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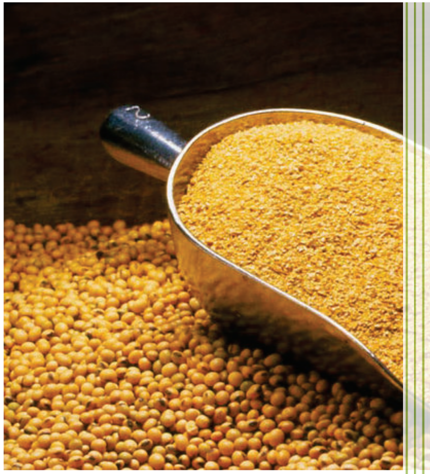
Life Cycle Assessment of U.S. Soybeans, Soybean Meal, and Soy Oil



Prepared For:
United Soybean Board
and the
National Oilseed Processors Association

January 2024

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Commissioned by the United Soybean Board and the National Oilseed Processors Association

LCA Practitioner: Sustainable Solutions Corporation

Prepared for:

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Conducted according to ISO 14040 and ISO 14044 International Standards

Life Cycle Assessment of U.S. Soybeans, Soybean Meal, and Soy Oil

Executive Summary

Life cycle assessment (LCA) is a rigorous study of the inputs and outputs of a particular product or product system which provides a scientific basis for evaluating the environmental impacts through each phase of the life cycle. LCA is an alternative to the single-criterion decision-making that currently guides many environmental choices.

This LCA is designed to be used by the United Soybean Board (USB) and the National Oilseed Processors Association (NOPA) to better understand the current state and environmental impact of the U.S. soybean industry's farming, processing, and oil refining operations. This report documents the methodology, data, details, and results of the LCA on the impacts of one kilogram (kg) of soybeans, one kilogram (kg) of soybean meal, one kilogram (kg) of crude soy oil, and one kilogram (kg) of refined soy oil produced in the United States. Primary data were obtained from direct information sources electronically collected from farmers and processors, with the assistance of USB and NOPA staff. Secondary data were obtained from the U.S. Department of Agriculture (USDA), U.S. Lifecycle Inventory (USLCI), and Ecoinvent databases.

Findings in this study provide a snapshot of industry performance based on acquired primary data from USB and NOPA members in support of this assessment:

- **Soybean cultivation data reflect 454 farms across 16 states.**
- **Soybean meal, crude soy oil, and refined soy oil data reflect 52 U.S. soybean processing plants and 27 co-located soy oil refineries operating across 18 states.**

Key Findings

Based on 2020 - 2021 harvesting yields reported by U.S. soybean farmers and 2021 operations and production data for U.S. soybean processing plants and co-located soy oil refiners as reported by NOPA members, **the global warming potential (GWP) profile decreased considerably for all evaluated U.S. soy commodities** compared to previously reported findings published in 2015 and 2010.

U.S. Soybeans, Soybean Meal & Soy Oil GWP Profile Reductions Since 2015

- 19% per kg U.S. soybeans
- 6% per kg U.S. soybean meal
- 22% per kg U.S. crude soy oil
    - 8% per kg U.S refined soy oil (produded at co-located processing/refining cites)

Previous life cycle assessments were commissioned by USB in collaboration with NOPA, each prepared and evaluated by different LCA practitioners. Data for oilseed processing operations was not formally collected as part of the 2015 assessment.*

Findings presented in this LCA show that herbicides, field operations, and fertilizer are the main drivers of most environmental impact categories assessed for soybean cultivation. **This analysis assumes an average production yield of 51 bushels per acre harvested, based on USDA estimates.** The percentages that each soybean agriculture component contributes to each impact category are shown in Table 0.1.

Table 0.1 – Agriculture Component Contributors by Impact Category

Impact Category	Field Operations	Fertilizer	Fungicide	Herbicide	Insecticide
Global Warming Potential	38.58%	24.37%	1.30%	31.92%	3.83%
Fossil Fuel Depletion	30.25%	27.82%	1.38%	36.61%	3.94%
Eutrophication	0.93%	90.69%	0.06%	8.08%	0.24%
Smog	51.00%	26.41%	0.58%	20.13%	1.87%
Acidification	28.81%	28.95%	1.09%	37.83%	3.32%
Ozone Depletion	5.92%	29.88%	2.22%	55.19%	6.80%
Carcinogenics	10.52%	51.12%	0.25%	37.06%	1.05%
Non-Carcinogenics	2.95%	22.71%	0.10%	7.68%	66.55%
Respiratory Effects	13.94%	42.22%	0.83%	40.51%	2.51%
Ecotoxicity	0.58%	4.73%	0.17%	36.48%	58.03%
Land Use	98.87%	0.57%	0.03%	0.42%	0.10%
Water Consumption	90.85%	5.99%	0.02%	2.92%	0.21%
Cumulative Energy Demand	25.44%	23.73%	1.78%	43.72%	5.33%

Soybean cultivation and harvesting, followed by energy usage in processing, are the main drivers of all impacts from soybean meal and soybean oil production. During processing, soybeans are

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* The 2015 LCA study relied on NOPA member data for 50 processing plants based on previously reported data used for the 2010 study. In preparing the processing operations data used for the 2015 study, NOPA members reviewed the 2010 dataset and elected to revise only the electricity use input value. As such, the 2015 dataset reported the weighted average value instead of the upper bound value which was used for the 2010 study. This change was made so that the input value better reflected typical operating conditions at a soybean processing plant.

responsible for approximately 65% of the crude soy oil and soybean meal cradle-to-gate impacts, while energy usage is responsible for approximately 32%, depending on the impact category.

To account for the high amount of variability in agricultural practices, a range of sensitivity studies were conducted to evaluate the validity of the results and their dependence on the assumptions made throughout the LCA. The specific studies focused on:

- *Harvest yields* – testing the extent to which lower (41 bushels per acre, past yields) or higher (61 bushels per acre, average high yields) harvest yield assumptions affect impacts. Impact results at the lower and upper bound of the soybean yields show a 20% change over the baseline case (51 bushels per acre, average yield used in this study).

- *Diesel* – testing the sensitivity of results to the amount of diesel used during soybean farming. The baseline of 1.4 gallons of diesel per acre was compared to 2.5 gallons per acre, 5 gallons per acre, and 6 gallons per acre. Most categories remained constant or showed a small (1% - 5%) to moderate (5% - 21%) increase in impacts. Smog, however, showed significant increase in impacts (20% - 90% increase for soybeans, 17% - 70% for crude soy oil and soybean meal, and 12% - 52% increase for refined soy oil) due to the chemical reactions that occur when diesel is combusted.

- *Allocation method* – testing how utilizing economic allocation or energy content allocation instead of mass allocation affects environmental impacts attributed to each product. Since four times more meal is produced than oil, meal will always have a higher percentage of the impacts. However, results show that the gap between their respective shares of impacts decreases with economic and energy content allocations: 20% oil / 80% meal for mass allocation, 33% oil / 67% meal for allocation by energy content, and 41% oil / 59% meal for economic allocation.

Sensitivity analysis is a tool used in LCA to identify whether the model and results are dependent upon assumptions made. Assumptions and uncertainties are inherent within LCA and cannot be avoided; however, sensitivity analyses allow the practitioner to validate the strength of the assumptions used in a study. The results of the various sensitivity analyses show that for certain impact categories, there can be significant deviation in the results based on the assumptions made.

The sensitivity analyses conducted focused on the assumptions that would have the largest impact on the LCI (i.e., method of allocation and yield per acre). Both assumptions are integrally intertwined with all the LCI calculations, therefore, variation in these assumptions is expected to cause significant deviations. These assumptions were developed through primary data collection, expert validation, and research into industry common practices. As such, these assumptions have been determined to be the most accurate way to represent the soy industry in the United States.

Acknowledgements

Sustainable Solutions Corporation (SSC) gratefully acknowledges John Jansen and Jack Cornell from USB, Lauren Maul from Smith Bucklin, and Katie Vassalli from NOPA for their significant support and contributions throughout this project. They provided domain expertise on soybean agriculture and soybean processing, led surveys, and provided accurate primary data.

Additionally, SSC, along with USB and NOPA, would like to thank all the U.S. soybean growers and soybean crushers who provided valuable facility operations data and shared their institutional

knowledge about soybean farming, processing, and oil refining operations to ensure the high quality of this study.

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1.0 Introduction

Life cycle assessment (LCA) is a powerful tool used to quantify the environmental impacts associated with the various stages of a product's life. This section provides a background and overview of LCA methodology and benefits.

1.1 Background

Soybean is a major commodity crop. Global production went from less than 50 million tons in the year 1970 to 161 million tons in the year 2000 and over 350 million tons in the year 2020. The U.S. and Brazil alone account for two-thirds of this production, with the U.S. being the largest producer and second largest exporter of soybeans. Soybeans comprise about 90% of U.S. oilseed production in the agricultural sector.

The use of LCA is growing rapidly in many industries including agriculture, food, chemical, and fuel. To support this growth and the increased demand for environmental profiles like carbon footprints, the United Soybean Board (USB) and the National Oilseed Processors Association (NOPA) commissioned an update to their life cycle assessment. This report is designed to benchmark the global warming potential of U.S. soybeans, soybean meal, and soy oil to help U.S. producers better assess and understand their contribution to the environmental impacts of U.S. soy lifecycle from farm gate (soybeans) to factory gate (soybean meal and soy oil). Findings of this study may also be used to evaluate what changes in industry practices may have contributed to the observed reductions between the data collection years (e.g. 2021, 2015 and 2010).

These datasets provided by USB and NOPA members will further be used to update public life cycle inventory database (e.g. U.S. GREET Model, Federal LCA Commons) for these commodities. These data may also be used to update LCA profiles of downstream products such as human foods, animal feeds, biofuels, and other industrial applications. This LCA is valuable to USB as a tool for competitive positioning.

1.2 Overview of Life Cycle Assessment

Life Cycle Assessment (LCA)[2] is an analytical tool used to comprehensively quantify and interpret the environmental flows to and from the environment (including emissions to air, water, and land, as well as the consumption of energy and other material resources) over the entire life cycle of a product (or process or service). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product and an accurate picture of the true environmental tradeoffs in product selection.

The standards in the ISO 14040-series set out a four-phase methodology framework for completing an LCA, as shown in Figure 1.1: (1) goal and scope definition; (2) life cycle inventory

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[2] This introduction is based on international standards in the ISO-14040 series, *Environmental Management – Life Cycle Assessment.*

(LCI); (3) life cycle impact assessment; and (4) interpretation. An LCA starts with an explicit statement of the goal and scope of the study; the functional unit; the system boundaries; the assumptions, limitations and allocation methods used; and the impact categories chosen. In the inventory analysis, a flow model of the technical system is constructed using data on inputs and outputs. The input and output data needed for the construction of the model are collected (including resources, energy requirements, emissions to air and water, and waste generation for all activities within the system boundaries). Then, the environmental loads of the system are calculated and related to the functional unit, to finalize the flow model. Inventory analysis is followed by impact assessment, where the LCI data are characterized in terms of their potential environmental impact (e.g., acidification, eutrophication, and global warming potential effects). The impact assessment phase of LCA is used to evaluate the significance of potential environmental impacts based on the LCI results. The impact assessment data are interpreted and validated by sensitivity analysis performed by the LCA practitioner to provide useful data to the company that commissioned the LCA.

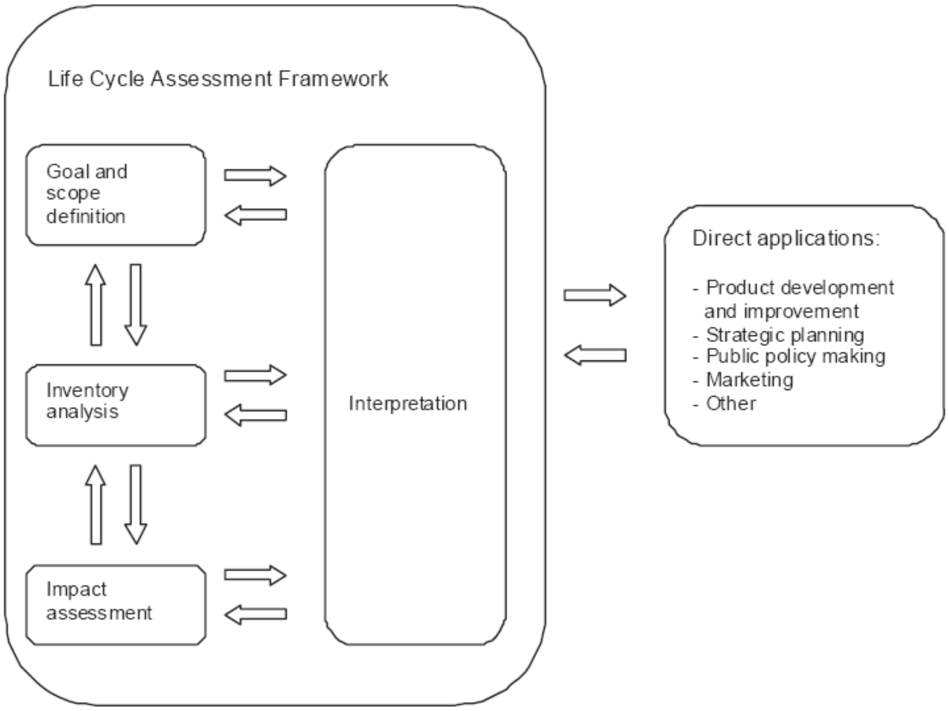


Figure 1.1 – The Four Stages of Life Cycle Assessment

The working procedure of LCA is iterative, as illustrated with the back-and-forth arrows in Figure 1.1. The iteration means that information gathered in a later stage can cause effects in a former stage. When this occurs, the former stage and the following stages must be reworked, taking into account the new information. Therefore, it is common for an LCA practitioner to work at several stages at the same time.

This LCA study is characterized as a “cradle-to-gate” study examining soybean cultivation and processing from raw material extraction through the processing facility gate. For this life cycle assessment, Sustainable Solutions Corporation (SSC) collected specific data on energy and material inputs, wastes, water use, emissions, and transportation impacts for the cultivation and processing of soybeans in the United States for the calendar year 2021. This LCA was conducted using SimaPro software with the National Renewable Energy Lab (NREL) USLCI database serving as the primary source of life cycle inventory data for secondary raw materials and processes. Where data were not available in the USLCI database, data from the Ecoinvent LCI database, private SSC LCI databases, and published reports were used. Data from any European databases were adapted using U.S. electricity impacts. The TRACI 2.1 impact assessment methodology was used to calculate the environmental impacts in this LCA. TRACI was developed by the U.S. Environmental Protection Agency (EPA) as a tool to assist in impact analysis in Life Cycle Assessments, process design, and pollution prevention. Impact categories include:

1. Global Warming Potential
2. Acidification
3. Carcinogens
4. Non-Carcinogens
5. Respiratory Effects
6. Eutrophication
7. Ozone Depletion
8. Ecotoxicity
9. Smog
10. Fossil Fuel Depletion
11. Water Consumption
12. Land Use
13. Cumulative Energy Demand

2.0 Goal and Scope Definition

The nature of life cycle assessment is to include a wide range of inputs associated with the product analyzed. Constraining the LCA scope is an essential part of the study. The following section defines the goal, scope, and boundaries of this LCA study.

This LCA went through a formal critical review by Marty Heller, AgResilience Consulting, LLC in January of 2024, as is required by ISO 14040 Standards for external release. The study was conducted following appropriate ISO standards and best practices and is intended to assist USB and NOPA with understanding the life cycle impacts of their products.

2.1 Goal of the Study

The goal of this analysis is to identify and quantify the environmental impacts associated with each stage in the cradle-to-gate life cycle of soybeans, soybean meal, crude soy oil, and refined soy oil, including soybean cultivation and harvesting, transportation, and processing.

USB and NOPA partnered together initially in 2010 to complete a similar analysis to ascertain the environmental impacts of soybeans, soybean meal, crude soy oil, and refined soy oil. In 2015, a second analysis was performed. For this study, NOPA members reviewed the 2010 LCA dataset and updated certain values to reflect a weighted average value. NOPA members concluded that this revision to the dataset was required in order to better represent the actual operating conditions required for soybean processing. See Appendix A for a detailed historical comparison of the results.

