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Balancing Individual Learning and Teamwork: A Life Cycle Assessment (LCA) Project for a Sophomore-level Environmental Engineering Course

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Balancing Individual Learning and Teamwork: A Life Cycle Assessment (LCA) Project for a Sophomore-level Environmental Engineering Course

In the first offering of a sophomore-level environmental engineering project-based course on sustainable waste management, we developed a life cycle assessment (LCA) project related to laboratory waste. The objectives of the project were for students to i) practice life cycle thinking, ii) apply systems thinking to a product life cycle model, iii) apply an iterative model design and analysis approach common in engineering practice, and iv) build teamwork skills. Teams consisted of four students, each of whom constructed their own LCA model of a common laboratory waste stream – paper towels, aluminum foil, pipette tips, and nitrile gloves. We used a jigsaw approach for student teams wherein students were members of a Home Team with a student representing each of the four waste products, and also an Expert Team which consisted of students working on LCA models for the same product. We used the MatterPD LCA software platform by EarthShift Global for the LCA analysis and the CATME platform to track Home Team function. Project deliverables were a mix of individual and Home Team assignments to ensure that every student experienced the full project. Deliverables included an estimate of the mass of each product used in the lab over a year of research (based on measured data) and a process flow diagram for each product; a Goal and Scope statement; draft and final LCA models; and a final poster which included all four LCAs. In their Home Teams, students presented their assessment of the highest impact laboratory waste stream during a live poster session. We used the PitchVantage platform to allow students to practice their poster presentation and to assess students individually on their content knowledge and oral communication skills. The topic of the project (laboratory waste streams) has changed in subsequent offerings while the overall project structure has remained largely the same.

Introduction

This lightning talk paper describes a life cycle assessment (LCA) project developed for a new second-year project-based course, *EENV 202 Sustainable Waste Management*. EENV 202 integrates concepts of sustainability, ethics, regulations, and social impacts with technical content focused on solid waste management. The course is now in its third offering, and the team project described here amalgamates revisions and improvements in project design, delivery, and assessment. The topic of the LCA has changed each semester while the overall project structure has remained the same. Student enrollment in the course has ranged from 30 – 43 students and students work on the project in teams of 3 – 4 students.

An LCA is a systematic analysis of the environmental impacts of a product over its whole life cycle, including raw materials extraction, manufacturing, distribution, use, and final disposal. This knowledge, in turn, allows decision-makers to intervene at the most significant point in the life cycle to improve the sustainability of a product or process.

Project Description

A single, semester-long LCA project was developed with the objectives of having students i) practice life cycle thinking, ii) apply systems thinking to a product life cycle model, iii) apply an iterative model design and analysis approach common in engineering practice, and iv) build teamwork skills. The project asked students to build LCA models of four laboratory waste streams to investigate how researchers on campus could improve the sustainability of our lab work. We chose four common products used in our own laboratory - paper towels, aluminum foil, pipette tips, and nitrile gloves. These products were chosen since they are made from different types of materials and have different manufacturing, use, and disposal pathways. They are also simple enough for students to be able to construct a simple screening-level LCA model while also being complex enough to be interesting.

We used a jigsaw approach for the student project teams. Students were assigned to a four-person Home Team where each team member was responsible for building an LCA model of one of the four lab waste products. Students working on the same product LCA formed separate Expert Teams to provide collaboration and support for the research and inventory analysis phase of the project. Students brought their working models, developed in collaboration with their Expert Teams, back to their Home Team for additional analysis and interpretation (Figure 1). Each team member was responsible for sharing their model with the other members of their Home Team so that all students could learn about all the products' life cycles.

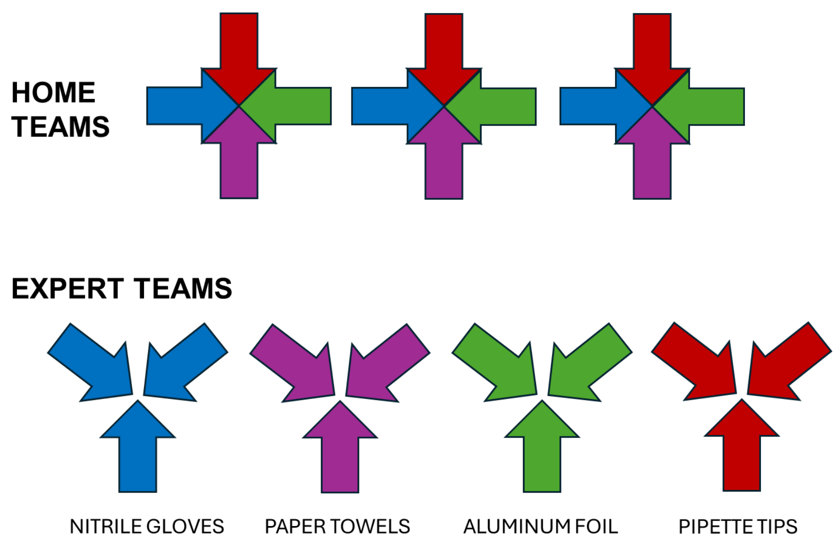


Figure 1. Team structure to be used for EENV 202 LCA project

The intent of this team structure was to ensure that each student had the opportunity to learn and apply LCA methods individually and contribute meaningfully to the team project, while also answering a question bigger than their model alone could address. At the same time, Home Teams with only 3 members were complete teams where nothing was missing from the student learning experience.

