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LIFE CYCLE ASSESSMENT OF PETROLEUM-BASED DIESEL FUEL AND BIODIESEL

FINAL SCOPING DOCUMENT

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1. PROJECT OVERVIEW

1.1 BACKGROUND

1.1.1 What is Biodiesel

For many centuries vegetable oils and animal fats have been used as fuels for lighting. In the early stages of development of the diesel engine one century ago, Rudolf Diesel tested vegetable oils as a fuel. In the 1930s and 1940s vegetable oils were occasionally used as diesel fuels, generally in emergency situations.[1] However, unmodified vegetable oils are glycerol esters, and when used in engines designed for petroleum diesel fuel, the glycerol poses engine wear and performance problems due to higher viscosities and lower volatility.[2]

To mitigate these problems a variety of processes have been researched and demonstrated for conversion of oil glycerides to molecular forms more similar to petroleum-based diesel fuels, including thermal and catalytic cracking, transesterification, and electrolysis.[1] The esters which result from transesterification processes have been given the generic name "biodiesel."[3]

Potential markets for biodiesel include both stationary power conversion (e.g., generators and pumps, particularly in developing country and agricultural applications) and a variety of transportation applications. Transportation applications have been demonstrated in a growing number of field demonstrations. The use of biodiesel in aquatic transportation applications has been suggested as a result of tests demonstrating that biodiesel fuels biodegrade relatively rapidly in aquatic environments.[4] A variety of biodiesels has been demonstrated in numerous road transport applications worldwide.[5] In the US alone, biodiesel has been tested in nearly eight million miles of use involving more than 1,500 vehicles in fleets, particularly in urban buses.[6] Much greater use of biodiesel occurs currently in Europe, where a methyl ester made from rapeseed oil receives near-total exemption from highway-use taxes in many EC countries.[7]

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[1] E. Griffin Shay, "Diesel Fuel from Vegetable Oils: Status and Opportunities," *Biomass and Bioenergy,* Vol. 4, No. 4, pp. 227-242, 1993.

[2] "Transesterification process converts vegetable oil, tallow to biodiesel." *Biomass Digest*, Vol. 2, No. 3, Western Regional Biomass Energy Program, Kansas State University, Spring 1993.

[3] Thomas Reed, "An Overview of the Current Status of Biodiesel," in *Proceedings, First Biomass Conference of the Americas*, August 1993, Burlington VT.

[4] X. Zhang et al., 1995, "Biodegradability of Biodiesel in the Aquatic Environment," presented at the 1995 ASAE Meeting, June 18-23, Chicago, IL, American Society of Agricultural Engineers, St. Joseph, MI, paper # 956742.

[5] See, for example, reference 1; also *Biofuels: Application of Biologically Derived Products as Fuels or Additives in Combustion Engines,* European Commission Directorate, Brussels, Belgium, 1994; Hemmerlein et al., "Performance, Exhaust Emissions and Durability of Modern Diesel Engines Running on Rapeseed Oil," SAE Technical Paper 910848, Society of Automotive Engineers, Warrendale, PA, 1991; and *Biodiesel: A Technology, Performance, and Regulatory Overview,* prepared for the National Biodiesel Board (NBB, formerly the National SoyDiesel Development Board), Jefferson City, MO, 1994.

[6] NBB 1994, *op. cit.*

[7] OICD, International Energy Agency, "Energy Prices and Taxes: 4th Quarter 1992," cited in NBB 1994.

1.1.2 Purpose of the Study

Several potential environmental benefits of biodiesel have been cited in the literature, including reduced (or zero) emissions of sulfur dioxide at the point of end-use, more rapid biodegradability in aquatic environments, and low or negative flows of carbon dioxide to the environment over the full product life cycle (when accounting for the CO_2 uptake during the feedstock growing stage).

However, the environmental aspects of using biodiesel vs. petroleum-based diesel fuel have not been comprehensively assessed. In fact, the ***full*** set of environmental aspects associated with a product such as a transportation fuel is very broad, both in terms of the environmental media or issues involved (including air emissions, water effluents, solid waste, toxicity, and the consumption/depletion of resources) and in terms of the scope of industrial processes involved, from production and extraction of raw materials, through intermediate conversion processes, transportation, distribution, and use. ***The purpose of the present study is to quantify and compare the comprehensive sets of environmental flows (to and from the environment) associated with both biodiesel and petroleum-based diesel, over their entire life cycles.***

1.1.3 Related Research

A European environmental life cycle assessment of rapeseed-derived biodiesel and petroleum diesel was recently completed.[8] A recent study examined the life cycle energy balance of soy-based biodiesel, including the steps of agriculture, extraction and refining, and esterification.[9] Another recent study compared the life cycle economic costs of biodiesel with those of petroleum diesel, methanol, and compressed natural gas (CNG), for application to a fleet of 300 urban buses.[10] An assessment of current commercial developments and the potential for biodiesel in the US, from the biodiesel perspective, is reported in a recent document produced for the National Biodiesel Board (formerly the National SoyDiesel Development Board).[11]

Biomass-derived ethanol, another plant-based transportation fuel alternative, has been the subject of considerable recent life cycle environmental and economic analysis as well. In 1993 three of the US Department of Energy's laboratories completed a life cycle comparison of biomass ethanol and reformulated gasoline.[12] There have also been a series of studies estimating the life cycle energy balance of ethanol derived from corn.[13] The most recent of these studies, by

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[8] Ecobalance-France (Ecobilan), *Ecobilan du Diester: Evaluation Comparee des Filieres Gazole et Diester,* ONIDOL, Paris, France.