Intended Uses

LCA is a tool that can effectively be applied for process improvements, education and market support, environmental management, and sustainable reporting. USB and NOPA, who are the primary audience of the study, intend to use the study results for the following purposes:

- To understand and evaluate the impacts of soybeans, soybean meal, crude soy oil, and refined soy oil across the products' life cycle.
- To prepare for sustainable supply chain requirements, carbon taxes, and other potential policy requirements.
- For competitive analysis and positioning to analyze and evaluate claims or LCA information published in the future by competing industries.
- As a basis for future publication of a soybean, soybean meal, crude soy oil, and refined soy oil LCA if required by the market or if desired by USB and NOPA for marketing or competitive purposes.
- As a tool to illustrate the reduced environmental impacts to regulatory agencies (such as state/local environmental agencies or U.S. EPA) of agricultural practice, process, facility, or raw material improvements.
- To meet future requirements for green purchasing programs for the U.S. government, corporations, or other businesses.

2.2 Functional Unit

All flows to and from the environment within the system boundary (see Section 2.3 below) are normalized to a unit summarizing the function of the system. The functions of soybeans, soybean meal, crude soy oil, and refined soy oil are to be used in food manufacturing, biodiesel production, and industrial production.

Once the primary functions of the systems are defined, a functional unit is selected in order to provide a similar basis, consistent with the above-mentioned goals, for summarizing the LCA. The functional units utilized for this study are one kilogram (kg) of each product. This functional unit is consistent with the goal and scope of the study. Table 2.1 list specific details of soybeans, soy oil, and soybean meal.

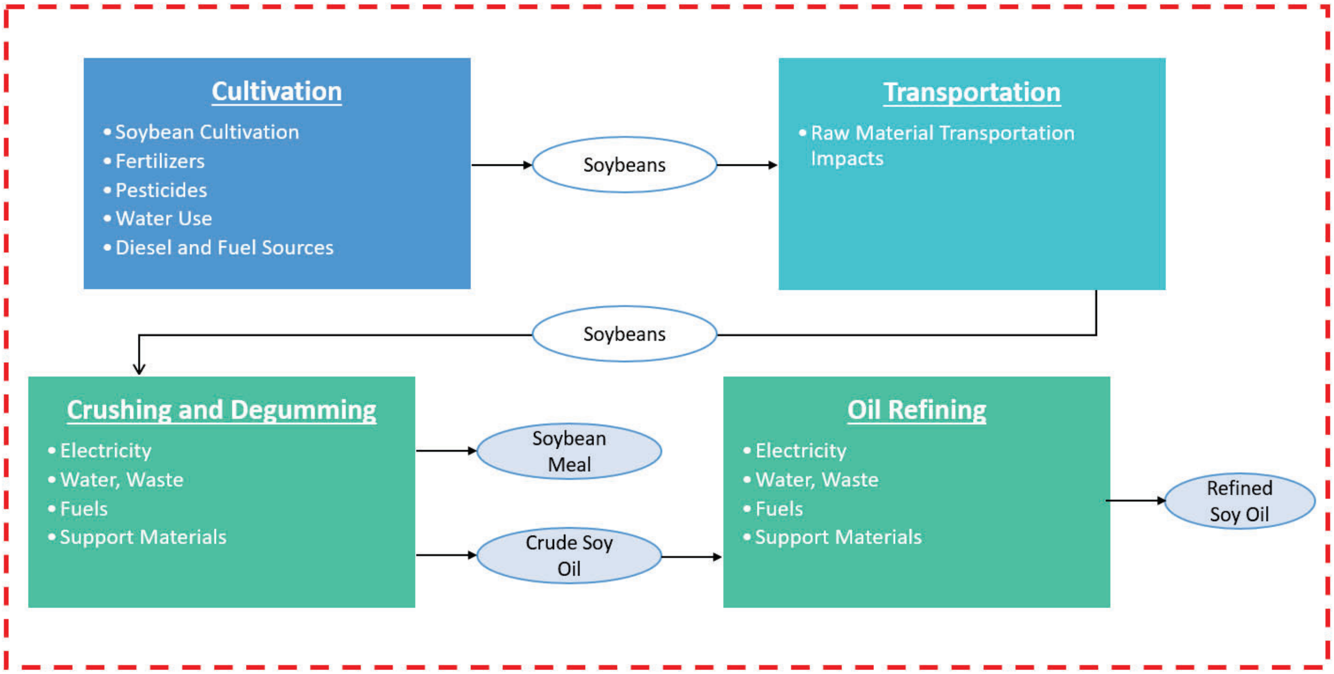
Table 2.1 – Soybeans, Soybean Meal, Crude Soy Oil, and Refined Soy Oil Product Details

	Soybeans	Soybean Meal	Crude Soy Oil	Refined Soy Oil
Processing Location	United States	United States	United States	United States
Functional Unit	1 kg of soybeans	1 kg of soybean meal	1 kg of crude soy oil	1 kg of refined soy oil
Weight	1 kg	1 kg	1 kg	1 kg

The functional unit is the basis for reporting in an LCA. It provides a unit of analysis and comparison for all environmental impacts. Both crude soy oil and soybean meal are produced simultaneously. This required the allocation of impacts between the meal and the oil. Mass allocation was selected in order to remain consistent with previous studies.

2.3 System Boundary

This project considers the life cycle activities from resource extraction through processing facility gate. Figure 2.1 defines the system boundary for soybeans and soybean products included in this study. The study system boundary includes the transportation of major inputs to (and within) each activity, based on logistics data provided by USB and NOPA by common modes. Any site-generated energy and purchased electricity is included in the system boundary. The extraction, processing and delivery of purchased primary fuels, e.g., natural gas and primary fuels used to generate purchased electricity, are also included within the boundaries of the system. Purchased electricity consumed at the various site locations is modeled based on U.S. grid averages, using the models published in the USLCI and Ecoinvent cut-off databases.



Cultivation

- Soybean Cultivation
- Fertilizers
- Pesticides
- Water Use
- Diesel and Fuel Sources

Transportation

- Raw Material Transportation Impacts

Crushing and Degumming

- Electricity
- Water, Waste
- Fuels
- Support Materials

Oil Refining

- Electricity
- Water, Waste
- Fuels
- Support Materials

Figure 2.1 – System Boundary for Soybeans, Soybean Meal, Crude Soy Oil, and Refined Soy Oil

Both human activity and capital equipment were excluded from the system boundary. The environmental effects of manufacturing and installing capital equipment and buildings have generally been shown to be minor relative to the throughput of materials and components over the useful lives of the buildings and equipment. Human activity involved in the cultivation and processing of soybean products and their component materials no doubt has a burden on the environment; however, the data collection required to properly quantify human involvement is particularly complicated and allocating such flows to the production of the soybean products, as opposed to other societal activities, was not feasible for a study of this nature. Typically, human activity is only considered within the system boundary when value-added judgments or substituting capital for labor decisions are considered to be within the scope of the study; however, these types of decisions are outside this study's goal and scope. The details of the data excluded from the system boundary can be found in the subsequent inventory sections.

Table 2.2 – System Boundary Description

Included	Excluded
• Soybean cultivation, harvesting, and agricultural waste • Soybean transportation to processing facilities • Energy and inputs for soybean processing (the crushing and degumming process) • Energy and inputs in oil refining process	• Construction of capital equipment • Transportation of chemicals applied in fields • Maintenance of operation and support equipment • Human labor and employee commute

2.3.1 Cut-off Criteria

Processes whose total contribution to the final result, with respect to their mass and in relation to all considered impact categories, is less than 1% can be neglected. The sum of the neglected processes may not exceed 5% by mass and by 5% of the considered impact categories. For that a documented assumption is admissible.

For Hazardous Substances, as defined by the U.S. Occupational Health and Safety Act, the following requirements apply:

- The Life Cycle Inventory (LCI) of hazardous substances will be included if the inventory is available.
- If the LCI for a hazardous substance is not available, the substance will appear as an input in the LCI of the product if its mass represents more than 0.1% of the product composition.
- If the LCI of a hazardous substance is approximated by modeling another substance, documentation will be provided.

This LCA complies with the cut-off criteria since no known processes were neglected or excluded from this analysis outside of the specific items listed under "Excluded" in Table 2.2.

3.0 Data Sources and Modeling Software

The quality of the results of an LCA study are directly dependent on the quality of input data used in the model. This section describes the data quality guidelines used in this study, the sources from which the data were selected, the software used to model the environmental impacts, and any data excluded from the scope of the study.

3.1 Data Quality

3.1.1 Primary Data

Primary data were obtained from direct information sources electronically collected from farmers and processors with the assistance of USB and NOPA staff.

Soybean Cultivation Data

An online survey performed by USB in partnership with OBP, a marketing firm for agriculture, tourism, and food provided soybean cultivation primary data. Farmers were asked about soybean yield and moisture content, how much was spent on electricity and natural gas, fuel usage, waste produced, soil health, water quality related practices, and conversion of acres. 454 U.S. soybean farmers across 16 states completed the survey providing data for 2020 and 2021.

Soybean Processing and Soy Oil Refining Data

Primary data for soybean processing were based on NOPA member company responses to an electronic data collection survey performed by NOPA in partnership with SSC and Clean Fuels Alliance America. NOPA member-owned companies were asked to provide facility data about the transportation of inputs, processing and refining inputs/outputs, energy usage, and related sources.

For this study, NOPA provided SSC with aggregated data based on survey responses for 11 NOPA member companies, representing a total of 52 soybean processing plants and 27 co-located soy oil refineries operating across 18 states.

NOPA member facility data were submitted for calendar year 2021 NOPA Member Soybean Processing Operations based on analysis of aggregated NOPA member facility data. Individual facility data was anonymized and aggregated, then validated by NOPA’s Certified Public Accountant. Analysis of the aggregated data was conducted by NOPA’s Environmental Advisory Group prior to submission to SSC.

3.1.2 Secondary Data

Secondary data were obtained from USDA, USLCI and Ecoinvent databases. Where used, this study adopts critically reviewed data for consistency, precision, and reproducibility to limit uncertainty. Secondary data sources used are complete and representative of the U.S. in terms of the geographic and technological coverage and are a recent vintage (i.e., less than ten years old). Datasets that utilized data that were more than ten years old were updated with more recent data when possible. Secondary datasets used from the USLCI database utilize mass or energy allocation (process dependent) and datasets from the Ecoinvent database utilize economic or energy allocation. The allocation methodology implemented in secondary datasets is not always consistent with the allocation methodology used in this LCA study; however, those datasets represent the most appropriate options for the inventory.

Deviations from these initial data quality requirements for secondary data are documented in the report, found in Appendix B.

3.1.3 Data Quality Factors

The results of an LCA are only as good as the quality of input data used. Important data quality factors include precision (measured, calculated, or estimated), completeness (e.g., unreported emissions or excluded flows), consistency (uniformity of the applied methodology throughout the study), and reproducibility (ability for another researcher reproduce the results based on the methodological information provided). The primary data collected from USB and NOPA members were from the latest data available. Secondary datasets were taken from SimaPro databases, either USLCI or Ecoinvent. These databases are widely distributed and referenced within the LCA community and are either partially or fully critically reviewed.

Precision

There is a wide variability of farming, and this study attempts to capture this breadth of farming practices. The precision for primary data for processors is considered high; however, the uncertainty of the primary data has not been quantified. While the uncertainty of the primary data was not directly quantified, steps were taken to ensure the datasets were appropriate for use in the study. These steps included data validation with USB and NOPA personnel, data comparison to the previous U.S. Soybean LCAs, and evaluation against data published by credible sources, most notably the USDA survey database. More information on these steps can be found in the *Consistency* section.

Secondary data sets were used for raw materials extraction and processing, end of life, transportation, and energy production flows. The Ecoinvent database was used for most of the raw material data sets, such as chemical applications and fuels. Since the inventory flows for Ecoinvent processes are very often accompanied by a series of data quality ratings, a general indication of precision can be inferred. Using these ratings, the data sets used generally have medium-to-high precision. Precision for the datasets used from the USLCI database was not formally quantified. However, many data sets from the USLCI were developed based on well-documented industry averages with data quality indicators provided for each flow.

Completeness

The processes modeled represent the specific situations in the soybeans' cradle-to-gate life cycle. Data were evaluated for completeness to ensure that all relevant inventory items that were above the required reporting threshold, per the cut-off criteria, were included. System boundaries and exclusions are clearly defined in the sections above, and no other data gaps were identified.

Consistency

Farming survey data represented soy production for 2020 and 2021. Primary soybean cultivation data were obtained through a survey that was filled out by 454 soybean farmers across 16 states in the U.S. Soybean farms below 300 acres were excluded along with three outliers, establishing a sample size of 377 farms. Operations below 300 acres were determined to not be representative of the common U.S. cultivation practices based on discussions with industry experts. These smaller scale operations have much lower production volumes than larger ones and tend to utilize more unconventional cultivation methods due to the flexibility of managing lower volumes. These unconventional methods were excluded as they were expected to cause inaccurate reductions of environmental impacts, based on efficiencies of managing lower volumes, that do not correctly represent the U.S. soybean industry's common cultivation practices.

Individual farming survey responses were summed at the state level, for each inventory input and output, and benchmarked using the sum of total production at the state level, to calculate a state average LCI based on the interests of USB. A weighted average based on total production of individual states, relative to the total U.S. production calculated from the farm surveys, was used to develop the U.S. average LCI. Non-responses and zero values were included in the average when the majority of questions were answered by the respondent but were otherwise excluded. A statistical analysis of key energy inputs is presented in Table 3.1. The mean depicts the average of all survey respondents, while the weighted mean (i.e., state-level production-weighted average) captures the LCI values found in Table 5.1 on a per acre basis.

In the NOPA data, four outliers were examined to ensure that their exclusion would not alter or distort the results of the study and removed from the data as appropriate. Two outliers were found in the crushing and degumming process and two were found in the oil refining stage. Since the data represented a reasonable sample size over a 12-month period under normal operating conditions, the consistency is considered high. Secondary data were modeled using either USLCI or Ecoinvent databases as available. Proxies were only identified and used if secondary data were not available in these or other databases. This methodology provided consistency throughout the model.

Table 3.1 – Statistical Analysis of Survey Energy Data

Input	Unit	Weighted Mean	Mean	Minimum	Maximum	Standard Deviation	Coefficient of Variation
Electricity	MJ/acre	8.47E+01	6.38E+01	2.12E-02	9.00E+02	1.01E+02	119%
Natural Gas	MJ/acre	1.78E+02	2.66E+02	1.75E-01	8.68E+03	7.53E+02	423%
Diesel	gal/acre	5.15E-01	7.79E-01	1.00E-05	2.56E+01	2.44E+00	474%
Gasoline	gal/acre	8.12E-02	1.22E-01	1.18E-05	4.26E+00	4.56E-01	562%

Methodological consistencies between the previous studies were intentionally kept similar where relevant and appropriate to ensure a level of comparability exists between studies. This was done so that USB and NOPA could use this study internally to evaluate the effect of operational changes that have been implemented geared towards regulatory compliance in environmental impacts, increasing reliability, lowering costs, and improving sustainability.

Reproducibility

Most datasets are from nationally accepted and publicly available databases, ensuring reproducibility by an average practitioner. Confidential data from the plant would inhibit reproducing these results without access to the data.

Representativeness

The representativeness of the datasets is chosen to be for the United States, capturing average technologies of the major producers and distributors. Soybean processing and refining has data for a significant and highly representative fraction of producers. The average soybean acreage harvested in 2020 and 2021 was 84,457,500 acres. The total soybean acreage of the 377 farms that met the inclusion criteria was 378,592 acres, meaning the survey responses utilized in this study accounted for 0.45% of the total soybean acreage harvested in the U.S. between 2020 and 2021. However, soybean agriculture data are deemed to be representative of the average farming conditions stemming from the key U.S. geographies. Of the farming survey respondents, 39% are from the “I” states (Iowa, Illinois and Indiana), which correlates strongly with the states regarded as most relevant to soybean production.

