ME 499
Sustainable Engineering and Design

ON CAMPUS EDITION
Fall 2014
3:30-5:00pm Monday and Wednesday
1311 EECS

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Director of Sustainability Education Programs, College of Engineering

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Syllabus

Course Mission
ME 499 offers students the ability to understand the economic, environmental and social aspects of sustainability as they pertain to engineering design, as well as the ability to speak professionally about environmental and sustainability issues. Students also leave the class with the ability to perform streamlined life cycle assessments, carbon/water/energy footprints, economic assessments, and mass and energy balances.

Learning Objectives
ME 499 provides the fundamental tools and concepts of sustainable engineering, permitting students to analyze engineering projects from the perspective of the “triple bottom line”. The “triple bottom line” emphasizes social and environmental factors in addition to economic factors (the single “bottom line”). The course covers engineering decision-making, air and water pollutants, modeling of environmental pollutant concentrations, engineering economics, social considerations, pollution prevention, resource conservation, environmental life cycle assessment, human and eco-toxicity, life cycle costing, and energy systems. These concepts are applied in case studies covering the design of systems that minimize environmental impact considering local, regional, and global scales.

Why is ME 499 an important course for engineers?
The world will change dramatically during the careers of engineers due to ecological constraints placed on the economic development of a large and growing human population. Already today, if everyone in the world lived at the U.S. standard of living, it would require roughly 6 Earths of resources. At current rates of population growth, we would require a new Earth’s worth of resources every 10-20 years to sustain today’s consumption rates. We exceeded the capacity for Earth to renewably support all humans living at a U.S. standard during the 1980s, which is before most of today’s undergraduates were born. Continuing down an economic growth path in ignorance of social and environmental constraints will lead to severe consequences, and as a result engineers of the future will need to become comfortable making technology decisions considering economic, environmental, and social dimensions simultaneously. ME 499 is meant to prepare students to make future engineering decisions from the perspective of the triple bottom line.

Course Outcomes
After this course, a student should be comfortable:

- Performing basic mass and energy balances to calculate resource consumption and emissions associated with engineering decisions;
- Explaining and applying quantifiable metrics of environmental impact from pollutant emissions at local, regional, and global scales;
- Quantifying energy efficiencies and emissions for mobile and stationary energy conversion systems, as well as buildings;
- Applying life cycle assessment and related footprint analyses for a material, product, process, or engineered system within an engineering decision-making context;
- Performing net present value and life cycle cost estimates among different design options using basic engineering economic principles;
• Identifying the trade-offs among social, economic, and environmental drivers in engineering decision making;
• Apply a process to determine whether a policy or technology goal is likely to be successful after considering environmental, economic, and social perspectives.

Course Logistics
ME 499 has:
• Two parts:
  o A “bootcamp” on Sustainable Engineering Fundamentals
  o Case Studies that apply the fundamentals
• Two exams (one at the mid-point of the class and the other during the final exam time)
• A term project on streamlined life cycle assessment
• A requirement to bring a nametent to each class: [click here for a template]

“Bootcamp” (20 lectures):
Students tour the major topics of sustainability engineering including: footprinting, population growth, millennium development goals, life cycle assessment, air resources, water resources, toxicity and risk, energy resources, global warming, and sustainability economics. These are often presented in the context of short case studies. Although the course is largely quantitative, deep understanding of sustainability requires awareness of qualitative and descriptive topics. As a result, most topics start with an introduction where students will watch 20-60 minutes of video before class and take a short quiz on the topic. The quizzes are due on the day indicated in the schedule above (and also noted in the class schedule below).

Whenever a pre-class video assignment is made, the first 20 minutes of the in-class session will be dedicated to student questions and class discussion. Five students will be called upon at random to ask a question in rapid succession without discussion. After all five students ask their questions, other students in class who were not called upon will ask questions that are motivated by the questions they heard. Students who are absent or who pass on the opportunity to ask a question will lose engagement points. Students who ask questions and participate in discussion will gain engagement points but students who dominate (e.g., participate more than three times per class (we have a big class!) for more than ten class periods will lose engagement points. Domination in the class will result in negative participation points for the day. Scoring well on the pre-class questions will also help the engagement score. Generally participation points are given for asking good questions, providing helpful comments, and contributing to discussion in a positive spirit.

Course engagement scores will be calculated as:

\[
= 0.4 \times (\text{% of pre-class quiz correct answers}) + 0.3 \times (\text{% of 7 useful contributions to class}) + 0.3 \times (\text{% determined by instructor and GSI discretion})
\]

Please be natural in your participation. It isn’t hard to make 7 useful contributions to class over 25 sessions; particularly given how much time we have allocated to discussion. Overly dominating any class session inappropriately will lead to a deduction in this score.
Lectures are recorded (available on CTools) for reference, convenience, and those who miss class. Please do not make a habit of missing class in favor of watching the in-class video sessions after they have occurred. This will not only impact your engagement score, it wrecks the class for students who want to gain from discussion. We had this experience in W14 and do not want a repeat.

**ME 499 has a coursepack:**
A coursepack is available for supplemental reading on technical concepts. This coursepack contains a few worked out examples that are not covered in class and is worth having for the course. It can be obtained from Dollar Bill Copying in electronic form, print form, or both.

Available for pick-up at 611 Church Street, Ann Arbor, 48104 / 734-665-9200
Call ahead or buy it on-line. Quantities will likely be short at the beginning of the term.

