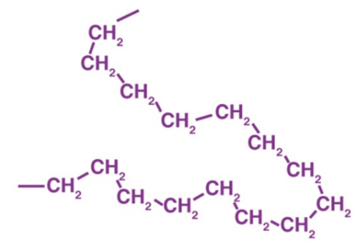
Hinkley Center for Solid and Hazardous Waste Management

Quantifying the Environmental Impact of Agricultural Plastic Mulch Film Burning

Yang Wang, Assistant Professor
Department of Chemical, Environmental and Materials Engineering
University of Miami

Sungyoon Jung, Assistant Professor
Department of Environmental Engineering Sciences
University of Florida

Background: Plastic mulch film – Benefits



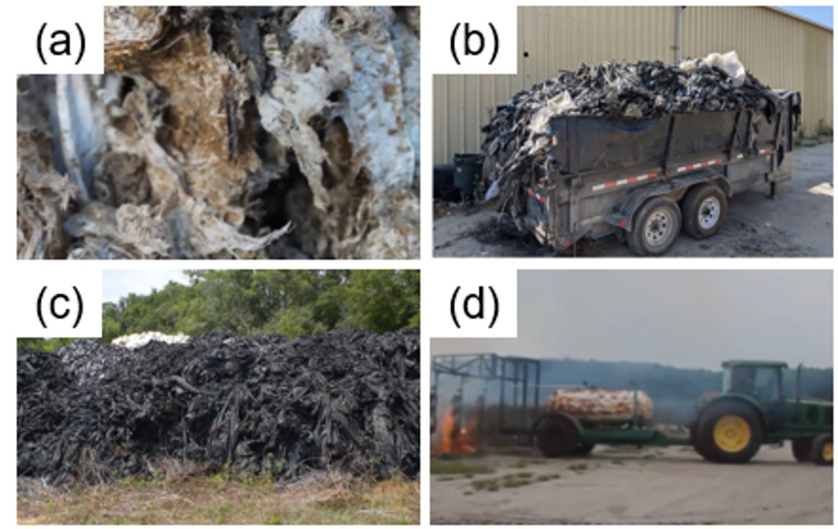
- Plastics are essential in modern agriculture
- Plastic mulch film (mostly polyethylene) comprises ~50% of all agricultural plastics
  - Others: irrigation tubing, trays, bags, etc.
- Benefits: weed and pest control, temperature and moisture control, lightweight, flexible, crop production enhancement
- Market in the US: annual growth rate of 7.1% by 2029 at $19.5 billion

- In the State of Florida, plastic mulch film is used in the production of almost all/most <u>tomato, pepper, strawberry, watermelon, eggplant, and cucumber</u> crops.
- ~ 100,000 acres of mulched vegetables in Florida (No.1 state in the U.S.)

Kasirajan, S. and Ngouajio, Agronomy for sustainable development, 32, 501-529, 2012.
Markets and Markets: Agricultural Films Market by Type (LDPE, LLDPE, EVA, Reclaim, HDPE), - Global Forecast to 2029, 2024.
Hochmuth, et al. Critical Issue: 1. Agricultural and Horticultural Enterprises,, 2021

Background: Plastic mulch film – Challenges

- Removal and disposal after every growing season
- Polyethylene fragments/degrades slowly under solar radiation
- Removed plastic mulch film contains high soil residue ~ 80% of weight, while recycling facilities require < 5%
- Less than 10% of plastic mulch film is recycled



- Current disposal approaches:
  - Landfilling: transportation cost and tipping fee (heavy weight)
  - Stockpiling and in-field burial: space limit and soil health impact
  - Burning (preferred method by growers): reduce size and weight

Cassou, E.: Agricultural Pollution - Plastics, 2018
Steinmetz et al., Science of the total environment, 550, 690-705, 2016.
Sarpong, et al.. Circular Agricultural Systems, 4(1) e005. 2024

