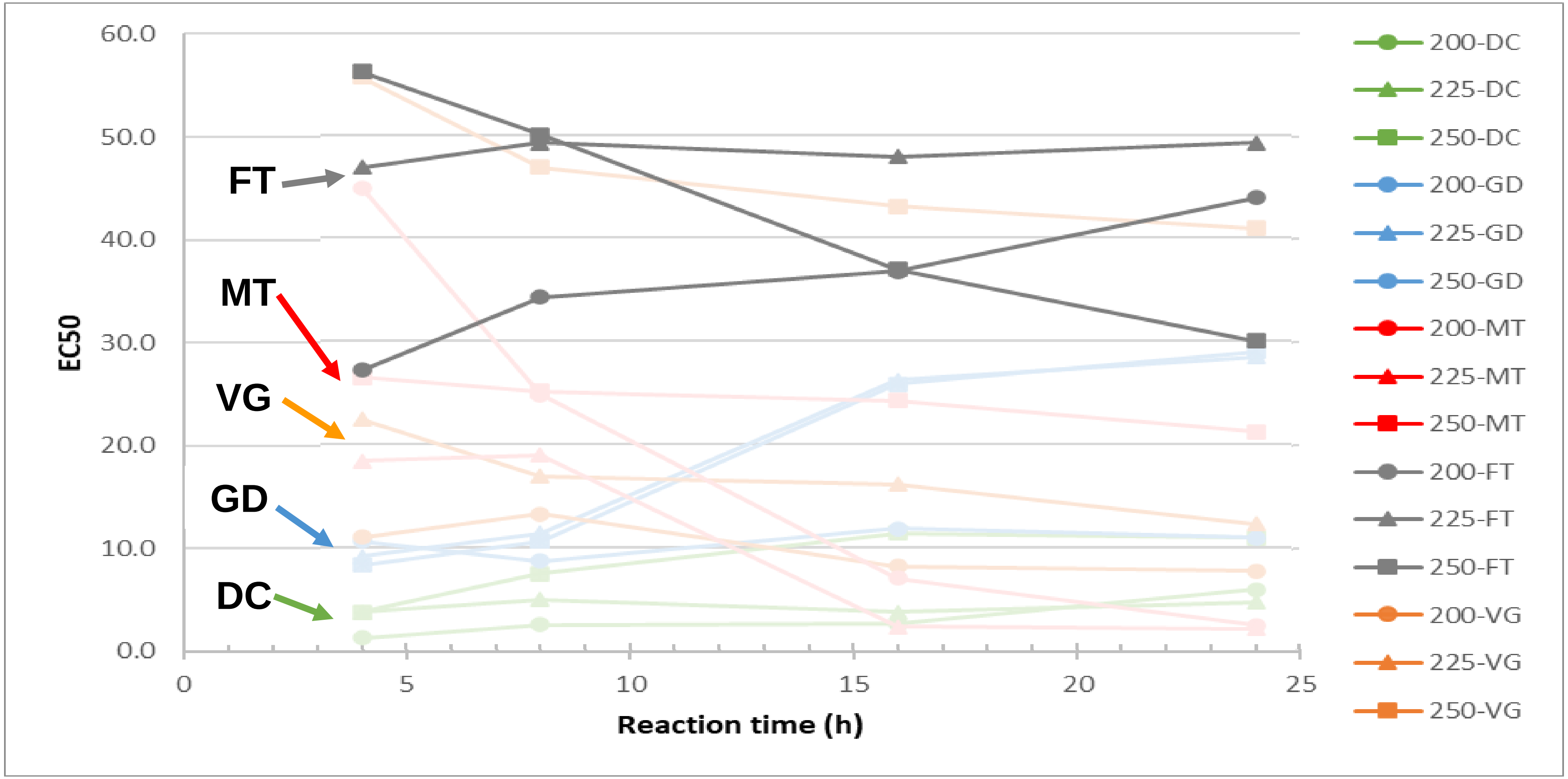
- As EC50 increases, toxicity decreases
- Trends depend on feedstock and carbonization conditions
- Overall, toxicity decreases with washing