**During Case Studies (last five lectures):**
Students read a case study prior to class. Then we will look at a policy or technology approach (e.g., expanding fracking or biofuels, banning incandescent bulbs, etc.) and consider stakeholder dimensions as we consider the social dimensions of sustainability and hone our decision-making skills in sustainability. Small in-class groups will be assigned some calculations that will add to the fact base that will be used to evaluate the policy or technology approach. In this way you will get practice considering the multi-dimensionality of sustainability issues and how to make relevant calculations to establish a “fact-base” from which to determine whether a decision is consistent with the goals of sustainability. Students will be asked to write a short essay regarding their view of the technology decision and it will be evaluated by a different group of students and nominated for extra credit points in addition to grading by the instructors.

**Office Hours (Professor Skerlos):** mailto:skerlos@umich.edu
9-10am Wednesday 3001F EECS Building
8-9pm Thursday Online Office Hours: [Click Here](mailto:skerlos@umich.edu)
Email for an appointment as needed

**Office Hours (Mr. Matt Vedrin):** mailto:vedrin@umich.edu
4-6pm Tuesday 2190 GG Brown Building
9-11am Friday 2190 GG Brown Building
Email for an appointment as needed

**Course Grades**
- Exam 1: 25%
- Exam 2: 25% (taken during final exam period; cumulative)
- Homework Assignments: 20%
- Engagement: 15%
- Term Project: 15%
HOMEWORK POLICY

Students are welcome to discuss problem sets with other students in the class. However, your written work must be your own. You may not discuss problem sets with members of previous classes, make use of solutions prepared in previous semesters, or transfer your work to future students of the class (directly or indirectly). This will be treated as a violation of the honor code and forwarded to the appropriate investigative body in the college.

Problem sets will be due one week after being assigned unless otherwise informed. Assignments should be submitted electronically. Scan and save your problem sets in PDF format and upload them on CTools under the Assignments section. Assignments will be accepted until 5:00 PM (Eastern Time) on the day they are due (usually Sunday) before they are considered late. Problem sets will be accepted up to a day late (by 5:00 PM the next day) with a 20% penalty. Graded problem sets will generally be returned within a week following their due date. These will be made available to students along with the grades on CTools under Gradebook section. Solutions to problem sets will be shared as soon as possible.

All problem sets should follow the guidelines below. You will find that the items listed below constitute a rational approach for completing any engineering assignment, both in school as well as on the job.

- Present your work clearly (If the grader cannot understand it, you will not get credit.)
- Use 8½” x 11” paper.
- Write legibly. Use a word processor if writing more than several sentences.
- Cite any sources that you use.
- Do not cram your work into unnecessarily small spaces.
- Include your name, the date and a title at the top of the first page (e.g., John Doe, 9/22/14, ME 499 Problem Set #1).
- Present problems in order.
- If appropriate, draw a picture or schematic and label important components.
- Write down assumptions.
- Show work.
- If a graph or spreadsheet calculations are required, demonstrate how you did your work.
- Use scientific notation if appropriate.
- Show units at the conclusion of each major step. Answer should include proper units.
- Indicate answer by underlining or circling or by some other means.
- Staple sheets together.
- Hand in on time.

Regrades: If you feel that the grader has made a mistake grading a homework assignment or exam, please print the assignment in question from the CTools site, return it to the GSI and explain why you believe you deserve more points. Re-grades must be submitted within three weeks of the assignment first being handed back and re-grading will occur for all problems on the re-submitted assignment. It is the student’s responsibility to pick up his or her assignments and exams in a timely fashion; this deadline will only be extended in cases of excused absences.
In-Class Professionalism and Class Norms
Computers/tablets encouraged in-class to review course notes and problem data in place of paper. As much material will be provided before class and you can reference this material during class as needed to facilitate your learning. Social media, email, and entertainment uses of computers/tablets/phones are not welcome in the classroom. Engagement points will be lost for students using electronics for non-class purposes in-class.

Attendance Policy: Attendance is expected at each lecture listed on the syllabus. Lecture will begin at 3:40pm, and entry after this time is discouraged as a courtesy to your classmates and lecturers. Consistently entering class late or leaving class early is irritating to everyone; so please refrain from this habit.

While we do have a large class, we also expect that you will be engaged fully in the lectures.

Email Policy: If you have a question or concern, please feel free to email the appropriate professor or the GSI. We may not be able to get back to you right away, but we will respond within 24 hours. Please begin the subject line with “ME 499” followed by the subject of your email.
# Overview of Sustainability Engineering and ME 499

## 1.1 Sustainability: The Economic, Environmental, Social & Technology Challenge (25 Minutes)

https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S1.1%20-%20Sustainability%20Challenges.pptx

## 1.2 Sustainable Development, Engineering, and Design (25 Minutes)

https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S1.2%20-%20Sustainable%20Development%2C%20Engineering%2C%20and%20Design.pptx

## 1.3 ME 499 Syllabus (30 Minutes)

# Ecological Footprint, Population Growth, and Social Responsibility

### Preclass Assignment (Due Sep 8)

#### 2.1 Millennium Development Goals Overview, and Goals 1, 2, 7 (20 Minutes)

http://www.youtube.com/watch?v=4pi9uVhK2UE
http://www.youtube.com/watch?v=hTKyAjyuus
http://www.youtube.com/watch?v=hNBvtM1hmzQ
http://www.youtube.com/watch?v=lx-1XFQDiUU