Background: Plastic mulch film – Burning

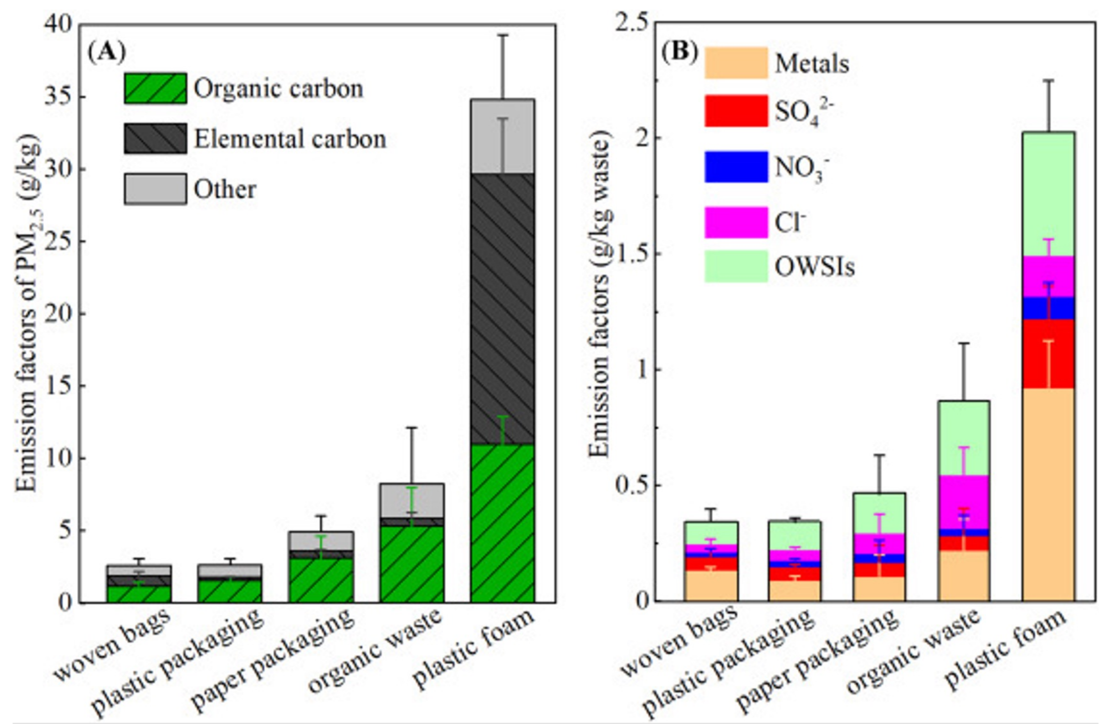
- High heating value 46 MJ/kg
  - > coal 18 MJ/kg
- Not accepted at waste-to-energy plant (not refuse-derived fuel)
- Florida Statutes Title XLVI, Chapter 823.145: "Polyethylene agricultural plastic, …, which are used in connection with agricultural operations related to the growing, harvesting, or maintenance of crops, may be disposed of by open burning…"

- Burning methods: pile burning and torch burning
- However, plastic burning can generate air and soil pollutants, and pollutant emission depends on the burning methods

The Engineering ToolBox (2014). Waste Fuel - Heat Values. Available at: https://www.engineeringtoolbox.com/waste-heating-value-d_1911.html [05/22/2024].
Video sources: Gene Jones, Southern Waste Information eXchange

Background: Plastic burning emissions

- <u>No previous research on plastic mulch film burning</u>
  - Influence of contaminants on burning emissions?
- Studies of plastic burning:



- Particulate matter
  - One of the EPA's six criteria air pollutants
  - Can lead to respiratory diseases if inhaled
  - Size matters: combustion generate submicron particles (D_p < 1 μm)
  - Composition matters: elemental carbon (carcinogen), organic carbon, and metals

Wu et al., Journal of Hazardous Materials 416 (2021): 125820.
Cheng et al., Environmental Pollution, 263, 114417, 2020.
Levitan, et al. Creating viable alternatives to open burning, 2005

Background: Plastic burning emissions

- No previous research on plastic mulch film burning
  - Influence of contaminants on plastic burning emissions?
- Studies of plastic burning
  - Particulate matter
    - One of the EPA's six criteria air pollutants
    - Can lead to respiratory diseases once inhaled
    - Size matters: combustion generate submicron particles
    - Composition matters: elemental carbon (carcinogen) and organic carbon, metals
  - Gaseous pollutants
    - Carbon monoxide - one of the six criteria air pollutants (incomplete combustion)
    - Volatile organic compounds (polycyclic aromatic hydrocarbons (PAH))
  - Microplastics (pollutant of emerging concerns)
    - Released into the environment and/or the human body via inhalation or ingestion.
    - Remain in the plastic burning bottom ash and air