[9] Ahmed, Decker, and Morris, *How Much Energy Does it Take to Make a Gallon of Soydiesel?* Institute for Local Self-Reliance, Washington DC, January 1994.

[10] Ahouissoussi, N.B.C, and M. Wetzstein, "Life-cycle costs of alternative fuels: is biodiesel cost competitive for urban buses?", in *Industrial Uses of Agricultural Materials: Situation and Outlook Report,* Economic Research Service, United States Department of Agriculture, publication IUS-5, September 1995.

[11] *Biodiesel: A Technology, Performance, and Regulatory Overview,* National Biodiesel Board, Jefferson City, Missouri, February 1994.

[12] *Fuel Cycle Evaluations of Biomass-Ethanol and Reformulated Gasoline,* NREL/TP-463-4950, by the National Renewable Energy Laboratory, Oak Ridge National Laboratory, and Pacific Northwest Laboratory, November 1993.

[13] Morris and Ahmed, *How Much Energy Does it Take to Make a Gallon of Ethanol?,* Institute for Local Self-Reliance, Washington DC, December 1992; see also four other studies since 1989, whose results are summarized on p.

researchers with the US Department of Agriculture's Economic Research Service, includes a review of this literature and summarizes the factors contributing to variability in published results and conclusions on this issue.

Finally, recent articles have summarized the status and prospects for biofuels from a broader perspective. Reed[14] and Shay[15] review the status and opportunities for biodiesel, the latter treating the subject more comprehensively and from a global perspective. The Commission of European Communities recently completed a survey of biofuel research and development, and the economic and environmental factors effecting biofuel's market potential in Europe.[16] A strategic perspective on renewable transportation fuels in the US was provided by Sheehan.[17]

To reiterate, the objective of the present study is to quantify and compare the comprehensive sets of environmental flows (to and from the environment) associated with both biodiesel and petroleum-based diesel, (including air emissions, water effluents, solid waste, toxicity, and the consumption/depletion of resources), over their entire life cycles, from production and extraction of raw materials, through intermediate conversion processes, transportation, distribution, and use. Life cycle *energy* consumption ("energy balance") is one (important) component of the more comprehensive scope of an environmental Life Cycle Analysis (LCA) such as undertaken in this study. Life Cycle Cost assessment (LCC) is outside the scope of the present study.

1.1.4 Stakeholder Involvement

A central ingredient of this project is the involvement of a broad group of interested stakeholders. Stakeholder involvement is important for several reasons. First, the results of a life cycle study such as this are strongly influenced by decisions made at the study outset, related to scoping, modeling, and methodology. Objectivity as well as acceptance of the results depend upon widespread critique and feedback from stakeholders on tentative scoping, modeling, and methodological decisions.

Second, the quality and utility of the study's results depend upon the use of data characterizing processes throughout the life cycles of *both* product alternatives (biodiesel and petroleum diesel) which are comprehensive, accurate, validly comparable, and up-to-date.

For both reasons, the formative and early stages of this project have included the involvement of an ever-widening set of stakeholders. In January of 1995, an industry/government working group was established around the topic of biodiesel. That group identified the importance of undertaking a comprehensive life cycle environmental analysis of biodiesel and petroleum diesel.

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3 of an additional study: Shapori, Duffield, and Graboski, *Estimating the Net Energy Balance of Corn Ethanol,* Economic Research Service, US Dept. of Agriculture, Report # 721, July 1995.

14 Thomas Reed, "An Overview of the Current Status of Biodiesel," in *Proceedings, First Biomass Conference of the Americas*, August 1993, Burlington VT.

15 E. Griffin Shay, "Diesel Fuel from Vegetable Oils: Status and Opportunities," *Biomass and Bioenergy,* Vol. 4, No. 4, pp. 227-242, 1993.

16 *Biofuels: Application of Biologically Derived Products as Fuels or Additives in Combustion Engines,* European Commission Directorate, Brussels, Belgium, 1994.

17 Sheehan, J., "Bioconversion for Production of Renewable Transportation Fuels in the United States," in *Enzymatic Conversion of Biomass for Fuels Production,* Himmel et al., eds., ACS Symposium Series No. 566, American Chemical Society, 1994.

Following the initiation of the project, an initial review of the scoping and modeling options for the study were presented in a kick-off meeting for this project held at the offices of the U.S. Department of Agriculture in Washington, D.C. in September of 1995. Background information on biodiesel and on life cycle analysis principles (the latter c.f. section 2.0 in this report) were also presented. Discussions at that meeting lead to an initial set of scoping and methodology recommendations which were summarized in the final section of a draft scoping document. That document was mailed, along with a request for review and comment, to over 100 stakeholders and interested parties, including representatives of both biodiesel and petroleum commercial interests, state, local, and federal government agencies, diesel fleet operators, government research laboratories, academic researchers, private consultants, and other interested members of industry.