Quiz

#### 2.2 Moral Capitalism (20 Minutes)

http://www.youtube.com/watch?v=qavl0KQ7f_0 (first 20 minutes)

Quiz

#### 2.3 Corporate Social Responsibility (5 Minutes)

http://www.youtube.com/watch?v=njef36Rhr_g

Quiz

Ecological Footprint, Population Growth, and Social Responsibility (Sep 8)

#### 2.4 Questions Regarding Modules 2.1-2.3 (20 Minutes)
2.5 **ECOLOGICAL FOOTPRINTS (20 MINUTES)**
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S2.5%20-%20Ecological%20Footprints.pptx

2.6 **MATHEMATICS OF GROWTH (20 MINUTES)**
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S2.6%20-%20Mathematics%20of%20Growth.pptx

2.7 **IPAT EQUATION, POPULATION GROWTH AND DISAGGREGATED GROWTH RATES (20 MINUTES)**
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S2.7%20-%20IPAT%20and%20Disaggregated%20Growth.pptx

Reading
Masters Pages 87-94 (Pages 3-7 of Coursepack)

# 3 LIFE CYCLE ASSESSMENT

Pre-Day 1 Assignment (Due Sep 10)

3.1 **EXAMPLES OF LIFE CYCLE ASSESSMENT IN DESIGN (15 MINUTES)**
http://www.youtube.com/watch?v=4pi9uVhK2UE
Quiz

3.2 **TRAPS, TRADE-OFFS AND TRIUMPHS (27 MINUTES)**
http://youtu.be/ad0eqLJ0u0M (Minutes 20-47 on YouTube video!)
Quiz

Pre-Day 3 Assignment (Due Sep 17)

3.3 **SUNCHIPS BAG & LiDS WHEEL STEPS 1 & 2 (20 MINUTES)**
http://www.youtube.com/watch?v=7CJNRL14g
http://www.youtube.com/watch?v=mlx5NHl8sPw
http://www.youtube.com/watch?v=onS_lMHwI-w&list=PLD06E6A3AD6590D9A
Quiz

3.4 **LiDS WHEEL STEPS 3, 4, 5 (20 MINUTES)**
http://www.youtube.com/watch?v=XwFrjv3qmVE
http://www.youtube.com/watch?v=zVGUOf4Vx8A
http://www.youtube.com/watch?v=ROakkB5GBRI
Quiz
3.5 **LiDS Wheel Steps 6-8 and FlipFlops Case Study (20 Minutes)**

http://www.youtube.com/watch?v=JfCuY6NVWKU
http://www.youtube.com/watch?v=1iSa2Hdp0Js
http://www.youtube.com/watch?v=6fRxwWY0jOk&list=PLD06E6A3AD6590D9A&index=10&featur e=plpp_video

Quiz

**Life Cycle Assessment: Day 1 (Sep 10)**

3.6 **Student Questions Regarding Modules 3.1-3.2 (20 Minutes)**

3.7 **What are Life Cycle Assessment, Life Cycle Thinking, and Sustainable Design (20 Minutes)**

https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S3.7%20-%20What%20is%20LCA%20-%20LCT%20-%20SD.pptx

3.8 **Steps of an LCA and Definitions (40 Minutes)**

https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S3.8%20-%20LCA%20Steps%20and%20Definitions.pptx

**Life Cycle Assessment: Day 2 (Sep 15)**

3.9 **Life Cycle Assessment: Refrigerator Example (40 Minutes)**

https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S3.9%20-%20Refrigerator%20Example%20of%20LCA.pptx

3.10 **Eco-Audit vs. LCA: Concepts and Bottle Example (20 Minutes)**

https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S3.10%20-%20Eco-Audit%20vs%20LCA%20Concepts.pptx

3.11 **Eco-Audit Example: Electric Kettle, Space Heater, Auto Bumper (20 Minutes)**

https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S3.11%20-%20Eco-Audit%20Examples%20-%20Electric%20Kettle%20Space%20Heater%20Auto%20Bumpers.pptx

**Life Cycle Assessment + Term Project Release: Day 3 (Sep 17)**

3.12 **Student Questions Regarding LiDS Wheel (10 Minutes)**

3.13 **Live Example of Eco-Audit: Coffee Maker and Improvement (50 Minutes)**

https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S3.13%20-%20Eco-Audit%20Live%20Example%20Coffee%20Maker.pptx
3.14 Term Project Release and Discussion (20 Minutes)

Reading

Ashby Pages 129-158 (Pages 9-24)

4 Material Resources and Sustainability

Pre-class Assignment (Due Sep 22)

4.1 Materials Production Examples and Issues (25 Minutes)
http://youtu.be/nSG6cyXWmYs
http://www.youtube.com/watch?v=fU_XNXOVC6g
http://www.youtube.com/watch?v=aF-slgcoY20
http://www.youtube.com/watch?v=HjNv iTsXn8
http://www.youtube.com/watch?v=P_EoUAVFJSY

Quiz

Material Resources and Sustainability (Sep 22)

4.2 Student Questions Regarding Module 4.1 (20 Minutes)

4.3 Resource Consumption: Exponential Model (20 Minutes)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S4.3%20-%20Exponential%20Model.pptx

4.4 Resource Consumption: Gaussian Model (20 Minutes)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S4.4%20-%20Gaussian%20Model.pptx

