EE80S Lab Packages

Table of contents for Lab 4- Life Cycle Analysis of Biofuels Part 2

ee80s2010: Lab 4: Life Cycle Analysis of Biofuels, Part II

Life Cycle Analysis: Determining the boundaries of a project (continued)

Learning Goals

Content: Understand the basic premise and process of life cycle analysis. Understand how life cycle analysis can complicate the desirability of biofuels.

Design Process Goals: Refining the problem by challenging problem boundaries.

Quantitative Reasoning Goals: Prioritizing which data to collect and understanding the tradeoffs in these decisions, utilizing different information gathering approaches, working through conflicting or black-boxed data, integrating quantitative and qualitative information in problem solving.

Technical Skills: Practice quantitative reasoning and life cycle analysis.

In last week's lab we discussed life cycle analysis and how LCA can be a useful tool for measuring the environmental impacts of a product. We also challenged the simplistic LCA used to promote ethanol as a carbon neutral alternative to gasoline. For your homework assignment you further investigated the life cycle of a particular biofuel. Today we will discuss the possibility of including qualitative factors in a life cycle analysis.

As a reminder, here are the four steps of a life cycle analysis:

1. Goal Definition and Scoping

a. **Defining purpose of the LCA**

b. **Determining decision criteria/Deciding on a metric**

b. **Setting system boundarie**s (What time frame should you consider? How far up the supply chain should count? Which major operations should be included? How should co-products (when two of more products are produced from the same raw material or process) be assigned?)

c. **Geographic scope** (National/regional data?)

2. Life Cycle Inventory (LCI)

a. **Develop flow diagram of the subsystems (See Lab 3, Figure 1)**

i. Raw materials acquisition from Earth

ii. Manufacture (material manufacture, fabrication, packaging)

iii. Use/Reuse/Maintenance (What it consumes/produces during use)

iv. End-of-life

b. **Develop a data collection plan for an impact category**

i. Energy (Btu, MW)? Carbon? Heat (therms, ccf)? Global Warming Potential?

ii. Natural resources? Raw materials? A toxic material? A rare or $$$ material?

iii. Green job creation? Economic multipliers?

iv. Air pollution? Solid or toxic waste?

v. Prices/Costs/Feed-in-tariffs/Rebates?

vi. Broader concerns/habitat/safety/land use

c. **Collect data (what level of accuracy is needed?)**

3. Life Cycle Impact Assessment

a. Evaluate and characterize impact categories

b. Weigh and emphasize most important aspects, identify values held by stakeholders

c. Identify most significant issues, evaluate, and document

4. Life Cycle Interpretation, Conclusions, and Recommendations for Life Cycle Management

a. While focusing on the original goal of the LCA, identify areas for improvement
b. Identify highest impact areas

Lab Exercise Step 1.

For your homework you explored several of the issues related to biofuel production. As a group you will now list some of the benefits and some of the potential problems associated with the biofuel you have investigated on this worksheet: Lab 4 Worksheet.doc

Lab Exercise Step 2.

You will now characterize and weigh the issues your group identified. In doing so you will be following phase 3 of a LCA.

LCA Phase 3. Life Cycle Impact Assessment (Complete steps a through c on your downloaded worksheet)

a. Evaluate and characterize impact categories
b. Weigh and emphasize most important aspects
c. Identify values held by stakeholders

Lab Exercise Step 3.

Considering all of the information you have encountered regarding the biofuel you have investigated, answer the following questions on your worksheet:

1. What are the potential tradeoffs?
2. Are there any critical issues that should trump all others?
3. Are there any ways some of the negative impacts can be mitigated in the design phase?

Lab Exercise Step 4 : Group Presentation

Using your group's answers to the questions in Steps 3 and 4, prepare a 2-3 minute presentation regarding your biofuel. The lab instructor will create a chart of the different biofuels and their tradeoffs.