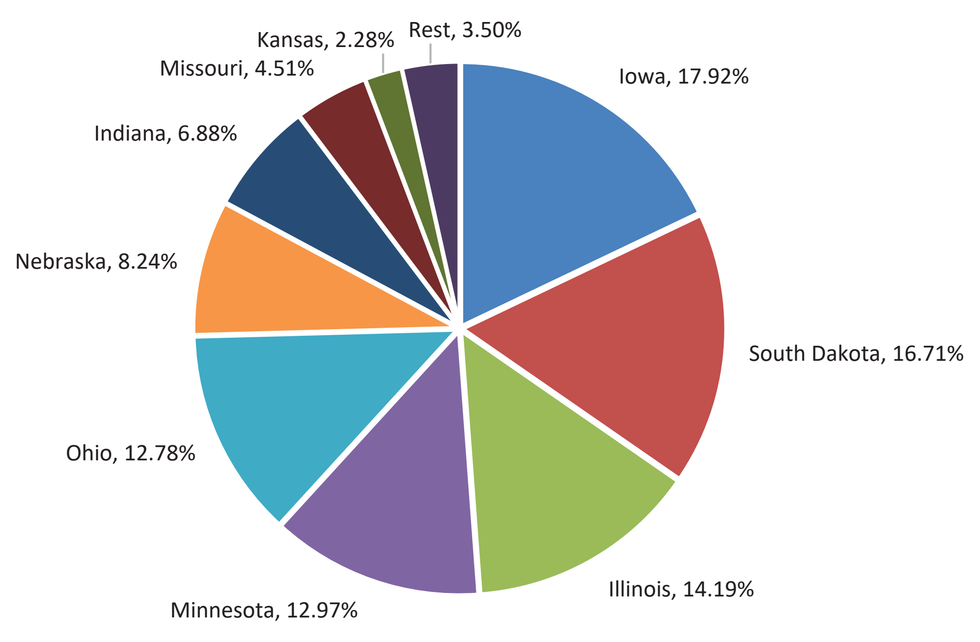


Figure 3.1 – Location of Farming Survey Respondents

Uncertainty

Uncertainty for primary energy data collected through the farming survey were quantified through statistical analysis. The collected data and allocation methodologies were determined to be accurate by USB and NOPA personnel based on the common industry practices, however, individual farming practices can vary widely due to a number of variables, so the range of input variables can vary significantly as shown in Table 3.1. Most of the secondary data sets in USLCI and Ecoinvent databases have some uncertainty information documented and varies per model.

The primary data from the manufacturer were from the latest data available, incorporating the most recent updates to the process into the model. Each dataset used was taken from SimaPro databases, either USLCI or Ecoinvent. These databases are widely distributed and referenced within the LCA community. The datasets use relevant yearly averages of primary industry data or primary information sources of the manufacturers and technologies. The uncertainty of each dataset is not formally quantitatively known. Each dataset is from publicly available databases, ensuring reproducibility. The datasets chosen are representative of the United States average technologies of the major producers and distributors and of recent and modern vintage. Below is a more detailed description of the datasets used in the model of raw materials extraction and processing for the major components of soybean cultivation and processing and refining of soy oil and soybean meal.

3.2 Data Sources

The United States is considered as the geographic boundary of this study. The reference year is 2021 since the primary soybean cultivation and processing data were gathered for that calendar year. Both primary and secondary LCI and metadata are used throughout the study.

3.2.1 Soybean Cultivation

Primary soybean cultivation data were obtained through a survey conducted by an independent third party in March of 2022. The third-party survey was focused on obtaining primary data from U.S. soybean farmers in order to accurately capture the practices used in U.S. soybean cultivation. Approximately 60,000 soybean farmers across the US were invited to participate in the survey by sharing data related to their growing metrics during the 2020 and 2021 growing seasons. The metrics of interest included yield; moisture content; spend on electricity, natural gas, and fuel; and volume of different types of waste produced. Of the participants invited, 454 soybean farmers spanning 16 different US states completed the survey. SSC determined that the states that responded to the survey represent an average approximation of U.S. soybean cultivation based on discussions with industry experts. Ranges in acreage, average yield per acre, and average moisture content were used to validate the discussions with industry experts. Data collected in the survey included the harvest acreage of alternate and cover crops. Soybeans are commonly grown in rotation with crops such as corn, wheat, and other crops in order to capture some of the operational benefits that exist utilizing this method. As such, the field operation inventory was allocated to soybean cultivation based on total harvest acreage.

During the data analytics process, SSC removed outliers from the utilized survey data by excluding data that could be deemed erroneous or irrelevant. An example of an erroneous data point is a response that indicated a yield of more than 100 bushels of soybeans per acre. An example of an irrelevant data point is a response from an operation with less than the minimum size which could accurately be classified as an “average” U.S. soybean operation. This number was determined to be 300 total acres. Operations below 300 acres were determined to not be representative of the common U.S. cultivation practices based on discussions with industry experts; and as such, these operations were excluded to focus the study on larger production practices.

Once outliers were removed from the dataset, the individual farming survey responses were summed at the state level, for each inventory input and output, and benchmarked using the sum of total production at the state level, to calculate a state average LCI based on the interests of USB. A weighted average based on total production of individual states, relative to the total U.S. production calculated from the farm surveys, was used to develop the U.S. average LCI on a 1 kg of soybean basis.

3.2.2 Soybean Processing

Data on primary soybean processing of soybean meal, crude soy oil, and refined soy oil were provided by NOPA, based on data gathered from 52 (crushing and degumming) facilities and 27 (oil refining) co-located facilities. All secondary data are taken from literature, previous LCI studies, and USDA and life cycle databases. The USLCI database (www.nrel.gov/lci) is frequently used in this analysis. Much of the LCI data residing in the USLCI database pertain to common fuels – their combustion in utility, stationary and mobile equipment inclusive of upstream or pre-combustion effects (i.e., raw material extraction). Generally, these modular data are of a recent vintage (less than ten years old). This study draws on these data for combustion processes, electricity generation, and transportation on a regional United States basis. These data are free and publicly available, and thus, offer both a high degree of transparency and an ability to replicate the results of the study; however, there are limitations, as some processes are missing for some of the products available in this LCI database, creating an issue with respect to completeness.

When United States data were not available for a product or process, North American or European Ecoinvent LCI database was utilized. This database contains over 3,500 LCI modules for processes and products, all of which have undergone peer review. The basic assumption when using these data is that North American and European production processes are generally similar to the United States, but that these data need to be adapted for United States circumstances (e.g., electricity grids, fuels and transportation modes and distances need to be modified to better reflect the United States operations). Such adaptation was conducted whenever necessary.

3.3 Modeling Software

SimaPro v9.2.0.2 software was utilized for modeling the complete cradle-to-gate LCIs for soybean agriculture, soybean meal, crude soy oil, and refined oil. All process data including inputs (raw materials, energy, and water) and outputs (emissions, wastewater, solid waste, and final products) are evaluated and modeled to represent each process that contributes to the life cycle of soybean products. The study's geographical and technological coverage has been limited to the United States. SimaPro was used to generate life cycle impact assessment (LCIA) results utilizing the TRACI impact assessment methodologies as well as single impact assessments (Global Warming Potential and Cumulative Energy Demand). See Section 4.1 for a description of the selected LCIA categories and characterization measures used in this study.

4.0 Life Cycle Impact Assessment (LCIA)

The environmental impacts of a product can be categorized and presented in many ways. This section briefly describes the methodology used to develop the impact assessment and defines the selected impact categories used to present the results. This section also lists assumptions of the study and describes the inherent limitations and uncertainty of the LCA results.

4.1 Impact Categories/Impact Assessment

As defined in ISO 14040:2006, "the impact assessment phase of an LCA is aimed at evaluating the significance of potential impacts using the results of the LCI analysis." In the LCIA phase, SSC modeled a set of selected environmental issues referred to as impact categories and used category indicators to evaluate the magnitude and significance of the potential environmental impacts. These category indicators are intended to "characterize" the relevant environmental flows for each environmental issue category to represent the potential or possible environmental impacts of a product system. The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risk.

ISO 14044 does not specify any specific methodology or support the underlying value choices used to group the impact categories. The value-choices and judgments within the grouping procedures are the sole responsibilities of the commissioner of the study.

The framework surrounding LCIA includes three steps that convert LCI results to category indicator results. These include the following:

1. Selection of impact categories, category indicators, and models.
2. Assignment of the LCI results to the impact categories (classification) – the identification of individual inventory flow results contributing to each selected impact indictor.

3. Calculation of category indicator results (characterization) – the actual calculation of the potential or possible impact of a set of inventory flows identified in the previous classification step.

To maximize the reliability and flexibility of the results, SSC used an established impact methodology for assigning and calculating impacts. The Tools for Reduction and Assessment of Chemical and other environmental Impacts (TRACI) methodology was used for all calculations of environmental impact. TRACI was developed by the U.S. EPA to assist in impact analysis in Life Cycle Assessments, process design, and pollution prevention.

4.2 Selected Impact Categories

While LCI practice holds to a consistent methodology, the LCIA phase is an evolving science and there is no overall generally accepted methodology for calculating all of the impact categories that might be included in an LCIA. Typically, the LCIA is completed in isolation of the LCI. The LCI involves the collection of a complete mass and energy balance for each unit process under consideration. Once completed, the LCI flows are sifted through various possible LCIA indicator methods and categories to determine possible impacts. Due to the United States focus of this LCA study, SSC used the TRACI LCIA methodology to characterize the study's LCI flows. Impact categories include:

1. *Ozone Depletion* (kg CFC-11 eq) – Certain chemicals, when released into the atmosphere, can cause depletion of the stratospheric ozone layer, which protects the Earth and its inhabitants from ultraviolet radiation. This radiation can have a negative impact on crops, materials, and marine life, as well as contributing to cancer and cataracts. This impact measures the release of those chemicals.
2. *Global Warming* (kg CO_2 eq) [IPCC AR5] – The methodology and science behind the Global Warming Potential calculation can be considered one of the most accepted LCIA categories. Because this study also tracks an overall life cycle carbon balance, the carbon dioxide emissions associated with biomass combustion are included in the Global Warming Potential calculation per the Intergovernmental Panel on Climate Change (IPCC) methodology. Carbon dioxide and other greenhouse gases are emitted at every stage in the life cycle. These gases can trap heat close to the Earth, and the global warming potential attempts to express the radiative forces of these different gasses and their contribution to global warming relative to the effect of carbon dioxide.
3. *Smog* (kg O_3 eq) – Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation. While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NOx). The Smog indicator is expressed as a mass of equivalent ozone (O_3).

4. *Acidification* (moles SO_2 eq) – Acidification is a more regional rather than global impact affecting fresh water and forests as well as human health when high concentrations of SO_2 (and other chemical compounds) are attained. Acidification is a result of processes that contribute to increased acidity of water and soil systems, frequently through air emissions that contribute to acid rain. The largest contributors to acid rain are sulfur dioxide and nitrogen oxide. The acidification potential of an air emission is calculated relative to the acidification produced by SO_2 molecules; and therefore is expressed as potential SO_2 equivalents on a mass basis.
5. *Eutrophication* (kg N eq) – Eutrophication is the fertilization of surface waters by nutrients that were previously scarce. When a previously scarce or limiting nutrient is added to a water body, it leads to the proliferation of aquatic photosynthetic plant life. This may lead to the water body becoming hypoxic, eventually causing the death of fish and other aquatic life. Contributions from both nitrogen and phosphorus nutrient emissions are included in this indicator. This impact is expressed on an equivalent mass of nitrogen (N) basis.
6. *Human Health: Carcinogens* (CTU_h) – This impact assesses the potential health impacts of more than 200 chemicals. These are average general health impacts, based on emissions from the various life cycle stages, and do not take into account increased exposure that may take place in manufacturing facilities or on farms. These impacts are expressed in terms of Comparative Toxic Units (CTU_h). For human health this represents the estimated increase in morbidity in the total human population per kg of chemical emitted.
7. *Human Health: Non-Carcinogens* (CTU_h) – This impact assesses the potential health impacts of more than 200 chemicals. These health impacts are general, based on emissions from the various life cycle stages, and do not take into account increased exposure that may take place in manufacturing facilities. These impacts are expressed in terms of Comparative Toxic Units (CTU_h). For human health this represents the estimated increase in morbidity in the total human population per kg of chemical emitted.
8. *Respiratory Effects* (kg $PM_{2.5}$ eq) – This impact methodology assesses the potential impact of increasing concentrations of particulates on human health, as well as emissions that may contribute to particulate matter formation. Most industrial and transportation processes create emissions of very small particles which can damage lungs and lead to disease and shortened lifespans. This impact is expressed in terms of $PM_{2.5}$ (particulates that are 2.5 microns or less in diameter).
9. *Ecotoxicity* (CTU_e) – Many chemicals, when released into the environment, can cause damage to individual species and to the overall health of an ecosystem. Ecotoxicity measures the potential damage to the ecosystem that would result from releasing that chemical into the environment. This impact is measured in terms of Comparative Toxic Units (CTUe) and provides an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of chemical emitted.

10. *Fossil Fuel Depletion (MJ surplus)* – Maintaining fossil fuel resources for future generations is an essential part of sustainable development. This impact category measures the depletion of those resources in terms of megajoules (MJ). Fossil fuels are used as energy sources as well as raw materials for chemical production.
11. *Land Use* (m^2a crop eq) [ReCiPe] – Development of uninhabited land has been a major focus in the sustainable development industry, especially in the agricultural sector, where developing for socio-economic gain often results in long-lasting changes to the soil. This impact category primarily measures the impact of the occupation of land on terrestrial species by change of land cover and actual use of new land. The impact assessment also accounts for some transformation of land from pre-existing ecosystems. Land use characterizes intensities in terms of the equivalent square meters of annual cropland land use. There are various characterization factors for different land use types; including transformation, occupation, and relaxation.
12. *Water Consumption* (m^3) [ReCiPe] – Freshwater consumption is a growing concern in the global sustainability community because the freshwater resource available on the planet has been rapidly depleted over the past century. This indicator quantifies the removal of water from the watershed such that it is not available for use by other users. This impact category reports the inventory of water consumption that the process requires, in terms of cubic meters.
13. *Cumulative Energy Demand* (MJ) – This impact methodology assesses the total energy consumed throughout the life cycle. Cumulative energy demand is the sum of all energy sources drawn directly from the earth, such as natural gas, oil, coal, biomass, hydropower energy, and more. It takes into account all upstream and downstream processes and calculates the energy demand during different stages in the life cycle. This is an important impact category as higher energy demand translates to higher environmental impact. This impact category can help identify areas for improving and optimizing energy efficiency.

While the TRACI methodology supports fossil fuel depletion (on a global scale), it does not readily report primary energy use as an impact category. Primary energy use on a cumulative energy demand basis is tabulated and summarized as an impact category based on the LCI flows. Energy use is a key impact indicator over which soybean farmers and soybean meal and oil producers are likely to assert a considerable level of control and, therefore, is a good internal target for resource conservation. Cumulative energy demand is the sum of all energy sources drawn directly from the earth, such as natural gas, oil, coal, biomass, or hydropower energy. The total primary energy contains further categories, namely non-renewable, renewable, and feedstock energy. Yield is another key indicator where soybean farmers have some control, and it plays a significant role in determining the average environmental impacts of each functional unit. Additionally, farmers can focus their efforts on optimizing other agricultural inputs, such as fertilizers and herbicides, to maximize their impact reduction while reducing costs.

5.0 Soybean Production

5.1 Important Assumptions

Life cycle analysis requires that assumptions are made to constrain the project boundary or model processes when little to no data are available. In this study of soybeans, the following assumptions were made:

- Data from the survey are complete and representative of the U.S. average farming practice based on the methodology outlined in Section 3.2.
- Data collected in the survey included the harvest acreage of alternate and cover crops. Soybeans are commonly grown in rotation with crops such as corn, wheat, and other crops in order to capture some of the operational benefits that exist utilizing this method. As such, the field operation inventory was allocated to soybean cultivation based on total harvest acreage.
- USDA data were used for fertilizers & pesticides. Survey data were collected for yield but then it was decided to use USDA data for yield to maintain a conservative value for yield and remain in alignment with the USDA data used for field applications.
- Nitrate and phosphorus emissions were modeled following existing soybean models, which obtained their information from the USDA digital commons project. Emissions rates were calculated in alignment with the IPCC methodology for managed soils.[3] Dinitrogen monoxide emissions from anthropogenic nitrogen conversion were calculated as 1.11 kilograms per hectare, using the IPCC methodology for managed soils.
    - The calculation methodology included accounting for tier 1 direct and indirect emissions from synthetic fertilizer, manure, crop resides, and nitrogen fixation.
- When a material is not available in the available LCI databases, another chemical which has similar manufacturing and environmental impacts may be used as a proxy to represent the actual chemical. The Proxy Chemical List used in this analysis includes:
    - Alachlor as a proxy for acetochlor.
    - Pesticides without Ecoinvent background data and representing a minority fraction of material inputs were aggregated and proxied as generic pesticides.

5.2 Life Cycle Inventory

A thorough analysis of the material inputs and the product recipe was completed for the inventory of this study. The soybean cultivation inputs are listed in Table 5.1 below.

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[3] IPCC N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application

This section describes the cradle-to-gate life cycle inventory of soybeans.

Primary data on field operations for 2020 and 2021 were collected from surveys completed by U.S. soybean farmers. Secondary data on fertilizer use were obtained from the USDA 2020 census. A detailed analysis of the cultivation process was completed by SSC to understand soybean farming practices.