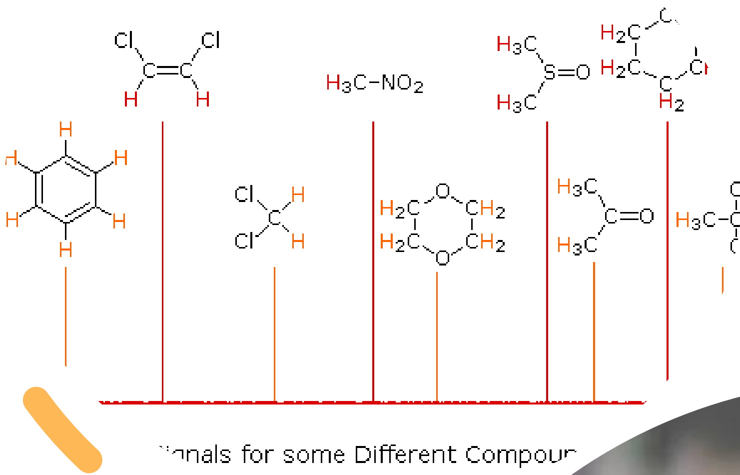
Wash Water Toxicity

- Acute toxicity to V. *fischeri* – Day 1 washing



Wash Water Composition

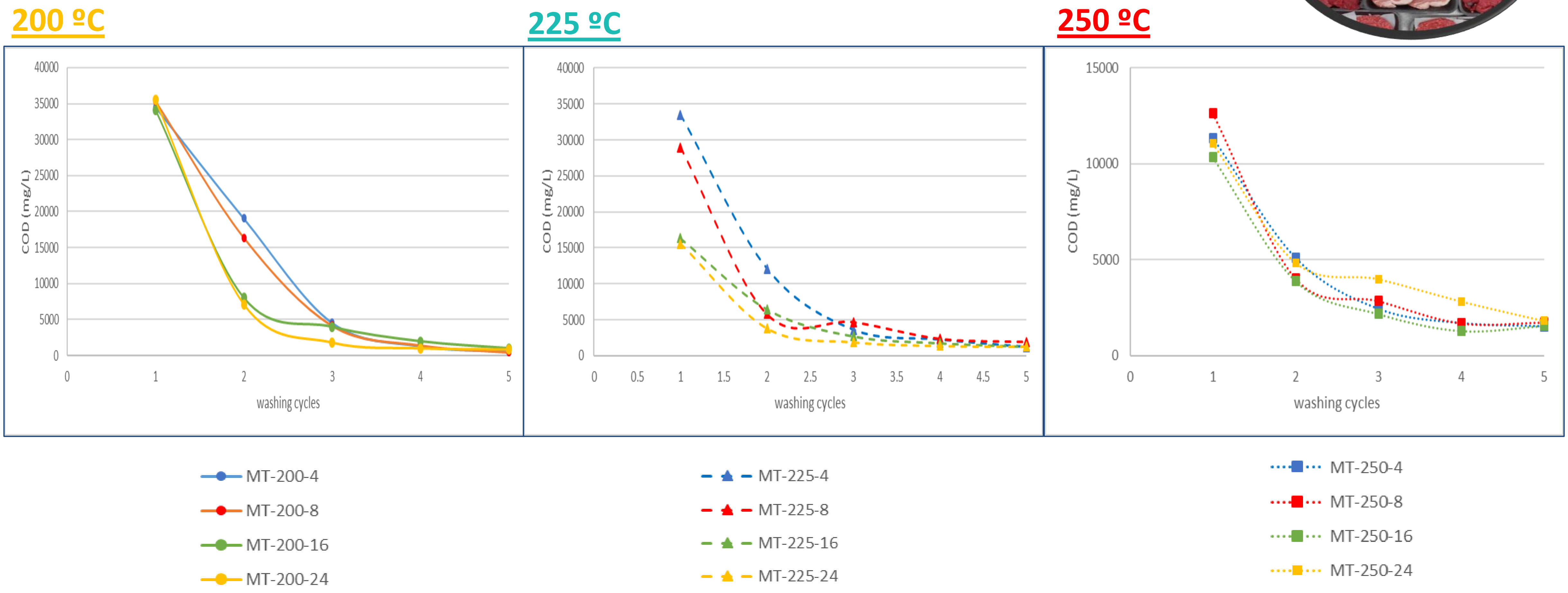
- Measured:
  - Nutrients (N, P, K)
  - pH
  - COD
  - TOC
  - ^{1}H-NMR to get general composition



