



Module 2: Waste-to-Resource Strategies in Agri-Food Systems

Instructor Guide

Module Overview

This module explores how agricultural and food waste can be transformed into valuable resources while reducing greenhouse gas emissions and building a circular economy. Students investigate five major waste-valorization pathways—landfill, aerobic composting, anaerobic fermentation/digestion (Bokashi & digesters), biochar pyrolysis, and insect bioconversion—learning how each works, what it produces, and its environmental trade-offs. The module blends science-based analysis with systems thinking and applied design activities, giving students the tools to calculate climate impacts, evaluate trade-offs, and design solutions for real-world waste challenges.

Materials Provided

- Slide deck with speaker notes
- Optional student-facing worksheets
- Extended learning activity on soil microbial diversity & bokashi
- Case studies and circular design sprint materials
- Vocabulary list and student notes
- Instructor lesson plan and optional lab activities

What Should Students Walk Away With

This module offers students a systems-level introduction to organic waste as a resource, framing discarded food and plant material not as trash, but as valuable inputs for fertilizer, energy, animal feed, and other co-products. While the module does not require deep prior knowledge of microbiology, thermodynamics, or soil chemistry, it provides multiple opportunities for students to engage with these concepts in real-world contexts. Students practice data analysis, design thinking, and trade-off evaluation, while also connecting waste management to climate action and resource recovery.

By the end of the module, students should be able to:

- Review the concept of circular vs. linear systems
- Identify the major waste-to-resource pathways for organic waste
- Quantify and compare the climate impacts of each waste pathway using real data
- Examine trade-offs/resources of each technology
- Analyze [campus] waste generation
- Apply systems thinking to propose solutions

Key Question:

How can we redesign food systems to reduce waste and regenerate natural resources instead of depleting them?

Essential Questions:

- *How can we redefine “waste” as a resource in agricultural and school settings?*
- *What are the environmental (carbon) impacts of different waste management strategies, and how can we quantify and compare them?*
- *How can implementing multiple waste-valorization methods together create a more sustainable, closed-loop campus or community?*

Lesson A: Beyond the Trash: The Five Pathways of Food Waste

Summary: In this lesson, students follow the journey of an orange peel through five waste management pathways. Using the 5R’s framework—Refuse, Reduce, Reuse, Repurpose, Regenerate—they are introduced to circular thinking in resource use. The class explores five waste-valorization strategies: landfilling, aerobic composting, anaerobic fermentation (Bokashi and digesters), biochar pyrolysis, and insect bioconversion. For each pathway, students examine the process and final outcomes, then predict which offers the greatest climate

benefit. The lesson also introduces double valorization and a case study on combining bokashi fermentation with biochar pyrolysis in citrus growth.

Focus: Understanding major waste-to-resource methods, their processes, and climate impacts

Slides: 3-45

Lecture Notes:

- Warm-Up Discussion: “How can we redefine ‘waste’ as a resource in agricultural and school settings?” Frame discussion with: “Where does your waste go?” to introduce organic waste and its environmental impact.
- Optional Review: Introduce linear vs circular systems and the 5 Rs (Reduce, Reuse, Recycle, Recover, Rot).
- Pathways of Organic Waste: Landfill (Aerobic Decay): Produces methane (28–36× CO₂ GWP), 0.25–0.75 t CO₂-eq per ton food waste. Aerobic Composting: Emits mostly CO₂, ~0.05–0.15 t CO₂-eq per ton (~75–90% less than landfill). Bokashi Fermentation / Anaerobic Digester: Processes diverse materials including meat, dairy, and cooked food; almost no GHG; byproduct liquid fertilizer; requires airtight seal and follow-up composting. Biochar Pyrolysis: Low-oxygen heating locks carbon long-term, retains water & nutrients, supports soil microbes; requires high heat, setup cost, but can be fueled by syngas. Insect Bioconversion: Uses insects to turn organic waste into protein and fertilizer.
- Double Valorization: First valorization: Convert waste into primary products. Second valorization: Use byproducts to create additional valuable outputs. Examples: Crop residues → mushroom substrate → compost; used cooking oil → biodiesel; fruit pulp → bioplastic; manure + food waste → algae fertilizer pellets.
- Case Study – LabtoFarm Citrus Waste Research: Challenge: Citrus nursery waste → landfill → methane emissions. Intervention: Combined Bokashi fermentation + Biochar pyrolysis. Bokashi: Converts citrus scraps into nutrient-rich soil, reduces chemical fertilizer use. Biochar: Stores carbon, improves soil water retention. Results: Diverted waste from landfill, enhanced tree growth, long-term carbon sequestration.

Student Activities (Optional):

- Dear Principal, Reimagining Waste (Think-Pair-Share): Students will pick a composting pathway and write a short letter to the principal asking for a change in waste management.