4.5 Mass Balances, Recycling, and Product Lifetimes (20 Minutes)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S4.5%20-%20Mass%20Balances%2C%20Recycling%2C%20Product%20Lifetimes.pptx

Reading

Masters Pages 95-120 (Coursepack Pages 25-38)
5 AIR RESOURCES AND SUSTAINABILITY

Pre-Class Assignment (Due Sep 24)

5.1 WHAT ARE THE AIR POLLUTANTS? (20 MINUTES)
http://www.youtube.com/watch?v=Hx_yWFQyJT4
http://www.youtube.com/watch?v=UtdKRvWC1yQ
Quiz

5.2 SMOG IN LOS ANGELES AND BEIJING (10 MINUTES)
http://www.youtube.com/watch?v=MOQjK3LWoK8
http://www.youtube.com/watch?v=oOk5G5vd2lw
Quiz

5.3 ACID RAIN AND OZONE DEPLETION (15 MINUTES)
http://www.youtube.com/watch?v=Nc6j7zz1_do
http://www.youtube.com/watch?v=MqHw1hMEkAQ
http://www.youtube.com/watch?v=PXV6ppONgUk
http://www.youtube.com/watch?v=qUFVMoglDr8
Quiz

Air Resources: Day 1 (Sep 24)

5.4 STUDENT QUESTIONS REGARDING MODULES 5.1-5.3 (15 MINUTES)

5.5 CONCENTRATIONS VS. EMISSIONS AND HAZARDOUS VS. CRITERIA AIR POLLUTANTS (25 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S5.5%20-%20Concentrations-Emissions-CAPs-HAPs.pptx

5.6 SMOG, OZONE, AND NO2 PHOTOLYTIC CYCLE (25 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S5.6%20-%20Smog%2C%20Ozone%20and%20NO2%20Photolytic%20Cycle.pptx

5.7 OZONE CONTROL STRATEGIES (15 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S5.7%20-%20Ozone%20Control%20Strategies.pptx
Air Resources: Day 2 (Sep 29)

5.8 Atmospheric Mixing and the Gaussian Plume Equation (35 Minutes)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S5.8%20-%20Atmospheric%20Mixing%20and%20Gaussian%20Plume%20Equation.pptx

5.9 Applications of Gaussian Plume Equation to Power Plant Emissions (25 Minutes)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S5.9%20-%20Application%20of%20Gaussian%20Plume%20Equation%20to%20Power%20Plant%20Emissions.pptx

5.10 Modeling Concentrations under Atmospheric Inversion (15 Minutes)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S5.10%20-%20Modeling%20Concentrations%20under%20Atmospheric%20Inversion.pptx

Air Resources: Day 3 (Oct 1)

5.11 Introduction to Airshed Box Models & Mass Balances (25 Minutes)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S5.11%20-%20Box%20Models%20of%20Airshed.pptx

5.12 Example of NOx Concentrations Created by Electric vs. Conventional Vehicles (30 Minutes)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S5.12%20-%20NOx%20Concentrations%20from%20Electric%20vs.%20Gasoline%20Vehicles%20Example.pptx

5.13 High Level Summary and Reflection of Air Pollutants (15 Minutes)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S5.13%20-%20High%20Level%20Summary%20and%20Reflection.pptx

Reading

Masters Pages: 367-401; 450-471 (Coursepack Pages 39-67)
6  WATER RESOURCES AND SUSTAINABILITY

Pre-Class Assignment (Due Oct 6)

6.1 WHAT ARE THE WATER POLLUTANTS? (20 MINUTES)
http://www.youtube.com/watch?v=obAuwp-MV08
Accompanying PPT Slides are here:
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Supplemental%20Resources/S7%20-%20Water%20Resources%20Pre-Class.pptx
Quiz

6.2 NITROGEN & THE WATER ENERGY NEXUS (20 MINUTES)
http://www.youtube.com/watch?v=uuwn6qxM7BU
http://www.youtube.com/watch?v=DnhuJk41fEE
Quiz

Water Resources: Day 1 (Oct 6)

6.3 STUDENT QUESTIONS REGARDING MODULES 5.1 & 5.2 (20 MINUTES)

6.4 INTRODUCTION TO WATERSHED BOX MODELS & MASS BALANCES (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.4%20-%20Watershed%20Box%20Models%20and%20Mass%20Balances.pptx

6.5 MODELING CONSERVATIVE & NON-CONSERVATIVE CONCENTRATIONS IN STEADY-STATE (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.5%20-%20Conservative%20vs%20Non-Conservative.pptx

6.6 MODELING CONSERVATIVE POLLUTANT CONCENTRATIONS NOT IN STEADY-STATE (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.6%20-%20Non-Steady-State.pptx

Water Resources: Day 2 (Oct 8)

6.7 EXAMPLE PROBLEMS POLLUTANT CONCENTRATIONS IN NON-STEADY STATE (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.7%20-%20Non-Steady-State%20Examples.pptx

6.8 BIOCHEMICAL OXYGEN DEMAND (BOD) (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.8%20-%20Biochemical%20Oxygen%20Demand.pptx
6.9 EUTROPHICATION AND NUTRIENTS (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.9%20-Eutrophication%20and%20Nutrients.pptx

6.10 ADDITIONAL BOD AND EUTROPHICATION EXAMPLES AND REVIEW OF UNITS
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.10%20-Additional%20BOD%20Examples.pptx

Water Resources: Day 3 (Oct 15)