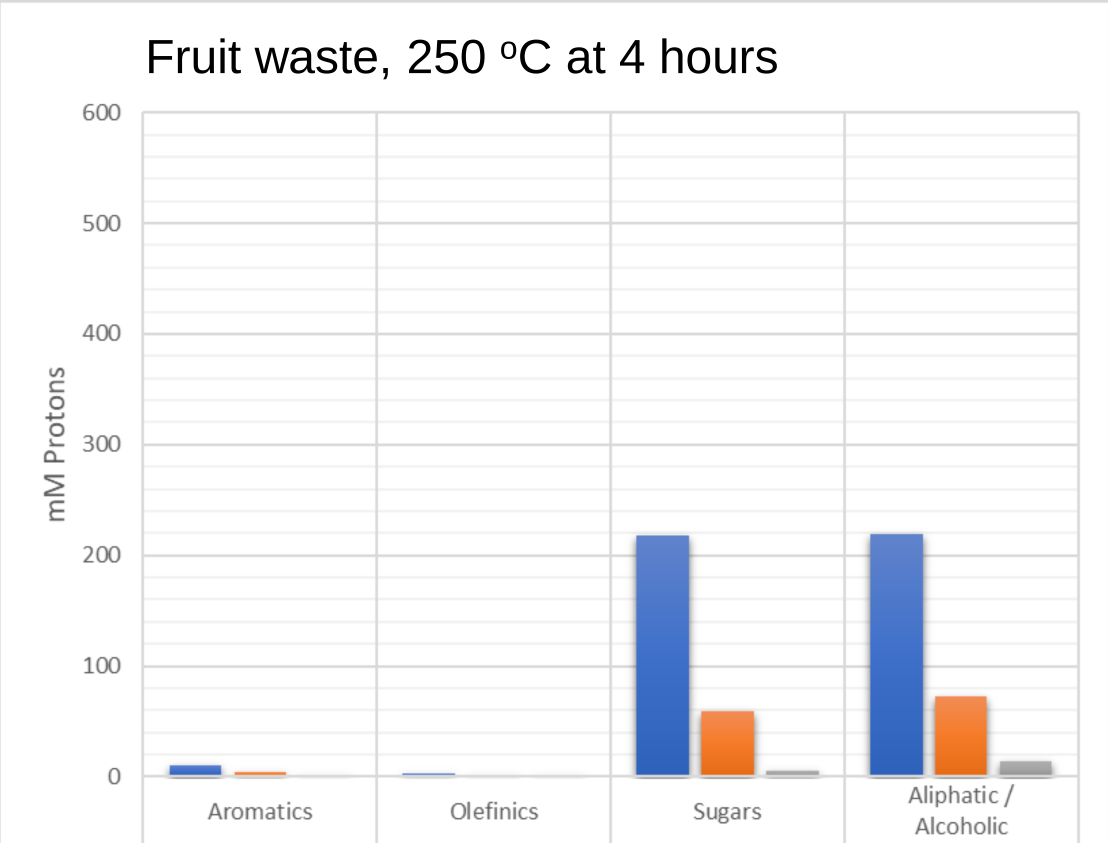
Wash Water COD

- Decreases with washing, TOC trends are similar
- Example:

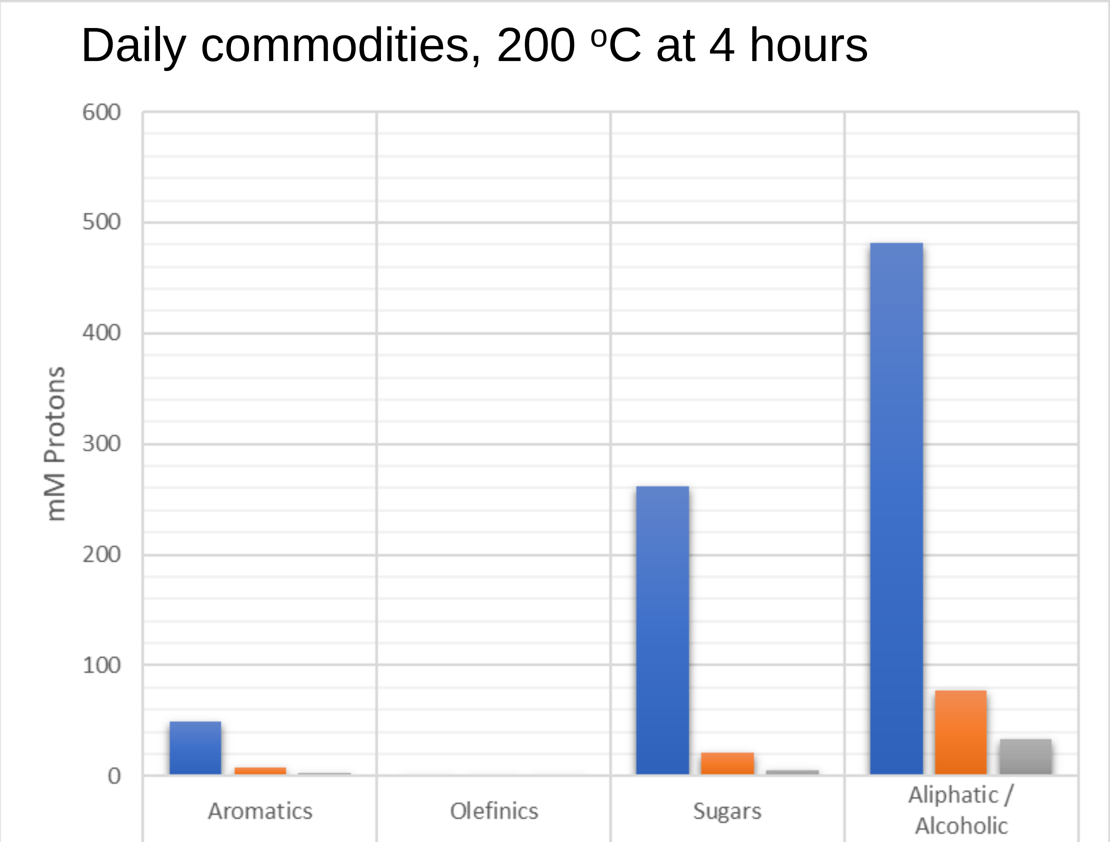
Meat



Wash Water Composition



	Aromatics	Olefinics	Sugars	Aliphatic / Alcoholic
Day 1	10.425	2.8638	218.435	219.6561
Day 3	4.6894	1.252	58.9655	72.2811
Day 5	1.7906	0.4644	5.5492	13.5758