Extensive and highly valuable comments were received from many of the scoping draft recipients. Their feedback has been incorporated into the present document. This final scoping document intends to communicate the initial project scoping decisions which are being made on the basis of these comments.

1.1.5 Purpose of the Scoping Document

This final version of the scoping document is intended to document and communicate the initial project scoping decisions which have been made in response to the series of stakeholder peer review processes described above. It is also intended to introduce the community of interested stakeholders to the life cycle assessment methodology which will be employed in this study. Further comment on the material presented here is invited from all interested stakeholders. The document will not be further revised or re-issued, but since the project is just now entering the analysis phase and some detailed scoping decisions remain open pending the analysis of further data, the potential to influence study parameters and approach remains. Stakeholder input to, and involvement in, subsequent stages of the project is therefore invited.

1.2 PROJECT PHASES

This project is jointly sponsored by the Department of Energy's National Renewable Energy Laboratory (NREL) Biofuels Systems Division, and the Department of Agriculture's Office of Energy and New Uses (OENU). The project is divided into four phases:

- **PHASE I**: ESTABLISH APPROACH TO LCA
  - Step 1: Collect Stakeholders Input on Study Scope and Goal
  - Step 2: Functional Unit and Project Boundaries
  - Step 3: Final Scoping Document for Biodiesel LCA

- **PHASE II**: DEVELOP A SUPPORTING DATA SET FOR LCA
  - Step 1: Obtain Data on Engine Emissions
  - Step 2: Obtain Data on Agricultural Aspect
  - Step 3: Obtain Data on Biodiesel Production
  - Step 4: Obtain Data on Petroleum Diesel
  - Step 5: Report on Biodiesel LCA Data Set

- **PHASE III**: CONDUCT LCA
  - Step 1: Set Software Tool for Biodiesel Analysis
  - Step 2: Generate Initial Results of LCA

- **PHASE IV**: FINALIZE RESULTS
  - Step 1: Collect Stakeholder Input on Initial LCA Results
  - Step 2: Finalize LCA Results
  - Step 3: Comprehensive Report on Biodiesel LCA
  - Step 4: Installation of the LCA Software Tool

Phase III of the project is scheduled for completion in June, 1996.

2. LIFE CYCLE ASSESSMENT PRINCIPLES

2.1 OVERVIEW

Life Cycle Assessment (LCA) is an analytical tool used to comprehensively quantify (and optionally to interpret) the environmental flows (to and from the environment, including air emissions, water effluents, solid waste, toxicity, and the consumption/depletion of energy and other resources), over the entire life cycle of a product or process. The life cycle is meant to be studied comprehensively as well, including production and extraction of raw materials, intermediate products manufacturing, transportation, distribution, use, and a final "end-of-life" stage which often includes multiple parallel paths such as recycling, incineration, landfilling, etc. This general principle for extending the system boundaries is illustrated in the figure below.