The process starts when soybean seeds are planted in the spring once soil temperature reaches sufficiently warm temperatures, typically in early spring. The type of seed depends on the location, as different soybean types are better suited to different climates and growing conditions. Water, fertilizers, and pesticides are used in custom quantities to help maximize yields without wasting resources. As soybean plants grow throughout the year, eventually their flowers turn into pods containing 1 - 4 seeds each. The soybeans are ready to harvest in the fall. In some countries, like Brazil, the warm climate allows for a second harvest in a year, but the U.S. is limited due to its cold winters. However, double cropping is practiced in some states in the South and southern Midwest, where winter wheat is planted in the fall and harvested in the spring. A variety of technologies are used by farmers throughout the process for everything from planting, irrigation, and fertilizing to harvesting.

Field operations data on electricity, fuel, and waste are based on survey responses from U.S. farmers. Of the respondents, 377 had soybean operations exceeding 300 acres and were included in the dataset. Production-weighted averages based on state-level production share were used to calculate the lifecycle inventory. The lifecycle inventory is based on an average yield of 51 bushels of soybeans per acre.

Soybean cultivation is modeled within LCA by considering energy, water, and materials which go into the field and waste and emissions that are outputs from the agricultural process.

Table 5.1 – U.S. Average Soybean Cultivation Inputs

Category	Product Recipe	Unit	Quantity per kg of Soybeans
Field Operations	Electricity	MJ	6.10E-02
	Natural Gas	MJ	1.28E-01
	Diesel	MJ	1.69E-01
	Gasoline	MJ	9.60E-02
	Propane	MJ	2.60E-02
	Water	m^3	4.18E-02
Fungicides	Picoxystrobin	kg	4.51E-05
	Pyraclostrobin	kg	3.95E-05
	Azoxystrobin	kg	3.69E-05

Category	Product Recipe	Unit	Quantity per kg of Soybeans
	Propiconazole	kg	3.43E-05
	Mefentrifluconazole	kg	3.33E-05
	All Other Fungicides	kg	1.70E-04
Herbicides	Glyphosate	kg	1.75E-03
	Dicamba	kg	1.06E-03
	Metolachlor	kg	1.04E-03
	Atrazine	kg	8.70E-04
	Acetochlor	kg	3.58E-04
	All Other Herbicides	kg	2.72E-03
Insecticides	Acephate	kg	3.55E-04
	Chlorpyrifos	kg	3.23E-04
	Methoxyfenozide	kg	4.77E-05
	Bifentrhin	kg	4.77E-05
	Chloratraniprole	kg	4.44E-05
	All Other Insecticides	kg	1.86E-04
Fertilizer	Potash	kg	2.91E-02
	Phosphate	kg	1.80E-02
	Nitrogen	kg	5.56E-03
	Sulfur	kg	4.25E-03

5.3 Soybean Production Results

This section presents the results of the LCA study. It includes energy, global warming, and other quantified impacts for each of the TRACI impact categories.

The impacts for one kg of soybeans were estimated based on the inputs detailed in Table 5.1, utilizing a modified TRACI v2.1 methodology that includes water consumption and land use (see

Section 4.2 for methodology explanation). Figure 5.1, found below, shows the graphical analysis of the driving factors in each impact category. Absolute values can be found in Table 5.2.

Table 5.2 – U.S. Soybean Analysis per 1 kg of Soybeans

Impact Category	Unit	Field Operations	Fertilizer	Fungicide	Herbicide	Insecticide	Total
Global Warming Potential	kg CO_2 eq	1.31E-01	8.30E-02	4.42E-03	1.09E-01	1.30E-02	**3.41E-01**
Fossil Fuel Depletion	MJ surplus	1.26E-01	1.16E-01	5.74E-03	1.53E-01	1.64E-02	**4.17E-01**
Eutrophication	kg N eq	3.52E-05	3.43E-03	2.36E-06	3.06E-04	9.05E-06	**3.79E-03**
Smog	kg O_3 eq	1.05E-02	5.44E-03	1.20E-04	4.14E-03	3.86E-04	**2.06E-02**
Acidification	kg SO_2 eq	5.75E-04	5.78E-04	2.17E-05	7.55E-04	6.62E-05	**2.00E-03**
Ozone Depletion	kg CFC-11 eq	1.84E-09	9.28E-09	6.89E-10	1.71E-08	2.11E-09	**3.11E-08**
Carcinogenics	CTUh	1.23E-09	5.95E-09	2.88E-11	4.32E-09	1.22E-10	**1.16E-08**
Non-Carcinogenics	CTUh	6.02E-09	4.63E-08	2.09E-10	1.57E-08	1.36E-07	**2.04E-07**
Respiratory Effects	kg $PM_{2.5}$ eq	2.62E-05	7.94E-05	1.56E-06	7.62E-05	4.71E-06	**1.88E-04**
Ecotoxicity	CTUe	3.48E-01	2.83E+00	9.99E-02	2.18E+01	3.47E+01	**5.97E+01**
Land Use	m^2a crop eq	1.75E+00	1.02E-02	4.58E-04	7.44E-03	1.83E-03	**1.77E+00**
Water Consumption	m^3	4.18E-02	2.76E-03	8.83E-06	1.35E-03	9.87E-05	**4.60E-02**
Cumulative Energy Demand	MJ	1.13E+00	1.06E+00	7.92E-02	1.95E+00	2.37E-01	**4.46E+00**

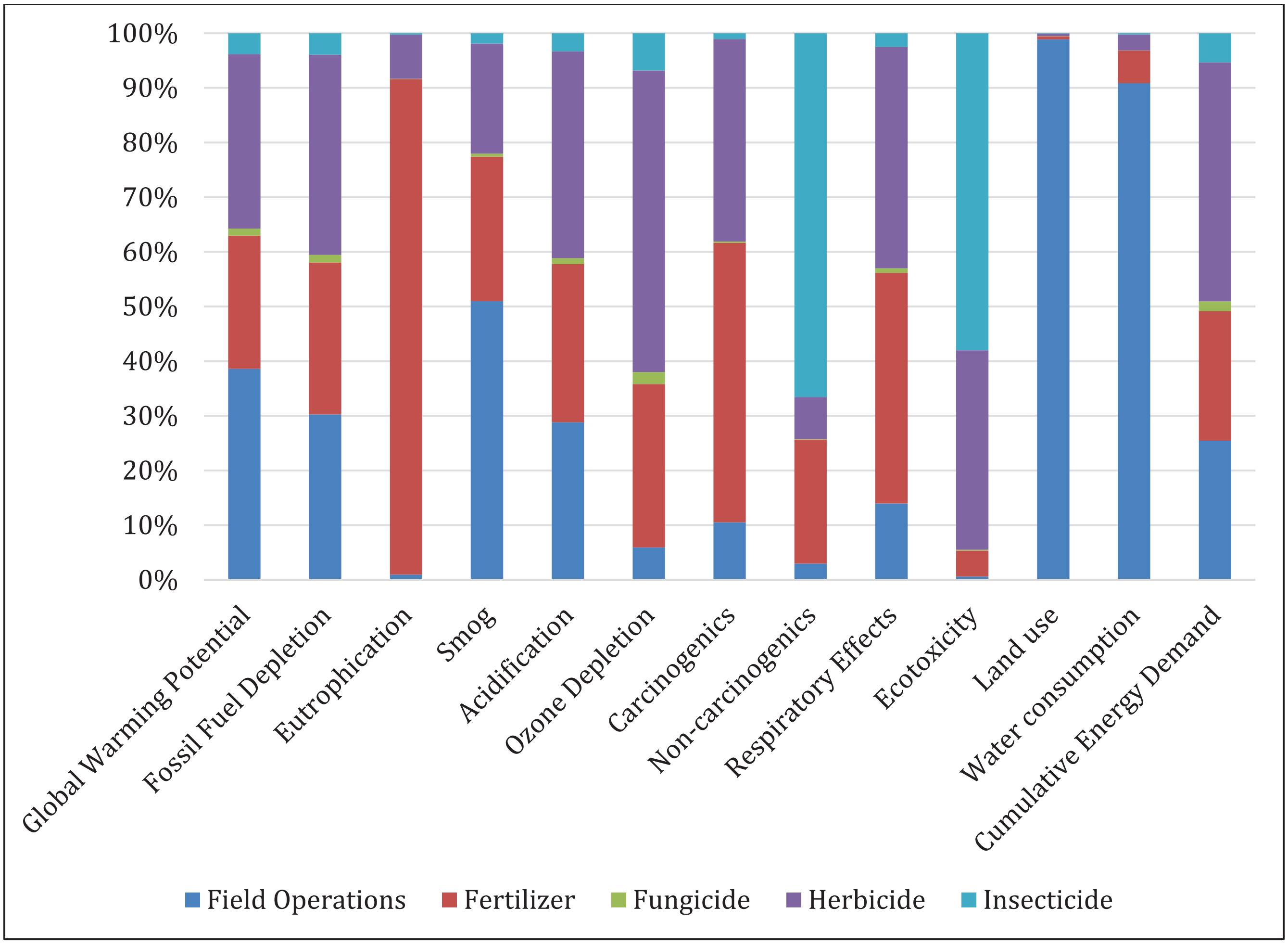

Figure 5.1 – U.S. Soybean Analysis per 1 kg of Soybeans

Figure 5.1 illustrates how each component is driving impacts in each of the 13 impact categories. Overall, field operations, fertilizer, and herbicides are significant contributors to impacts in most categories. Field operations are particularly substantial when it comes to land use and water consumption. Field operations include the measurement of the use of land, as well as energy and water inputs. Land use impacts are driven by operations, as agriculture requires vast quantities of land, and soybeans are an agricultural product. Similarly, while producing fertilizers and pesticides requires some energy, agriculture is much more energy-intensive due to the quantity of fuel needed to operate the equipment required to plant and harvest the soybeans.

Field operations, fertilizer, and herbicide are further analyzed next. Figure 5.2 and Table 5.3 show the breakdown of the different components that make up field operations.

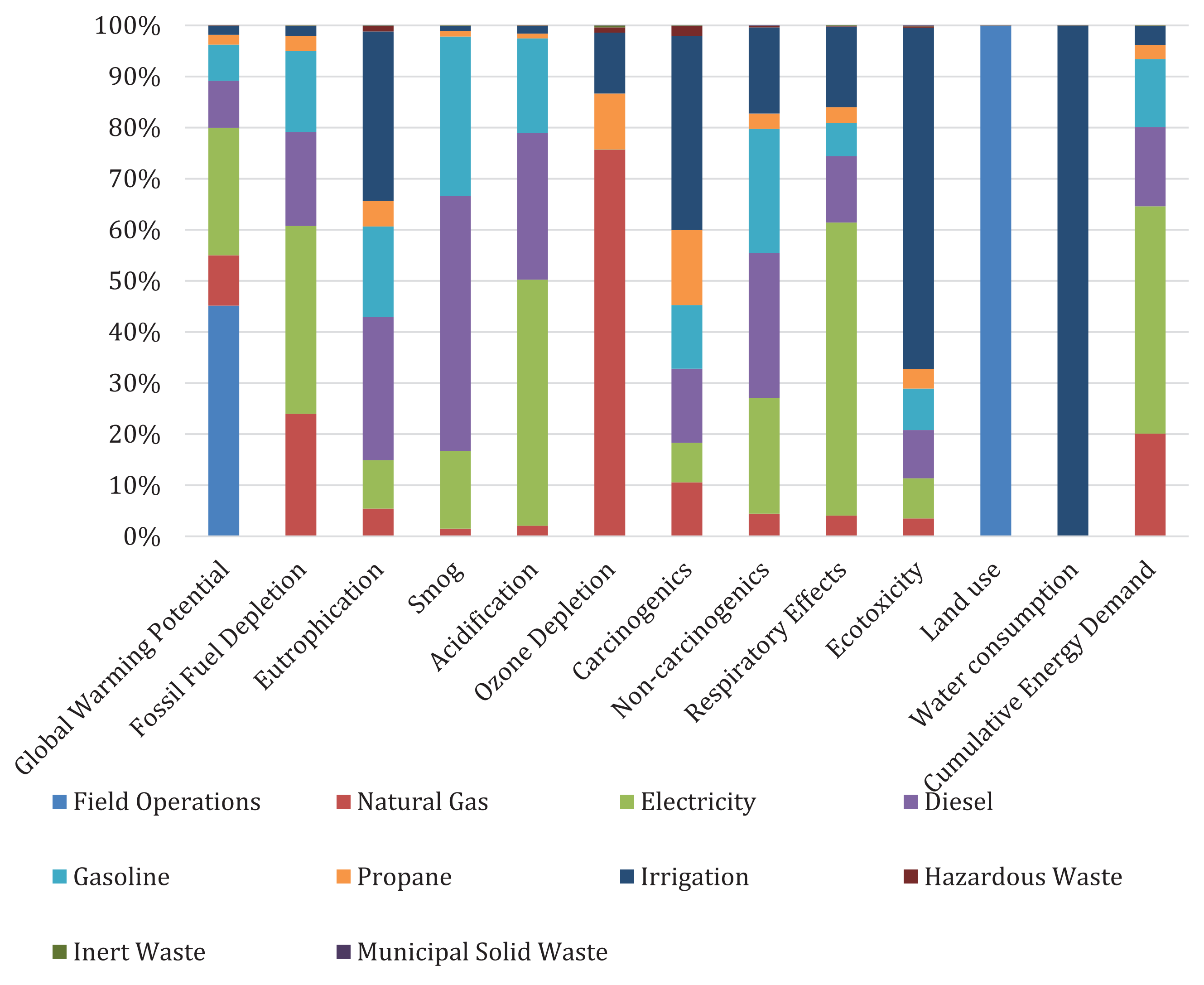

Figure 5.2 – Impacts of Field Operations per kg of Soybeans

Note: Field Operations includes impacts from land occupation and direct emissions to air from N_2O.

Table 5.3 – Impact of Field Operations per kg of Soybeans

Impact Category	Unit	Field Operations	Natural Gas	Electricity	Diesel	Gasoline	Propane	Irrigation	Hazardous Waste	Inert Waste	Municipal Solid Waste	Total
Global Warming Potential	kg CO_2 eq	5.94E-02	1.29E-02	3.28E-02	1.21E-02	9.27E-03	2.55E-03	2.24E-03	1.54E-04	1.63E-05	3.90E-06	**1.31E-01**
Fossil Fuel Depletion	MJ surplus	0.00E+00	3.03E-02	4.64E-02	2.32E-02	1.99E-02	3.73E-03	2.49E-03	8.53E-05	6.31E-05	2.57E-07	**1.26E-01**
Eutrophication	kg N eq	0.00E+00	1.91E-06	3.34E-06	9.87E-06	6.26E-06	1.77E-06	1.17E-05	3.82E-07	2.70E-08	5.19E-09	**3.52E-05**
Smog	kg O_3 eq	0.00E+00	1.59E-04	1.59E-03	5.24E-03	3.28E-03	1.10E-04	1.10E-04	3.07E-06	3.43E-06	6.03E-08	**1.05E-02**
Acidification	kg SO_2 eq	0.00E+00	1.19E-05	2.77E-04	1.65E-04	1.07E-04	5.38E-06	8.81E-06	2.10E-07	1.38E-07	2.20E-09	**5.75E-04**
Ozone Depletion	kg CFC-11 eq	0.00E+00	1.39E-09	3.51E-13	4.92E-13	4.22E-13	2.02E-10	2.19E-10	1.88E-11	7.07E-12	2.77E-14	**1.84E-09**
Carcinogenics	CTUh	0.00E+00	1.29E-10	9.48E-11	1.78E-10	1.52E-10	1.80E-10	4.65E-10	2.44E-11	1.11E-12	3.55E-13	**1.23E-09**
Non-Carcinogenics	CTUh	0.00E+00	2.67E-10	1.36E-09	1.71E-09	1.46E-09	1.81E-10	1.01E-09	1.58E-11	1.65E-12	6.20E-12	**6.02E-09**
Respiratory Effects	kg $PM_{2.5}$ eq	0.00E+00	1.07E-06	1.50E-05	3.40E-06	1.71E-06	8.07E-07	4.14E-06	3.66E-08	1.83E-08	1.71E-10	**2.62E-05**
Ecotoxicity	CTUe	0.00E+00	1.22E-02	2.74E-02	3.29E-02	2.82E-02	1.33E-02	2.33E-01	9.57E-04	8.23E-05	5.50E-04	**3.48E-01**
Land Use	m^2a crop eq	1.75E+00	9.04E-06	0.00E+00	0.00E+00	0.00E+00	1.50E-05	4.37E-05	8.20E-07	2.63E-06	8.65E-09	**1.75E+00**
Water Consumption	m^3	0.00E+00	2.10E-06	0.00E+00	0.00E+00	0.00E+00	2.61E-06	4.18E-02	5.15E-07	4.93E-07	8.55E-09	**4.18E-02**
Cumulative Energy Demand	MJ	0.00E+00	2.28E-01	5.04E-01	1.76E-01	1.51E-01	3.13E-02	4.19E-02	8.26E-04	4.96E-04	2.57E-06	**1.13E+00**

Field operations, which accounts for land occupations and direct air emissions, are the main drivers of eutrophication and land use. Soybeans are a nitrogen fixing crop, meaning that they naturally release nitrogen, in the form of nitrate, into the ground. This can be carried by rain and irrigation into nearby bodies of water, such as lakes and rivers, resulting in higher levels of eutrophication. Figure 5.3 and Table 5.4 show the results of impacts from fertilizer.