Lab Exercise Step 5: Class Discussion - Life Cycle Interpretation, Conclusions, and Recommendations for Life Cycle Management

1. What does a life cycle perspective allow a designer to optimize?
2. Who should “participate” in the design of biofuels? (who or what should be considered?) What should the design process look like?
3. How would we choose a "least bad" biofuel considering the multiple levels of tradeoffs? How might you design biofuels to be more optimal or "eco-effective"?
4. Can we fairly compare progress around social issues to more objective measure of energy and resource consumption?
5. When might a life cycle analysis be an inappropriate tool to determine the desirability of a product?

We will now begin Lab 5: Evaluating Alternative Solutions for Solar PV

Lab 4 Worksheet

Group ID: __________
Student Names: __________, __________, __________, __________, __________
Biofuel your group is investigating: __________ __________

Step 1: Identifying Issues

What key environmental issues can you have identified regarding your biofuel?

What other issues (social, economic) did you identify?

Step 2: Life Cycle Impact Assessment

a. Identify major impact categories:

b. Weigh and emphasize most important aspects (i.e., of the impact categories established in part a) above, what is the most important and why? What is the least important? Justify your ranking.)

c. Identify values held by stakeholders: Who are the major stakeholders in the life cycle of your biofuel? How might they agree or disagree with your rankings in part b)?

Step 3: Evaluating Tradeoffs

1. Describe the tradeoffs of your biofuel.

2. Are there any critical issues that should trump all others?

3. Are there any ways some of the negative impacts can be mitigated in the design phase?

4. For some biofuels the negative impacts seem to dramatically and clearly outweigh the positive impacts. If this is the case with your group's biofuel, why is this biofuel being produced at all? (i.e. what are the politics and economics that are leading to its continued production?)

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Chapter 1 - Biological energy production

1.1 Energy and environmental issues

The widespread use of fossil fuels, has brought numerous benefits to industrialized societies. Large amounts of agricultural, domestic and industrial wastes generated in these countries as a result of development, have potentially detrimental effects both on the environment and on human health. Itai-itai and Minamata diseases in Japan, are just two examples of the effects of air and water pollution on human health. The importance of protecting the environment and restoring environmental damage cannot be overemphasized.

In recent years, environmental pollution has become a global problem. Internationalization of industrial and social activities has given rise to problems such as global warming, desertification, and acid deposition. These global problems are rooted in the materially-rich lifestyles which are supported by abundant and wasteful use of fossil fuels in industrialized countries. Rapidly increasing industrial activities in China, India, and in other developing countries implicates that these countries will inevitably contribute to deterioration of the global environment and to destruction of the global ecosystem. Lifestyle changes, and changes in our key industrial systems are required in order to minimize the impact of environmental pollution. The recycling of materials, and thus minimizing the generation of waste, is a basic concept which must be implemented in order to meet the new demands of sustainable development in both industrialized and developing countries.

Mechanisms for implementing this concept and for establishing environmentally compatible technologies which support the future "recycling" world are required. Systems, which utilize energies produced from biomass are typical examples of energy recycling systems. Biotechnology is one of the future-oriented technologies, and one that will play a major role in the exploitation of biomass energy. All biomass (plant, animal and microbial), originates through CO_2 fixation by photosynthesis. Biomass utilization is consequently included in the global carbon cycle of the biosphere. Biomass energy in developing countries, originates from fuelwood, animal wastes, and agricultural residues, and is primarily utilized for activities which are essential to survival, such as cooking and obtaining water. Improvements in the living standards in these countries will result in the non-essential use of energy. Development of technologies that efficiently produce biomass, and convert it to more convenient forms of energy is therefore very important.

1.2 Photosynthesis and biomass

1.2.1 Photosynthetic efficiency

Photosynthesis can be simply represented by the equation:

$CO_2 + H_2O$ + light !' 6 $(CH_2O) + O_2$

Approximately 114 kilocalories of free energy are stored in plant biomass for every mole of CO_2 fixed during photosynthesis. Solar radiation striking the earth on an annual basis is equivalent to 178,000 terawatts, i.e. 15,000 times that of current global energy consumption. Although photosynthetic energy capture is estimated to be ten times that of global annual energy consumption, only a small part of this solar radiation is used for photosynthesis. Approximately two thirds of the net global photosynthetic productivity worldwide is of terrestrial origin, while the remainder is produced mainly by phytoplankton (microalgae) in the oceans which cover approximately 70% of the total surface area of the earth. Since biomass originates from plant and algal photosynthesis, both terrestrial plants and microalgae are appropriate targets for scientific studies relevant to biomass energy production.