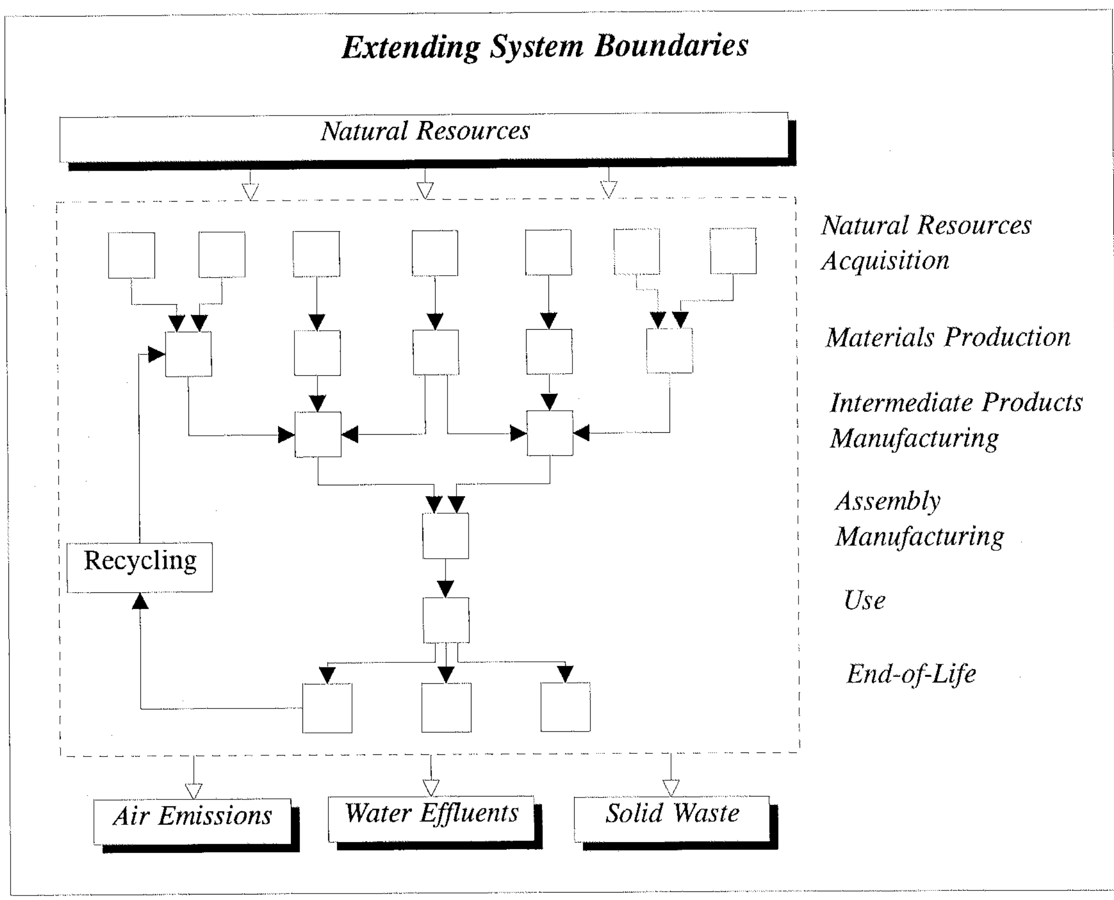

Figure 1: Life Cycle Analysis Principles

An LCA involves two main steps: (i) the *Inventory*, in which the material and energy inputs and outputs from the system under study are calculated; and (ii) the *Interpretation*. The methodology of Life Cycle Inventory (LCI) analysis is fairly standardized and well-agreed upon by its practitioners and users;[18] approaches to the interpretation step are much more varied.

In the most straightforward and transparent approach to LCI interpretation, the life cycle inventory results may be used ***as-is*** to help identify and prioritize opportunities for pollution prevention or increases in material and energy efficiency for processes within the life cycle. A particular advantage of LCI applied in this way is its comprehensiveness. Life cycle analyses help detect the shifting of environmental burdens from one life cycle stage to another (e.g., lower energy consumption during use, achieved at the cost of much higher manufacturing energy consumption), or from one media to another (e.g., lower air emissions at the cost of increased solid waste).

Because the resulting number of flows calculated during a life cycle inventory analysis often exceeds 100, subsets of the flows are sometimes consolidated or aggregated to facilitate interpretation, especially when two or more products or processes are being compared using life cycle analysis. This consolidation/aggregation of flows has been given the (perhaps misleading) name of Life Cycle Impact Assessment (LCIA). In fact, actual *impacts* of the environmental flows in the inventory are *not* estimated with LCIA. Instead, the inventory flows are consolidated and aggregated using information about their relative potential strength of influence with respect to separate categories of potential environmental impact. The results within each LCIA impact category are useful for *comparison* of one product or process versus another, but have little meaning in an absolute sense (i.e., relative to estimating the actual environmental impacts of a product or process).

Finally, because the results of an LCI and an LCIA are influenced by a significant number of assumptions and uncertainties, the interpretation phase should include some sensitivity analyses which assess the robustness of the baseline results and conclusions to potentially influential assumptions, methodological choices, future scenarios, and uncertainties.

Principal aspects of LCI and LCIA are discussed briefly in the sections which follow. Further information about Life Cycle Assessment methodology is provided in a number of publications from the Society of Environmental Toxicology and Chemistry (SETAC),[19] the US EPA,[20] as well as a variety of European sources.[21]

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[18] See, for example, SETAC, *A Technical Framework for Life-Cycle Assessments,* Society of Environmental Toxicology and Chemistry, Washington DC, January 1991.

[19] SETAC, *A Technical Framework for Life-Cycle Assessments,* Society of Environmental Toxicology and Chemistry, Washington DC, 1991; SETAC, *Guidelines for Life-Cycle Assessment: A "Code of Practice",* Society of Environmental Toxicology and Chemistry, Washington DC, 1993; SETAC, *A Conceptual Framework for Life-Cycle Impact Assessment,* Society of Environmental Toxicology and Chemistry, Washington DC, 1993; SETAC, *Life Cycle Assessment Data Quality: A Conceptual Framework,* Society of Environmental Toxicology and Chemistry, Washington DC, 1994.

[20] US Environmental Protection Agency, *Life Cycle Design Manual: Environmental Requirements and the Product System,* EPA/600/R-92/226, 1993; US Environmental Protection Agency, *Life-Cycle Assessment: Inventory Guidelines and Principles,* EPA/600-R-92-245, 1993; US Environmental Protection Agency, *Guidelines for Assessing the Quality of Life-Cycle Inventory Analysis,* EPA/530-R-95-010, 1995.

[21] See, for example, Heijungs, R., et al., eds, *Environmental Life Cycle Assessment of Products,* Center of Environmental Science, University of Leiden, Netherlands, 1992; and SETAC Europe, *Life-Cycle Assessment,* Society of Environmental Toxicology and Chemistry - Europe, Brussels, Belgium, 1992.