6.11 REVIEW OF WATER POLLUTANTS AND LAWS (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.11%20-Water%20Pollutants%20and%20Laws.pptx

6.12 WATER FOOTPRINTS AND VIRTUAL WATER (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.12%20-Water%20Footprints%20and%20Virtual%20Water.pptx

6.13 COMPUTING A WATER FOOTPRINT (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.13%20-Computing%20Water%20Footprint.pptx

6.14 NET ZERO WATER HOME IN ANN ARBOR (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S6.14%20-Net%20Zero%20Water%20Home%20in%20Ann%20Arbor.pptx

Reading

Masters Pages: 1-21; 173-227 (Coursepack Pages 69-108)
7  **TOXICITY AND RISK**

Toxicity and Risk: Day 1 (Oct 20)

7.1  **ASSESSING RISK AND DOSE-RESPONSE (15 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S7.1%20-%20Assessing%20Risk%20and%20Dose%20Response.pptx

7.2  **CALCULATING RISK FOR CARCINOGENS (30 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S7.2%20-%20Carcinogens%20Risk.pptx

7.3  **ASSESSING RISK FOR NON-CARCINOGENS (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S7.3%20-%20Non-Carcinogens%20Risk.pptx

7.4  **RISK, CONCENTRATION AND UNITS CONVERSIONS (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S7.4%20-%20Risk%20Concentration%20and%20Units%20Conversions.pptx

Reading

Masters Pages: 127-166 (Coursepack Pages 109-129)

8  **ENERGY RESOURCES AND SUSTAINABILITY**

Pre-class Assignment (Due Oct 29)

8.1  **GLOBAL ENERGY: SUPPLY, DEMAND, CONSEQUENCES, OPPORTUNITIES (1ST 40 MIN. ONLY)**  
http://www.youtube.com/watch?v=oRGnpBngXDU

Quiz

Energy Resources: Day 1 (Oct 29)

8.2  **STUDENT QUESTIONS REGARDING MODULE 8.1 (20 MINUTES)**

8.3  **DIRECT CONVERSION EFFICIENCY (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S8.3%20-%20Direct%20Conversion%20Efficiency.pptx
8.4 **LIFE CYCLE ENERGY (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S8.4%20-%20Life%20Cycle%20Energy.pptx

8.5 **NET ENERGY AND ENERGY RETURN ON INVESTMENT (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S8.5%20-%20Net%20Energy%20and%20Energy%20Return%20on%20Investment.pptx

Energy Resources: Day 2 (Oct 27)

8.6 **THERMODYNAMIC EFFICIENCY AND WATER HEATING (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S8.6%20-%20Thermodynamic%20Efficiency%20and%20Water%20Heating.pptx

8.7 **THERMAL POLLUTION AND POWER PLANT EXAMPLE (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S8.7%20-%20Thermal%20Pollution%20and%20Power%20Plant%20Example.pptx

8.8 **ENERGY SAVING WITH BUILDING INSULATION (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S8.8%20-%20Energy%20Saving%20with%20Building%20Insulation.pptx

8.9 **EARTH ENERGY BALANCE AND INTRODUCTION TO GREENHOUSE GASES (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S8.9%20-%20Earth%20Energy%20Balance%20and%20Introduction%20to%20Greenhouse%20Gases.pptx

**Reading**

Masters Pages: 21-40 (Coursepack Pages 131-141)

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9 **GLOBAL WARMING AND CARBON FOOTPRINTS**

**Pre-class Assignment (Due Nov 3)**

9.1 **JAMES HANSEN’S CAREER STUDYING CLIMATE CHANGE (20 MINUTES)**  
http://www.youtube.com/watch?v=fWlnyaMWBY8

*Quiz*
9.2 **GLOBAL WARMING BASICS (30 MINUTES)**  
http://www.youtube.com/watch?v=i5Jv293oPzQ  
Quiz

Climate Resources and Carbon Footprints: Day 1 (Nov 5)

9.3 **STUDENT QUESTIONS REGARDING MODULES 9.1 & 9.2 (20 MINUTES)**

9.4 **CARBON FOOTPRINT INVENTORY EXAMPLE (40 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S9.4%20-%20Carbon%20Footprint%20Inventory%20Example.pptx

9.5 **CARBON FOOTPRINT INTERPRETATION AND IMPROVEMENT EXAMPLE (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S9.5%20-%20Carbon%20Footprint%20Interpretation%20and%20Improvement%20Example.pptx

Climate Resources and Carbon Footprints: Day 2 (Nov 10)

9.6 **ESTIMATING GREENHOUSE GAS EMISSION IMPACTS ON EARTH TEMPERATURE CHANGE: CONCEPTS (25 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S9.6%20-%20Estimating%20Greenhouse%20Gas%20Emission%20Impacts%20on%20Earth%20Temperature%20Change.pptx

9.7 **GREENHOUSE GAS FORCING AND TEMPERATURE CHANGE EXAMPLE (20 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S9.7%20-%20Greenhouse%20Gas%20Forcing%20and%20Temperature%20Change%20Example.pptx

9.8 **GLOBAL WARMING POTENTIAL (25 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S9.8%20-%20Global%20Warming%20Potential.pptx

9.9 **AVOIDING DANGEROUS ANTHROPOGENIC INTERFERENCE (10 MINUTES)**  
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S9.9%20-%20Avoiding%20Dangerous%20Anthropogenic%20Interference.pptx
Climate Resources and Carbon Footprints: Day 3 (Nov 12)