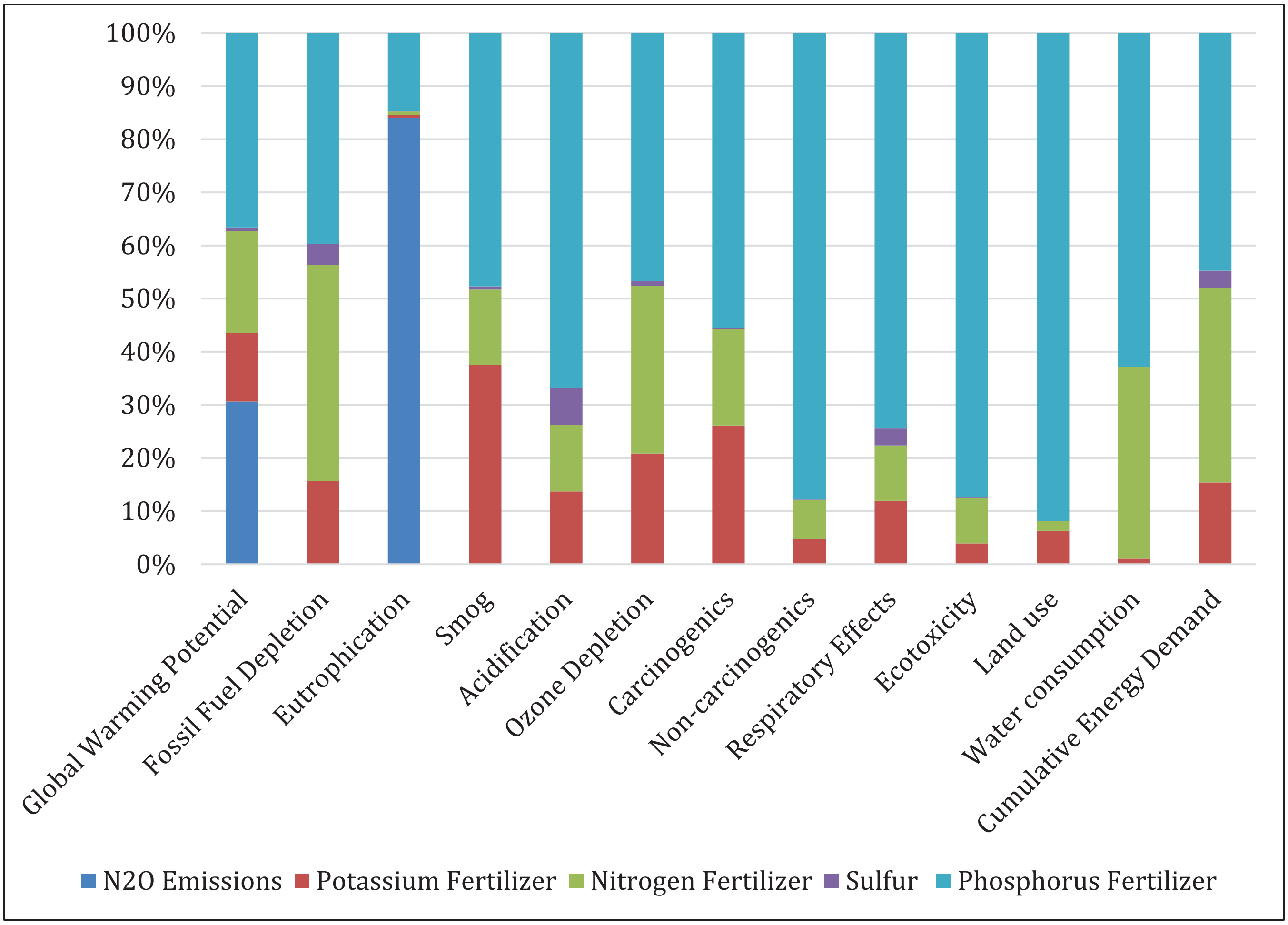

Figure 5.3 – Impacts of Fertilizer per kg of Soybeans

Table 5.4 – Impacts of Fertilizer per kg of Soybeans

Impact Category	Unit	N_2O Emissions	Potassium Fertilizer	Nitrogen Fertilizer	Sulfur	Phosphorus Fertilizer	Total
Global Warming Potential	kg CO_2 eq	2.54E-02	1.07E-02	1.59E-02	5.57E-04	3.04E-02	**8.30E-02**
Fossil Fuel Depletion	MJ surplus	0.00E+00	1.82E-02	4.72E-02	4.66E-03	4.61E-02	**1.16E-01**
Eutrophication	kg N eq	2.89E-03	1.77E-05	2.30E-05	4.42E-07	5.07E-04	**3.43E-03**
Smog	kg O_3 eq	0.00E+00	2.04E-03	7.72E-04	3.23E-05	2.59E-03	**5.44E-03**
Acidification	kg SO_2 eq	0.00E+00	7.92E-05	7.25E-05	4.01E-05	3.86E-04	**5.78E-04**
Ozone Depletion	kg CFC-11 eq	0.00E+00	1.94E-09	2.93E-09	8.63E-11	4.33E-09	**9.28E-09**
Carcinogenics	CTUh	0.00E+00	1.55E-09	1.08E-09	1.73E-11	3.30E-09	**5.95E-09**
Non-Carcinogenics	CTUh	0.00E+00	2.19E-09	3.38E-09	6.32E-11	4.07E-08	**4.63E-08**
Respiratory Effects	kg $PM_{2.5}$ eq	0.00E+00	9.49E-06	8.26E-06	2.52E-06	5.91E-05	**7.94E-05**
Ecotoxicity	CTUe	0.00E+00	1.11E-01	2.42E-01	2.12E-03	2.47E+00	**2.83E+00**
Land Use	m^2a crop eq	0.00E+00	6.40E-04	1.87E-04	2.98E-06	9.32E-03	**1.02E-02**
Water Consumption	m^3	0.00E+00	2.90E-05	9.95E-04	1.52E-06	1.73E-03	**2.76E-03**
Cumulative Energy Demand	MJ	0.00E+00	1.63E-01	3.86E-01	3.50E-02	4.73E-01	**1.06E+00**

The main driver of environmental impacts in most categories is phosphorus fertilizer. This is because phosphates represent the second most used fertilizer for farming soybeans and energy intensive materials in their upstream manufacturing (e.g., sulfuric acid). The one exception is eutrophication, which is dominated by fertilizer emissions to water. Fertilizer runoff, due to rain or irrigation, can reach nearby bodies of water, leading to algae blooms. The results shown above account for the soybean nutrient uptake from applied fertilizers, thus the impacts are attributed to excess fertilizer application.

There were also multiple types of herbicides, as illustrated in Figure 5.4. below.

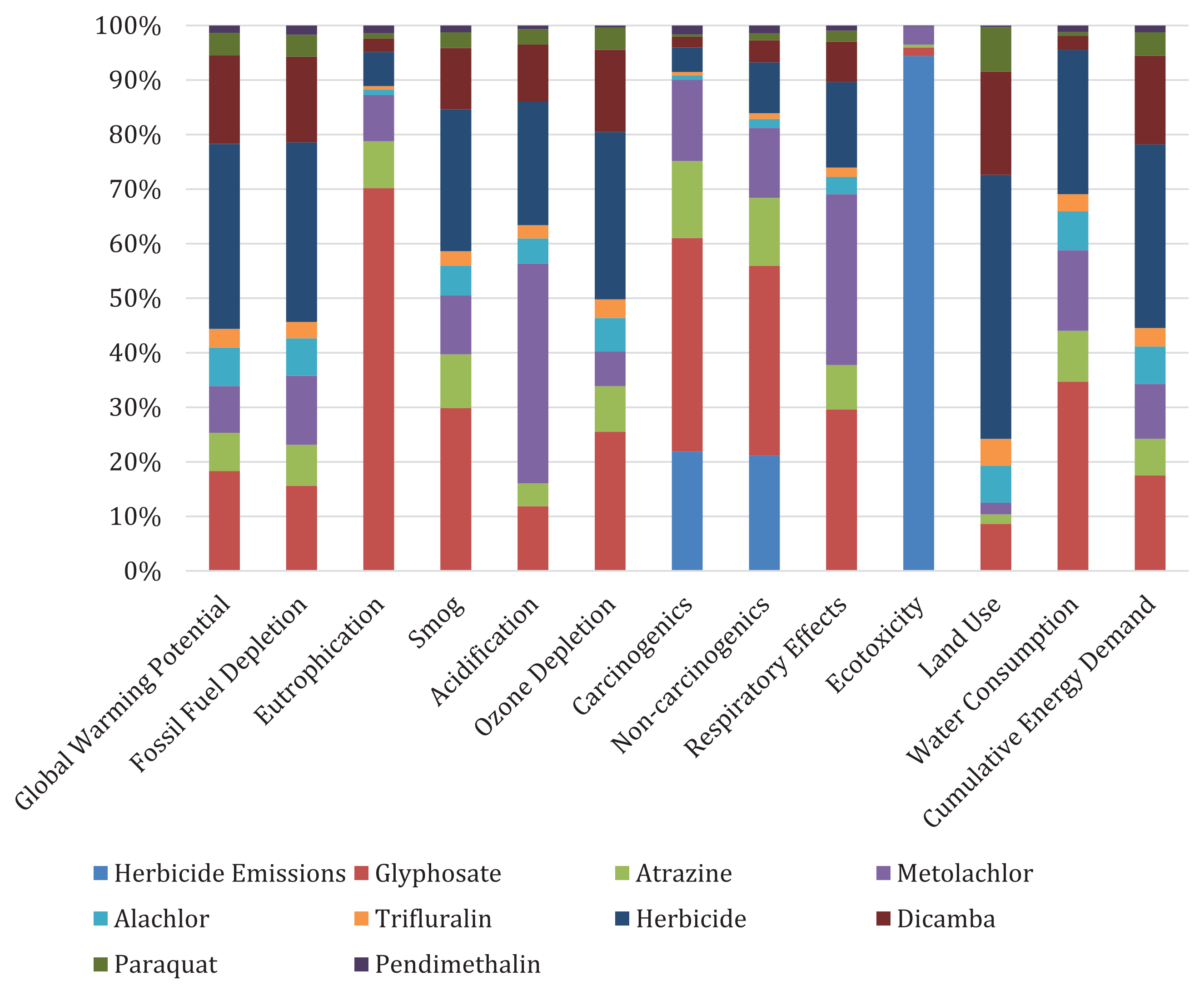

Figure 5.4 – Impacts of Herbicides per kg of Soybeans

Table 5.5 – Impacts of Herbicides per kg of Soybeans

Impact Category	Unit	Herbicide Emissions	Glyphosate	Atrazine	Metolachlor	Alachlor	Trifluralin	Herbicide	Dicamba	Paraquat	Pendimethalin	Total
Global Warming Potential	kg CO_2 eq	0.00E+00	1.99E-02	7.63E-03	9.32E-03	7.69E-03	3.71E-03	3.69E-02	1.76E-02	4.54E-03	1.42E-03	**1.09E-01**
Fossil Fuel Depletion	MJ surplus	0.00E+00	2.39E-02	1.15E-02	1.94E-02	1.05E-02	4.57E-03	5.03E-02	2.40E-02	6.15E-03	2.60E-03	**1.53E-01**
Eutrophication	kg N eq	0.00E+00	2.15E-04	2.64E-05	2.60E-05	2.98E-06	2.00E-06	1.91E-05	7.62E-06	2.91E-06	4.37E-06	**3.06E-04**
Smog	kg O_3 eq	0.00E+00	1.24E-03	4.08E-04	4.48E-04	2.26E-04	1.10E-04	1.08E-03	4.66E-04	1.20E-04	5.17E-05	**4.14E-03**
Acidification	kg SO_2 eq	0.00E+00	8.95E-05	3.17E-05	3.04E-04	3.47E-05	1.84E-05	1.71E-04	7.94E-05	2.12E-05	5.16E-06	**7.55E-04**
Ozone Depletion	kg CFC-11 eq	0.00E+00	4.37E-09	1.44E-09	1.09E-09	1.05E-09	5.84E-10	5.26E-09	2.58E-09	7.00E-10	6.79E-11	**1.71E-08**
Carcinogenics	CTUh	9.44E-10	1.69E-09	6.09E-10	6.41E-10	3.77E-11	2.65E-11	1.93E-10	8.55E-11	1.85E-11	7.06E-11	**4.32E-09**
Non-Carcinogenics	CTUh	3.31E-09	5.44E-09	1.96E-09	2.01E-09	2.56E-10	1.64E-10	1.46E-09	6.37E-10	2.03E-10	2.19E-10	**1.57E-08**
Respiratory Effects	kg $PM_{2.5}$ eq	0.00E+00	2.26E-05	6.19E-06	2.39E-05	2.41E-06	1.30E-06	1.19E-05	5.68E-06	1.52E-06	7.14E-07	**7.62E-05**
Ecotoxicity	CTUe	2.06E+01	3.29E-01	1.23E-01	7.31E-01	1.91E-03	1.34E-03	1.05E-02	4.40E-03	1.17E-03	1.40E-02	**2.18E+01**
Land Use	m^2a crop eq	0.00E+00	6.43E-04	1.28E-04	1.58E-04	5.03E-04	3.70E-04	3.60E-03	1.41E-03	6.10E-04	2.04E-05	**7.44E-03**
Water Consumption	m^3	0.00E+00	4.66E-04	1.26E-04	1.99E-04	9.56E-05	4.25E-05	3.56E-04	3.47E-05	9.37E-06	1.65E-05	**1.35E-03**
Cumulative Energy Demand	MJ	0.00E+00	3.41E-01	1.31E-01	1.96E-01	1.34E-01	6.60E-02	6.55E-01	3.17E-01	8.35E-02	2.42E-02	**1.95E+00**

Glyphosate and herbicide are the most prominent drivers of several impact categories. This is because of higher impact materials and energy needs in the synthesis of glyphosate and other herbicides.

Results were compared to those found in the previous LCA study performed by Quantis in 2015. This comparison can be found in Appendix A.

6.0 Crude Soybean Oil and Soybean Meal Production

6.1 Important Assumptions

In this study of soybean meal and crude soy oil, SSC made the following assumptions:

- Data provided are complete and representative of U.S soybean processing operations.
- Allocation by mass of co-products was used to distribute impacts to crude soy oil and soybean meal.
    - Allocation was determined to be 20.17% to crude soy oil and 79.83% to soybean meal, based on the mass output of the co-products when processing a single soybean. Consequently, the impacts associated (on a per kg basis) with soybean meal and soybean oil production are identical.
    - Soybean hull allocation was conducted by mass and included with soybean meal as it doesn't go through further processing after crushing phase.
- Hexane inputs are directly related to solvent loss, which typically occurs during extraction in the form of emissions. Actual hexane data were not collected for the purposes of this study. Instead, the total hexane emissions value used in the model is based on a solvent loss factor of 0.2 gallons/ton of conventional soybeans crushed as specified under the National Emission Standards for Hazardous Air Pollutants: Solvent Extraction for Vegetable Oil Production [40 CFR 63.2840].
    - Using this value provides a conservative estimate of total hexane emissions as it represents the maximum hexane loss threshold allowed under U.S. regulations. This approach is consistent with the previous 2015 and 2010 LCA studies where hexane emissions from soybean processing facilities were estimated using the same loss factor as designated under 40 CFR 63.2840.
- Soybeans are the primary material input and used in their entirety to produce soybean hulls, soybean meal, and crude soy oil. Soybean hulls are not discarded, rather they are either cycled back into the process to be added to soybean meal or sold as is to downstream manufacturers for further use.
    - Hull output values have been combined and reported as part of the meal hull output value. Soy hulls are not the primary outputs resulting from soybean processing, and thus were not called out as a specific product for analysis as part of this study.
- Actual total pounds of soybean inputs were reported as an aggregated average, while other input/output values were reported per 1,000 bushels with an assigned weight of

60 lbs. bu. Consequently, the aggregated data used in the analysis of soybean processing operations did not reflect a 1:1 mass balance for soybean inputs and product output values reported in Table 6.1.