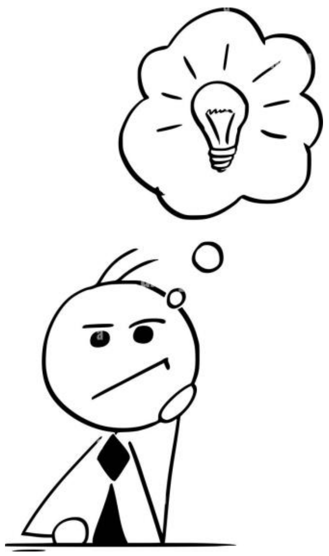


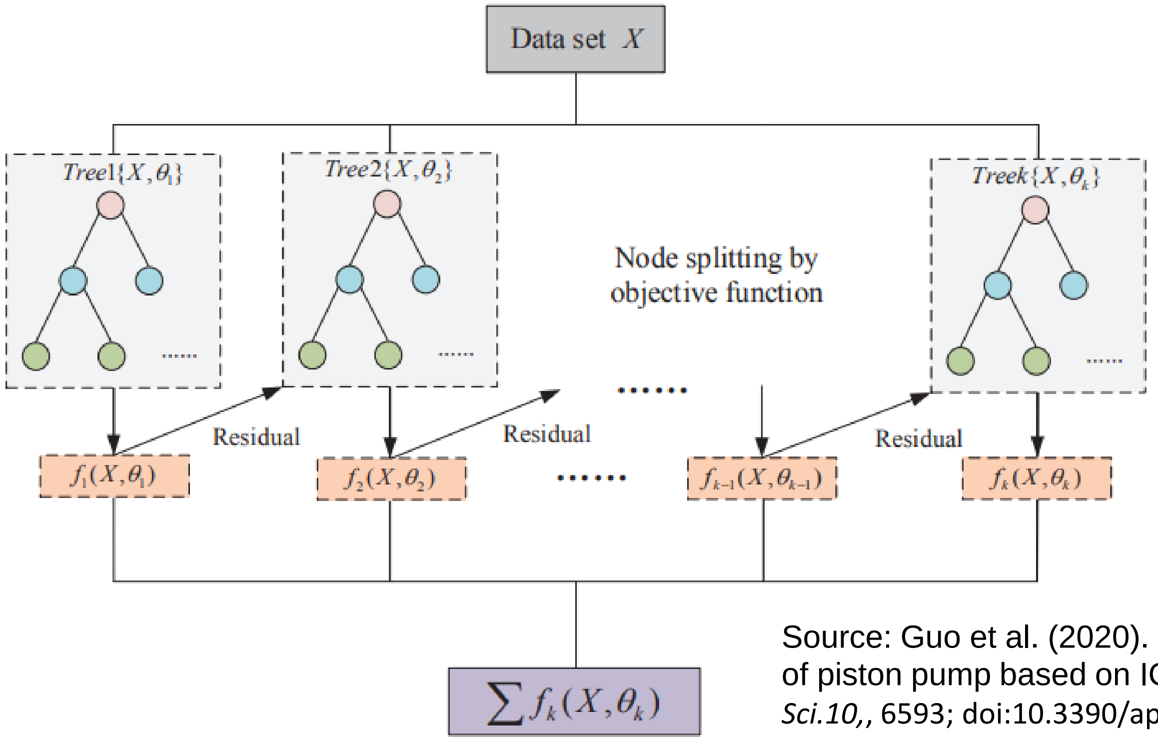
	Aromatics	Olefinics	Sugars	Aliphatic / Alcoholic
Day 1	49.1722	2.0101	262.3383	481.0887
Day 3	8.1345	0.8758	20.7052	76.7692
Day 5	2.3752	0.0845	4.8626	33.3385

- Correlation of these data with toxicity is not clear

Factors that Influence Wash Water Toxicity: Machine Learning Model

- Model predictions: Ensemble of decision trees and gradient boosting
  - XGBRegressor from XGBoost in Python
- Trained model with 75% data

