SCI 1410: materials science & solid state chemistry

EXAM THREE.

INTRODUCTION

Instructions: This is a **team-based** exam. I'll assess these exam questions and count the scores toward your quantitative and qualitative analysis competency grade. You may work on this as much as you like, and start whenever you like. Submit one exam per team to me via email (stolk@olin.edu) no later than **11:59 pm on Saturday, February 14.** Spend your Valentine's Day with materials science analysis! Can you feel the love?

ENVIRONMENTAL & SOCIETAL IMPACTS

This week, your team has an opportunity to spend some time gathering and analyzing data on the broader impacts of the material(s) in your product. There are many ways to approach this exam, but I'd like each project team to do two things: (a) impact(s) **analysis**, and (b) materials selection for **design**. I'd also like you to make this exam work for your team, so please do approach the exam with your team's interests and questions in mind.

PART A. ANALYSIS (PICK ONE ANALYTICAL ANGLE)

As a team, select an approach to analyzing environmental and societal impacts that works for your project topic and direction. It may be helpful to think about specific questions your team is interested in answering, e.g., What material in our product has the biggest environmental impact? What phase of the product life cycle is the most harmful? Where do the raw materials originate, and who is involved in the extraction of these materials? Is this material recycled, and what are the costs of recycling – energy, water, waste, performance loss, etc.? How do living systems interact with this material, or with waste from the processing of this material? What societal needs does this product address (i.e., who uses it, and why)?

With that in mind, please allow me to suggest a few analytical possibilities. You don't have to choose one of these four options, and you don't have to do things in exactly the way I suggest here. You can create your own approach to the analysis of impacts. The goals is to do some high quality analyses that are relevant to your project.

OPTION 1. ECO IMPACT ANALYSIS. Your team could quantitatively analyze the environmental impacts of your product, or a component of your product, using values in the CES Edupack software. This could involve:

a. Component selection. Identify the component(s) of your object for this analysis. Try to pick components that are interesting to you, and interesting from an environmental perspective.

b. Identify how materials in your components are processed, e.g., injection molding, rolling, drawing, powder sintering, etc. The CES software suggests a couple of common processing methods near the bottom of each material data sheet, and these are generally good places to start. You can also browse different processing methods in CES if you go to the ProcessUniverse part of the software.

c. Environmental impact analysis. For the material(s) used in your component(s), look up the following values in the CES Edupack software:

- Embodied energy (report in MJ/kg)
- CO_2 footprint (kg/kg)
- Recycle fraction.
- Energy required for processing (report in MJ/kg)

d. Contextualization. Can you make sense of these values? Are the values significant or not, in terms of global materials or consumer product production, i.e., should we care, or why should we care? Are the values large compared to other materials? Are there other impacts associated with the manufacture of your component that are not reflected in this list of embodied energy, CO_2, and processing energy? If so, what are these?

OPTION 2. INPUTS (START OF LIFE) ANALYSIS. You've done some reading on sustainability, including the two articles for this week, a couple of textbook chapters on material consumption and life cycle. Could you construct an interesting and informative narrative about the sustainability of your modern consumer product, i.e., tell a story? There are a lot of things you could consider when putting together your narrative, such as:

- **Depletion.** What's the state of the natural sources for your material(s), in terms of levels, quality, and location? What are the depletion rates? How plentiful or scarce are the sources?
- **Process.** What steps are required to convert ore or feedstock into the raw material used in processing, e.g., how do polymers go from oil or coal to pellets for injection molding, to finally a bottle or shoe sole?
- **Technical requirements.** What are the energy inputs throughout the raw material extraction and material processing? How big or small are these energy values? What are the land or water requirements during extraction and processing? Is this a lot?

- **Waste.** What waste streams are produced during the initial and final processing stages of your material? Where does the waste go? What are the toxicity levels of the chemicals and impurities used during extraction, purification? How do these substances impact the local ecosystem? How bad is this stuff? Were the 10,000 Maniacs right, is there Poison in the Well?
- **Social impacts and equity.** Where is the processing (or extraction or recycling) happening? Who is doing it, and how? How does the extraction, production, or recycling of your material impact people or communities (consider both positive and negative impacts)? Who gains the most, and who pays the most?