Any analysis of biomass energy production must consider the potential efficiency of the processes involved. Although photosynthesis is fundamental to the conversion of solar radiation into stored biomass energy, its theoretically achievable efficiency is limited both by the limited wavelength range applicable to photosynthesis, and the quantum requirements of the photosynthetic process. Only light within the wavelength range of 400 to 700 nm (photosynthetically active radiation, PAR) can be utilized by plants, effectively allowing only 45 % of total solar energy to be utilized for photosynthesis. Furthermore, fixation of one CO_2 molecule during photosynthesis, necessitates a quantum requirement of ten (or more), which results in a maximum utilization of only 25% of the PAR absorbed by the photosynthetic system. On the basis of these limitations, the theoretical maximum efficiency of solar energy conversion is approximately 11%. In practice, however, the magnitude of photosynthetic efficiency observed in the field, is further decreased by factors such as poor absorption of sunlight due to its reflection, respiration requirements of photosynthesis and the need for optimal solar radiation levels. The net result being an overall photosynthetic efficiency of between 3 and 6% of total solar radiation.

1.2.2 Biomass wastes and their conversion

Wastes and residues currently constitute a large source of biomass (1). These include solid and liquid municipal wastes, manure, lumber and pulp mill wastes, and forest and agricultural residues. With the exception of feedstocks of low water content, most of this biomass cannot be directly utilized, and must undergo some form of transformation, prior to being utilized as a fuel. Biological processes for the conversion of biomass to fuels include ethanol fermentation by yeast or bacteria, and methane production by microbial consortia under anaerobic conditions.

Wood wastes in the paper and pulp industries and bagasse from the sugar-cane industry are examples of biomass likely to accumulate at a single site. The cellulosic nature of these biomass materials, necessitates their hydrolysis to glucose, prior to ethanol fermentation. The net energy balance for the processes involved can, however, be problematic in that energy requirements for cellulose hydrolysis and distillation, must be lower than the energy in the output ethanol.

Unlike ethanol fermentation, anaerobic digestion for methane production, utilizes organic materials containing carbohydrates, lipids, and proteins. Many species of microbes work cooperatively in an anaerobic digester, in which these polymeric materials (i.e. carbohydrates, proteins and lipids) are first decomposed to organic acids, and then to hydrogen and carbon dioxide, from which methane is synthesized by methanogens. A variety of raw materials which include agricultural wastes, municipal solid wastes, market garbage, and waste water from food and fermentation industries, are applicable as substrates for this process. Waste products derived from animal husbandry are applicable to anaerobic digestion, with the added bonus of solving the environmental issues of unpleasant odors and eutrophication. Although small-scale digesters are popularly used at both the farm and village levels, large-scale operations are still in need of considerable technical improvement and cost reduction, and thus require both microbial and engineering studies.

Methane and ethanol can also be produced from cultured microalgal biomass through anaerobic digestion and microbial fermentation processes, respectively. The economics of fuel production from microalgal biomass is however largely dependent on a microalgal CO_2 fixation step similar to that required for the production of H_2 and algal oils.

1.2.3 Fuel production via microalgal CO2 fixation

One of the most serious environmental problems today is that of global warming, caused primarily by the heavy use of fossil fuels. In Japan, large amounts of CO_2 are released into the atmosphere from electric power plants and industry. The CO_2 generated by these large point sources could potentially be recovered with relative ease through the use of an established technology such as chemical absorption. The enormity of the amounts of potentially recoverable CO_2 would however necessitate the development of technologies for sequestering or, more favorably, utilizing this CO_2.