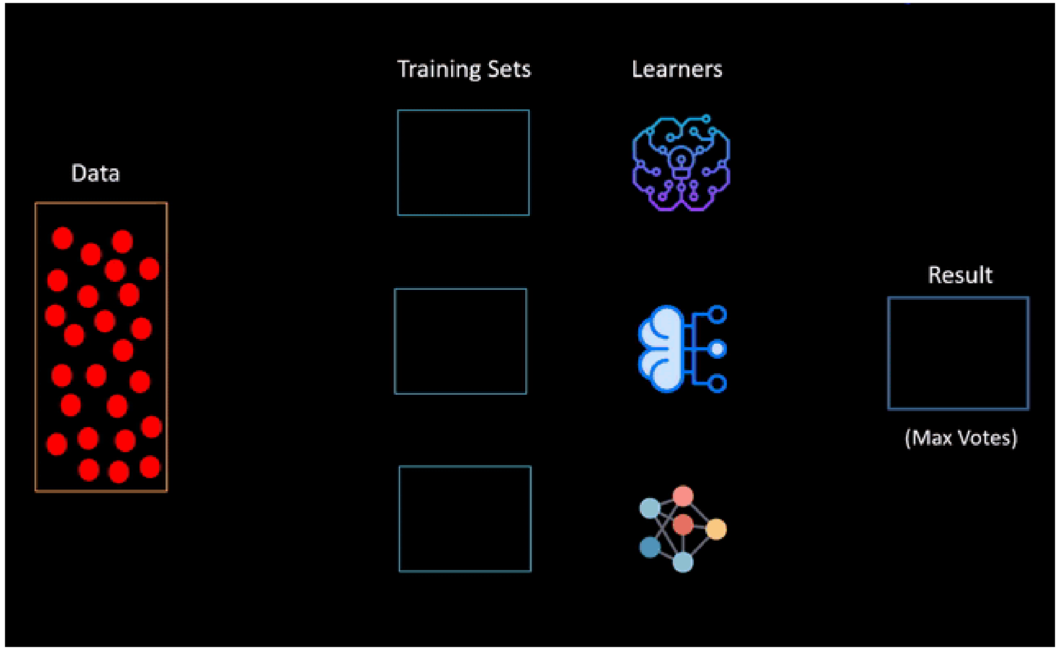


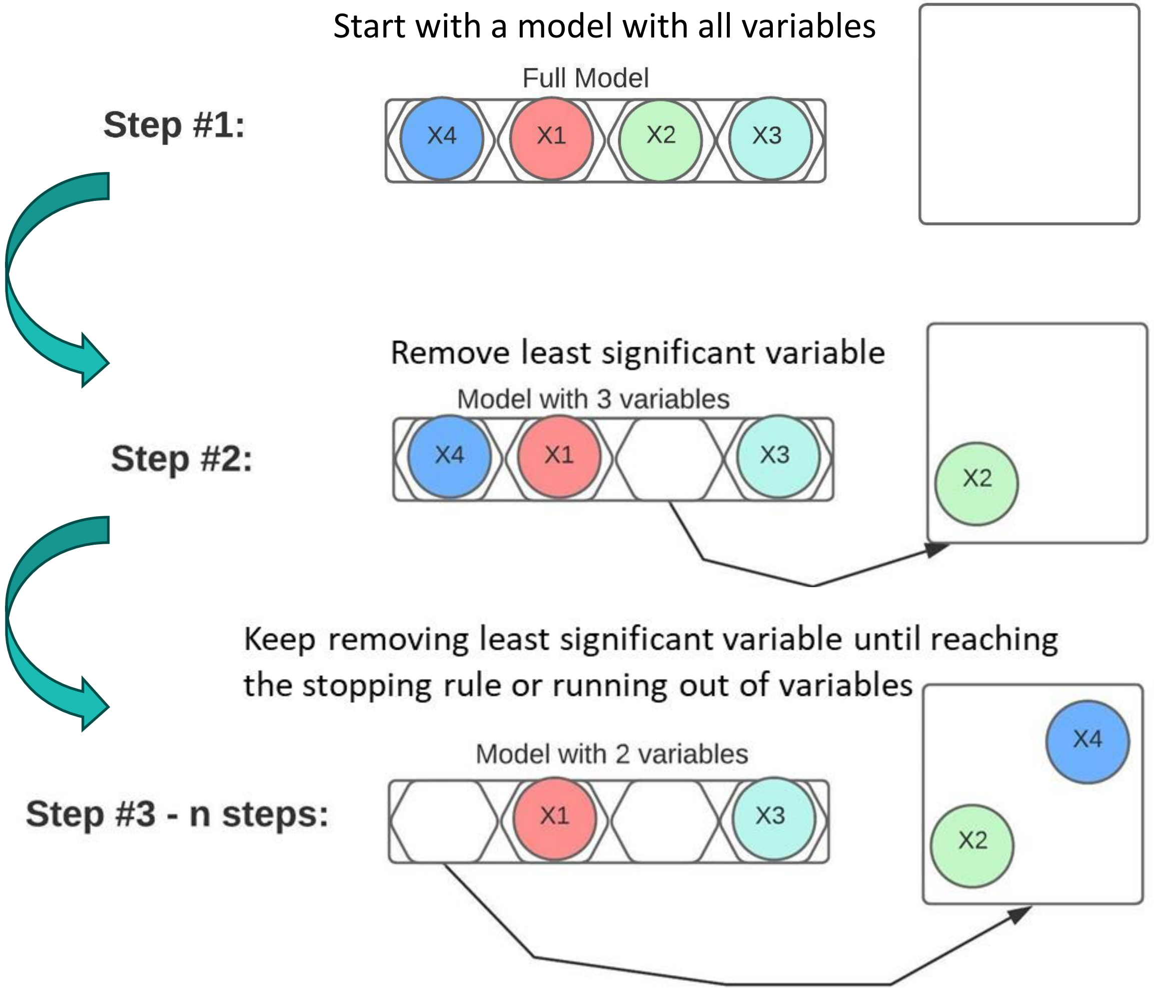


Source: Guo et al. (2020). Degradation state of recognition of piston pump based on ICEEMDAN and XGBoost. *Appl. Sci.10,*, 6593; doi:10.3390/app10186593

Factors that Influence Wash Water Toxicity: Machine Learning Model

- Permutation feature importance
  - Successively eliminate variables with low feature importance
  - Change in model score indicates importance