- Other factors that may further contribute to the mass balance misalignment that resulted in the 1.03 kg soybean input value reported in Table 6.1:
    - USB reports an average bushel weight of 58.6 pounds,[4] whereas NOPA assumed an average bushel weight of 60 pounds in aggregating individual facility data for oilseed processing and co-located refining operations. This was done in order to align with data as reported in previous studies, and to maintain consistency with assumptions for hexane use based on the maximum threshold as allowed by EPA under 40 CFR 63.2840, identified above.
        - Actual bushel weight may vary due to a variety of product quality factors including amount of moisture within the soybean, amount of residual crop-waste and size of individual beans. Soybeans are sold as a commodity by bushel based on an average weight that is adjusted to account for product quality impacts.
    - There is a recognized material loss that occurs during processing due to dust generation and soybean hull spillage during the crushing and degumming process. Dust generation that is not captured by filter systems can be aggregated and incorporated back into the process for soybean meal production. Due to the variation in the number of cycles through the process, the output material is difficult to trace to a final system output. As such, the loss is captured as additional input material.
- All soybean products are transported by bulk via barge, railcar, tank truck, and/or pipeline.
- When a material is not available in the available LCI databases, another chemical which has similar manufacturing and environmental impacts may be used as a proxy, representing the actual chemical. The Proxy Chemical List used in this analysis includes:
    - Heat, onsite boiler, softwood mill average, NE-NC/MJ/RNA as proxy for “Biomass.”
    - Heat, from steam, in chemical industry {RoW}| steam production, as energy carrier, in chemical industry | Cut-off, U” as proxy for “Purchased Steam.”
    - Diesel as proxy for “Other Fuels.”

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[4] See Appendix D for crude soy oil and soybean meal inventory adjusted for USB bushel weight of 58.6 pounds.

6.2 Life Cycle Inventory

This section describes the cradle-to-gate life cycle inventory of soybean meal and crude soybean oil. Data on the soybean crushing and degumming process were collected from members of the National Oilseed Processors Association (NOPA) processing facilities located in the U.S. for the 2021 calendar production year. The participating processing plants provided resource transportation mode and distance data to support the calculation of raw material transportation flows. The transportation LCI data from the USLCI database (kg-km basis) were used to develop the resource transportation LCI profile.

Over 50 percent of NOPA member companies that participated in this study reported data for crushing and degumming as well as co-located refining processes. SSC completed a detailed analysis of the manufacturing process steps involved in the production of soybean meal, crude soybean oil, refined soybean oil, and specialty products following the solvent extraction stage to understand these production processes, as illustrated in Appendix C.

NOPA member soybean facilities operate seven days a week, 24 hours a day, 365 days a year and modifying its production schedule as needed to perform routine maintenance inspections, replace/repair equipment, address facility permitting requirements, advance facility modification/construction projects, etc. Transportation data was provided by NOPA to account for the delivery of soybeans at the processing facility. Soybeans are received at the processing facility by truck (84% of soybeans delivered); rail (13% of soybeans delivered); or barge (3% of soybeans delivered). Upon delivery, the first step is to grade the beans for moisture, damage, foreign materials, and color.

In the U.S. up to 13% moisture is allowed, though a moisture level within the range of 8-9% is typically observed. Some facilities may use non-invasive Near Infrared (NIR) to measure oil content as well. Following inspection, soybeans are sent to a temporary storage container.

From the storage bin. the soybeans are first dehulled, dried and cracked, either through a conventional or hot dehulling process. The hulls are ground and pelletized while the “crack” is rolled into thin flakes to expose the oil cells.

The flakes are then sent through an extractor where hexane is used to separate the oil from the flake. The flakes are then removed from the oil and hexane mixture, desolventized to remove residual solvent from the flakes, then toasted, dried and cooled before being ground into soybean meal. Concurrently, hexane is separated from the oil which can then be placed in a centrifuge to remove gums from the oil to produce degummed crude soybean oil.

Soybean hulls, meal and crude soy oil are co-products of NOPA member oilseed processing operations, and as globally traded commodities, all products must meet federal, state and industry standards in accordance with U.S. laws and regulations. Consequently, because these commodities are produced simultaneously, this study allocates the impacts between meal and oil as equal. Mass allocation was selected in order to remain consistent with previous studies.

To produce soybean meal and crude soy oil, energy, water, and materials go into the process and wastewater and emissions are outputs from the manufacturing process. SSC conducted an inventory based on the allocation described above. Table 6.1 details the process inputs and outputs.

Table 6.1 – Soybean Processing Inventory

Energy Inputs	Unit	Quantity per kg of Soybean Meal or Crude Soy Oil
Electricity	kWh	3.90E-02
Natural Gas	mmbtu	6.71E-04
Coal	mmbtu	5.55E-05
Biomass	mmbtu	5.18E-06
Other Fuels	mmbtu	8.13E-06
Purchased Steam	mmbtu	5.20E-04
Material Inputs	**Unit**	**Quantity per kg of Soybean Meal or Crude Soy Oil**
Soybeans	kg	1.03E+00
Hexane	kg	5.52E-04
Water	**Unit**	**Quantity per kg of Soybean Meal or Crude Soy Oil**
Inflow	L	3.54E-01
Wastewater	L	1.41E-01
Evaporated Water	L	2.13E-01
Transportation	**Unit**	**Quantity per kg of Soybean Meal or Crude Soy Oil**
Truck	kgkm	7.20E+01
Rail	kgkm	4.82E+01
Barge	kgkm	2.21E+01
Emissions	**Unit**	**Quantity per kg of Soybean Meal or Crude Soy Oil**
Hexane	kg	5.52E-04
Note: Soybean meal and crude oil are co-products resulting from crushing operations. Consequently, inventory data was unable to be allocated to product specific processes and the product values are the same.		

6.3 Crude Soy Oil and Soybean Meal Production Results

Processors purchase the raw materials and control operational processes used to produce meal and oil; however, their ability to directly influence the production of raw materials, and thus environmental impact, is typically outside their control. Environmental impacts that occur in soybeans shipping, processing, and final product shipping are directly under NOPA members' purview. This puts much of the environmental impact of the final product out of the control of soybean processors unless material substitutions can be made. However, since this is a cradle-to-gate study that ends at the factory gate, final product shipping is not be included in this paper.

6.3.1 Crude Soy Oil and Soybean Meal Processing Impacts ONLY

Energy is the main component of the crushing and degumming process to manufacture soybean meal and crude soybean oil. It is also required to grow or extract, process, and ship raw materials to the plant.

Table 6.2 below lists the amount of cumulative energy consumed during the manufacturing process for crude soy oil and soybean meal most directly under the control of NOPA member processing facilities. All the energy consumption was calculated in megajoules (MJ), using the cumulative energy demand impact category defined in Section 4.2, to allow for comparison of energy consumption across all uses. Cumulative energy demand is the sum of all energy sources drawn directly from the earth, and accounts for all upstream and downstream processes. This energy consumption is based on the original manufacturing inventory in Section 6.2 where allocation and fuels and energy sources are discussed.

Table 6.2 – Energy Use During Soybean Processing

Manufacturing Energy Consumption	Energy Use per kg of Crude Soy Oil or Soybean Meal (MJ/kg)
Electricity	1.40E-01
Natural Gas	7.08E-01
Coal	5.85E-02
Biomass	5.46E-03
Other Fuels	8.58E-03
Purchased Steam – Natural Gas	2.94E-01
Purchased Steam – Coal	7.18E-02
Purchased Steam – Biomass	1.78E-01
Purchased Steam – Liquid Petroleum Gas	4.39E-03
Total	**1.47E+00**

Note: Soybean meal and crude oil are co-products resulting from crushing operations. Consequently, the energy use data was unable to be allocated to product specific processes and the product values are the same.

Figure 6.1 shows the same energy breakdown in a pie chart. This further illustrates the overwhelming contribution that natural gas (and purchased steam from natural gas) contributes to energy used to produce crude soy oil and soybean meal in the U.S.

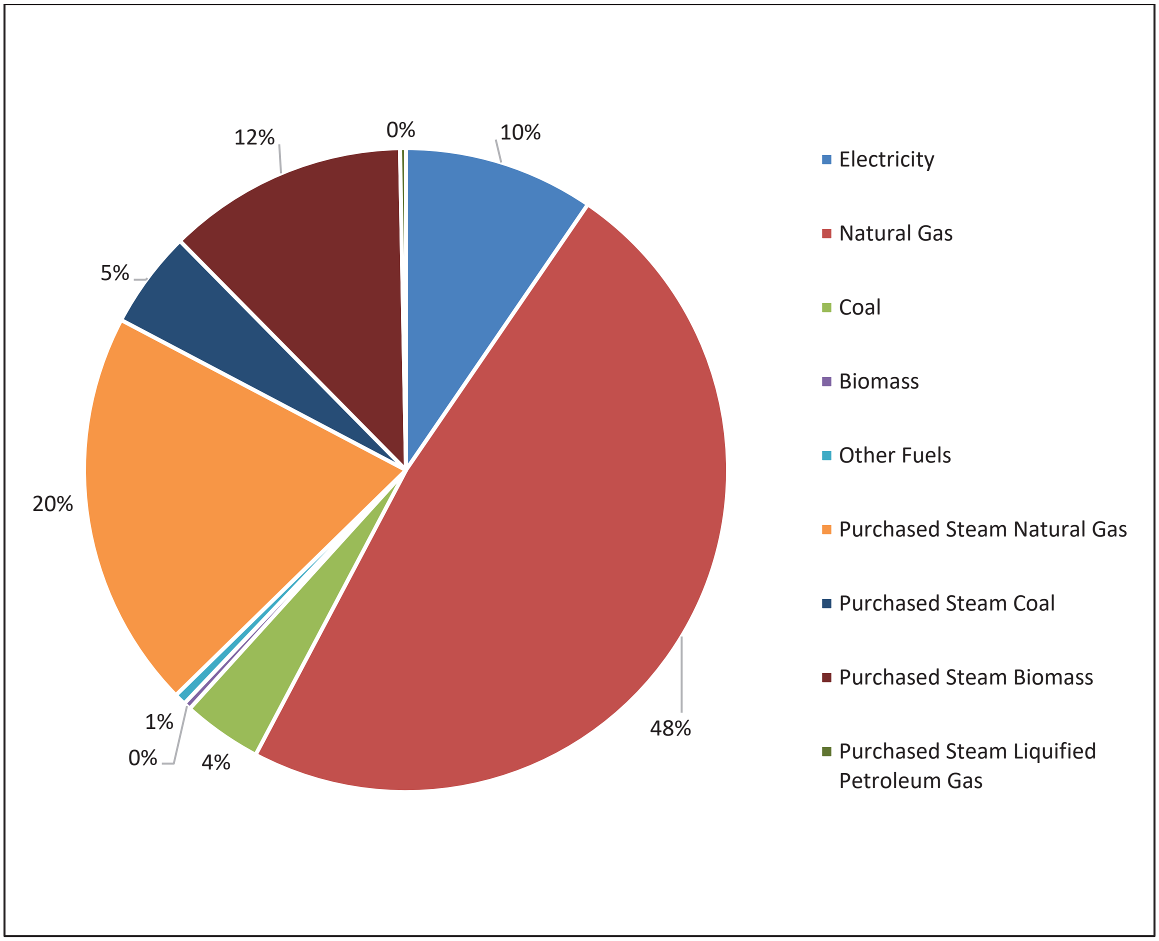

Figure 6.1 – Energy Breakdown for Crude Soy Oil and Soybean Meal Production

The impacts of processing of one kilogram of soybean meal or one kilogram of crude soybean oil from the inputs included in Table 6.1 were estimated utilizing the modified TRACI v2.1 methodology. The results are displayed in Figure 6.2 and quantified in Table 6.3.

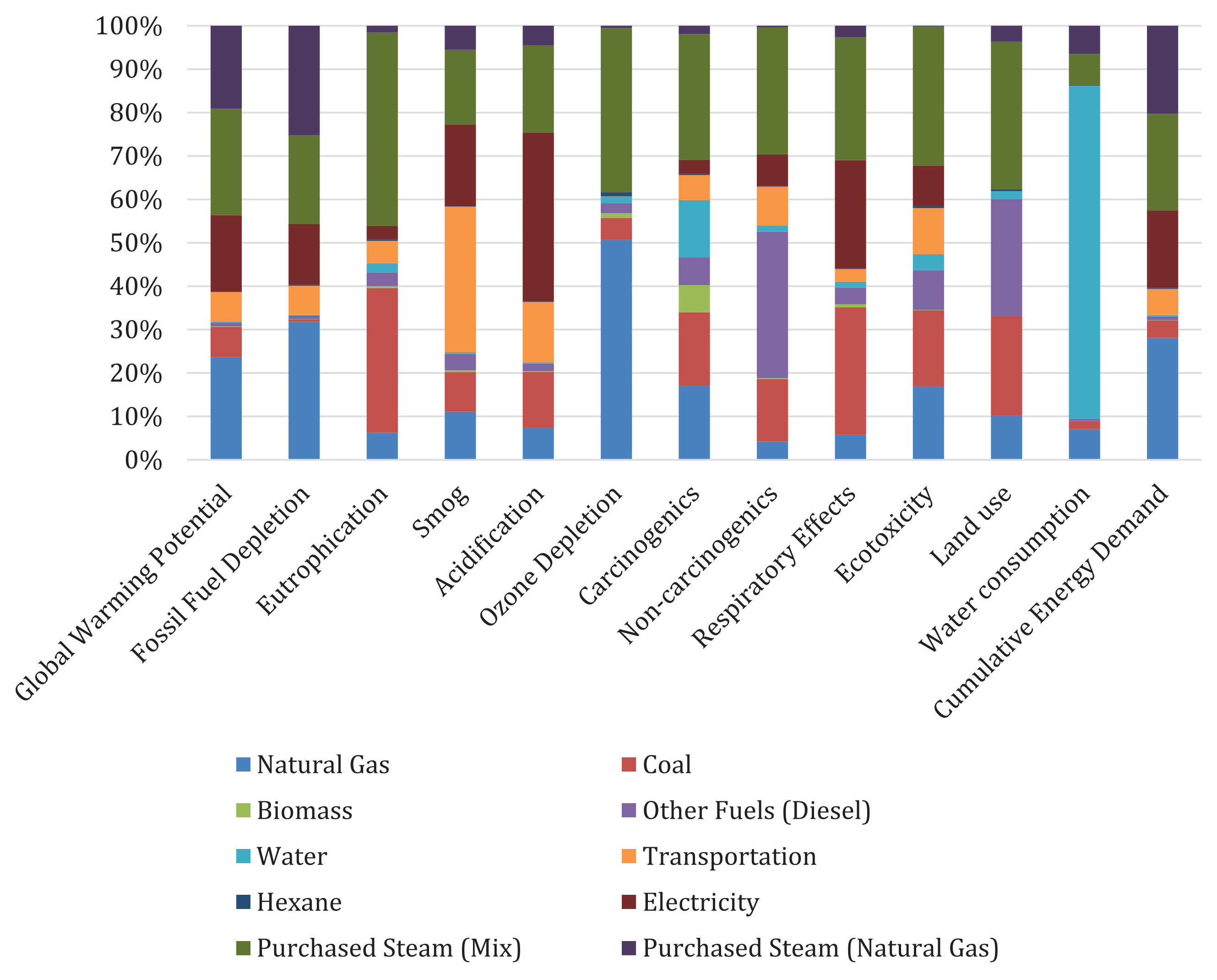

Figure 6.2 – Impacts of Soybean Processing for 1 kg of Soybean Meal or 1 kg Crude Soy Oil

As expected, natural gas and purchased steam are significant components of most impact categories, followed by electricity. Natural gas is typically used for heating and steam generation which is used during drying and oil/solvent recovery process steps.