Photosynthetic microalgae are potential candidates for utilizing excessive amounts of CO_2, since when cultivated these organisms are capable of fixing CO_2 to produce energy and chemical compounds upon exposure to sunlight. The derivation of energy from algal biomass is an attractive concept in that unlike fossil fuels, algal biomass is rather uniformly distributed over much of the earth's surface, and its utilization would make no net contribution to increasing atmospheric CO_2 levels. Although algal biomass is regarded as a low-grade energy source owing to its high moisture content, through biological processes, it may be converted to modem gaseous and liquid fuels such as hydrogen, methane, ethanol, and oils.

Hydrogen is regarded as a potential energy source of the future, since it is easily converted to electricity and bums cleanly. Hydrogen is currently produced by fossil fuel-based processes which emit large amounts of CO_2, and relatively smaller amounts of other air pollutants such as sulphur dioxide and nitrogen oxides. Biological H_2 production has thus recently received renewed attention owing to urban air pollution and global warming concerns (2). Biological hydrogen production methodologies incorporating artificial reconstitution systems with chloroplast, ferredoxin, and hydrogenase; a heterocystous cyanobacterial system with oxygen scavengers; and an algal system in a day-and-night cycle, have been studied in

Japan. From an engineering point of view, however, bacterial fermentation mechanisms for hydrogen production under either dark or light conditions is currently of importance in terms of environmental issues and the utilization of organic wastes such as waste effluent of the food and fermentation industries, pre-treated sewage sludge, and market garbage.

The use of microalgae as sources of liquid fuels is an attractive proposition from the point of view that microalgae are photosynthetic renewable resources, are of a high lipid content, have faster growth rates than plant cells, and are capable of growth in saline waters which are unsuitable for agriculture. While the lipid content of microalgae, on a dry cellular weight basis varies between 20 and 40 %, lipid contents as high as 85 % have been reported for certain microalgal strains. *Botryococcus braunii,* is a unique microalgal strain, having a long-chain hydrocarbon content of between 30 and 40% (dry weight basis), which is directly extractable to yield crude oil substitutes. Both physical and chemical processes are applicable in the production of liquid fuels from algal strains of high lipid content. These processes include direct lipid extraction in the production of diesel-oil substitutes, transesterification in the formation of ester fuels, and hydrogenation in the production of hydrocarbons (3). Oily substances are also produced via liquefaction of microalgal biomass through thermochemical reactions under conditions of high pressure and temperature.

1.3 General problems

Among the biomass conversion processes discussed thus far, methane and ethanol production from various wastes is economically feasible within the restraints of scale and location. Although biological processes for the production of gaseous and liquid fuels have been well demonstrated with cultured microalgal biomass, these processes must still be integrated into a system capable of meeting basic requirements for overall efficiency of converting solar energy into biofuels. Furthermore, a model system must at least in principle, be capable of easy scale-up and not be limited by either engineering or economic factors. Under the current petroleum economy, prospects for the use of H_2 or oils produced by biological processes seem remote. However, future requirements for a "clean environment" necessitate fundamental research into microbial and algal physiology and genetics, together with basic engineering research on converters and total systems.

In its effort to address global warming and other environmental problems, the Research Institute of Innovative Technology for the Earth (RITE), engaged in investigating projects, including the Project for Biological CO_2 Fixation and Utilization, and the Project for Biological Production of Hydrogen Through The Use of Environmentally Acceptable Technologies was established by the Japanese Government in 1990. These projects employ researchers from both national institutes and private companies who are engaged in the research and development of technologies for microbiological CO_2 fixation and the production of hydrogen. At the same time, research efforts at the university level include biochemical and genetic studies on CO_2-fixing and H_2-producing enzymes, and the application of these enzymes to the development of more efficient energy systems.

The following Chapters, address biological and engineering aspects of alternative sustainable energy production, with emphasis on recent progress in four specific areas: (i) fuel alcohol production from cellulosic biomass, (ii) improved methane fermentation from industrial and agricultural residues, (iii) biological H_2 production from water and various wastes, and (iv) oil production through thermochemical liquefaction of microalgal biomass. The final Chapter outlines prospects for the future of renewable energy systems, although this is by no means a simple task, since problems concerned with energy, the environment, population, and food, are all interrelated.

References

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