2.2 METHODOLOGY

2.2.1 Functional Unit

The comparison of different industrial systems can only be achieved if they perform the same function. Once this shared function is defined, a unit has to be chosen in order to compare the systems on the same quantitative basis. All the energy and mass flows in the inventory are normalized to this functional unit.

Examples of how this is done are presented below:

- The comparison of different indoor paints (solvent-borne, water-borne, etc.) would be made on the following basis:
    - *function*: covering a surface,
    - *functional unit*: the quantity of paint required to cover 10 square feet of wall (this function could be further refined to take into account secondary functions like opacity, washability, durability and lifetime, etc.).

- The comparison of different milk bottles (glass, plastics, etc.) would be made on the following basis:
    - *function*: packaging of liquids,
    - *functional unit*: packaging of one gallon of liquid.

2.2.2 Definition of the System Boundaries

For each option being compared on a life cycle basis, the corresponding systems are then determined (i.e., relevant processes to be included in the system are selected). The three main issues to address, for each of the systems, are:

(i) Exhaustivity of the systems. The LCA theoretical principle implies that *each* material and constituent be studied and traced *back* to natural resources, and *forward* through final disposal. The strict application of this principle would lead to the study of almost every industrial process, as all industrial operations work within a complex network.

In order to focus LCA projects on the main operations, quantitative rules are applied to exclude the constituents and ancillary materials whose impacts are estimated to be negligible compared to those of the overall studied system.

(ii) Identification of steps/operations that are different from one system to another. As the project focuses on a comparison, steps that are functionally equivalent for the compared products could be excluded from both systems. On the other hand, steps or operations which are not functionally equivalent for the compared products should be taken into account, i.e., included in the system boundaries.

(iii) Identification of coproducts and determination of the appropriate partitioning parameter, in order to allocate to a defined product its share of the total pollution, energy consumption and material flows for which the process is responsible. Such coproducts are the various cuts obtained during the refining process, as well as the agricultural coproducts.

2.2.3 Interpretation: Life Cycle Impact Assessment

In this section of the Life Cycle Assessment, after the Inventory has been prepared, there are two further steps which need to be considered:

- Whether and how to aggregate/consolidate the inventory data using information about each flow's relative potential strength of influence with respect to separate categories of potential environmental impact; and

- Whether and how to aggregate the results of the step mentioned above, *across* the impact categories considered.

Note that the first of these two steps is pursued *in addition* to the life cycle inventory analysis, not as a replacement for it. Note additionally that this step involves considerable uncertainties, which will be taken explicitly into account in this project, and the results will be presented as *ranges* rather than point estimates which would convey artificial precision. In instances where the results obtained in this step are extremely uncertain, these will not be included in the final report, to prevent subsequent mis-use of the results.

The second of these two aggregation steps is only used by those attempting to develop a final "score" for comparing products or processes. It will *not* be used in this project because it is fraught with numerous problems whose discussion is beyond the scope of this document.

3. PROJECT SCOPING OPTIONS AND CONCLUSIONS

This section presents the various parameters that should be considered in order to precisely define the scope of the project. These parameters can be addressed sequentially, as indicated in Figure 2. We begin by first considering "project" level parameters that involve high-level choices that can have profound impact on the general orientation and outcome of the project. These choices involve geographic, temporal, and technical aspects of the life cycle scenarios considered. Next, we need to consider more specific product parameters, including the exact nature and form of the products studied and the type of application in which they are used. The third group of parameters involves the production processes used to make the product. Both product and process-related parameters are influenced by the types of choices made for high level project parameters. Finally, there is a group of parameters that must be defined regarding the methodology of the LCA itself.

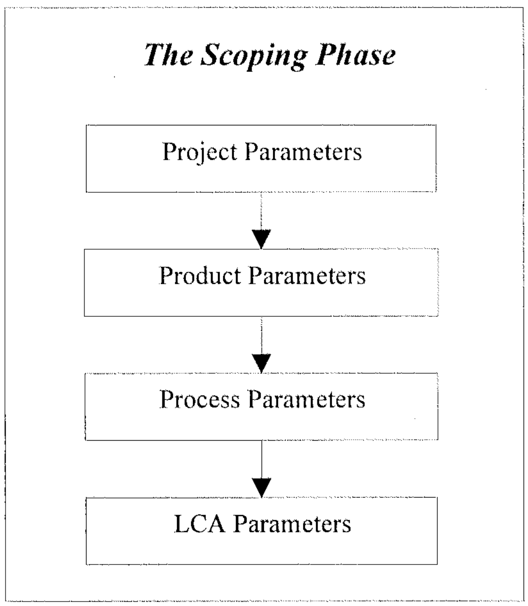

Figure 2: Elements of the Scoping Phase for Life Cycle Analysis

Subsequent sections address the separate scoping elements in turn, as follows:

Project Parameters	⇒	Section 3.1
Product Parameters	⇒	Section 3.2
Process Parameters	⇒	Section 3.3
LCA-Specific Parameters	⇒	Section 3.4

The key criteria which have been accounted for in selecting an option for each parameter are:

- relevance to the project's goals
- availability of data, and,
- time and cost constraints

3.1 PROJECT PARAMETERS

3.1.1 Geographical Scope

The focus of the project is, in generic terms, biodiesel and petroleum diesel applications in the US. However, the geographic scope of particular data items will pertain to whatever locations are dictated by actual plant locations, feedstock origins, sources of electricity, etc.