Key Vocabulary:

- Organic waste, valorization, circular economy, landfill, aerobic composting, anaerobic digestion, bokashi fermentation, biochar pyrolysis, insect bioconversion

Objectives:

- **Identify:** Five major waste-valorization pathways—landfill, aerobic composting, anaerobic fermentation / digestion (Bokashi & digesters), biochar pyrolysis, and insect bioconversion
- **Describe:** Inputs, process conditions, and primary outputs of each pathway
- **Compare:** Greenhouse-gas profiles of the five pathways and determine which emit or avoid the most CO₂-equivalent
- **Predict:** Which pathway would deliver the greatest carbon reduction for a given food-waste scenario

Optional Extended Learning:

- Students will learn about soil microbes, particularly in Bokashi fermentation, and learn subsequent graph readings for Shannon Diversity / Index graphs
- Think-Pair-Share Activity Corner: Reading a Graph – Soil Microbial Diversity & Bokashi
- Career Pathways: Waste Management Engineer, Environmental Scientist, Sustainability Officer, Agri-Food Systems Educator, etc.

Lesson B: Carbon Math

Summary: In this lesson, students will quantify the carbon impacts of various waste-to-resource strategies using ΔCO₂-equivalent as a standard metric. They will work through a guided example converting methane (CH₄) emissions into CO₂-equivalent values to build fluency with greenhouse gas accounting. Students will then compare multiple waste management approaches—including landfilling, traditional composting, Bokashi fermentation, biochar production, and insect-based bioconversion—by ranking each method according to its potential for carbon savings. In addition, students will assess trade-offs such as scalability, economic cost, and

nutrient recovery efficiency. The lesson concludes with application to real-world scenarios: analyzing campus food waste streams and evaluating a case study on citrus waste reuse that integrates Bokashi fermentation with biochar amendment.

Focus: Calculating and comparing climate impacts; evaluating trade-offs between pathways.

Slides: 46-59

Lecture Notes:

- Warm-Up Discussion: “What are the environmental (carbon) impacts of different waste management strategies, and how can we quantify and compare them?”
- Explain why each pathway works, and introduce $\Delta\text{CO}_2\text{-eq}$ with the question: “If 1 kg of food waste goes to landfill vs. compost, how many kg of $\text{CO}_2\text{-eq}$ are emitted in each case?”
- Emphasize that every pathway has trade-offs, and that each balances climate benefit, cost, speed, and usability differently
- Introduce the idea that context matters in determining which path shrinks emissions the most
- Show the comparison of different pathways and their efficiency with carbon math, introducing the equation and defining the terms associated with it
- Explain the difference between a positive and negative value for $\Delta\text{CO}_2\text{-eq}$, as well as the reasoning behind the $\Delta\text{CO}_2\text{-eq}$ numbers for each pathway (landfill, compost, bokashi, biochar, larvae feed)
- Work through a guided calculation on carbon math with methane as an example
- Delve into a case study on LabtoFarm, where a combination of 10% bokashi and 10% biochar was used in creating bigger, healthier plants

Student Activities (Optional):

- Toolkit Trade-Offs Discussion (Think-Pair-Share): In pairs or groups, students will fill in 1–2 points per cell with realistic examples, choose the best pathway for a school cafeteria waste stream, and be ready to defend their choice with at least two criteria from the table provided

Key Vocabulary:

- Greenhouse gases (GHGs), methane, $\text{CO}_2\text{-equivalent}$, emission factor

Objectives:

- **Understand:** Recognize the $\Delta\text{CO}_2\text{-equivalent}$ for landfilling 1 kg of food waste versus treating it with alternative valorization options, using provided emission factors or data.
- **Create:** Design an optimal valorization route for a specific real-world waste stream (e.g. cafeteria leftovers or farm waste), supporting the recommendation with evidence from carbon calculations and practical considerations.
- **Evaluate:** Assess the trade-offs of each pathway – considering factors like cost, scalability, speed, and nutrient recovery – to justify which option might be preferable in a given context.
- **Rank:** Categorize different waste-to-resource technologies by their net carbon impact (most to least climate-friendly) and also compare their energy requirements and useful co-products.

Lesson C: Measuring Waste & Calculating CO_2 Impact

Summary: Students identify and map campus “waste hotspots,” quantifying waste streams by type (food, yard, paper). They will calculate associated CO_2 footprints and design strategies to close resource loops at each location. Working in teams, students develop and present prototype waste-to-resource solutions, while also evaluating how multiple valorization pathways operating in parallel can contribute to a circular campus system.

Focus: Identifying local waste “hotspots” and designing loop-closing interventions.