In the project, student teams used a software tool by EarthShift Global to build LCA models using the Ecoinvent database. MatterPD is a cloud-based tool which students accessed from their own laptops during in-class work sessions. Licenses for the software were paired with instructor training sessions and technical support during the semester. Moreover, the software developers were able to accommodate the needs of instructors having access to everyone's model while the teams had access only to their own team's models. Students could analyze their single-product

LCA individually or combine all four models into the same analysis to see how the various products compared with each other in terms of environmental impacts.

Project deliverables were a mix of individual and Home Team assignments to ensure that every student experienced the full project. The project deliverables were distributed over the semester so that feedback could be incorporated into subsequent deliverables. As described in Table 1, deliverables included an estimate of the mass of each product used in the lab over a year of research (based on measurements of sampled waste) and a process flow diagram for each product; a Goal and Scope statement; draft and final LCA models; and a final poster which included all four LCAs. We used the PitchVantage platform to allow students to practice their poster presentation and to assess students individually on their content knowledge and oral communication skills. A live public poster session was held in the department hallway during the final exam period and students presented their posters in their Home Teams.

Table 1. LCA Project Deliverables

Deliverable	**Submitted by**	**Time to complete**
PD1 - Mass assessment/process flow diagram	Individual	1 week
PD2 - Goal and Scope	Home Team	2 weeks
PD3 - Draft Model	Individual	4 weeks
PD4 – Revised Model and Analysis	Home Team	7 weeks
Final Poster	Home Team	9 weeks
Recorded Poster Presentation	Individual	9 weeks
Live Poster Presentation	Home Team	9 weeks

Validation

Given the potential complexity of even a simple product LCA, we did not attempt to quantitatively validate results of the student LCA models with respect to environmental impacts. Several factors drove this choice. First, it was impractical under the time constraints of a class project for students to obtain relative certainty about any item's supply chain – where did the virgin pulp originate for the paper towels? Which factory location produced the nitrile gloves we used in the lab? We asked students to research the product and the manufacturer and make reasonable assumptions. These included assumptions related to where component parts were manufactured and how they were transported during manufacturing and distribution. For example, students assumed that imported nitrile gloves were shipped on a cargo ship rather than via air cargo, but did not attempt to confirm this. Second, the inventory items available in the LCA software made some approximations necessary. For example, nitrile wasn't available as a material in the database. Some students used a 'synthetic rubber' entry while others used precursor chemicals. Similarly, the truck transport options available in Ecoinvent generally correspond to European cargo truck specifications rather than US semi-trailers. Finally, our focus was on student understanding of life cycle assessment and the process of performing a complex and iterative analysis with a team. Simplifying assumptions were useful, and necessary, for keeping the project manageable and informative.

We did validate the total mass of product students modeled. We collected, sorted, and weighed waste from our laboratory over two weeks of research. Students used the data to make projections for a year of research in the lab and estimate the total mass of each item to model. We ordered new lab supplies and had students un-pack and weigh the items as-received so that they could include appropriate masses of product packaging in their LCA analysis. We also verified that distances traveled and modes of travel were consistent with students' stated assumptions about where their products were manufactured.

Project Assignment, Deliverables, and Rubrics

This section of the paper contains the key project assignments and rubrics. Assignments included here are 1) the initial Project Description to introduce the project, 2) Partial Deliverable (PD) 1 – the mass assessment worksheet and process flow diagram students completed for their product, 3) PD2 – the team goal and scope statement, 4) PD3 – Base LCA model, 5) PD4 – Revised LCA models and analysis, and 6) Final LCA Poster.

1) Project Description

During _________ , _____________ conducted a laboratory waste audit in their research laboratory. All waste streams produced in the laboratory over two one-week periods were categorized, collected separately, and measured prior to final disposal. These two weeks of data collection represent a busy week of summer research, and an average week during the semester. Based on this waste audit, we have selected four products commonly used in the laboratory to analyze with a life cycle assessment (LCA). These products are paper towels, aluminum foil, pipette tips, and nitrile gloves.

An LCA is a systematic analysis of the environmental impacts of a product over its whole life cycle, including raw materials extraction, manufacturing, distribution, use, and final disposal (Figure 1). In this project, student teams will use a software tool, MatterPD, to build LCA models of the 4 products identified from the laboratory waste audit.