Oilseed Production Regions

The region emphasized for studying agricultural oilseed production will be the North Central region (central midwest and northern midwest). The table and plot below indicate that this region accounts for the bulk of US lands usable for this purpose. However, data characterizing the inputs to oilseed production in the other regions are also available (from the US Department of Agriculture), and the study will not *artificially* assume that all biodiesel feedstocks come from a single region of the country.

Region	*Percent of Total US Lands Capable of Growing Biomass Crops without Irrigation*[22]
North Central	57%
South Central	22%
Northeast	11%
Southeast	9%
Pacific Coast	1%
Rocky Mountains	< 1%

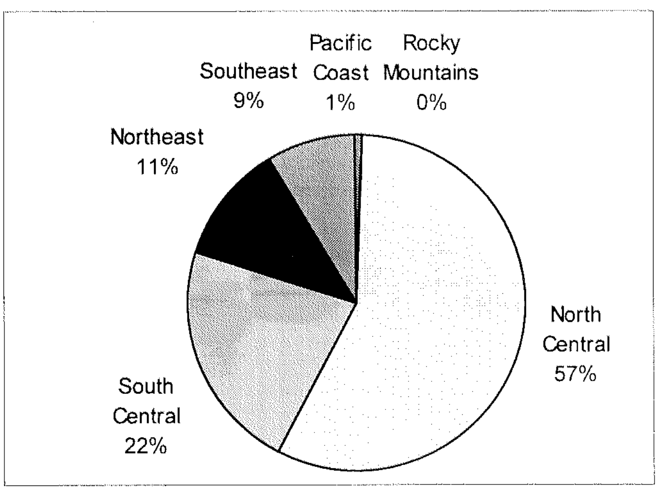

Figure 3: Regional Shares of Land for Growing Biomass Crops

[22] Source: US Department of Energy, National Renewable Energy Laboratory, *Biofuels for Transportation*, NREL/SP-420-5439, January 1995.

End-use Regions

Three representative end-use regions were identified for the study:

- West Coast (California)
- Northeast
- Midwest

Each of these regions will be modeled by selecting a specific urban area (see product parameter discussion below). Chicago is an ideal choice for the midwest given the participation of the City of Chicago in this study.

3.1.2 Temporal Scope

The issue here is whether to study a current situation or to model a future situation. Current and future scenarios for biodiesel could be quite different. For example, current scenarios would be limited to existing sources of vegetable and/or animal oils, while future scenarios might project the availability of new feedstocks or conversion processes. One stakeholder suggested studying a mid- to long-term time frame, noting that widespread use of biodiesel in the very near-term is not probable. However, the results of this study are data-driven, and the use of forecasted (rather than current, empirically-based) production, conversion, and end-use technology parameters would greatly increase the uncertainty in the final results.

Perhaps the most important issue relates to predicting engine performance and emission characteristics in the future. Related studies have concluded that a very large contributor to total life cycle air emissions is the combustion phase (fuel end-use); therefore, it is highly advisable to use accurate, empirical-based emissions data for the combustion phase instead of models.

For these reasons, a near-term time frame has been selected. Because of capital stock lifetimes, a study reflecting current technologies should remain relevant into the next decade. Also, a study of current end-use technologies based upon empirical data provides the most logical starting point for future projections or extrapolations.

3.2 PRODUCT PARAMETERS

3.2.1 Application

The application parameters proposed for the study include the following:

- Use of biodiesel in urban buses
- Fleet use only (a consequence of the previous assumption)
- engine-specific comparisons

It is important to limit the product application scope to a single application. As discussed in several of the references cited in section 1, there appear to be a number of viable niche applications for biodiesel in the near term. The selection of urban buses is not an indication necessarily that this is the best or only option for biodiesel market penetration. However, transit bus applications are among the most heavily-studied biodiesel applications in the US to date, making them best-characterized by empirical data. The choice of urban buses leads to a focus on cities within each region, rather than on the entire regions themselves, and makes usage parameters well-defined, with available data. Fleet use establishes the use of central fueling in the modeling.

Engine-specific comparisons of the two fuel alternatives (biodiesel and petroleum diesel) is highly important. Data on engine performance for diesel and biodiesel have shown considerable variability in emissions and performance characteristics among different engine designs. Therefore, comparisons must pertain to a given engine, and must clearly state the engines to which the results correspond.

The Detroit Diesel 6V92 series is an engine for which a great deal of data on diesel and biodiesel are available. Also, the 6V92 is a staple of the bus market. Thus, it will be one of the engines included in the study. However, because of the variability in emissions and performance among engines, *all transit bus engines for which reliable emissions test data are available for both fuels will be included in the study*. The sensitivity of project final results to engine type will be analyzed and reported.