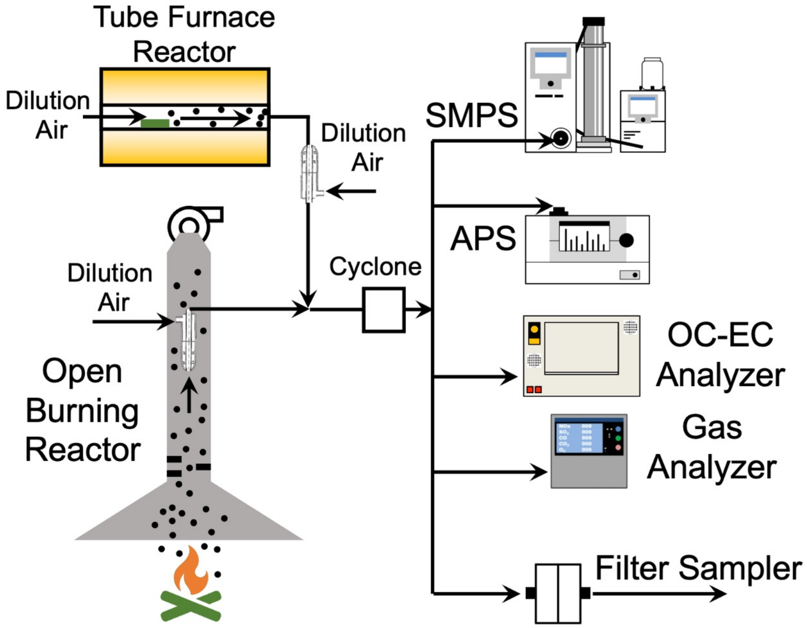
- **Pollutant emission depends on the burning conditions and methods**

Wu, Di, Qing Li, Xiaona Shang, Yingguang Liang, Xiang Ding, Hao Sun, Shuya Li, Shuxiao Wang, Yingjun Chen, and Jianmin Chen. "Commodity plastic burning as a source of inhaled toxic aerosols." Journal of Hazardous Materials 416 (2021): 125820.
Shen et al., Science of the Total Environment, 779, 146528, 2021.

Objectives:

- Quantifying the emission factors of air pollutants and microplastics from plastic mulch film burning using two different combustion systems
  - Tube furnace reactor (controlled burning temperature, burning time, combustion efficiency, etc.)
  - Open burning reactor (realistic small-scale burning environment)
- Optimizing the burning methods to reduce pollutant emission during plastic mulch film burning

Methodology: Plastic mulch film burning



Parameters	Ranges
Tube Furnace Reactor	
Types of plastic mulch	Black, clear, white*
Conditions of plastic mulch	New or Used
Furnace temperature	200 ^{o}C, 450 ^{o}C, 700 ^{o}C, and 950 ^{o}C
Carrier gas flow rate	0.5, 1, and 2 lpm (burning time of 70, 35, and 18 seconds)
Open Burning Reactor	
Types of plastic mulch	Black, clear, white*
Conditions of plastic mulch	New or Used
Combustion method	Assisted with liquid fuel (gasoline, ethanol, lighter fluid) or sustained by flame torch (methane, propane)

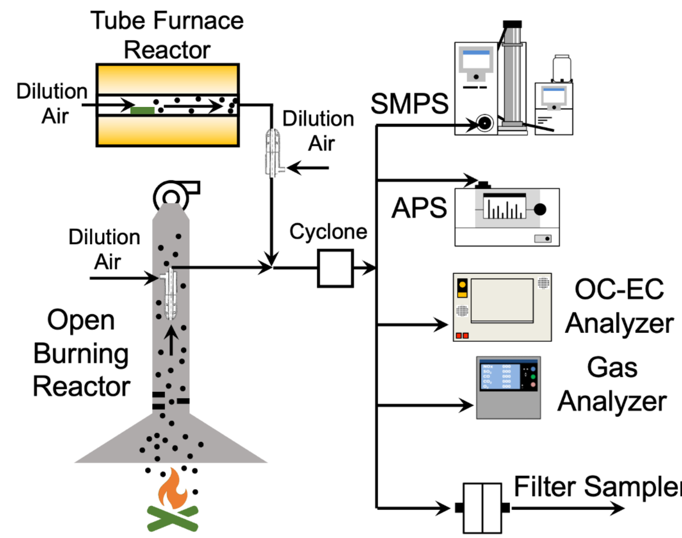
Gene Jones

- Brief procedure:
  - Plastic mulch film sample weighted before burning
  - Sample flows controlled by mass flow controllers to ensure consistent sample measurement
  - Air samples are diluted before measurement and collection
  - Burning residue weighted after experiment