Slides: 60-71

Lecture Notes:

- Warm-Up Discussion: “How can implementing multiple waste-valorization methods together create a more sustainable, closed-loop campus or community?”
- Introduce the rationale behind measuring waste, the steps to calculate waste, and the subsequent $\text{CO}_2\text{-equivalent}$ value
- Delve into a case study on kitchen food waste (with Juan and Katie) to guide the calculation of waste and $\text{CO}_2\text{-equivalent}$

Student Activities (optional):

- Mini Waste-to-Resource Pilot (Think-Pair-Share): Students will pick 1 cafeteria waste item and design a mini blueprint that chooses the best valorization method while estimating CO₂ reduction

Key Vocabulary:

- Carbon sequestration, nutrient cycling

Objectives:

- **Analyze:** Quantify their campus's waste-generation hotspots, estimating weekly amounts of food, yard, and paper waste at key locations and computing the associated CO₂-equivalent emissions for each.
- **Apply:** Utilize the feasibility and projected carbon savings of their proposed solution in a brief presentation or "mini-pitch," using data (emission reductions, etc.) and practical reasoning to persuade peers.
- **Create / Evaluate:** Design a prototype waste-to-resource system for one selected hotspot or waste stream, specifying how the waste could be collected and processed (composted, fermented, fed to insects, etc.) to close the nutrient or energy loop.
- **Reflect:** How can implementing multiple different valorization routes in parallel move the entire campus toward a circular economy, and identify challenges and next steps for making it happen.

Optional Extended Learning: Bokashi Microbial Diversity

- Students will learn about soil microbes particularly in Bokashi fermentation, and learn subsequent graph readings for Shannon Index graphs.
- Optional Extended Learning Activity Corner (Think-Pair-Share): Reading a Graph – Soil Microbial Diversity & Bokashi
- Career Pathways: Waste Management Engineer, Environmental Scientist, Sustainability Officer, Agri-Food Systems Educator, etc.

Hands-On Labs (Optional, 25-30 Minutes):

- Cafeteria Waste Audit: Students create an audit station in the school cafeteria to collect and measure food waste, while interviewing peers to understand the reasons behind their leftovers
- DIY Bokashi Bucket Set-Up: Students will create their own Bokashi bucket, where they will gather cafeteria scraps and other materials to ferment
- Biochar Experiment: Students will participate in a series on lab-related activities to learn about the benefits and chemical properties of biochar

Assessment & Wrap-Up:

- Use the student worksheet (think-pair-share) to guide notetaking, exit tickets, and small-group review
- Exit tickets at the end of each lesson
- Assign a short reflection: "If you could implement one waste pathway here, which would it be and why?"

Teaching Tips:

- You do not need to cover all activities or notes—adapt to your students and your schedule
- Use the speaker notes to guide flow, but feel free to personalize delivery
- Vocabulary and mind map can be used as review tools or built upon throughout the module

Recommended Duration:

Approximately 3–5 class periods (45–55 minutes each). Lessons A, B, and C can be completed in one class period, with two-three additional periods suggested for hands-on lab activities or extension projects. The module's timeline is flexible: educators may extend the design project or include the optional labs described below to deepen inquiry and real-world skill development.

Recommendations for Instruction:

- **Begin with relevance:** Open by asking students what happens to cafeteria food scraps or yard waste at school. Use this as a springboard to introduce the concept of waste valorization and the circular

economy. Connecting everyday experiences to sustainability issues makes the science more tangible and engaging.

- **Reinforce systems thinking:** Continuously highlight connections between waste pathways and broader system outcomes. For example, compare methane emissions from landfills with carbon savings from biochar, then apply these insights to campus waste audits. Encourage students to see waste not in isolation, but as part of nutrient cycles, carbon cycles, and closed-loop systems.
- **Use interactive tools:** Incorporate structured worksheets for CO₂-equivalent calculations, flow diagrams for the 5R's framework, and graphic organizers for comparing valorization strategies. Visualization tools (e.g., Sankey diagrams of waste flows or carbon footprint calculators) can help students make sense of abstract data and trade-offs.
- **Encourage local observation:** Ground abstract concepts in real-world context. For example, have students trace the path of a single cafeteria orange peel into different waste routes, or invite them to map “waste hotspots” around campus before conducting the formal audit. This builds relevance and ownership of the project.
- **Differentiate as needed:** Depending on class time and student readiness, simplify or extend activities. For introductory classes, keep carbon math to guided worked examples. For AP-level students, emphasize independent calculations, data interpretation, and critical comparison of trade-offs. Each lesson provides a core activity with optional extensions (e.g., microbial diversity graphs in Lesson A, case study analysis in Lesson B).
- **Sustain positivity:** While highlighting the environmental risks of landfilling and poor waste management, emphasize practical solutions and success stories—such as bioplastics made from fruit pulp or algae fertilizer derived from food waste. Reinforce that sustainability is not only about reducing harm, but also about innovation, creativity, and opportunity in building circular food systems.

Need Support?

Contact the curriculum team:

Deborah Pagliaccia , Arunabha Mitra , Leticia Meza