Chapter 3
Life Cycle Assessment

Abstract Due to the diversity of impacts the fuel industry has on society, it is often difficult to comprehensively evaluate the benefits and drawbacks of any given fuel or fuel production process. This is especially true when the impacts influence disparate fields that have their own considerations and metrics that may not be compatible. The analysis framework of a life cycle assessment (LCA) provides a comprehensive methodology for studying the combined consequences of different influences and has been implemented in many industries including biofuels. While LCA can be used to retrospectively analyze existing systems, it is also possible to use LCA to prospectively analyze a system to evaluate and determine the most promising choices to pursue. LCA is a potentially powerful component in helping to guide decision making for target biofuel research and development.

The fuel industry has direct impacts on many different aspects of society. This is especially true when considering biofuels where there are numerous considerations including economic, environmental, and social considerations. With the diversity of considerations affecting fuel production, distribution, and consumption it is often difficult to make decisions on which fuel or production scheme may be most suitable to meet certain criteria. One method for assembling and assessing different criteria to arrive at a decision is to conduct an life cycle assessment (LCA).

LCA is fundamentally a process for tabulating or collating information to facilitate analysis. As a process, there can be many different ways to conduct an LCA, but most commonly accepted and standardized method is the series of standards set by the International Standards Organization (ISO) (http://www.iso.org/iso/iso14000). A typical LCA includes the implementation of four major steps:

1. Define the system boundaries for assessment.
2. Life cycle inventory: create an inventory of inputs and outputs for the defined system. This step often includes determining a functional unit as a basis for evaluation.
3. Life cycle impact assessment. This step often includes normalization/weighting of inventory items.
4. Interpretation of results.

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The LCA analysis framework provides two main benefits, both of which are relevant to biofuel processes. The first benefit is that there is a requirement to consider and explicitly define the system that you will consider for analysis. This may seem like an intuitive and obvious step, but it has not always been given proper consideration in process development where there is often a technical impediment that causes perspectives to become narrowed to the single step in question. By considering the system definition, most LCAs ideally try to consider all aspects of a process from the raw materials and transportation to manufacture, consumption, and disposal. As such, LCAs have often been colloquially referred to as "cradle-to-grave" analyses.

The comprehensive view provided by a good LCA is meant to help to provide a broad, unbiased analysis of a process system that can be used for decision-making purposes. From a research perspective, increasing the chemical production yield using your favorite organism can be intellectually fruitful, but there is no guarantee that such research progress would translate to a process with commercial relevance. Engineering a strain of an organism with a 50 % increase in butanol production is great; however, if an organism is limited to using carbon sources that are expensive or available in limited quantities then it would be difficult to develop a commercial-scale bioprocess based on that organism. Another common biofuel-related example is the body of work focused on pretreatment of lignocellulosic biomass to hydrolyze cellulose and hemicellulose to hexoses and pentoses, respectively. In the pretreatment cases, a balance needs to be made between the severity (chemical and reaction parameters) of the pretreatment process and the output stream from the pretreatment process. Relatively harsh conditions can be used to hydrolyze the polymeric sugars into monomeric sugars that can be used for conversion to biofuels, but carryover chemicals or temperatures from the pretreatment process can be inhibitory to downstream processes. Thus, sometimes it may be necessary to consider a less severe pretreatment process that has lower yields if it interfaces with downstream bioprocesses better.

The second benefit of an LCA is that it is a generic analysis framework and information from diverse fields can be all considered within the same framework. As stated previously, biofuel production involves a number of different facets including technological, social, environmental, and economic. Each of these fields has its own terminology, considerations, and metrics. If considered individually, the exercise of comparing the impacts in each of these different fields would be the equivalent of comparing apples to oranges as numbers and values from one field do not necessarily translate comparably to a different field. The LCA framework is meant to facilitate this by defining a functional unit that can be used as a standard in each of the different fields. Thus, information from all relevant fields can be tabulated using a base functional unit and analysis can take into account impacts in different fields.

For biofuel processes, there are many different functional units that can be considered to be appropriate. The natural consideration is a gallon of fuel since we are all familiar with a gallon of gasoline (and the price of a gallon of gasoline at a gas station). The use of the volumetric quantity of a gallon is not necessarily the best to use however as it prohibits the comparison of different types of fuels that would have different energy content in a gallon. For fuels, the function that is being considered is the energy content or for transportation fuel applications the distance that can be traveled. If functional unit for an LCA is defined according to energy content, then all of the data that are tabulated, from environmental gas emissions to pricing, must be considered by the energy content functional unit. Then a comprehensive analysis can be accomplished that incorporates information from different fields in a coherent manner.

3.1 Life Cycle Assessment of Biofuels

Due to the large number of variables that can be involved with biofuel production, there exist a vast number (thousands) of different LCA studies. These different studies can vary in many aspects including the scope of the system being considered, and they most frequently differ in terms of starting material, process detail, and target fuel produced. Due to these variations, it is often difficult to directly compare the results of different LCA studies.

One relatively recent review article attempted to compare different published LCA studies to determine if any generalized results could be found (Cherubini and Strømman 2011). This study considered 97 different life cycle studies on biofuels. These studies included a broad spectrum of variables including the locale of the study, the input and outputs considered, processes involved, and scope of analysis. The definition of functional units for analysis also varied (input-related units, output-related units, agricultural land units, and year) again making it difficult to directly compare results. Despite these challenges in analysis, two general results were found. When considering a balance on greenhouse gas (GHG) emissions, biofuels resulted in a net reduction in GHG emissions when compared to fossil fuel-derived products. In addition, biofuel production schemes required a lower amount of fossil fuel input for production of fuels and thus resulted in a reduced consumption of fossil fuel.

For additional details on LCA studies of biofuels, there exist a large number of individual studies that can be considered and found through literature search engines. LCA studies can be conducted for different purposes but generally they can be conducted retrospectively on existing processes or prospectively on developing processes. Prospective use of LCA can be used as a decision-making tool as a framework to help guide research and process development efforts to identify the most promising avenues to pursue.

Reference

Cherubini F, Strømman AH (2011) Life cycle assessment of bioenergy systems: state of the art and future challenges. Bioresour Technol 102(2):437–451 (Epub 2010 Aug 6)