* Black, clear, and white mulch films are commonly used in Florida according to Hochmuth, et al. Critical Issue: 1. Agricultural and Horticultural Enterprises,, 2021

Methodology: Instruments and sample analysis

- Analysis focus: particulate matter, gaseous pollutants, and microplastics
- Particulate Matter:
  - Scanning Mobility Particle Sizer (SMPS): Size and mass distribution of particulate matter with sizes between 10 and 500 nm
  - Aerodynamic Particle Sizer (APS), Model 3321, TSI Inc.: Size and mass distribution of particulate matter with sizes between 0.5 and 20 μm
  - Mass of elemental and organic carbon in the particulate matter: Organic Carbon-Elemental Carbon (OC-EC) Analyzer, Sunset Laboratory Inc.
  - Metals: Inductively Coupled Plasma Mass Spectrometry (ICP-MS)
- Gaseous Pollutants:
  - Combustion Gas Analyzer, Model 310, Testo Inc.: Carbon monoxide, carbon dioxide, and combustion efficiency
  - Gas chromatography/mass spectrometry (Shimadzu Inc.): Volatile organic compounds
- Microplastics (filter and burning residue):
  - Physical analysis: stereomicroscope, scanning electron microscopy-energy dispersive spectroscopy (FEI Nova NanoSEM 430)
  - Chemical analysis: pyrolysis-gas chromatography/mass spectrometry (Agilent Inc.)



Methodology: Data analysis

- **Emission factor (EF)**: Mass of pollutant emitted per unit mass of fuel burned
$$EF_i = \Delta m_i / \Delta m_b$$
- Δm_i is the increase of mass for pollutant *i*, and Δm_b is the mass of burned plastic mulch film.
- Increase of mass for pollutant *i*
$$\Delta m_i = \Delta C_i \times Q \times t$$
- ΔC_i is the change of concentration in the smoke, Q is the flowrate through the reactor (corrected to standard conditions), and t is the sampling time.
- Determine emission factors for particulate matter, elemental and organic carbon, carbon monoxide, volatile organic compounds, metals, and microplastics

Comparisons

- Air pollutant concentrations compared against the EPA's National Ambient Air Quality Standards (NAAQS)
- Emission factors compared against EPA's combustion emission inventory
- Metal content will be compared against Soil Cleanup Target Levels established by the Florida Department of Environmental Protection

FDEP: Table II - Soil Cleanup Target Levels, 2024.
EPA: AP-42: Compilation of Air Emissions Factors from Stationary Sources, 2024a.
EPA: National Ambient Air Quality Standards (NAAQS) Table, 2024b.

Novelty

- Examining the burning emission of plastic mulch film using realistic combustion platforms
  - High soil content and potentially other chemicals in the used mulch film (pesticides, plant residue, etc.)
  - Existing studies cannot be directly translated to mulch film burning
  - Identify optimal and economical burning conditions that minimize pollutant emissions
- Advanced pollutant characterization systems in sample analysis
  - Real-time monitoring of air pollutant concentration and particulate matter properties
  - Microplastic identification and quantification in plastic mulch film burning soil residues

Team qualification

- Yang Wang

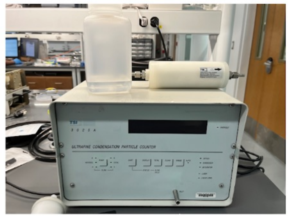
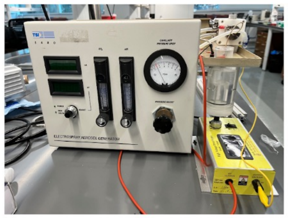
- Dr. Wang's research focuses on particle formation and dynamics in engineering and atmospheric systems. Our research projects are enabled by the real-time characterization of particulate matter in the sub-micron and sub-nanometer range.
- Dr. Wang's group will conduct combustion experiments and air pollutant emission monitoring systems