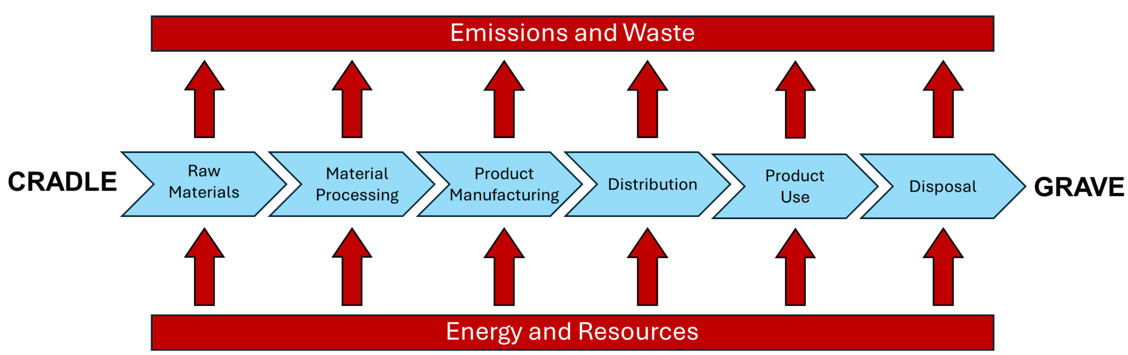


Figure 1. Overview of the scope of life cycle assessment of a product.

LCA involves identifying the relevant environmental interactions associated with a product and using quantitative data to estimate the environmental impacts that occur over the product life cycle. LCA models can provide insight into 1) which phase of the product life cycle produces the most environmental impact, 2) which component of the product produces the most environmental impact, and 3) how various products compare to each other in terms of environmental impact. This knowledge, in turn, allows decision-makers to intervene at the most significant point to improve the sustainability of a product or process.

Project Objectives and Scope

The objectives of this project are for students to

- practice life cycle thinking
- apply systems thinking to a product life cycle model
- apply an iterative model design and analysis approach common in engineering practice
- build teamwork skills

In assigned teams, students will develop Goal and Scope statements to define their LCA, build simplified models of each product using a curated selection of inventory items in the MatterPD database, analyze the product life cycles to assess impacts, and interpret the results of the LCA (Figure 2). Each of these steps is an iterative process wherein students are expected to consult their peers, instructors, and outside resources for guidance.

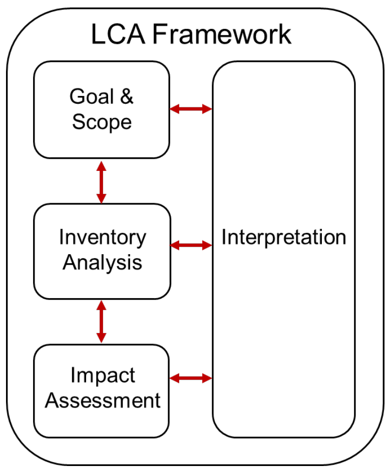


Figure 2. LCA framework showing the major process steps and iterative nature of LCA.

NOTE: Instructors and students should not expect the LCA models and results developed during this course to be "right," especially on the first iteration. It is impossible within the constraints of this course to obtain perfect data and complete, accurate information related to every aspect of our products' life cycles. Rather, the LCA project is intended to teach students about life cycle thinking and environmental impacts; develop skills to make appropriate assumptions and approximations; and apply systematic methods to solve complex problems.

Project Teams

Students have been assigned to a 4-person Home Team where each team member will be responsible for building an LCA model of one of the four lab waste products. Students working on the same product LCA will form separate Expert Teams to provide collaboration and support for the research and inventory analysis phase of the project. Students will bring their working models, developed in collaboration with their Expert Teams, back to their Home Team for additional analysis and interpretation (Figure 3). Each team member will be responsible for sharing their model with the other members of their Home Team so that all students can learn about all the products' life cycles. Project deliverables will be tied to the Home Teams, unless otherwise specified.

{Figure 1 from this paper was included here in the assignment to students showing the Home and Expert Team structure.}

The intent of this team structure is to ensure that each student has the opportunity to learn and apply LCA methods individually and that each student contributes meaningfully to the course project. We reserve the right to assign different grades to individual team members based on their participation and performance on their own part of the team project.

Team function and teamwork skill-building will be assessed using CATME. Peer and self-evaluations will be conducted via CATME at least three times during the semester. These evaluations will be used to determine students' grade for the Teamwork component of the final semester grade (10%).

<u>Project Deliverables and Timeline</u>

Research phase: mass assessment and process flow diagram ________
Goal and Scope phase: written document ________
Life Cycle Inventory phase: preliminary MatterPD model ________
Interpretation and re-assessment phase: final MatterPD model ________
PitchVantage presentation ________
Final poster and presentation ________

Additional information regarding the four products and detailed requirements for the deliverables will be posted on D2L at a later date.

<u>Lab Waste Audit Results</u>
All waste streams produced in the laboratory over two one-week periods were categorized, collected separately, and measured prior to final disposal. These two weeks of data collection represent a busy week of summer research, and an average week during the semester (Table A). The products of specific interest are paper towels, plastic pipette tips, aluminum foil, and nitrile gloves since they represent major components of the waste stream.