Table 6.3 – Impacts of Soybean Processing for 1 kg of Soybean Meal or 1 kg Crude Soy Oil

Impact Category	Unit	Natural Gas	Coal	Biomass	Other Fuels (Diesel)	Water	Transportation	Hexane	Electricity	Purchased Steam (Mix)	Purchased Steam (Natural Gas)	Total
Global Warming Potential	kg CO_2 eq	2.98E-02	8.75E-03	9.75E-05	1.07E-03	3.65E-04	8.50E-03	6.07E-05	2.22E-02	3.08E-02	2.40E-02	**1.26E-01**
Fossil Fuel Depletion	MJ surplus	7.16E-02	1.35E-03	1.81E-04	1.66E-03	3.21E-04	1.52E-02	5.92E-04	3.14E-02	4.60E-02	5.70E-02	**2.25E-01**
Eutrophication	kg N eq	4.60E-06	2.45E-05	2.93E-07	2.34E-06	1.56E-06	3.76E-06	2.86E-07	2.26E-06	3.28E-05	1.12E-06	**7.35E-05**
Smog	kg O_3 eq	6.32E-04	5.21E-04	2.34E-05	2.16E-04	2.01E-05	1.91E-03	5.51E-06	1.08E-03	9.78E-04	3.18E-04	**5.71E-03**
Acidification	kg SO_2 eq	3.59E-05	6.19E-05	9.38E-07	8.22E-06	1.58E-06	6.70E-05	4.79E-07	1.87E-04	9.74E-05	2.17E-05	**4.83E-04**
Ozone Depletion	kg CFC-11 eq	3.99E-09	3.91E-10	8.39E-11	1.88E-10	1.22E-10	3.22E-13	7.03E-11	2.37E-13	2.97E-09	4.32E-11	**7.86E-09**
Carcinogenics	CTUh	3.42E-10	3.35E-10	1.25E-10	1.28E-10	2.62E-10	1.16E-10	5.62E-12	6.41E-11	5.77E-10	3.85E-11	**1.99E-09**
Non-Carcinogenics	CTUh	5.27E-10	1.80E-09	3.12E-11	4.20E-09	1.74E-10	1.11E-09	1.64E-11	9.21E-10	3.64E-09	4.94E-11	**1.25E-08**
Respiratory Effects	kg $PM_{2.5}$ eq	2.36E-06	1.19E-05	3.06E-07	1.55E-06	5.63E-07	1.17E-06	5.05E-08	1.02E-05	1.15E-05	1.10E-06	**4.07E-05**
Ecotoxicity	CTUe	3.41E-02	3.55E-02	2.42E-04	1.85E-02	7.34E-03	2.15E-02	1.07E-03	1.85E-02	6.48E-02	4.79E-04	**2.02E-01**
Land Use	m^2a crop eq	3.66E-05	8.19E-05	0.00E+00	9.62E-05	6.60E-06	0.00E+00	1.64E-06	0.00E+00	1.22E-04	1.31E-05	**3.58E-04**
Water Consumption	m^3	3.27E-05	8.48E-06	1.51E-07	2.58E-06	3.54E-04	0.00E+00	9.36E-07	0.00E+00	3.28E-05	3.00E-05	**4.61E-04**
Cumulative Energy Demand	MJ	5.37E-01	7.77E-02	1.47E-03	1.61E-02	5.87E-03	1.15E-01	4.57E-03	3.41E-01	4.26E-01	3.88E-01	**1.91E+00**

Table 6.4 displays the breakdown of Global Warming Potential (GWP) from the manufacturing of crude soy oil and soybean meal in the U.S. Similar to energy use, the majority of GWP in the manufacturing process is from purchased steam and natural gas consumption, as well as electricity.

Table 6.4 – GWP from the Manufacture of Crude Soy Oil and Soybean Meal in the U.S.

Processing Component	Crude Soy Oil or Soybean Meal GWP (kg CO_2 eq/kg)
Natural Gas	2.98E-02
Coal	8.75E-03
Biomass	9.75E-05
Other Fuels (Diesel)	1.07E-03
Water	3.65E-04
Transportation	8.50E-03
Hexane	6.07E-05
Electricity	2.22E-02
Purchased Steam (Mix)	3.08E-02
Purchased Steam (Natural Gas)	2.40E-02
Total	**1.26E-01**

Note: Soybean meal and crude oil are co-products resulting from crushing operations. Consequently, the GWP data was unable to be allocated to product specific processes and the product values are the same.

Figure 6.3 shows the same GWP breakdown in a pie chart. This further illustrates the contribution that purchased steam, natural gas, and electricity contribute to GWP from the production of crude soy oil and soybean meal in the U.S.

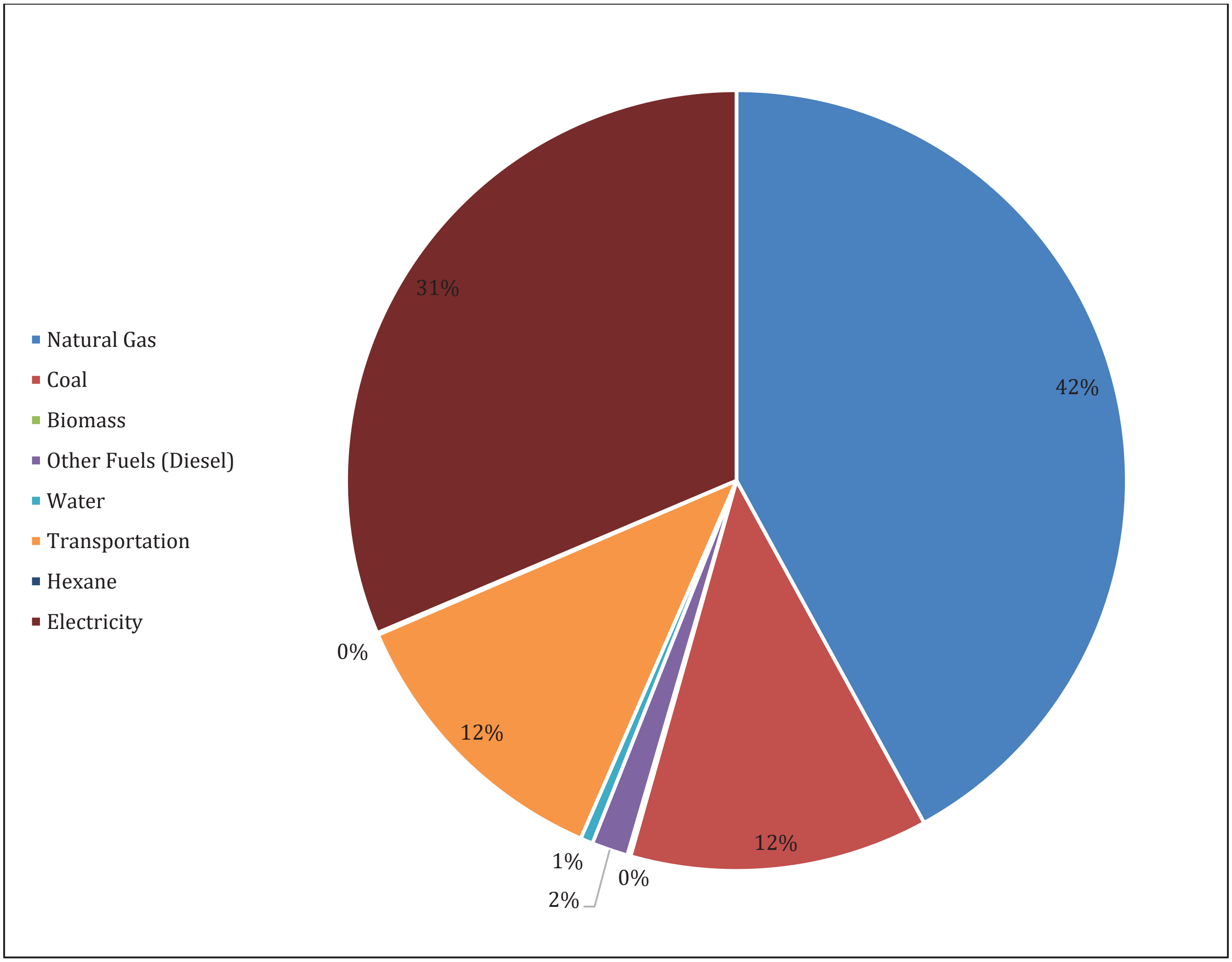

Figure 6.3 – GWP of 1 kg of Crude Soy Oil or 1 kg of Soybean Meal

6.3.2 Overall Impacts

Besides energy demand and carbon emissions during processing, the soybeans also have embodied impacts. SSC ran a modified TRACI analysis to include the soybeans needed for making 1 kg or crude soy oil or 1 kg of soybean meal, as presented in Table 6.1. Results are displayed in Figure 6.4, and specific numbers are included in Table 6.5 and Table 6.6.

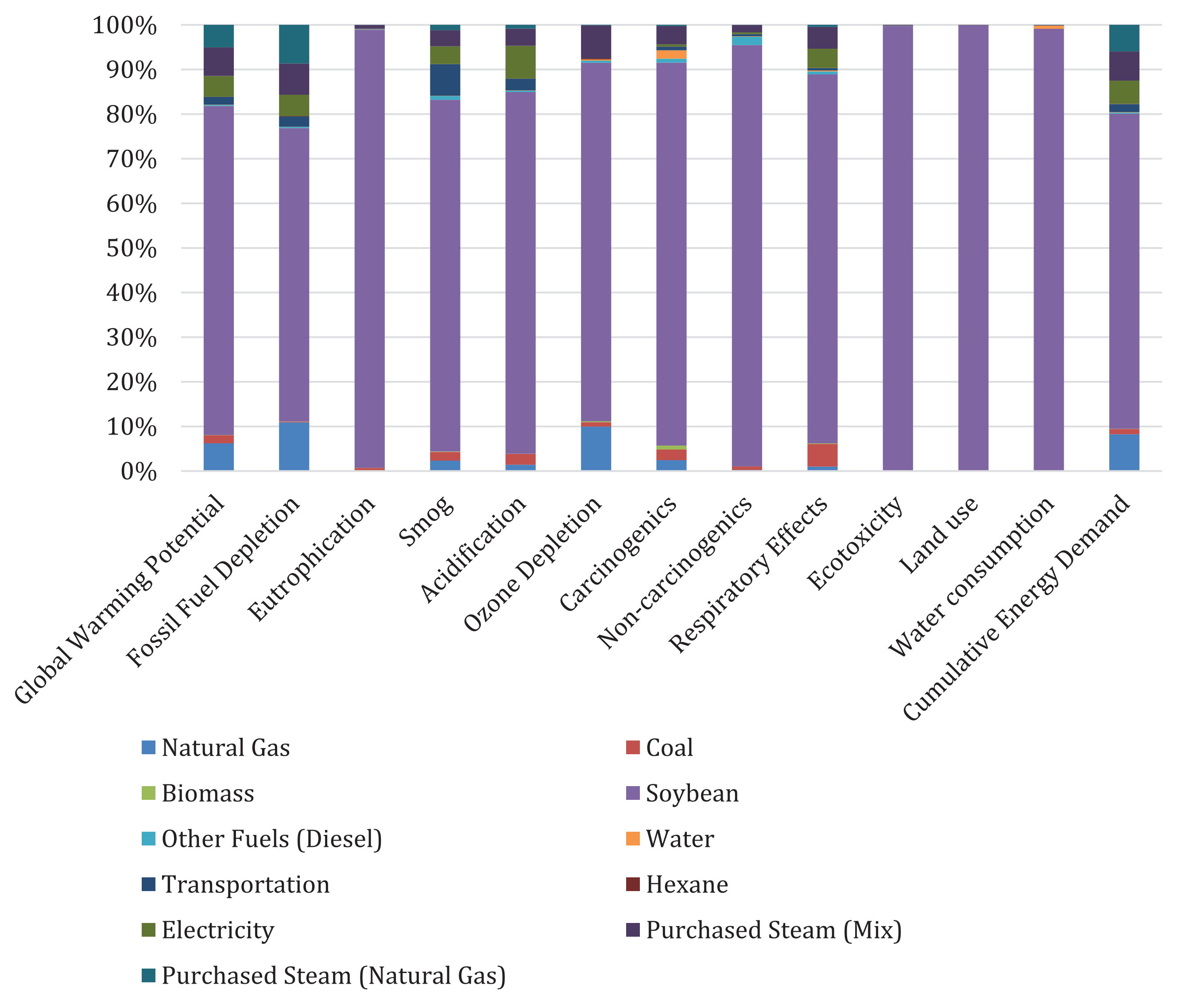

Figure 6.4 – Overall Impacts of the Crushing and Degumming Process for 1 kg of Crude Soy Oil or 1 kg of Soybean Meal

Table 6.5 – Environmental Impacts from Producing 1 kg of Crude Soy Oil

Impact Category	Unit	Natural Gas	Coal	Biomass	Soybean	Other Fuels (Diesel)	Water	Transportation	Hexane	Electricity	Purchased Steam (Mix)	Purchased Steam (Natural Gas)	Total
Global Warming Potential	kg CO_2 eq	2.98E-02	8.75E-03	9.75E-05	3.52E-01	1.07E-03	3.65E-04	8.50E-03	6.07E-05	2.22E-02	3.08E-02	2.40E-02	**4.78E-01**
Fossil Fuel Depletion	MJ surplus	7.16E-02	1.35E-03	1.81E-04	4.32E-01	1.66E-03	3.21E-04	1.52E-02	5.92E-04	3.14E-02	4.60E-02	5.70E-02	**6.57E-01**
Eutrophication	kg N eq	4.60E-06	2.45E-05	2.93E-07	3.92E-03	2.34E-06	1.56E-06	3.76E-06	2.86E-07	2.26E-06	3.28E-05	1.12E-06	**3.99E-03**
Smog	kg O_3 eq	6.32E-04	5.21E-04	2.34E-05	2.13E-02	2.16E-04	2.01E-05	1.91E-03	5.51E-06	1.08E-03	9.78E-04	3.18E-04	**2.70E-02**
Acidification	kg SO_2 eq	3.59E-05	6.19E-05	9.38E-07	2.06E-03	8.22E-06	1.58E-06	6.70E-05	4.79E-07	1.87E-04	9.74E-05	2.17E-05	**2.55E-03**
Ozone Depletion	kg CFC-11 eq	3.99E-09	3.91E-10	8.39E-11	3.21E-08	1.88E-10	1.22E-10	3.22E-13	7.03E-11	2.37E-13	2.97E-09	4.32E-11	**4.00E-08**
Carcinogenics	CTUh	3.42E-10	3.35E-10	1.25E-10	1.20E-08	1.28E-10	2.62E-10	1.16E-10	5.62E-12	6.41E-11	5.77E-10	3.85E-11	**1.40E-08**
Non-Carcinogenics	CTUh	5.27E-10	1.80E-09	3.12E-11	2.11E-07	4.20E-09	1.74E-10	1.11E-09	1.64E-11	9.21E-10	3.64E-09	4.94E-11	**2.23E-07**
Respiratory Effects	kg $PM_{2.5}$ eq	2.36E-06	1.19E-05	3.06E-07	1.94E-04	1.55E-06	5.63E-07	1.17E-06	5.05E-08	1.02E-05	1.15E-05	1.10E-06	**2.35E-04**
Ecotoxicity	CTUe	3.41E-02	3.55E-02	2.42E-04	6.18E+01	1.85E-02	7.34E-03	2.15E-02	1.07E-03	1.85E-02	6.48E-02	4.79E-04	**6.20E+01**
Land Use	m^2a crop eq	3.66E-05	8.19E-05	0.00E+00	1.83E+00	9.62E-05	6.60E-06	0.00E+00	1.64E-06	0.00E+00	1.22E-04	1.31E-05	**1.83E+00**
Water Consumption	m^3	3.27E-05	8.48E-06	1.51E-07	4.76E-02	2.58E-06	3.54E-04	0.00E+00	9.36E-07	0.00E+00	3.28E-05	3.00E-05	**4.81E-02**
Cumulative Energy Demand	MJ	5.37E-01	7.77E-02	1.47E-03	4.61E+00	1.61E-02	5.87E-03	1.15E-01	4.57E-03	3.41E-01	4.26E-01	3.88E-01	**6.52E+00**