9.10 REDUCING GHG EMISSIONS FROM FURNACES AND REFRIGERATORS: EXAMPLE (45 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S9.10%20-%20GHG%20Emissions%20from%20Furnaces%20and%20Refrigerators.pptx

9.11 WATER HEATER GHG EMISSIONS EXAMPLE (15 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S9.11%20-%20Water%20Heater%20GHG%20Emissions%20-%20Example.pptx

9.12 GLOBAL WARMING WRAP-UP QUESTIONS AND DISCUSSION (20 MINUTES)

Reading Assignment
Masters Pages: 501-575 (Coursepack Pages 143-180)

10 ECONOMICS AND SUSTAINABILITY

Pre-Day 1 Assignment (Due Nov 17)

10.1 REVIEW OF ECON 101: PART 1 (FIRST 20 MINUTES)
http://youtu.be/1FaHisI-1Ww
Quiz

10.2 REVIEW OF ECON 101: PART 2 (LAST 20 MINUTES)
http://youtu.be/1FaHisI-1Ww
Quiz

Pre-Day 2 Assignment (Due Nov 19)

10.3 TIME VALUE OF MONEY (20 MINUTES)
http://youtu.be/WhfXyDbfqE
Quiz

Economics and Overconsumption: Day 1 (Nov 17)

10.4 STUDENT QUESTIONS REGARDING MODULES 10.1 & 10.2 (20 MINUTES)

10.5 OVERFISHING EXAMPLE (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S10.5%20-%20Overfishing%20Example.pptx
10.6 OVERFISHING IN POLLUTED LAKE EXAMPLE (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S10.6%20-%20Overfishing%20in%20Polluted%20Lake%20Example.pptx

10.7 REGULATORY MECHANISMS TO REDUCE OVERFISHING (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S10.7%20-%20Regulatory%20Mechanisms%20to%20Reduce%20Overfishing.pptx

Finance and Undervaluing the Future: Day 2 (Nov 19)

10.8 STUDENT QUESTIONS REGARDING MODULE 10.3 (20 MINUTES)

10.9 ECONOMIC DECISION MAKING METRICS (40 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S10.9%20-%20Economic%20Decision%20Making%20Metrics.pptx

10.10 LIFE CYCLE COST OF ELECTRIC VS. CONVENTIONAL VEHICLE EXAMPLE (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S10.10%20-%20Life%20Cycle%20Cost%20of%20Electric%20vs.%20Conventional%20Vehicle%20Example.pptx

Finance and Undervaluing the Future: Day 3 (Nov 24)

10.11 EXAMPLE: LED VS. CONVENTIONAL LIGHT BULBS (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S10.11%20-%20LED%20vs.%20Conventional%20Light%20Bulbs%20Example.pptx

10.12 RISK ASSESSMENT AND PAYBACK TIME (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S10.12%20-%20Risk%20Assessment%20and%20Payback%20Time.pptx

10.13 LEVELIZED ANNUAL COST, COST PER UNIT PRODUCT, MARGINAL COST (20 MINUTES)
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/S10.13%20-%20Levelized%20Annual%20Cost%20Per%20Unit%20Product%20Marginal%20Cost%20of%20Pollution%20Control.pptx

10.14 WRAP-UP DISCUSSION ON ECONOMICS AND SUSTAINABILITY (20 MINUTES)

Reading

Titenberg Pages 18-38 & Rubin Pages 545-583 (Coursepack Pages 181-212)
C2 Fracking Case Study

This fracking case study will help students to evaluate different technologies in a triple bottom line (social, economic, and environmental) framework that will allow them to engage in conversations with economists and policymakers. It is a case study involving large uncertainties owing to a lack of experience with the technology as well as poor transparency with respect to fracking operations and chemicals. After participating in Sessions 24 and 25, students will understand the complexities of technology deployment and predicting unintended consequences and externalities.

After participating in this session, students should gain knowledge: Explain the controversy around fracking.

- Have an understanding of the limitations of nature, and the interconnection between environment, society and technology. When evaluating a design project, students can identify a list of stakeholders, interests and potential risks as well as the unintended consequences of the project.
- Understand that there are externalities (such as the cost of healthcare and cost of increasing global warming potential) inherent within the current system that have traditionally been overlooked.

Skills:

- Be able to calculate the net present value and return on investment of a potential project.
- Know how to use the discount rate to factor in the time value of money in economic analyses
- Apply LCA principles to a new engineering context

Dispositions:

- Develop a general idea of the systems thinking framework through this project and are able to utilize the systems thinking approach towards their future engineering projects.
- Recognize the importance of scientific understanding in the policy decision-making process (and vice versa).
- Be able to evaluate and communicate trade-offs between economic interest, social concerns, environmental impact and ethical considerations. Concepts such as social justice and environmental justice can also be introduced to demonstrate the strong connection between ethics and sustainability.