Table A. Mass of waste made in the laboratory for the various products

	Busy Week (kg)	Average Week (kg)
Sharps/Glass Box*	2.498	0.177
Aluminum Foil	0.168	0.031
Paper Towels	1.017	0.14
Gloves	1.766	0.22

*We measured the mass of the entire box of plastic and glass waste that must be autoclaved. We can assume that 10-15% of that overall mass comprises pipette tips.

2) PD1: Mass assessment and process flow diagram

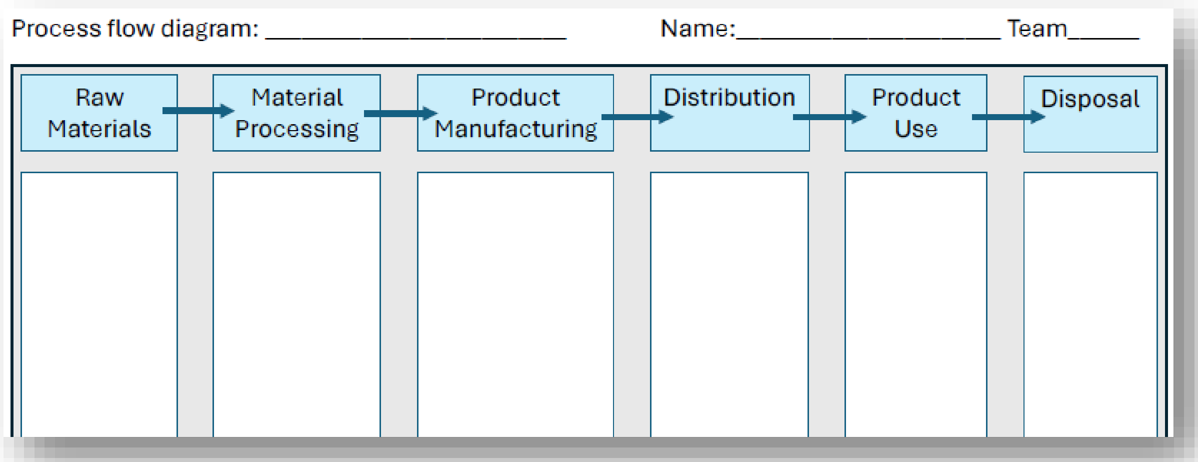
EENV 202 Sustainable Waste Management
Laboratory Waste LCA Project

Mass Assessment Worksheet

Name: ______________________
Expert Team Product: ______________________

Description	Mass	Unit	Total Mass for 1 year
Exterior Packaging			
Full package (product and all packaging)			
master carton (outer packaging, for shipping)			
master carton tape			
Product Packaging			
plastic film wrapping			
kraft paper wrapping			
closed box (product packaging)			
additional packaging			
Product Components			
unit product (i.e. one glove? or one box of gloves?)			
unit used:			
unit count per product package:			
additional product components			

Using the masses above and the data from the laboratory waste audit, estimate the total mass of product used during one year of research. Show your work.



3) PD2: Goal and Scope

Please prepare a written report that includes the components outlined below using section headings to orient and guide readers. Your report should be approximately 1 ½ - 2 pages in length. This information will be refined during the project and will be included on your final project poster.

1. Introduction to Life Cycle Assessment (LCA) and Project Motivation:
    - Provide a brief overview of LCA and LCA methodology.
    - Describe the motivation for conducting this LCA on laboratory waste. (This is a big-picture level statement that tells readers why the stakeholders 'commissioned' this study in the first place.)
2. Goal Definition:
    - Describe the goal of your LCA study on laboratory waste streams. (This should be aimed toward a very specific, well-defined, and achievable question that can be answered by analyzing the particular products your team will model.)
    - Identify the researchers, stakeholders, and audience for the study.
    - Explain how you are going to present your findings.
3. Scope Definition:
    - Define the boundaries of the LCA study, including:
        - The functional unit for the team's comparative assessment and the reference flow for each product
        - System boundaries: identify the stages of the life cycle to be included and identify significant components that have been excluded
    - Identify the sources of information or data that will be used, both primary and secondary and any assumptions/limitations associated with these data sources.
    - Identify the environmental impact categories to be assessed (e.g., greenhouse gas emissions, energy consumption, water usage, etc.).

