Teaching Manufacturing and Sustainability with the U.S. Life Cycle Inventory Database

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Abstract

At Murray State University, Manufacturing Processes and Materials is a freshman course designed to teach contemporary concepts in manufacturing and industrial materials. In this study, a project module, which utilizes the U.S. Life Cycle Inventory (LCI) Database and GaBi Life Cycle Assessment (LCA) tool, is analyzed for its effectiveness in teaching sustainability, LCA, and fundamental manufacturing processes. Project module is based on the LCA of a simple product made of three to five components that can be easily found at a local hardware store. Students identify the material and manufacturing processes for each component and use the U.S. LCI Database and GaBi LCA software to analyze the environmental impacts. Surveys show significant impact of the project module on the students learning and interest in the concepts of sustainability, Life Cycle Assessment and manufacturing processes. The study also demonstrates the uniqueness of the tools and methods selected for this project module.

Keywords

Sustainability, LCA, Manufacturing, Technology, Education,

Introduction

Unless there is a war or a natural catastrophe, human welfare is continuously improving. Although welfare improvement is a positive indicator of prosperity and economic development, it comes with a price. As the human welfare increases, so does our ecological footprint on earth.

The alarming numbers about global warming, air and water pollution, cost of energy, and dwindling natural resources have been shifting the focus of manufacturing from productivity to sustainability. Sustainability, as defined by the U.S. Environmental Protection Agency from a manufacturing point of view, is “the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound”[1].

Maintaining a continuously improving or at least a stable standard of living with the current population growth and consumption of natural resources is not possible unless sustainable approaches are adopted by governments and private businesses[2]. Currently, sustainability is supported and implemented mainly by governments through regulations and restrictions. However, there are reports[3, 4] pointing to an increasing public awareness that has started pushing some large companies to look for more sustainable and environmentally cautious methods of production.

Sustainability Education

It's widely accepted that universities have a role to transform the individuals and societies[5]. In this regard sustainability must be one of the fundamental values that a university education should give to students. Mulder[6] (2010) believes that values shouldn't be taught as just a subject of lecture because if students are confronted with material or lectures that is strongly defending a specific value position, they might reject that course and value altogether as "just a view." Moore's (2005) extensive research[7] on sustainability education recommends infusing sustainability into all university functions by integration of sustainability into university plans, decision-making structures, evaluative measures, research, service and teaching components of the university.

There is a consensus on the need to teach sustainability at the undergraduate level. However, there are various ways that the subject can be incorporated into the curriculums. In some programs, there are stand-alone courses solely dedicated to sustainability education[8] but because of program credit limits and large numbers of core courses, many programs prefer incorporating sustainability subjects into existing courses[9]. In our case, environmental sustainability is taught through the practice of Life Cycle Assessment in a manufacturing course (ITD 130 – Manufacturing Processes and Materials).

Course Design

ITD 130 (Manufacturing Processes and Materials) is a 3 credit core course in the industrial technology program. Class has a 50% lecture and 50% lab format with 5 contact hours per week. Course is taken by Manufacturing Technology, Engineering Graphics and Design Technology, Interior Design Technology, and Occupational Safety and Health majors. In the first half of the semester, characteristics of materials and their effects on manufacturing process selection and product specifications are studied. Sustainability concepts and principles are introduced in the second half of the semester with fundamental traditional and non-traditional manufacturing processes.

In order to teach sustainability principles and develop awareness and consciousness in sustainability, environmental impacts of manufacturing processes were presented first through lectures. The key component that merges manufacturing processes, materials, and sustainability is the group project that allows students to practice what they learn and deepen their knowledge through practice and research.

The group project was focused on the "Life Cycle Assessment" (LCA) of a small hardware (with less than five components) that was readily available at a local supply store. At the beginning, student groups were provided with a pliers, an adjustable wrench, a door hinge pin stop, and a clevis grab hook. Students were required to perform a complete LCA on one of these provided products. In order to perform an LCA study, students had to study the materials, manufacturing activities, packaging, transportation, energy consumption and recycling of each component as described in the next section "Life Cycle Assessment." Through the project, students learned about the materials and manufacturing processes used in the making of the hardware, their impacts on the environment, and sought alternative methods and materials to lower the environmental impacts of existing products.

Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is a method defined and standardized by ISO 14040[10] and 14044[11] to analyze the environmental, technical, and economical effects of products, processes, and systems. The technique analyzes the environmental impacts of a product at every stage of its life from cradle to grave. The LCA steps are outlined in ISO 14040 and 14044 as: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation.

At the “goal and scope definition” step, the subject of the study (functional unit) should be defined. The subject can be as simple as a single component like a bolt or a very complex system like the entire production processes for manufacturing an automobile. The study period can be the entire life cycle from cradle to grave or for a specific period of subject’s full life cycle. Moreover, the subject can be studied for any of the environmental impact categories.

At the heart of any LCA is the “inventory analysis.” Inventory analysis is identifying and quantifying all material and energy inputs and outputs of a process or activity. For example, if a cast aluminum component is being studied, melting is one of the processes that has to be analyzed. In this case, inputs would be recycled aluminum, electricity and natural gas, and outputs would be various gasses, heavy metals and the aluminum component. In this step, all processes and activities for each component should be identified and their inventory tables (input/output) should be developed. This step is the most labor intensive step that requires significant amount of time and resources to collect data.

In the third step, amount and significance of potential environmental impacts of each input and output is calculated according to standardized methods. There are numerous impact categories developed for analysis, such as, “global warming potential (GWP),” “acidification potential (AP),” “ozone depletion potential (ODP),” “eutrophication potential (EP)” etc. Each input and output item from the inventory tables are converted into reference units using characterization factors. For example, the reference factor for GWP is carbon dioxide (CO_2) and its reference unit is defined as “kg CO_2-equivalent.” All output inventory items (emissions) that has GWP must be converted to kg CO_2-equivalents according to standardized characterization factor. (For example, Methane (CH_4) is estimated to have a GWP of 28–36 times the CO_2.)

In the last step the results are evaluated. Significant issues related to data collection, accuracy and consistency are checked. It is also suggested to run a sensitivity analysis to evaluate the effects of uncertainties, assumptions and methods on the results.

LCA Software and Life Cycle Inventory Database

Thinkstep GaBi LCA software was selected for the implementation of the project. GaBi provides a free license to educational institutes with built in Life Cycle Inventory databases. National Renewable Energy Laboratory’s (NREL) U.S. Life Cycle database[12] is also available in GaBi’s libraries. NREL database was selected for its unit process based open structure. In other databases, fundamental processes are designed as a black box. For example: for the environmental impacts of a cast iron part, GaBi's own database will give all the inputs (materials, resources, energy) and outputs (emissions to water, land and air) as an aggregate data. The user doesn't have access to sub-processes such as transportation modes and distances, raw material extraction and preparation methods, energy usage and energy production methods, and so on. On the other hand, in NREL's database, inventory tables are created for unit process. It means that, every process is in its simplest form, so, in order to calculate the environmental impact of a cast iron part, the user must determine all the sub-processes required to produce a cast iron part, and link them in the form of a flow diagram. Figure 1. presents the difference between both approaches.