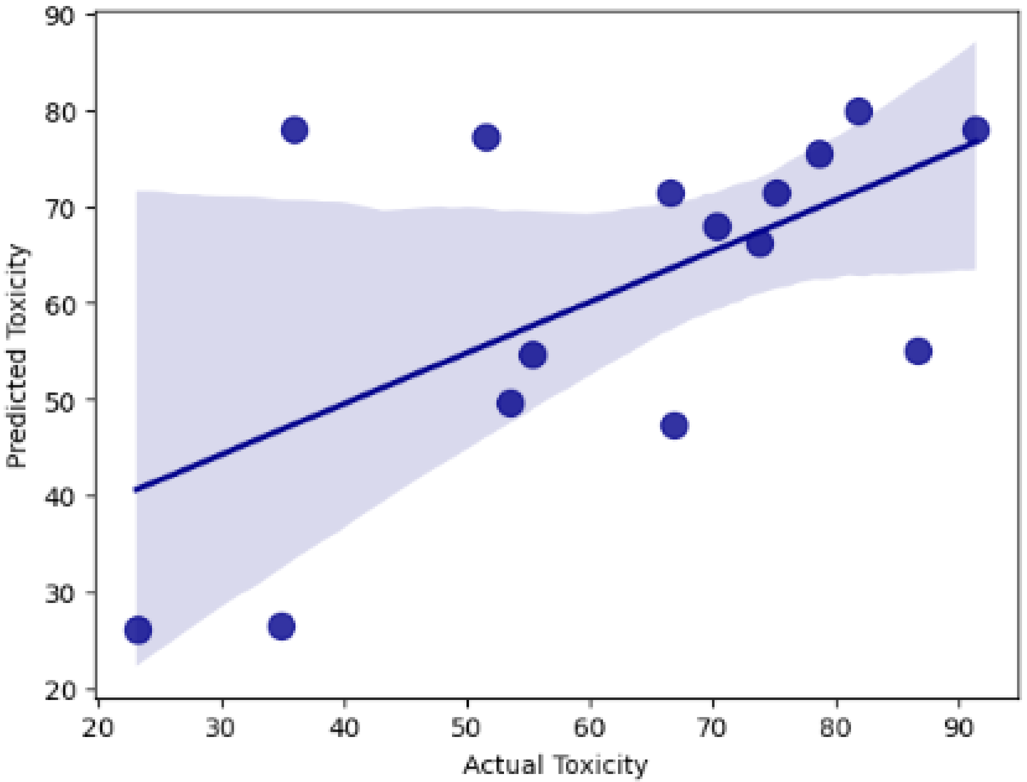




Important Wash Water Properties

Parameters of Importance:

1. Aromatic content
2. pH
3. Ammonia
4. TOC



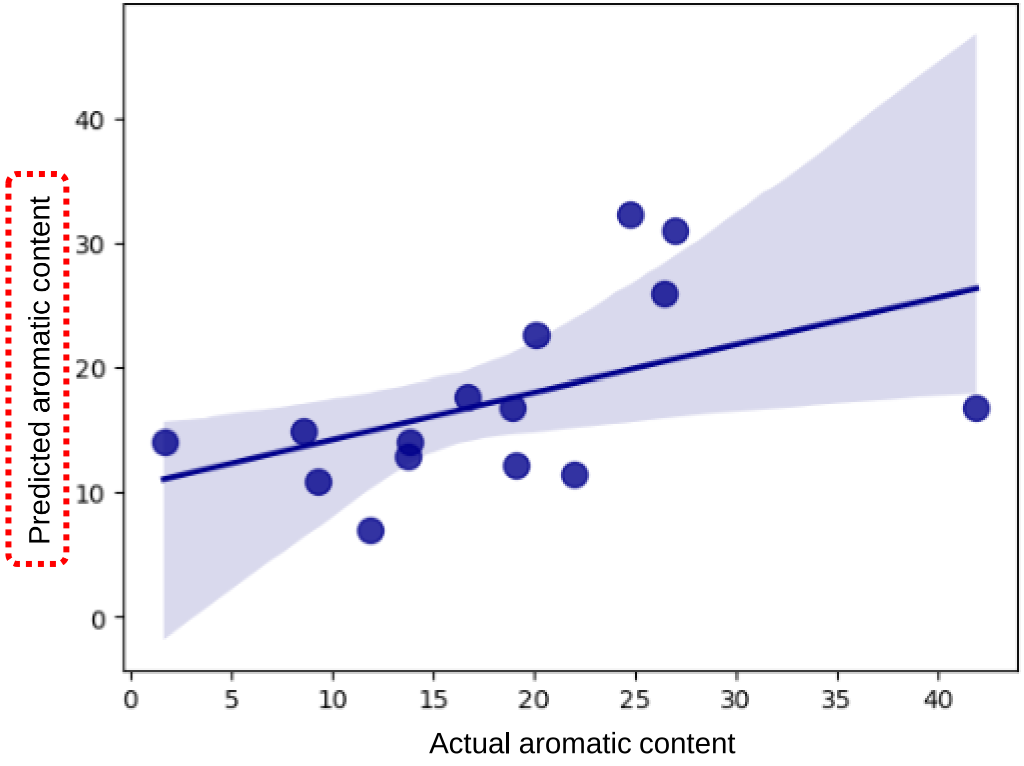
Mean Square Error = 279.3

High MSE suggests we are not measuring some parameters that are important

Can we predict aromatic content of the wash water?