4) PD3 – Base LCA model

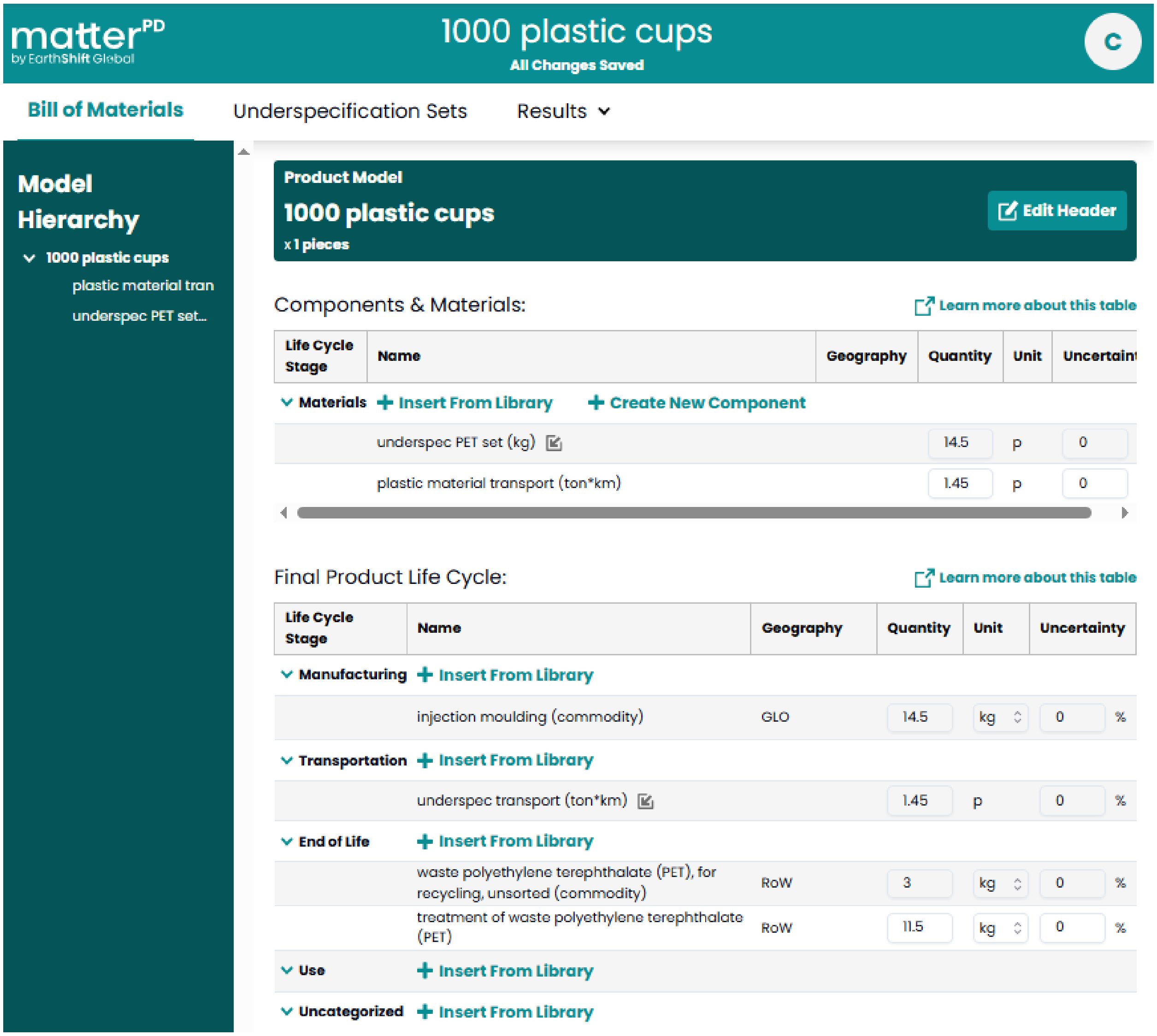
The purpose of this assignment is to allow us to verify your progress and assumptions, identify errors and omissions in your model before they cost you a lot of time or points, and provide feedback for model refinement.

