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An introduction to life cycle assessment with hands-on experiments for biodiesel production and use

*Stephanie Farrell**, *Eduardo Cavanagh*

Department of Chemical Engineering, Rowan University, 201 Mullica Hill Road, Glassboro, NJ, USA

ABSTRACT

This paper describes a hands-on project that introduces first year engineering students to life cycle assessment (LCA) through the comparison of the environmental impact of the production and use of three diesel fuels: petroleum diesel, biodiesel from new vegetable oil, and biodiesel from waste vegetable oil. The purpose of this LCA project was to incorporate life cycle thinking into the engineering design process, to apply the four main steps of LCA (definition and scope, inventory analysis, impact assessment and improvement assessment), and to explore some of the challenges associated with each step. The inventory for biodiesel production (from both new and waste vegetable oils) was based on measurements obtained by the students in laboratory experiments. The fossil diesel production inventory was obtained from the SimaPro® database. The inventory for the use of all three fuels was obtained from measurements taken during combustion of the fuels in a generator. A cradle-to-grave life cycle analysis was then conducted using SimaPro® for each fuel. The assessment of learning outcomes indicates a significant increase in conceptual understanding of the four stages of life cycle assessment, and an average gain of over 55% in overall knowledge of life cycle assessment.

Keywords: Life cycle assessment; Biodiesel; First-year project; How people learn

1. Introduction

As we face now the unintended consequences of rapid population growth, economic growth and consumption of natural resources, the unsustainability of our current way of life has become evident. Long-term maintenance of human well-being requires the adoption of sustainable practices that reconcile environmental, social, and economic demands, known as the three pillars of sustainability. The concepts of sustainability and life cycle thinking have entered mainstream consciousness and have become priority issues for global corporations. Chemical engineers play an important role in developing sustainable technologies through chemical process improvement, reducing energy demands, maximizing the use of byproducts, decreasing the use of natural resources, and reducing emissions to the environment. As a technique that allows the evaluation of the environmental impacts of a product or process from cradle to grave, life cycle assessment is an important tool used by chemical engineers who are involved in the development and impact assessment of industrial processes and products.

Biodiesel fuel has received increasing attention as a renewable, biodegradable, nontoxic fuel that can contribute to alleviating energy problems (Balat and Balat, 2010; Veranda et al., 2011). In this context, biodiesel fuel production and life cycle assessment (LCA) have been used as the focal point of a semester-long, project-based introductory engineering course at Rowan University. A series of hands-on experiments related to biodiesel production and performance testing were conducted as described previously (Farrell and Cavanagh, 2014). The focus of this paper is on the addition of a module on life cycle assessment into the freshman biodiesel project. In this

* *Corresponding author*. Tel.: +1 856 256 5315.
E-mail addresses: Farrell@rowan.edu (S. Farrell), Cavana81@students.rowan.edu (E. Cavanagh).
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LCA module, students used experimental data from their production and performance experiments as the basis of the life cycle inventory.

This paper describes previous work related to LCA education, the teaching and learning rationale for the module, details of the implementation, and assessment of learning outcomes.

1.1. *Previous work in life cycle assessment education*

A paradigm shift is in engineering education calls for sustainability to be presented as a way of thinking and integrated throughout courses (Mitchell, 2000), and a number of chemical engineering programs have been successful in doing so (Glassey and Haile, 2012; Hesketh et al., 2004; Othman et al., 2012). Life cycle assessment is an important method used to minimize the environmental impact of products and processes by employing sustainable practices. The current literature on life cycle analysis in the undergraduate chemical engineering curriculum is scant. Evans et al. (2008) describe every-day examples that illustrate the principles of LCA to first year students in a meaningful context. In these examples students were provided with information required to apply intuitive material balances to develop the process inventory and perform impact assessment, considering energy usage and carbon and sulfur dioxide emissions. Students then performed optimization to minimize impacts at local and global scales. Heard and Matthews (2008) describe a multidisciplinary project in an interdisciplinary course, in which students assessed the life cycle impact of equivalent products made from both steel and wood.