Pre-Class Assignment

1) Watch (20 minutes): [http://www.youtube.com/watch?v=_DD4IGMFsCI](http://www.youtube.com/watch?v=_DD4IGMFsCI)
   i. Slides for 50 minute video are here: [https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-](https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-
In-Class Experience

In Class Slides for Day 1 and Day 2:
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-

da2f678be721/Class%20Sessions/C2%20-%20Fracking%20Case%20Study/C2%20-%20Frackin

g%20Pre-Class%20Slides.pdf

Day 1:
1) Question and Answer about Pre-Class Videos (50 minutes)
2) Quantitative Fracking Problems
   Quiz

Day 2:
1) Engineer’s Approach to Evaluating Policy Mechanisms
2) Fictitious Fracking Case Study
3) Discuss one among potentially several prime objectives: should fracking be banned in
case study?
4) List stakeholders with respect to the prime objective(s)
5) Find facts related to the prime objective(s):
   a. Run relevant analyses on design alternatives related to the prime objective(s).
   b. Quantitative Case Study Problems
6) Integrate the facts
7) Reflect on the facts and draw conclusions regarding the prime objective(s) (class
discussion and extension into homework assignment)

Supplemental Resources

- http://www.energyfromshale.org/
- http://reason.com/archives/2013/03/13/frack-to-the-future
- http://www.marcellus.psu.edu/resources/PDFs/marcellusengelder.pdf
- http://www.mndaily.com/2012/10/15/fracking-won%E2%80%99t-lead-us-energy-golden-age
- http://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm

C3 BIOFUELS CASE STUDY

We will present the Sustainable Design approach and teaching pedagogy used by Granta Design
and Professor Michael Ashby (Cambridge University). We will discuss the methodology and
apply it using an electric vehicle case study so that the class has a good handle regarding not just
what the methodology is but how it gets applied to sustainable design and how we can use it in the classroom for the rest of our case studies this semester. This approach will be applied to the biofuels case study.

Biofuels have a significant potential to reduce the global warming potential of transportation systems. However, not all biofuels are created equal and their ability to reduce GWP is a strong function of local conditions, as well as assumptions made in LCA. This study will investigate the life cycle of biofuels from an energy perspective while also considering some of the social impacts of biofuel use on food prices.

After participating in this session, students should gain knowledge:

- Define the terms biofuels, net energy balance (energy efficiency).
- Understand the major steps involved in the production of biofuels from sugars and biomass, and their environmental impacts.
- Define the term global warming potential, eutrophication potential, land use change, and embodied energy.
- Understand the impacts of biofuels relative to fossil fuels on a volumetric and energy basis.
- Understand the social impact if rise in food prices from biofuel production.
- Understand how to interpret the sensitivity of a conclusion to changes in context.

Gain Skills:

- Calculate net energy use, eutrophication potential and global warming potential from production, transport and use of biofuels.
- Calculate the cost of avoided greenhouse gas emissions in $/ton through government biofuel subsidies.
- Compare corn ethanol, sugarcane ethanol, and biodiesel based on their net energy balance and contribution of greenhouse gases to the environment, including:
  - Where in the life cycle of the product is the most energy used and in what form
  - Where in the life cycle of the product are greenhouse gases emitted or avoided
  - What quantity of greenhouse gases is offset by biofuel use
- Compare corn ethanol and biodiesel based on their contribution to eutrophication from fertilizer runoff into the environment.

Gain Dispositions:

- Broadly consider an entire system along with all of the energy+material inputs and outputs involved to determine the real efficiency of that system. This type of “systems thinking” is of great importance in all technical analyses.
- Appreciate the importance of an LCA in evaluating the impact of a product or practice on the environment.
- To consider the role that scientific input plays in policy decision-making processes. The case stresses that, despite the importance of this input, it is only one of a number of
factors that influence such decisions; it alone generally does not determine the outcome of these processes.

- Appreciate the complexity of the qualitative and quantitative decisions that have to be made to properly analyze and compare technology options, and recognize that other social and political factors may limit the extent to which a favorable option is adopted, even when the benefits are clear.
- Appreciate the importance of context in assessing the favorability of one option over another.

In-Class Experience

In Class Slides: https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/C3%20%20Biofuels%20Case%20Study/Biofuel%20Case%20Study_F14.pptx

1) Discussion of Biofuels Case Study and Hill et al. Paper
2) Discuss prime objectives of biofuel policy articulations.
3) List stakeholders with respect to the prime objective(s)
4) Find facts related to the prime objective(s):
   a. List design alternatives that could meet the prime objective(s)
   b. Run relevant analyses on design alternatives related to the prime objective(s).
      These analyses will include the problems found at the following link:
5) Integrate the facts
6) Reflect on the facts and draw conclusions regarding the prime objective(s) (class discussion and extension into homework assignment)

Quiz

C1 LIGHTING CASE STUDY

We will assess the question of whether incandescent light bulbs should be banned. Our goals are as follows:

Gain Knowledge:

- Define the terms watt, lumen, incandescent, and fluorescent
- Explain how light is generated in incandescent and compact fluorescent lamps
- Explain how the different methods of light generation lead to the relative efficiencies of the two different light sources in lumens per watt
- Describe the basic principles and process of a life cycle assessment (LCA)
- Understand how to interpret the sensitivity of a conclusion to changes in context.
- Explain how carbon-offsets work.
- Explain the difference between a kg of CO2 and a kg of CO2-equivalent.
Gain Skills:

- Calculate the payoff time for the switch to a compact fluorescent lamp (CFL) - (i.e., the time required before the cost savings from operations equals the additional cost of the lamp itself).
- Calculate the cost of avoided greenhouse gas emissions in $/ton both in terms of additional purchase cost and life cycle cost.
- Compare incandescent and CFL based on their contribution of greenhouse gases into the environment, including:
  - Where in the life cycle of the product the greenhouse gases are emitted
  - The amounts of greenhouse that are likely to enter the environment as a result of using each type of lamp.
- Compare incandescent and CFL lights based on their contribution of mercury into the environment, including:
  - Where in the life cycle of the product mercury enters the environment.
  - The amount of mercury that is likely to enter the environment as a result of using each type of bulb.
  - Who would be most at risk from the mercury released by each type of bulb.
- Use quantitative data to draw conclusions and support a position.