3.2.2 Fuels Studied

The petroleum diesel studied will be low sulfur #2 diesel. As long as data are provided by the petroleum industry (for example, the American Petroleum Institute), the study will use average actual properties of low sulfur #2 diesel, rather than specifications for the fuel.

Among biodiesel blend ratios, 20% and 30% biodiesel fractions have been by far the most extensively studied. The National Biodiesel Board further has determined that these two blend ratios span the optimum range for near-term commercialization in non-niche transportation markets.[23] A 20% biodiesel blend ("BD-20," containing 80% low-sulfur #2 diesel) is selected as the baseline for this study. If adequate end-use performance data is available for transit bus engines using an alternative 30% or 35% biodiesel blend, such an alternative blend will be examined in a sensitivity analysis, and compared with the baseline results for BD-20. The final report will also attempt to summarize the extent to which particular results parameters do or do not vary in a predictable (e.g., linear) fashion as a function of blend ratio.

3.2.3 Functional Unit

End-use emissions data are generally available in terms of grams of emissions per brake-horsepower-hour (g/bhp-hr), as the result of standardized EPA transient cycle testing procedures, designed to characterize average speed and load cycles in use. Therefore, the functional unit to be used in this study will be brake-horsepower-hour. By using this functional unit, the life cycle assessment will compare the two fuels in terms of actually-delivered energy from combustion within real engines under tests designed to reflect realistic operating conditions.

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[23] *Biodiesel: A Technology, Performance, and Regulatory Overview,* National Biodiesel Board, Jefferson City, Mossouri, February 1994.

3.3 Process Parameters

These parameters are strongly affected by the choices made on the previous project-related and product-related parameters.

The assumption of current technology bases for all process leads to a number of conclusions about fuel production and feedstock supplies. The primary feedstock for biodiesel production will be soybeans. The table and chart below present US 1994 production of edible fats and oils. Because production fluctuates from year to year, also shown are five-year production averages for the period 1990-1994. The data clearly show soybeans to be the dominant oilseed source in the US at present. In addition, nearly all recent and current US testing of biodiesel pertains to soy-based biodiesel. These considerations *do not* mean that soy is the most economically or environmentally promising vegetable/animal oil source for biodiesel. They simply indicate why, when a particular oil source must be selected for this study, soy has been selected. The sensitivity of the project results to the choice of other oil sources will be an important topic for subsequent research.

Oil Source	***1994 US Production*** *(million pounds of oil)*	***Avg. 1990-1994 Production*** *(million pounds of oil)*
Corn	2200	1892
Cottonseed	1275	1193
Lard	1075	1001
Peanut	327	279
Canola (Rapeseed)	334	167
Safflower	103	90
Soybean	15487	14194
Sunflower	1103	772
Tallow: edible	1605	1506

Source: *Oil Crops: Situation and Outlook Report,* USDA Economic Research Service, OCS-1995, July 1995, p. 21.

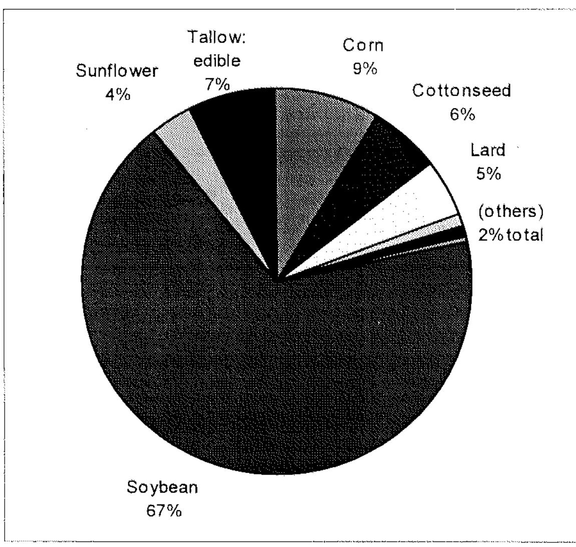

Figure 4: Shares of US Edible Fat and Oil Production: 1990-1994 Average

USDA data characterizing the chemical, land, energy, water and other inputs to soybean production in the US will be used to establish current performance characteristics for soybean production and harvesting. Sources and distribution of soybean oil will be identified for each region studied. Available end-use data on soy-derived biodiesel is based on refined oils. The report will clearly state the state-of-science relating to the issue of whether the refining step, which adds processing impacts, is a necessary part of biodiesel production. If it is found that omission of the refining step is a technical possibility at present or in the near term, the project and report will also include analysis which tests the sensitivity of the final results to the omission of the refining step.

Production of biodiesel is assumed to be based on transesterification processes. Methyl ester production will be assumed, given that there is more production and end-use data available for methyl ester than for ethyl ester.

Feedstock for petroleum diesel is crude oil produced domestically and imported from foreign countries. Data characterizing the split between foreign and domestic crude oil supplies to diesel fuel production will be used, with regional differences taken into account if supported by data.