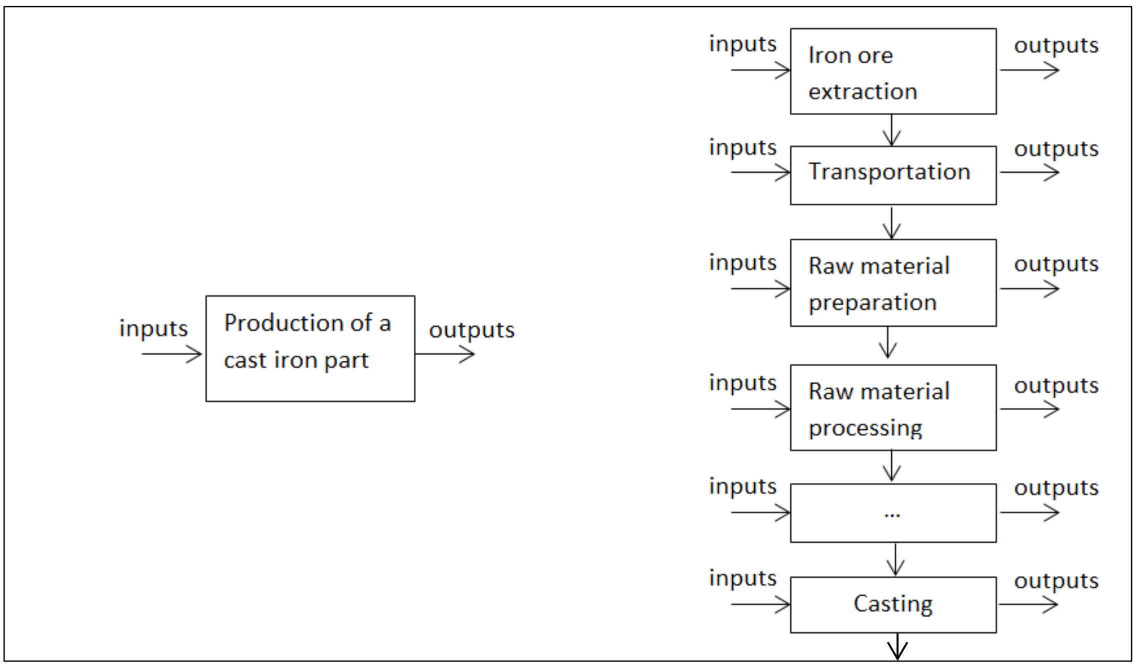

Figure 1. Comparison of modeling with NREL (on the right side) and other databases (on the left side).

The advantage of using NREL's database for the student project is that it allows students to investigate all of the primary and secondary manufacturing processes, transportation activities and energy production methods involved in producing one single component and environmental impacts of every single activity. With this database, students not only gain knowledge in sustainability but also do extensive research to identify relevant manufacturing activities to produce the products that are provided to the students for the project. Figure 2. presents an actual model of an LCA study created on GaBi software. Each box represents a unit process and they are linked according to the sequence of manufacturing.

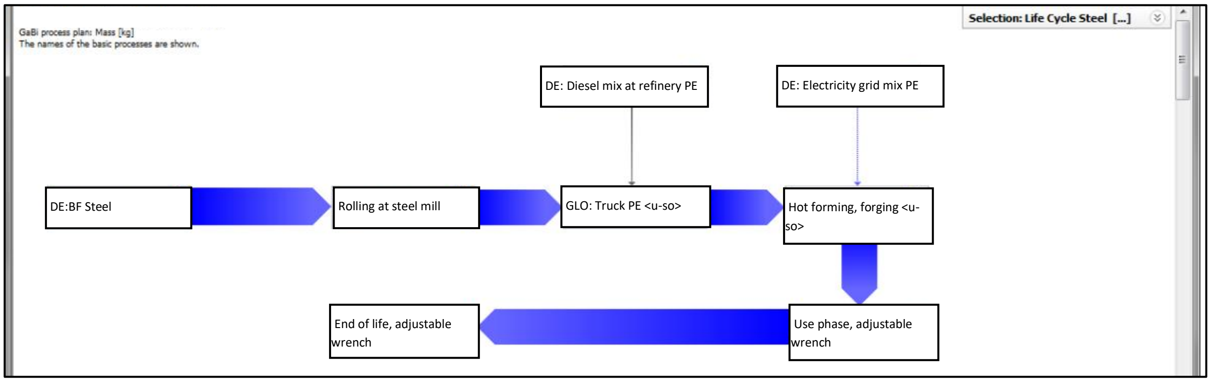

Figure 2. LCA model in GaBi.

After the model is completed with all the relevant information about manufacturing processes, transportation activities, energy production methods, distances and regional characteristics the GaBi runs the impact analysis according to selected impact characterization method. In the U.S., Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) is used for characterization purposes. The results are created for each impact category level, for each activity and for the model. Typical output of the impact analysis is presented in Figure 3.