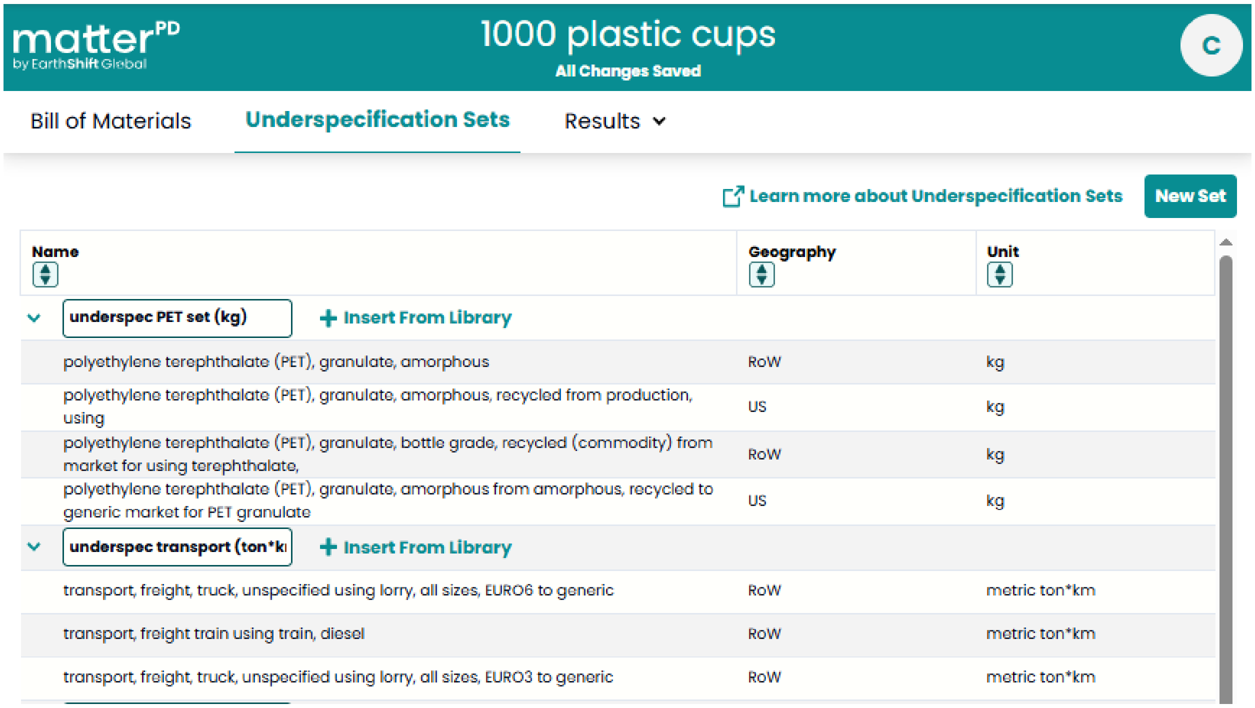
1. Prepare a summary of your initial MatterPD model – your base model – and submit a pdf file. Your report should include:
   a. a title in the form of <u>PD3 Last name Team # Product</u>
   b. a brief outline that includes
      i. your reference flow (i.e one item or one box of the item or a year's worth of the item?);
      ii. any assumptions you have made related to raw materials, processing, factory locations, modes of transport, etc;
      iii. uncertainties that will require some additional research on your part (you should have at least a couple of these); and
      iv. any points of confusion related to using MatterPD from a technical standpoint.
   c. a screenshot (use the Snipping tool) of the Bill of Materials page your model and any Underspecification Sets you have included in your model.
2. Run a Contribution Analysis for your model and export the data. Submit the data as an Excel file (.xlsx). You may increase column widths, add shading/borders, or change font to improve readability but do not modify or plot the data.

The following is an example of what I am looking for, using the 1000 Plastic Cups model as an example.

PD3 _________ Team # plastic cups

i. My reference flow is 1000 plastic cups.
ii. I am assuming that the PET plastic is produced in Country A and shipped via truck 1,000 km to Country B where the cups are made. Finished cups are transported 1,000 km to _______ via xxxx.
iii. I am uncertain about what fraction of the plastic used in the cups comes from recycled vs virgin PET. I am uncertain about the kind of truck that carries the cups from the factory to ________.
iv. I don't know how to compare my model to my teammates' models. I don't know how to account for the power required to put the cups in the packaging. I am still working on producing figures that show all the main impact categories on one graph (*for example*).


matter PD
by EarthShift Global
1000 plastic cups
All Changes Saved
C
Bill of Materials
Underspecification Sets
Results
Model Hierarchy
1000 plastic cups
plastic material tran
underspec PET set...
Product Model
1000 plastic cups
x 1 pieces
Edit Header
Components & Materials:
Learn more about this table
Life Cycle Stage
Name
Geography
Quantity
Unit
Uncertaint
Materials
Insert From Library
Create New Component
underspec PET set (kg)
14.5
p
0
plastic material transport (ton*km)
1.45
p
0
Final Product Life Cycle:
Learn more about this table
Life Cycle Stage
Name
Geography
Quantity
Unit
Uncertainty
Manufacturing
Insert From Library
injection moulding (commodity)
GLO
14.5
kg
0
%
Transportation
Insert From Library
underspec transport (ton*km)
1.45
p
0
%
End of Life
Insert From Library
waste polyethylene terephthalate (PET), for recycling, unsorted (commodity)
RoW
3
kg
0
%
treatment of waste polyethylene terephthalate (PET)
RoW
11.5
kg
0
%
Use
Insert From Library
Uncategorized
Insert From Library



Calculation Setup Name	1000 plastic cups - Contribution Analysis - results
Calculation Type	Contribution Analysis
Montecarlo Iterations	100

Items Calculated

1000 plastic cups
Complete-Product Processing
Use
Uncategorized
Manufacturing
market for injection moulding | GLO
Transportation
underspec transport (ton*km)
transport, freight, lorry, all sizes, EURO6 to generic market for transport, freight, lorry, unspecified | RoW
transport, freight train, diesel | RoW
transport, freight, lorry, all sizes, EURO3 to generic market for transport, freight, lorry, unspecified | RoW
End of Life
treatment of waste polyethylene terephthalate, sanitary landfill | RoW
market for waste polyethylene terephthalate, for recycling, unsorted | RoW
Parts & subassemblies
plastic material transport (ton*km)
transport, freight, lorry, all sizes, EURO3 to generic market for transport, freight, lorry, unspecified | RoW
underspec PET set (kg)
polyethylene terephthalate production, granulate, amorphous | RoW
polyethylene terephthalate production, granulate, amorphous, recycled | US
market for polyethylene terephthalate, granulate, bottle grade, recycled | RoW
polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | US