Gain Dispositions:

- Appreciate the importance of an LCA in evaluating the impact of a product or practice on the environment.
- Recognize that other (social) factors such as aesthetic preferences or other constraints may limit the extent to which a favorable option is adopted, even when the benefits are clear.
- Appreciate the importance of context in assessing the favorability of one option over another.

Pre-Class Assignment

1) Read how incandescent lightbulbs work:

2) Read how Compact Fluorescent Lightbulbs (CFLs) work:
   [http://science.howstuffworks.com/environmental/green-tech/sustainable/cfl-bulb.htm](http://science.howstuffworks.com/environmental/green-tech/sustainable/cfl-bulb.htm)

3) Read a life cycle assessment on an incandescent vs. CFL lightbulb:
   [https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13ada2f678be721/Class%20Sessions/C1%20-%20Lightbulb%20Case%20Study/S22%20-%20Lightbulb%20LCA.pdf](https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13ada2f678be721/Class%20Sessions/C1%20-%20Lightbulb%20Case%20Study/S22%20-%20Lightbulb%20LCA.pdf)
In-Class Experience

In Class Slides:
https://ctools.umich.edu/access/content/group/77e0ab88-f619-4805-b13a-da2f678be721/Class%20Sessions/C1%20-%20Lightbulb%20Case%20Study/C1%20-%20Lightbulb%20Case%20Study_F14.pptx

1) Discuss one among potentially several prime objectives: should incandescent bulbs be banned? (other prime objectives?)
2) List stakeholders with respect to the prime objective(s)
3) Find facts related to the prime objective(s):
   a. List design alternatives that could meet the prime objective(s)
   b. Run relevant analyses on design alternatives related to the prime objective(s).
4) Integrate the facts
5) Reflect on the facts and draw conclusions regarding the prime objective(s) (class discussion and extension into homework assignment)

Quiz
TERM PROJECT

ME 499 Term Project Fall 2014
Environmental Performance Evaluation Case Study

The objective of this term project is to familiarize students with the process of Eco-Audits, a form of streamlined LCA, and to think critically about environmental issues the Eco-Audit may miss. You are challenged to evaluate multiple different products using the Eco-Audit method, to identify gaps in the method, and to identify eco-improvement design options that would make a notable difference in the environmental performance of these products.

Due with Assignment #3 on October 12

You will select four relatively simple product systems (see examples provided in class) on which you will conduct an Eco-Audit this semester. The four products must have identifiable materials composition, manufacturing methods (at a high level, not at a detailed level), use phase, and end-of-life characteristics. The four products will be different in that one product will have no significant use-phase material/energy/water consumption (e.g., a music stand), one product that has significant energy consumption in the use-phase (e.g., a desk light), one product that has significant material consumption in the use-phase (e.g., diapers), and one product that has significant water consumption in the use-phase (e.g., a water bottle).

In the assignment for each product you will submit:
1. Bill of materials
2. Manufacturing Processes
3. Transportation characteristics
4. Use-Phase characteristics
5. End-of-life characteristics

For the final assignment, you will conduct an Eco-Audit from two situational contexts: Ann Arbor, USA and a developing country in Asia, Africa, or South America. You will also inform us in Assignment #3 what city you will select besides Ann Arbor. While the Eco-Audit may not change much, in your final report you will also comment on the sustainability of all four products from the perspectives of the two locations.

Due with Assignment #8 on December 14

You will revise the mid-term assignment submitted with Assignment #3 as needed; including changing the products under consideration if needed.

Part A: Setup

For each product (using Ann Arbor scenario) you will submit:
1. Bill of materials
2. Manufacturing Processes
3. Transportation characteristics
4. Use-Phase characteristics
5. End-of-life characteristics

Part B: Eco-Audits
For each product you will submit:

1. A plot of energy vs. life cycle stage in the Ann Arbor scenario, for example:

   ![Energy and CO2 Footprint Summary](image)

   2. A plot as above but with life cycle stages plotted against CO2 in the Ann Arbor Scenario.
   3. Repeat #B.1 for the developing city context
   4. Repeat #B.2 for the developing city context

Part C: Synthesis and Sustainability

1. For the Ann Arbor case, plot CO2 emissions for material, manufacture, transport, use, and disposal with all four products shown on the plot (i.e., there should be four bars for each life cycle stage).
2. For each product, list three important non-CO2 (and non-energy) pollutants in the order you believe is a priority for the Ann Arbor scenario AND the developing city scenario. Provide your rationale using concepts learned in the class.
3. For each product, evaluate the economic and social characteristics as they relate to the contexts of your two cities. What are the economic and social challenges associated with these products?
4. For each product, list the top two issues (across the dimensions of economic, environment, social, and functional) in the Ann Arbor and developing city contexts. Identify which of the two issues is more important.
5. For each product, propose one design change targeted for Ann Arbor and one design change targeted for the developing city. The design changes should address the most important issue identified in #C.4 above. Discuss the implications of the design change on the product functionality and on its life cycle cost.