OPTION 3. OUTPUTS (END OF LIFE) ANALYSIS. Along the lines of Weisman's thought experiment ("Plastics are Forever" reading), you could develop a narrative that describes the end-of-life impacts of your consumer product. There are a lot of things you could consider when putting together an end-of-life narrative, such as:

- **Disposal.** How much volume of your product ends up in a landfill each year? Do you see any potential issues with disposal in a landfill?
- **Recycling or reuse.** What fraction of products made from your material are recycled? For what applications is recycling practical? Does it end up in the same products, or is it "downcycled" into lower quality or reduced functionality products? What are the costs (e.g., energy, waste streams) of recycling? If your material is not recycled, how and where is it permanently disposed?
- **Waste.** What waste streams are produced during or after disposal or recycling? Where does the waste go? What are the levels of the harmful substances? How do these substances impact the local ecosystem? How bad is this stuff?
- **Social impacts and equity.** Where is the disposal or recycling happening, i.e., is any of your product, or its materials, shipped elsewhere for disassembly or disposal or recycling? Who is doing it, and how? How do these activities impact people or communities (consider both positive and negative impacts)? Who gains the most, and who pays the most?
- **Technological or societal advances.** What advances in sustainable production or reuse/recycling are being explored or implemented? Are we generally moving in the right direction, or are there major problems still to solve? How's the long-term outlook for your material – will we still be using this material in 10 years, 100 years, or longer?

  Of course, you can't address all of these questions in your brief narrative, so focus on the issues that are of greatest interest to your team or most compelling from a sustainability perspective. Perform some online (or other) research and use specific details such as excerpts, colorful quotes, statistics, maps, and diagrams to support and illustrate your points. Above all else, try to tell a story that is interesting, coherent, compelling, and supported by citations; and do it in a manner that aligns with your project goals.

OPTION 4. PRICE TAG VS. REAL COST (EXTERNALITIES). We know that the life cycle of consumer products (of "stuff" if you prefer) is complex and multifaceted, and that many impacts arise as materials move from extraction to disposal. But we also know that consumer products are remarkably cheap. As it turns out, the price of consumer products often fails to reflect the real costs of those products, for a variety of reasons. We refer to the unaccounted costs as "externalities," defined by Google as a side effect or consequence of an industrial or commercial activity that affects other parties without this being reflected in the cost of the goods or services involved, such as the pollination of surrounding crops by bees kept for honey.

Here's an example. While we were shopping for matsci stuff in Wal-Mart, Rob Martello and I noticed that you could purchase a hand-held flashlight with two C cell batteries for $2.00. For an additional $1.00, or $3.00 total, you could get a *second* flashlight and another set of batteries. These prices seem crazy, when you think about the potential tart-of-life and end-of-life issues associated with consumer products. And once we realize the craziness of consumer product pricing, we can begin to ask some interesting questions. What if the manufacturer were required to take back the product at the end of its useful life? What if the environmental impacts associated with disposal or recycling were factored into the cost? What if there were a CO_2 tax associated with the embodied energy of the product, or a tax associated with transportation of the product from manufacturing site to retail store? What if the people assembling the product were paid a living wage, or provided with health care? What if we had to pay for purification of the waste stream water from the manufacturing phase? What if there were no government subsidies for raw materials? You get the idea.

Your team could do some research on the purchase price of your product, and then attempt to determine **how much your product should cost**, if we were to fairly consider its environmental and societal impacts. Show the process of how you arrived at your new cost for the product, and state all of the assumptions you're making along the way. Which factors did you include and how did you quantify them? Support your arguments with citations from reliable sources.

PART B. DESIGN (PICK ONE APPROACH)

Take your eco impact analysis from part (a) to the next level, by exploring materials that may be used in your product to reduce its negative environmental or societal impacts. Using your knowledge of your product's property and performance requirements, select and analyze alternative materials choices for one component in your product. In other words, do some design work! There are many ways to approach this design task. Some options:

OPTION 1. START WITH ALTERNATIVE IN MIND. Depending on your product, you might already have a more eco-friendly replacement material in mind. If this is the case, you could do a side-by-side property/performance and eco impact comparison of the two options. Use reliable sources to compare some of the most significant impacts of each material, and examine some of the trade-offs you need to make in properties and performance (including cost) with the alternative material.