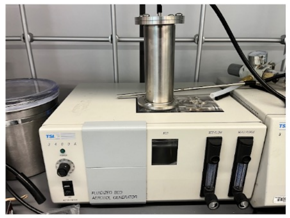
- Sungyoon Jung

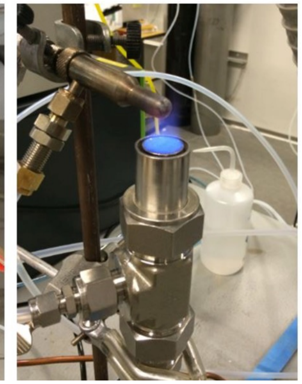
- Dr. Jung's research focuses on identifying and quantifying emerging air pollutants, such as micro- and nanoplastics, and their remediation using advanced nanomaterials.
- Dr. Jung's group will identify and quantify microplastics using various analytical skills and instruments.

- Dr. Wang lab equipment

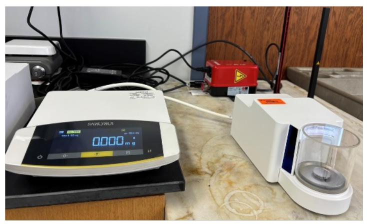
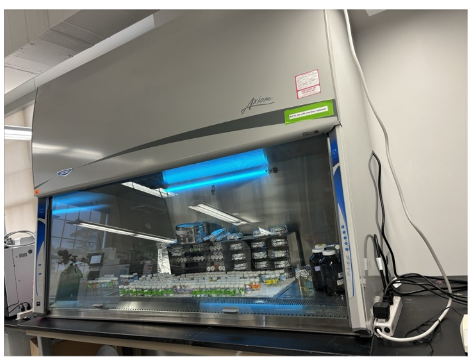