Impact Categories

Impact Assessment Method	Impact Assessment Category	Impact Assessment Category Detail
ReCiPe 2016 v1.03, endpoint (H)	total: human health	human health
ReCiPe 2016 v1.03, endpoint (H)	total: ecosystem quality	ecosystem quality
ReCiPe 2016 v1.03, endpoint (H)	total: natural resources	natural resources
IPCC 2021	climate change	global warming potential (GWP100)
Cumulative Energy Demand (CED)	total	energy content (HHV)
ReCiPe 2016 v1.03, midpoint (H)	water use	water consumption potential (WCP)

Component Name	Impact Assessment Method	Impact Assessment Category	Impact Assessment Category Detail	Mean	Median	ndard Deviat	Q,025	Q,25	Q,75	Q,975
1000 plastic cups	Cumulative Energy Demand (CED)	total	energy content (HHV)	802.2448	627.933	382.04437	493.5494	568.9348	752.822	1761.626
1000 plastic cups	IPCC 2021	climate change	global warming potential (GWP100)	43.13341	37.65552	12.0279961	31.49312	35.39041	44.7982	70.47996
1000 plastic cups	ReCiPe 2016 v1.03, endpoint (H)	total: ecosystem quality	ecosystem quality	1.97E-07	1.78E-07	4.7306E-08	1.51E-07	1.64E-07	2.11E-07	3.05E-07
1000 plastic cups	ReCiPe 2016 v1.03, endpoint (H)	total: human health	human health	0.000142	0.000118	0.00059718	-0.00109	-0.00021	0.000467	0.001318
1000 plastic cups	ReCiPe 2016 v1.03, endpoint (H)	total: natural resources	natural resources	4.550826	3.017311	3.02905462	2.350717	2.742939	3.841978	11.81046
1000 plastic cups	ReCiPe 2016 v1.03, midpoint (H)	water use	water consumption potential (WCP)	0.352165	0.264621	0.17854009	0.225833	0.244081	0.309204	0.773456

5) PD4 – Revised LCA models and analysis

The purpose of this assignment is 1) to provide an opportunity for feedback and support as your team begins to compare the 3-4 independent LCA models in your overall project and 2) to help you communicate your LCA models and sustainability suggestions on your final team poster.

1. a title in the form of PD4 Team #
2. a summary table of the form:

Product	LCA reference flow unit	1-yr product mass (kg)	1-yr total mass w/ packaging (kg)
Aluminum foil			
Pipette tips			
Nitrile gloves			
Paper towels			

3. a paragraph explaining how you intend to present your model assumptions on your poster. The major assumptions to address here are related to where the various components of each product come from, where the manufacturing occurs, and how the materials/products are transported from place to place.
4. a paragraph presenting your initial assessment of what impact, and by what product, you would like to target to improve sustainability of research in the laboratory. Include some brainstorming ideas about potential suggestions or other analyses you could run in the models to test your ideas.
5. the refined BOM (bill of materials) for each of your team members' models, including corrections from PD3, model refinements, and additional use-phase impacts, like autoclaving, if applicable.
6. a snip/screenshot of the Overall Comparison analysis figure showing the comparison of all the LCA models
7. a snip/screenshot of the Multi-Indicator Comparison analysis figure that includes all the team's models

6) Final LCA poster

The purpose of this assignment is to provide your team an opportunity to 1) document your LCA models and analysis through effective visual and oral communication for a general audience and 2) demonstrate your skills in life cycle thinking, systems thinking, and teamwork.

1. Your team's poster should be approximately 4' x 3' (horizontal). Use the standard template dimensions provided on D2L (PowerPoint slide).
2. Your team's poster should take the form of a scientific/academic research poster.
3. Your team's poster must include:
   - descriptive title and all co-authors
   - goal and scope of your LCA
   - LCA methods – data sources, software, inventory database, and impact categories
   - functional unit and reference flows
   - assumptions and uncertainties
   - impact graphs – contribution analysis, overall comparison, and multi-indicator comparison
   - images – photos, maps, etc.
   - discussion/interpretation of impacts
   - recommendation for laboratory sustainability

4. Submit your poster as a .pdf file. You are not responsible for printing your poster.

Rubrics for the LCA models were made available to students prior to assignments to set clear expectations. The following rubric was used to evaluate PD4, the revised MatterPD model and LCA analysis. A similar rubric was used for PD3, the draft model. Also included in this section is the rubric used for the live team poster presentation.