OPTION 2. FOCUS ON ONE PHASE OF THE LIFE CYCLE. You could identify a particular phase of the product life cycle that you think offers a good opportunity for improvement. For example, you could say, *"wow, none of the materials in my product can be reused or recycled or biodegraded at the end of life… I want to find better end-of-life options…"* or *"hmm, some nasty chemical waste streams result from the extraction and processing, so we should explore materials with more benign processing outputs…"* or *"wow, the use phase of this product is really short… if we change material x to material y, could it last longer?"*

OPTION 3. START WITH PROPERTY REQUIREMENTS. Begin your search for alternative materials with a list of property requirements for a component of your product, and see if you can discover a lower impact material using the CES Edupack software. For example,

a. Think about property requirements for manufacturing and performance of your component. Identify the **most important properties** for your component, and specify **acceptable property ranges** for each of these properties. For example, if you decide that melting temperature is important for low cost manufacturing of your product, and the material used in your component melts at 150 °C, you may specify an acceptable property range of 115 to 155 °C. If, however, the melting temperature is important for high temperature service of your product, you may specify an acceptable melting temperature range of 145 to 180 °C.

b. Based on your specified property ranges, **identify one alternative material** that you think could be used in your product and provide a **reduced environmental impact but no loss in performance**. Note that your alternative material does not need to be from the same material classification, e.g., a metal may be replaced by ceramic or polymer or composite, etc.

   The CES Edupack software provides an excellent way to identify alternatives based on property screening. To do this, click on the **Select** icon at the top of the screen. Under (1) **Selection Data**, select the database you'd like to use (typically "MaterialUniverse: All Bulk Materials". Under (2) **Selection Stages**, click the Limit button. To the right you'll see lots of properties you can use to limit your search. Enter values for your screening properties, and click the Apply button. You'll see a list of materials that fit your criteria on the lower left. If you'd like to graph the materials, click the **Graph** button under (2) Selection Stages. This opens a New Graph Stage Wizard window, in which you can choose what you want as your x-axis and y-axis. For example, you could choose to plot the list of materials on graph of Embodied energy (J/kg) versus Melting Temperature (degrees C). To get a graph of just the materials that passed your property screening, simply click the "Result Intersection" and "Hide Failed Records" icons at the top of the graph. At this point, you can click on the different material bubbles to find out what each one represents, and double click the bubbles to open the detailed property data sheets. Fun!

c. **Compare environmental Impact.** Compare your original material and alternative material in terms of embodied energy, CO_2 footprint, recycle fraction, and energy required for processing (report in MJ/kg). How did you do – is your new material better with regard to these factors?

Whatever way you choose to approach this design assignment, you'll need to do some research to quantify the differences in impact between your original and alternative materials. You should also consider the trade-offs associated with properties and performance, if you were to replace the original material with an alternative.

RESOURCES

For this exam, you may want to access the CES Edupack software, which is available in several locations:

- Library. The CES software is on a lower level computer located next to the class assignments boxes. There is a small CES sticker on the machine.
- Computer Lab, lower level of Milas Hall. You'll find the CES software on a couple computers in the lab.
- Materials Lab. The CES software is on several machines in the mat sci lab. In AC413, CES is on the computer near the front of the room, as well as on the mini-Instron computer. In AC409, CES is on the FTIR computer.

If you're looking for an alternative to the CES software, you can use the Material Profiles in Ashby's *Materials and the Environment* book, available electronically through Olin's Knovel resources. Ashby did a nice job of including detailed material data for the most commonly used materials in this section of the book, so you can do some analysis without buying expensive software. If you decide to avail yourself of this opportunity, all that I ask is that your team sit together at dinner tonight, fill your glasses to the brim with the watery colloid that emerges from the "orange juice" spout, and raise them in unison in silent tribute to Ashby. Oh, also, there's a hard copy of the Material Profiles on top of the bookshelf at the front of the room in AC413, if you prefer turning physical pages to electronic scrolling. Rock on.