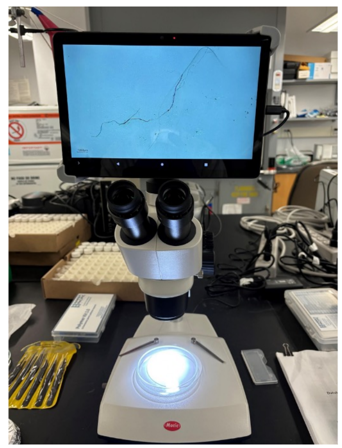





- Dr. Jung lab equipment

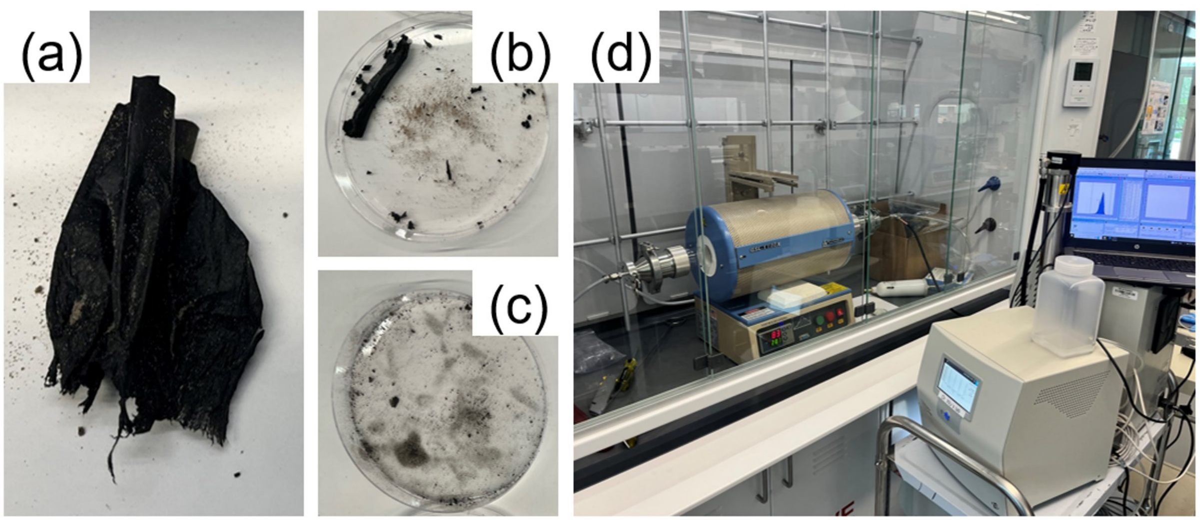

Preliminary results

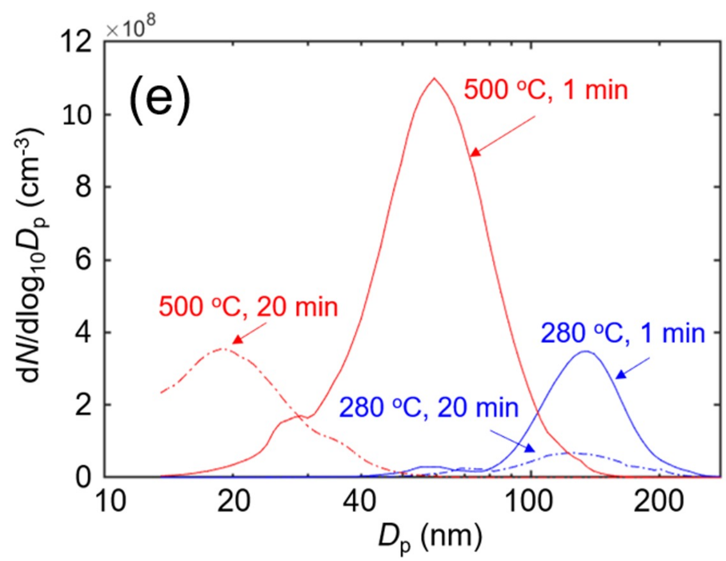
Courtni Spencer

- Established protocol for combustion experiment
- Collected used plastic mulch film
- Compared to higher temperature (500 ℃), lower temperature burning (280 ℃) generated lower level of particulate matter, but larger amount of unburned residue (panel b)
- Particle concentration and particle size gradually decrease as a function of time

AGRICULTURAL PLASTIC BURNING EXPERIMENT PROTOCOL

1. Ensure all connections are secure (mass flow controllers, APS, SMPS, CPC).
2. Power on furnace and begin heating to desired temperature.
3. Power on the APS, SMPS and CPC and start up the AIM software on the computer. Set the required parameters and scheduling settings.
4. Turn the mass flow controllers on to the desired flow and leave to run for 15 minutes.
5. Weigh the ceramic boat without plastic and record the weight.
6. Cut a small piece of the plastic (dirty or clean, black or white) and roll it to fit in the ceramic boat.
7. Weigh the boat and plastic together and record the weight.
8. Once the required temperature is reached in the furnace, place the ceramic boat with the plastic into the furnace and seal it with the clamp.
9. Begin measurements with the AIM software.
10. Once measurements are finished, save the data and export it to an external drive, power off all instruments and wait for the furnace to cool before removing the boat.
11. Once the boat is cool, weigh the boat with its contents and record the weight. Discard the residue.