Competency	4 – Exceeds Expectations	3 – Meets Expectations	2 – Below Expectations	1 - Unsatisfactory	Rating
Completion (12 points)	All required components of the assignment are present, thoughtfully completed, and free of errors and inconsistencies (12 points)	All required components of the assignment are present and contain only minor errors or inconsistencies (11 points)	A required component of the assignment is missing, contains meaningful errors or inconsistencies, or lacks sufficient detail to provide feedback (10 points)	The assignment is incomplete, error-ridden, or provides little opportunity to provide substantive feedback (5 points)	
Overall Feedback:					
Text (3 points)	Text thoroughly describes how to communicate assumptions on the poster and thoughtfully addresses feasible preliminary sustainability suggestion(s) given the team's combined LCA (3 points)	Text addresses how to communicate assumptions on the poster and offers preliminary sustainability suggestion(s) given the team's combined LCA (2.5 points)	Text addresses required points in a cursory manner, offers unreasonable sustainability suggestion(s), and/or lacks sufficient detail to provide feedback (1.5 point)	Text fails to address required points and/or provides little opportunity to provide substantive feedback (0 points)	
Text Feedback:					
Competency	**4 – Exceeds Expectations**	**3 – Meets Expectations**	**2 – Below Expectations**	**1 - Unsatisfactory**	**Rating**

BOMs (3 points)	Masses and distances are accurate and consistent with assumptions; all necessary components are included in the model using appropriate inventory items; and the structure of the components and life cycle are properly constructed (3 points)	Masses and distances are in the right ballpark and are generally consistent with assumptions; major components are included in the model and generally appropriate inventory items are modeled; and the structure of the components and life cycle are well-constructed in general (2.5 points)	There are several/minor errors in masses and/or distances based on stated assumptions; major components are missing from the model or are inappropriately modeled; and/or the structure of the components and life cycle contain inaccuracies that influence the results (1.5 point)	There are significant errors and omissions in the model such that there is little opportunity to provide substantive feedback (0 points)	
BOMs Feedback:					
Figures (2 points)	Figures are clearly legible and present reasonable results to guide/support sustainability suggestion(s) (2 points)	Figures are legible and present results that are generally consistent with sustainability suggestion(s) (1 point)	Figures are not legible and/or present results that are unreasonable or inconsistent with the sustainability suggestion(s) (0.5 points)	Figures are rife with error and/or provide little opportunity to provide substantive feedback (0 points)	
Bar Chart Feedback:					
Total Score /20					

EENV 202 Sustainable Waste Management
Grading Rubric for Poster Session

Team # __________ **Members** ____

(1=strongly <u>dis</u>agree; 3=neutral; 5=strongly agree).

Appearance (25%)	**5 is strong agreement**
1. Poster is well organized, attractive, and easy to follow.	1 2 3 4 5
2. Words are easy to read from an appropriate distance (3-5 ft).	1 2 3 4 5
3. Graphics and other visuals enhance presentation.	1 2 3 4 5
4. Fonts on graphics are easy to read from an appropriate distance (3-5 ft).	1 2 3 4 5
5. The poster is free of spelling errors and other distracting formatting errors.	1 2 3 4 5
Appearance Score (/25)	
Content (50%)	
6. The poster contains all the required elements (title and authors, goal and scope, methods, functional unit and reference flows, assumptions and uncertainties, figures and images, discussion and recommendations).	1 2 3 4 5
7. The goal and scope of the project is clearly outlined and is appropriate for the class context.	1 2 3 4 5
8. Key assumptions are identified for each product, and these assumptions are reasonable in context.	1 2 3 4 5
9. There is enough detail about methods to understand the results, and the description of LCA is accurate.	1 2 3 4 5
10. Poster contains a thoughtful and accurate discussion of uncertainties associated with the LCA.	1 2 3 4 5
11. Poster contains impact graphs that include each product modeled.	1 2 3 4 5
12. Poster contains two impact graphs comparing all the products (overall and multi-indicator comparison).	1 2 3 4 5
13. The impact graphs are reasonably accurate given LCA model limitations and uncertainties.	1 2 3 4 5
14. Conclusions and recommendations are stated clearly on the poster.	1 2 3 4 5
15. Conclusions and recommendations are supported by results and are reasonable given the class context.	1 2 3 4 5
Content Score (/50)	

16. Presenter(s) explained the goal and scope of the project clearly.	1 2 3 4 5
17. Presenter(s) clearly explained assumptions and uncertainty in the context of LCA and their products.	1 2 3 4 5
18. Presenter(s) identified major impacts and accurately explained the meaning of the impact categories.	1 2 3 4 5
19. Presenters' responses to questions demonstrated knowledge of LCA and the products studied.	1 2 3 4 5
20. Presenters could clearly explain and support their team's recommendation to improve sustainability at MSU.	1 2 3 4 5
Presentation Score (/25)	

Comments

Lessons Learned for Future Offerings

We observed that students tended to focus on finding the "right" product or process in the software database and placed less emphasis on understanding the impact categories and interpreting the LCA results. Future offerings could include an assignment or additional discussion around sensitivity analysis that demonstrates to the students how some choices of the product/process did not make much of a difference in the ultimate LCA results. We also recommend focused discussion related to the impact category metrics and units. Many students compared the numerical values calculated by the software across disparate metrics. For example, the cumulative energy demand (in units of MJ) will always produce a higher numerical value than the human health impact (in units of DALY, or disability adjusted life years) but that doesn't necessarily mean that the energy demand is a more important or meaningful impact than decreased healthspan. This sounds self-evident after the explanation but can easily get lost in students' experience of the complexity of this project.