<u>Parameters of Importance</u>:

1. Temperature
2. Feedstock H
3. Feedstock C
4. Time



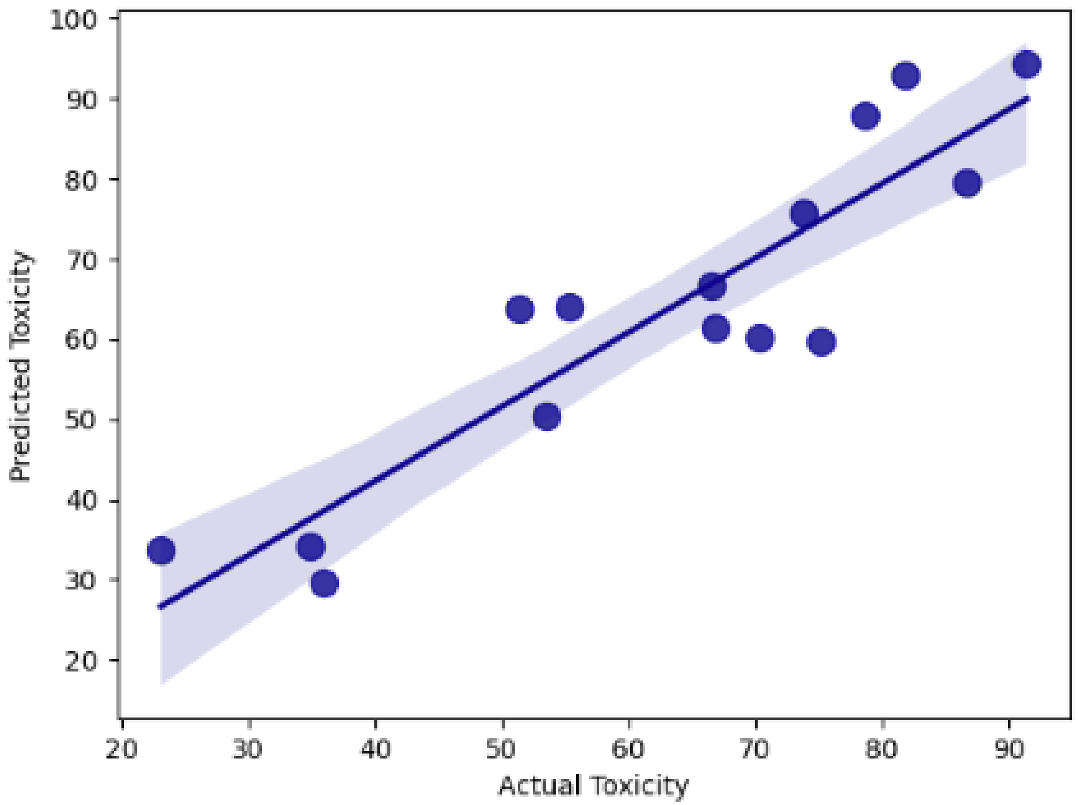
Mean Square Error = 73.0

Decent prediction with parameters that make sense

Important Wash Water Properties

<u>Parameters of Importance</u>

1. Nitrogen
2. Molybdenum
3. Calcium
4. Cobalt
5. Chromium
6. Volatile matter
7. Phosphorus

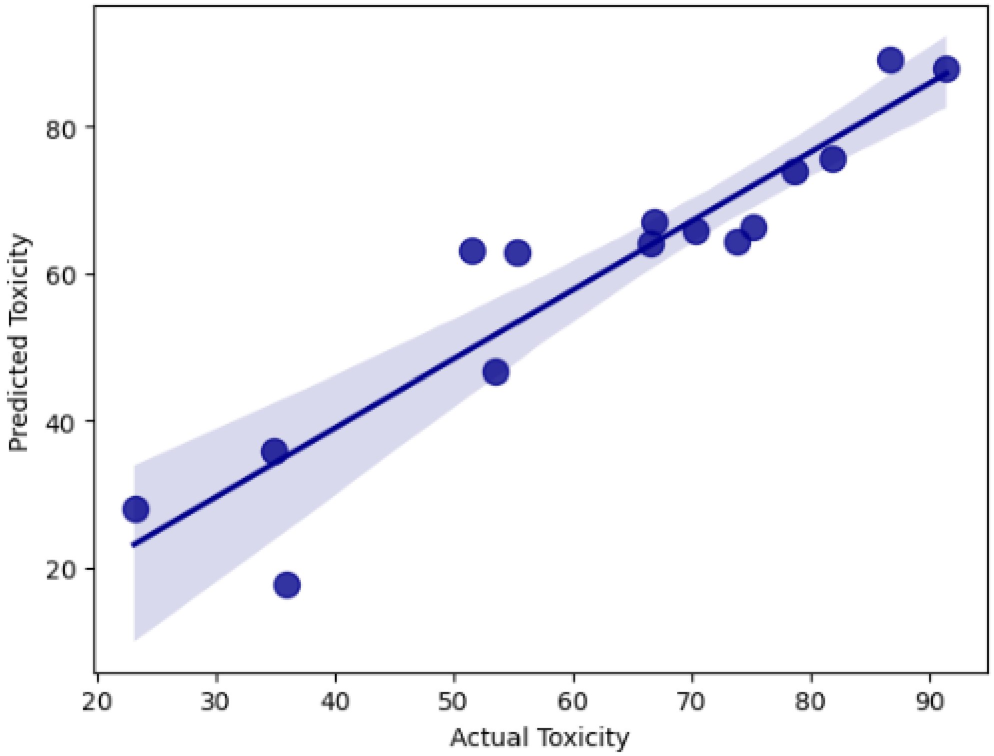


Mean Square Error = 69.1

Important Wash Water Properties

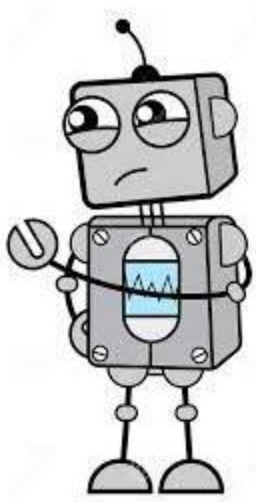
Parameters of Importance:

1. Feedstock H
2. Temperature
3. Time
4. Feedstock C
5. Feedstock VM



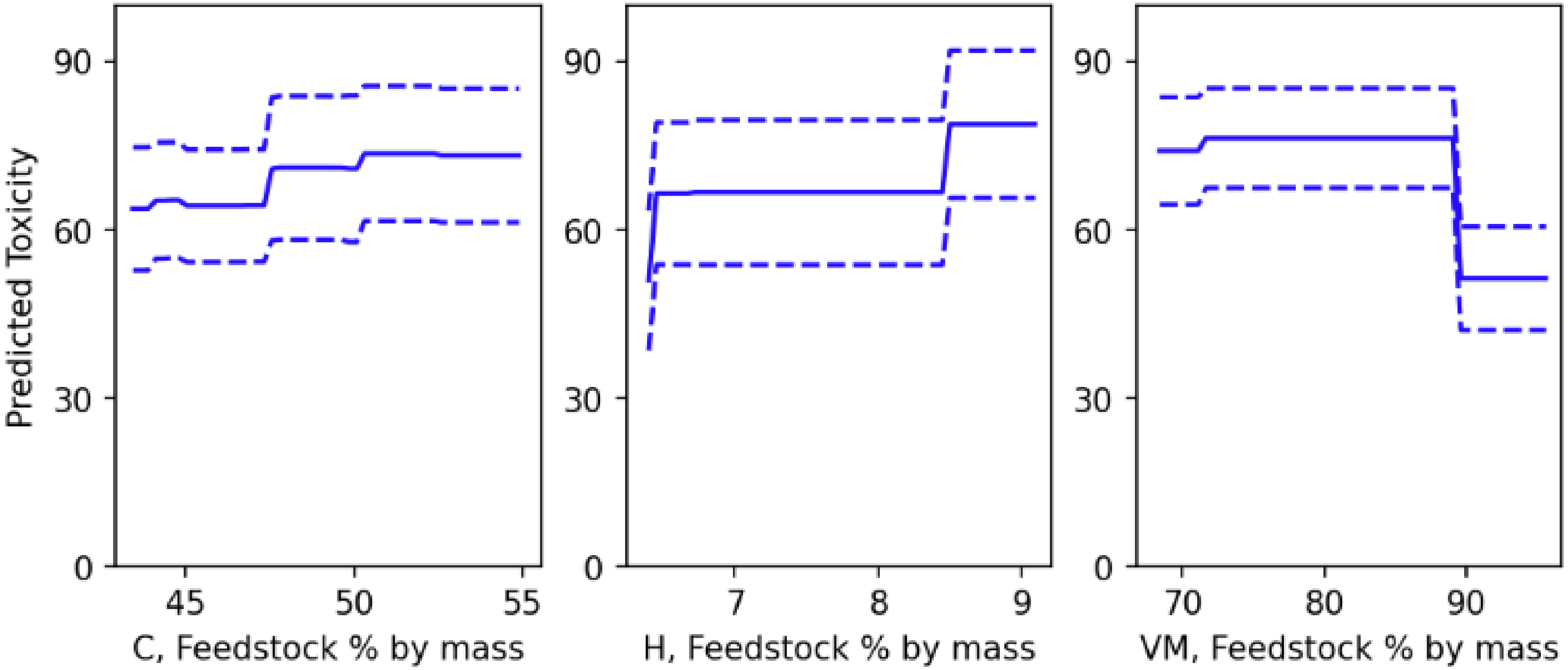
Mean Square Error = 57.7

What does this mean with respect to choosing a feedstock?



Predicted trends

- Fixed one variable, randomized others with a uniform distribution



Conclusions

Energy value can be approximated and feedstocks chosen appropriately

Possible acute toxicity in wash water from leaching of hydrochar can be predicted

Link between specific waste properties and hydrochar characteristics can be identified

Future Work

LEACHING MODEL TO PREDICT WASHING REQUIREMENTS

REFINE MACHINE LEARNING MODEL

DETERMINE PARAMETERS IMPORTANT FOR ENERGY-RELATED HYDROCHAR USE

INVESTIGATE DIFFERENT METHODS FOR REDUCING POTENTIALLY TOXIC SUBSTANCES ON THE HYDROCHAR

PERFORM AN LCA TO DETERMINE FACTORS THAT INFLUENCE THE SUSTAINABILITY OF HYDROCHAR USE

EVALUATE COMPONENTS OF THE LIQUID STREAM TO INVESTIGATE ITS TOXICITY

ACTIVACHAR (CTM2016-76564-R)

WASTEVALOR (PID2019-108445RB-I00)

VALIDAWASTE (PDC2021-120755-I00)

BIOTRES-CM (S2018/EMT-4344)

Industrial PhD 2019

(IND2019/AMB-17092)

NEWIR Manure (NSF#CBET-1856009)

(NSF#NSFC-1902419)

UAM-Santander (EE.UU.; 2017/EEUU/07)

Programas de Transferencia UAM (2019; 2020)

Thank You!

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