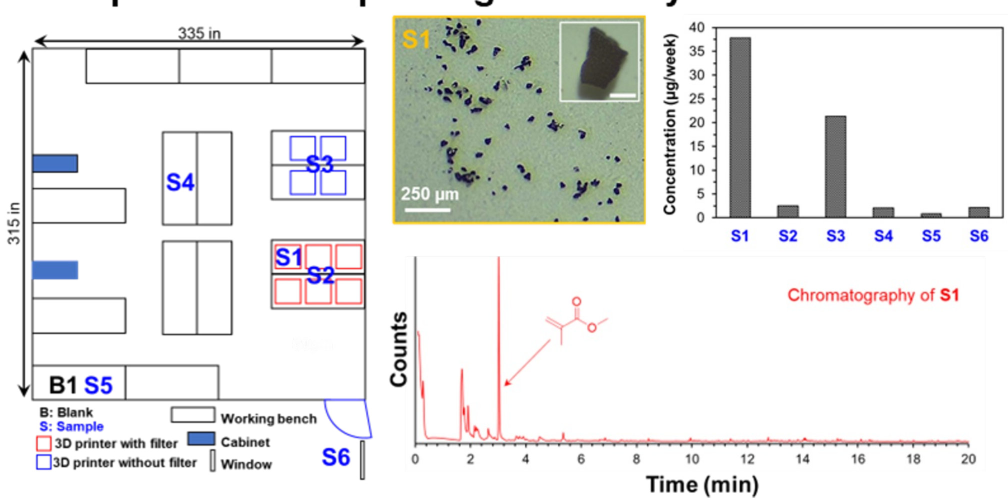
Preliminary results


Peyton Thompson

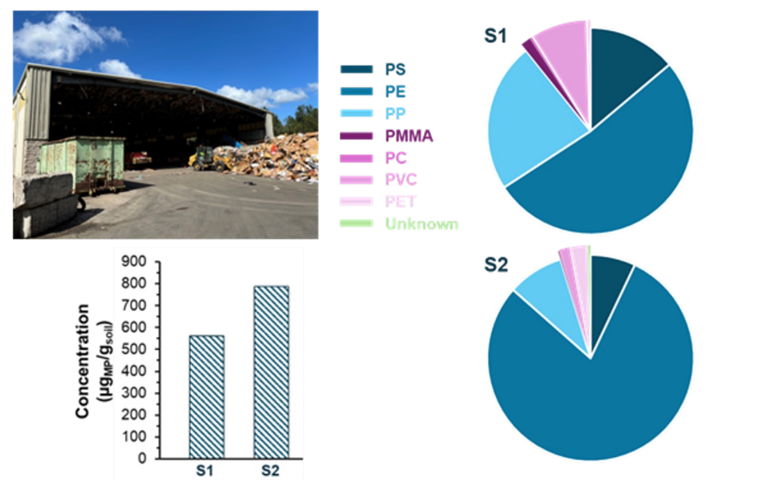

Madelyn Hotaling

- Jung group established methodologies to identify and quantify microplastics.
- Collected various types of samples, including air and soil.
- The preliminary data below demonstrate the ability to identify and quantify microplastics in different environmental media.
- The physicochemical properties of microplastics were evaluated using a stereomicroscope and Py-GC/MS. All samples indicated the presence of microplastics with varying characteristics, likely due to differences in their sources.

Microplastics in 3D printing laboratory



Microplastics in waste collection center in Gainesville



Practical and Specific Benefits for End Users

- Farmers: The project will provide practical guidance cleaner and more effective burning methods. By optimizing burning practices, the project may help reduce costs associated with tipping, transportation, and long-term soil degradation or air pollution violations.
- Regulators: The project will provide a new set of emission data and pollutant profiles, potentially guiding updates to open burning regulations, landfill acceptance criteria, and incentives for recycling and alternative disposal technologies.
- Waste management professionals: The project will evaluate risks associated with agricultural plastic waste disposal. These results can help support the design of better waste-handling infrastructure for agricultural plastics.
- Public health and environmental researchers: The project will provide datasets for modeling pollutant transport, assessing human exposure risks, and understanding ecosystem impacts associated with the agricultural plastic burning.

Deliverables

- Quarterly Progress Reports, Draft and Final Technical Reports, and Metrics Summary
- TAG meetings, stakeholder engagement, and outreach:
  - Three TAG meetings
  - Concise and accessible educational materials
  - A dedicated research website including the project results
- Database, publications and presentations
  - Database maintained by the repositories of University of Miami and University of Florida
  - At least one peer-reviewed journal article for submission
  - Results will be presented at research conferences, such as the Annual Conference for the American Association for Aerosol Research, the Association of Environmental Engineering and Science Professors Research and Education Conference, and the Air & Waste Management Association's Annual Conference.

Plan for Seeking Funding from Other Sources

- The proposed work serves as an essential first step in agricultural plastic mulch management. We will seek future support from
  - National Science Foundation (NSF): Both Wang and Jung are currently funded by the Environmental Engineering program and Combustion and Fire Systems programs at NSF (e.g., NSF Awards 2034198, 2132655, 2324142, and 2519559) and are experienced with proposal preparation and submission.
  - United States Department of Agriculture (USDA), through its Foundational and Applied Science Program, which funds research addressing sustainable agriculture, waste minimization, and environmental stewardship on farms.
  - Florida Department of Environmental Protection (DEP), which funds state-focused environmental monitoring, pollution control, and solid waste innovation initiatives.
  - Office of Naval Research (ONR): Jung is currently funded to investigate the chemical properties of tidal flats (N00014-25-1-2180).
- Future project themes:
  - Conduct comprehensive characterization of pollutant monitoring (including detailed volatile organic compounds and chemical characterizations)
  - Development of recycling and reuse technologies for agricultural plastic mulch film: use electrostatic method (e.g., mechanical shaking and electric curtain for dust removal)
  - Small-scale waste-to-energy feasibility studies to take advantage of the high heating value of plastics

Technical Awareness Group (TAG)