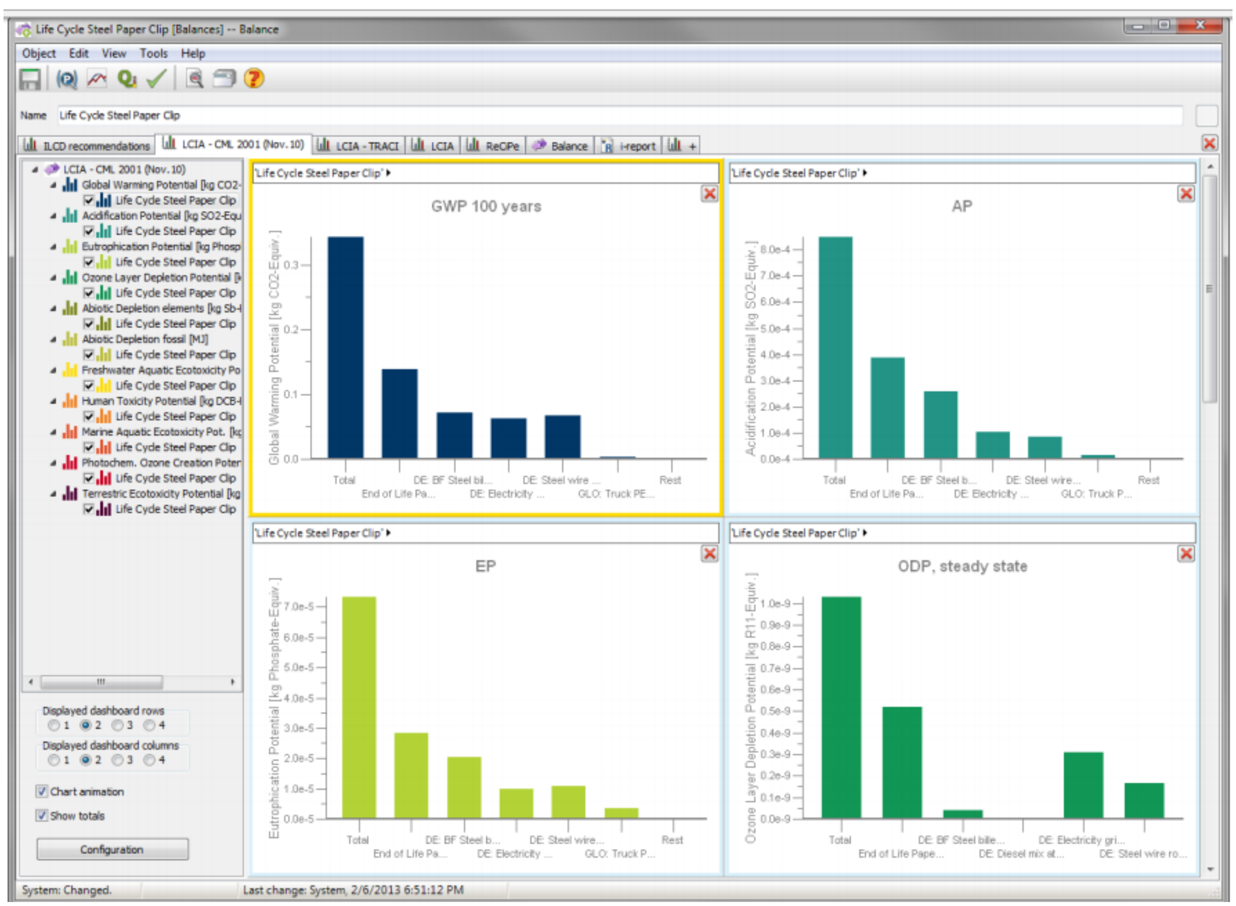

Figure 3. GaBi Life Cycle Impact Analysis Result Screen

Results

Success of the implementation of the sustainability module was tested with pre and post surveys. Students were asked on their understanding of sustainability concepts by the following questions:

What is sustainable manufacturing?
Why is sustainability important?
What are the environmental impacts of manufacturing activities?

On the pre-test, most of the answers suffered from lack of detailed information or examples. By comparison, post-test answers were rich with examples and demonstrated the grasp of fundamental issues and concepts of sustainable manufacturing. When answering the first question on the pre-test, out of nineteen students, sixteen of them mentioned solar panels, eco-friendly cars and recycling. The remaining students didn't answer the question. However, on the post-test, every student clearly stated at least one of the issues of resource consumption, energy usage and environmental impacts in their answers. On the second question, most of the pre-test answers were focused on gas and oil consumption and electric cars (seventeen out of nineteen), whereas, all of the post-test answers were concentrated on the environmental impacts and resource depletion. The pre-test answers to the last question were mainly about air and water pollution (seventeen out of nineteen), however, all post-test answers mentioned at least two impact categories studied through the LCA project.

Conclusion

From these observations, it is clear that sustainability can be taught at engineering, engineering technology and industrial technology programs at the undergraduate level to prepare students with the tools and mindsets ready to take on the challenge for more sustainable manufacturing practices. GaBi is a useful tool to teach sustainability concepts and integrating them into the study of manufacturing.

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