3.4 LCA-Specific Parameters

3.4.1 Allocation Rules

The production of both biodiesel and petroleum-based diesel fuel generates other products (various refining cuts, cattle feed, glycerol, etc.), which are recovered and used in other product systems. They are considered as co-products. The problem is the apportioning or allocating of energy resources, raw materials, pollutants, etc. from the common production steps to between the product studied (fuels) and the co-products.

Inputs and outputs of the common steps can be partitioned across the co-products on various bases, including (for example):[24]

- Mass
- Dry mass
- Energy content
- Economic value
- Reduced production of alternative

The last approach, *substitution-based* or *scenario-based* modeling of co-products, calls for the environmental burdens associated with alternate production of the co-product to be subtracted from the studied system. The selection of the allocation rule (which might differ from co-product to co-product) will be documented in the final report. However, since there is no ideal rule *per se*, sensitivity analyses will be carried out on the use of different allocation rules in order to report a wider range of possible results.

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3.4.2 Accounting for CO_2 Uptake and Agricultural Impacts

Much of the content in carbon (C) of the biomass portion of the biodiesel is derived from the CO_2 absorbed by plants while growing (photosynthesis). These carbon atoms are released at the end of life of the products, in CO_2, CO, hydrocarbons or CH_4 molecules, during biodiesel combustion. The CO_2 releases are offset by the CO_2 uptake or sequestering during plant growth. In order to ease the interpretation phase, a distinction between net CO_2 emissions from the production of biomass products and from the combustion of biomass products and CO_2 emissions from the combustion of fossil fuels will be made. The CO_2 uptake by plants will be accounted for as a credit.

Also, to the maximum extent supportable by reliable data, modeling of the agricultural system will include the use, production, and fates of chemicals used including fertilizers, herbicides, etc. It will also account for the acreage of land used to produce a functional unit of biodiesel, and particular reliably-documented impacts on the soil (beneficial or otherwise) associated with crop cultivation and harvesting.

3.4.3 Results Interpretation

The following steps will be used to facilitate interpretation of the inventory results:

- CLASSIFICATION: The organization of inventory data into environmental impact and resource consumption categories, such as ozone layer depletion, radiative forcing, acidification, eutrophication, natural resource depletion, etc.

- CHARACTERIZATION: Weighted summing of inventory data within each environmental impact category, based upon each flow's *relative* strength of *potential* influence upon the identified environmental impact or effect. Thus, for ozone layer depletion, each flow with the potential to reduce stratospheric ozone is converted to an estimated effect-equivalent amount of a reference chemical (such as CFC-11), and the resulting flows (expressed in "grams of CFC-11-equivalents") are summed.[25]

The characterization step will take explicit account of the latest scientific assessments of the *uncertainty* inherent in the equivalency factors, such as Global Warming Potentials and Ozone Depletion Potentials. In addition, the discussion accompanying the characterization results will clearly state that the results of a characterization analysis serve strictly to normalize the multiple flows within the life cycle inventory with respect to a particular environmental issue (e.g., ozone depletion) in terms of their *relative strength* of *potential* contribution to that issue. Characterization *is not* in any way intended to estimate the actual impact of the emissions upon environmental issues (e.g, actual damage to the ozone layer in the stratosphere).

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[25] Further details concerning the characterization step, for many of the most commonly-studied environmental impact categories, are provided in chapters 3 and 4 of Heijungs, R., et al., eds, *Environmental Life Cycle Assessment of Products,* Center of Environmental Science, University of Leiden, Netherlands, 1992.

Further, some of the inventory flows themselves may be highly uncertain, with an estimable magnitude of uncertainty. For example, emissions of N_2O from the cultivation of soybeans may be only estimable to within an order of magnitude. This uncertainty will be appropriately combined with the uncertainty inherent the equivalency factors used in the characterization step. In cases where the final uncertainty of the characterized results for a particular impact category is extreme, the results will not be included in the final report, in order to prevent subsequent misuse of highly uncertain information.

3.5 SUMMARY OF SCOPING DECISIONS AND APPROACHES

The following table summarizes the scoping decisions and approaches to be used in this project, which were described in the previous sections 3.1 through 3.4.

Summary of Scoping Decisions and Approaches

Element	*Parameter Type*	*Decision or Approach*
Project	Spatial	• Fuel production: actual feedstock origin • Fuel use: 3 cities: Northeast, Midwest, California
	Temporal	Near-term
Product	Application	• Urban bus • Fleet (central refueling) • Engine: Detroit Diesel 6V92, others as data permit
	Fuel	• Actual, not specification • Petroleum: #2 low-sulfur diesel • Biodiesel: 20% biodiesel, 80% #2 low-sulfur
	Functional Unit	Brake horsepower-hour
Process	Biomass	• Oilseed feedstock : soybean • Conversion: transesterification • Ester type: methyl
	Petroleum	• Feedstock: domestic plus imports • Refining: current processes
LCA	Co-product Allocation	Various (mass-, energy-based, etc.) w/ sensitivity analysis
	Agricultural Modeling	Include inputs, impacts, and CO_2 uptake
	Interpretation	• Classification and characterization • Uncertainty propagation • Omit extremely uncertain results from final report