Name	Title and Affiliation	Sector	Email
Gene Jones	CEO of Southern Waste Information eXchange	Private Sector	gene@swixusa.org
Sam Sugerman	Sustainability Manager in agricultural sector (affiliation not provided due to request)	Private Sector	srsugerman@gmail.com
Samir Elmir	Division Director, Florida Department of Health Miami-Dade Environmental Public Health and Engineering	Public Sector	Samir.Elmir@flhealth.gov
John Wong	Assistant Director, Department of Solid Waste Management, Technical Services and Environmental Affairs	Public Sector	John.Wong@Miamidade.gov
Nicholas Ciancio	Chief of Resilience Engineering & Environmental Compliance, Department of Solid Waste Management	Public Sector	Nicholas.Ciancio@miamidade.gov
Lisa Wasko DeVetter	Associate Professor, Department of Horticulture, Washington State University	Researcher	lisa.devetter@wsu.edu
Marwa El-Sayed	Assistant Professor, Department of Civil Engineering, Embry-Riddle Aeronautical University	Researcher	elsayedm@erau.edu
Jiannan Chen	Assistant Professor, Department of Civil, Environmental, and Construction Engineering, University of Central Florida	Researcher	jiannan.chen@ucf.edu

Project Timeline with Milestones

Months 1–2: System setup and instrument calibration

- Milestone 1: Establish reactors and sampling systems
  - Assemble and test the tube furnace reactor and open burning reactor
  - Calibrate particulate matter and gas analyzers (SMPS, APS, OC/EC analyzer, and gas monitors).
  - Coordinate system validation and dry runs to ensure measurement accuracy and repeatability.
  - Finalize sampling protocols and data analysis procedures.
  - Establish project website on **Wang**'s research website: https://pmtl.coe.miami.edu/. Project abstract and general information on the experimental methods will be introduced.

Milestone deliverable: Operational and validated reactor and sampling system; finalized experimental protocol document.

1	2	3	4	5	6	7	8	9	10	11	12

Project Timeline with Milestones

Months 3–5: Combustion Experiments and Sample Collection

- Milestone 2: Execute combustion experiments and collect samples
  - Burn selected new and used plastic mulch film samples under controlled burning conditions using both reactors.
  - Collect particulate matter, gases, and residual ash samples.
  - Shipping burning residue and particulate matter filters to the University of Florida for microplastics analysis.
  - TAG Meeting (Month 4) to present the experimental system and early-stage data and gather stakeholder input.
  - Accomplish the 1st Quarterly Progress Report and post on the project website.

  Milestone deliverable: Dataset of raw combustion emissions under all test conditions; TAG meeting summary.

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Project Timeline with Milestones

Months 6–9: Pollutant Characterization and Data Analysis

- Milestone 3: Complete laboratory analysis of air and soil samples
  - Analyze particulate matter for size distribution, carbon content (OC/EC), and mass-based emission factors.
  - Conduct microplastic identification and quantification.
  - Compare pollutant emission factors against EPA NAAQS and FDEP Soil Cleanup Target Levels.
  - Drafting technical reports and publications based on initial findings.
  - TAG Meeting (Month 8) to present additional research finding and collect feedback from stakeholders.
  - Accomplish the 2nd Quarterly Progress Report and post on the project website.

Milestone deliverable: Emission factors for air pollutants and microplastics; summary report for internal review.

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Project Timeline with Milestones

<u>Months 10–12: Synthesis, Communication, and Reporting</u>

- Milestone 4: Finalize project documentation and outreach
  - Develop educational materials (e.g., fact sheets, emission guides) for farmers and waste managers.
  - TAG meeting (Month 12) to present comprehensive results and gather feedback for future research.
  - Submit manuscripts for peer-reviewed publication.
  - Accomplish the 3rd Quarterly Progress Report, Technical Reports, and Metrics Summary, and share the resources and datasets to the project webpage for public access.

Milestone deliverables: Final technical report; policy brief; stakeholder education toolkit; conference abstract/paper submission; public access webpage.

1	2	3	4	5	6	7	8	9	10	11	12

Communication Plan

- Stakeholder engagement
  - TAG meetings
  - Field visits (sample collection and information distribution)
- Data management and data sharing
- Communication in research communities
  - Research conferences
  - CAST workshop
- Educational outreach in local communities
  - Undergraduate and graduate courses
  - Museum outreach

Thank you!
Questions?