1.2. *Course context*

Rowan's two-semester Freshman Clinic sequence introduces all freshmen engineering students to engineering in a hands-on, project-based learning environment. Key features of the course include: (1) multidisciplinary education through collaborative laboratory and course work; (2) teamwork as the necessary framework for solving complex problems; (3) incorporation of state-of-the-art technologies; (4) creation of continuous opportunities for technical communication. The two-credit course meets twice per week: there is one 50-min class meeting and one 3-h laboratory meeting. Several previous articles have described the course in greater detail and have described specific projects ranging from beer production to reverse engineering the human body (Farrell et al., 2001, 2002, 2004, 2005; Farrell and Hesketh, 2002).

In the laboratory component of this course, students produced biodiesel fuel using both new vegetable oil and waste vegetable oil. The two biodiesel fuels and fossil commercial fossil diesel were then combusted in a generator to obtain emissions data. The laboratory experiments required approximately nine weeks to complete; these experiments are described in detail in Farrell and Cavanagh (2014). Students used their experimental data from both production and combustion in a life cycle assessment to compare the environmental impact of the production of three fuels: biodiesel from new vegetable oil, biodiesel from waste vegetable oil, and commercial petroleum diesel fuel. The purpose of this LCA module was to incorporate life cycle thinking into the engineering design process, to introduce and apply the four main steps of LCA (definition and scope, inventory analysis, impact assessment and improvement assessment) in a meaningful context, and to explore some of the challenges associated with each step. Two laboratory periods were devoted to performing the LCA in the College's computer laboratory where a graduate assistant and the instructor were available to answer student questions. Two out-of-class assignments required students to perform additional life cycle assessments to explore different process scenarios.

1.3. *Pedagogical framework*

The project was conducted in the context of the How People Learn (HPL) framework (Bransford et al., 2000), which has four main pillars: knowledge-centeredness, learner-centeredness, assessment-centeredness, and community-centeredness. HPL has been shown to enhance learning outcomes when used as a framework for bioengineering modules (Cordray et al., 2009; Greenberg et al., 2003; Roselli and Brophy, 2006; Vernengo and Dahm, 2012). Farrell and Cavanagh (2014) described how each experiment in Rowan's freshman biodiesel project was implemented using an HPL framework similar to that described by Linsenmeier et al. (2008). Here we describe how the same pedagogical framework was applied to the LCA module in our freshman engineering course. The motivating challenge for the entire biodiesel project was to compare the environmental impact of fossil diesel and biodiesel fuels. The LCA module began with an introduction in which students' prior conceptions were uncovered through discussion, and new concepts were connected and built upon this knowledge. The discussion opened with a question that has received recent attention: "is walking better [for the environment] than driving?" Cohen and Herberger (2008) explore this question using LCA, and their conclusion is "it depends": walking is generally better *unless* the energy used is replaced by a very greenhouse-intensive food such as beef. This opens discussion to the implications of our purchases, choices and activities, and also cautions us against making decisions based on analyses and comparisons that may be faulty or rely on unrealistic assumptions. We then turned to the motivating problem that would be explored during the LCA module, helping students to organize their body of knowledge (knowledge-centered).

The assessment-centered leg of the HPL framework was provided by the pre-lab discussion as well as LCA reviews during the computer laboratory. The in-class discussion provided formative feedback to both the students and the professor. The professor was able to assess the accuracy and quality of students' pre-existing knowledge and linkages to new conceptual understanding, and to provide relevant formative feedback to the students. The students were required to submit their life cycle inventories based on experimental data prior to the lab, and the inventories were checked by the instructor before students began the computer lab. During the computer lab, students were required to complete one complete life cycle comparison of the three fuels. Their results were reviewed by the instructor or assistant before the students left the laboratory, and formative feedback was given regarding accuracy and quality of the investigation and analysis.

The course was community-centered in the use of in-class breakout groups for brainstorming and discussion, followed by whole-class discussion. Students worked in teams of 3–4 throughout the project with cooperative learning structures employed to promote positive interdependence and individual accountability.