Table 6.6 – Environmental Impacts from Producing 1 kg of Soybean Meal

Impact Category	Unit	Natural Gas	Coal	Biomass	Soybean	Other Fuels (Diesel)	Water	Transportation	Hexane	Electricity	Purchased Steam (Mix)	Purchased Steam (Natural Gas)	Total
Global Warming Potential	kg CO_2 eq	2.98E-02	8.75E-03	9.75E-05	3.52E-01	1.07E-03	3.65E-04	8.50E-03	6.07E-05	2.22E-02	3.08E-02	2.40E-02	**4.78E-01**
Fossil Fuel Depletion	MJ surplus	7.16E-02	1.35E-03	1.81E-04	4.32E-01	1.66E-03	3.21E-04	1.52E-02	5.92E-04	3.14E-02	4.60E-02	5.70E-02	**6.57E-01**
Eutrophication	kg N eq	4.60E-06	2.45E-05	2.93E-07	3.92E-03	2.34E-06	1.56E-06	3.76E-06	2.86E-07	2.26E-06	3.28E-05	1.12E-06	**3.99E-03**
Smog	kg O_3 eq	6.32E-04	5.21E-04	2.34E-05	2.13E-02	2.16E-04	2.01E-05	1.91E-03	5.51E-06	1.08E-03	9.78E-04	3.18E-04	**2.70E-02**
Acidification	kg SO_2 eq	3.59E-05	6.19E-05	9.38E-07	2.06E-03	8.22E-06	1.58E-06	6.70E-05	4.79E-07	1.87E-04	9.74E-05	2.17E-05	**2.55E-03**
Ozone Depletion	kg CFC-11 eq	3.99E-09	3.91E-10	8.39E-11	3.21E-08	1.88E-10	1.22E-10	3.22E-13	7.03E-11	2.37E-13	2.97E-09	4.32E-11	**4.00E-08**
Carcinogenics	CTUh	3.42E-10	3.35E-10	1.25E-10	1.20E-08	1.28E-10	2.62E-10	1.16E-10	5.62E-12	6.41E-11	5.77E-10	3.85E-11	**1.40E-08**
Non-Carcinogenics	CTUh	5.27E-10	1.80E-09	3.12E-11	2.11E-07	4.20E-09	1.74E-10	1.11E-09	1.64E-11	9.21E-10	3.64E-09	4.94E-11	**2.23E-07**
Respiratory Effects	kg $PM_{2.5}$ eq	2.36E-06	1.19E-05	3.06E-07	1.94E-04	1.55E-06	5.63E-07	1.17E-06	5.05E-08	1.02E-05	1.15E-05	1.10E-06	**2.35E-04**
Ecotoxicity	CTUe	3.41E-02	3.55E-02	2.42E-04	6.18E+01	1.85E-02	7.34E-03	2.15E-02	1.07E-03	1.85E-02	6.48E-02	4.79E-04	**6.20E+01**
Land Use	m^2a crop eq	3.66E-05	8.19E-05	0.00E+00	1.83E+00	9.62E-05	6.60E-06	0.00E+00	1.64E-06	0.00E+00	1.22E-04	1.31E-05	**1.83E+00**
Water Consumption	m^3	3.27E-05	8.48E-06	1.51E-07	4.76E-02	2.58E-06	3.54E-04	0.00E+00	9.36E-07	0.00E+00	3.28E-05	3.00E-05	**4.81E-02**
Cumulative Energy Demand	MJ	5.37E-01	7.77E-02	1.47E-03	4.61E+00	1.61E-02	5.87E-03	1.15E-01	4.57E-03	3.41E-01	4.26E-01	3.88E-01	**6.52E+00**

As shown in the figure above, the manufacturing impacts are dominated by the soybeans. This is because soybeans are the only ingredient in making crude soybean oil and soybean meal. Furthermore, growing soybeans is a process that takes several months before a harvest. This is more energy and resource-intensive than processing after harvesting. These results were also compared to the 2015 study, which can be found in Section A.2 of Appendix A.

7.0 Refined Soy Oil Production

7.1 Important Assumptions

In this study of refined soy oil, SSC made the following assumptions:

- Data provided are representative of U.S soy oil refining operations. NOPA member companies provided soy oil refinery data for 27 refineries co-located with soybean processing plants that produce crude soy oil and soybean meal.
- Crude soy oil is the primary material input used in the production of refined oil. Depending on plant design and co-location of processing and refining operations, crude soy oil may be delivered as degummed or not degummed oil.
    - Crude soy oil inputs were determined based on total percentage of degummed (39%) and not degummed (61%) crude soy oil reported by NOPA member companies.
- Actual total pounds of crude oil inputs were reported as an aggregated average, while all other input/output values were reported based on unit per short tons refined. Consequently, the aggregated data used in the analysis of soy oil refining operations did not reflect a 1:1 mass balance for crude soy oil inputs and refined oil output values reported in Table 7.1.
- Assumptions outlined in Section 6.1 also contributed to mass balance misalignment that resulted in the 1.02 kg crude soy oil equivalent value.
- This study assumes crude oil was delivered to the refinery from the processing plant via intra-facility piping, due to the co-located nature of the facilities represented in data provided. However, some facilities may also receive crude oil inputs from other transportation modes (e.g., truck, barge, rail). Refineries which are not co-located with a processing plant will typically receive crude soy oil by truck, rail or barge. For this reason, secondary transportation data were used for analysis.
- When a material is not available in the available LCI databases, another chemical which has similar manufacturing and environmental impacts may be used as a proxy, representing the actual chemical. The Proxy Chemical List used in this analysis includes:
    - Diesel as proxy for “Other Fuels.”

7.2 Life Cycle Inventory

This section describes the life cycle inventory of refined soy oil. Data were collected from NOPA members for 27 soy oil refineries that are co-located with crushing operations. Once the solvent has been separated from the oil (discussed under Section 6.2 above and illustrated within Appendix C), crude oil is placed in a centrifuge to remove gums and soap stocks from the oil. Soy oil may be sold at this stage as “crude, degummed soy oil,” primarily as a feedstock for vegetable oil refining.

After degumming is completed, the oil is run through diatomaceous earth to take out impurities. Soy oil may be sold at this stage as “once refined soy oil”, primarily as a feedstock for the production of biodiesel.[5] The next step is to modify color and clarify the oil using bleaching clays. Soy oil may be sold at this stage as “once refined and bleached soy oil”, primarily as a feedstock for the production of renewable diesel and sustainable aviation fuel.[6] Finally, the soy oil may undergo a final deodorization step to meet U.S. Department of Agriculture and U.S. Food and Drug Administration product quality standards. Soy oil sold following this stage are typically used in the manufacturer and production of animal feed and human food applications.[7]

An inventory detailing the process steps for soy oil refining are shown in Table 7.1. The term inventory is used in LCA to refer to the list of inputs and outputs that are required to achieve the product function unit (e.g., 1.0 kg for purposes of this LCA).

Table 7.1 – Soy Oil Refining Inventory

Energy Inputs	Unit	Quantity per kg of Refined Soy Oil
Electricity	kWh	6.09E-02
Natural Gas	mmbtu	5.57E-04
Coal	mmbtu	4.33E-05
Other Fuels	mmbtu	3.99E-06
Material Inputs	**Unit**	**Quantity per kg of Refined Soy Oil**
Crude Soy Oil	kg	1.02E+00
Sodium Hydroxide	kg	1.14E-03
Bleaching Earth	kg	2.74E-03
Water	**Unit**	**Quantity per kg of Refined Soy Oil**
Inflow	L	7.90E-01
Wastewater	L	7.39E-01
Evaporated Water	L	5.10E-02
NOTE: Inventory data based on weighted average values as reported by NOPA member companies for 27 soy oil refineries which are co-located on the same site with a soybean processing facility.		

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[5] Marketed as "Once Refined Soybean Oil” under the *NOPA Trading Rules for the Purchase and Sale of Soybean Oil*.

[6] Marketed as "Once Refined & Bleached" under the *NOPA Trading Rules for the Purchase and Sale of Soybean Oil*.

[7] Marketed as "Refined, Bleached, and Deodorized (RBD)" under the *NOPA Trading Rules for the Purchase and Sale of Soybean Oil*.

7.3 Refined Soy Oil Environmental Impacts

7.3.1 Oil Refining Impacts ONLY

Crude soy oil can be further processed to become refined soy oil. The refining process consists of eliminating any impurities from the crude soy oil. SSC estimated the impacts of this process with the modified TRACI methodology based on the inputs included in Table 7.1 and are displayed in Figure 7.1 and quantified in Table 7.2.

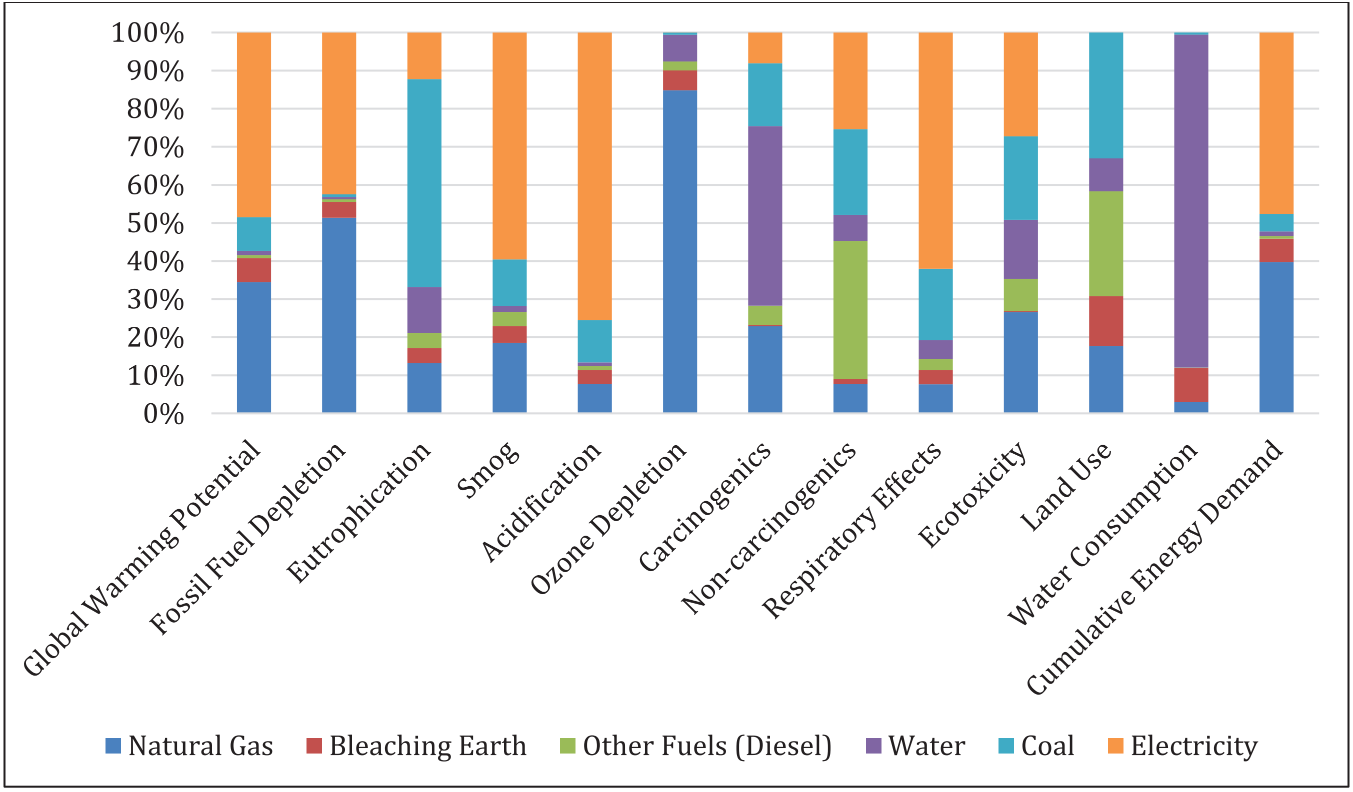


Figure 7.1 – Soy Oil Refining Impacts

Here, natural gas and electricity are the main drivers of most impacts. This is because most of the inputs for refining oil are energy, and natural gas and electricity are the main two sources of energy used for soybean oil refining.

Table 7.2 – Soy Oil Refining Impacts

Impact Category	Unit	Natural Gas	Bleaching Earth	Other Fuels (Diesel)	Water	Coal	Electricity	Total
Global Warming Potential	kg CO_2 eq	2.46E-02	4.56E-03	5.22E-04	8.16E-04	6.30E-03	3.47E-02	**7.16E-02**
Fossil Fuel Depletion	MJ surplus	5.93E-02	4.77E-03	8.14E-04	7.17E-04	7.78E-04	4.91E-02	**1.15E-01**
Eutrophication	kg N eq	3.81E-06	1.15E-06	1.15E-06	3.48E-06	1.57E-05	3.53E-06	**2.89E-05**
Smog	kg O_3 eq	5.24E-04	1.24E-04	1.06E-04	4.50E-05	3.44E-04	1.68E-03	**2.82E-03**
Acidification	kg SO_2 eq	2.97E-05	1.46E-05	4.03E-06	3.53E-06	4.31E-05	2.93E-04	**3.88E-04**
Ozone Depletion	kg CFC-11 eq	3.30E-09	2.01E-10	9.21E-11	2.72E-10	2.37E-11	3.71E-13	**3.89E-09**
Carcinogenics	CTUh	2.83E-10	4.74E-12	6.26E-11	5.84E-10	2.04E-10	1.00E-10	**1.24E-09**
Non-Carcinogenics	CTUh	4.36E-10	7.22E-11	2.06E-09	3.88E-10	1.28E-09	1.44E-09	**5.67E-09**
Respiratory Effects	kg $PM_{2.5}$ eq	1.95E-06	9.55E-07	7.57E-07	1.26E-06	4.81E-06	1.59E-05	**2.56E-05**
Ecotoxicity	CTUe	2.82E-02	2.00E-04	9.07E-03	1.64E-02	2.32E-02	2.89E-02	**1.06E-01**
Land Use	m^2a crop eq	3.03E-05	2.24E-05	4.72E-05	1.48E-05	5.66E-05	0.00E+00	**1.71E-04**
Water Consumption	m^3	2.71E-05	8.06E-05	1.26E-06	7.90E-04	5.04E-06	0.00E+00	**9.04E-04**
Cumulative Energy Demand	MJ	4.45E-01	6.88E-02	7.91E-03	1.31E-02	5.19E-02	5.33E-01	**1.12E+00**

7.3.2 Overall

The graphs in this section are designed to communicate the overall cradle-to-facility-gate environmental impacts of refined soybean oil. These include soybean agriculture, transportation to oil processing facility, the crushing and degumming process, and soybean oil refining.

Table 7.3 and Figure 7.2 demonstrate the overall environmental impact (using the modified TRACI methodology) of manufacturing one kilogram of refined soybean oil. The figure illustrates the relative impact contribution from each of the life cycle stages (soybean cultivation and harvesting, soybean transportation, the crushing and degumming process, and soy oil refining) to each of the environmental impacts. In this analysis, soybean transportation impacts are separated from the "soybean cultivation and harvesting" stage.

Table 7.3 – Refined Soybean Oil Environmental Impacts using the TRACI Impact Methodology

Impact Category	Unit	Crushing and Degumming	Soybeans	Natural Gas	Bleaching Earth	Other Fuels (Diesel)	Water	Coal	Electricity	Transport	Total
Global Warming Potential	kg CO_2 eq	1.28E-01	2.71E-01	2.46E-02	4.56E-03	5.22E-04	8.16E-04	6.30E-03	3.47E-02	2.87E-02	**4.99E-01**
Fossil Fuel Depletion	MJ surplus	2.30E-01	4.41E-01	5.93E-02	4.77E-03	8.14E-04	7.17E-04	7.78E-04	4.91E-02	5.14E-02	**8.39E-01**
Eutrophication	kg N eq	7.51E-05	4.01E-03	3.81E-06	1.15E-06	1.15E-06	3.48E-06	1.57E-05	3.53E-06	1.27E-05	**4.12E-03**
Smog	kg O_3 eq	5.84E-03	2.18E-02	5.24E-04	1.24E-04	1.06E-04	4.50E-05	3.44E-04	1.68E-03	6.46E-03	**3.69E-02**
Acidification	kg SO_2 eq	4.94E-04	2.11E-03	2.97E-05	1.46E-05	4.03E-06	3.53E-06	4.31E-05	2.93E-04	2.26E-04	**3.22E-03**
Ozone Depletion	kg CFC-11 eq	8.04E-09	3.29E-08	3.30E-09	2.01E-10	9.21E-11	2.72E-10	2.37E-11	3.71E-13	1.09E-12	**4.48E-08**
Carcinogenics	CTUh	2.04E-09	1.23E-08	2.83E-10	4.74E-12	6.26E-11	5.84E-10	2.04E-10	1.00E-10	3.91E-10	**1.60E-08**
Non-Carcinogenics	CTUh	1.28E-08	2.16E-07	4.36E-10	7.22E-11	2.06E-09	3.88E-10	1.28E-09	1.44E-09	3.76E-09	**2.38E-07**
Respiratory Effects	kg $PM_{2.5}$ eq	4.16E-05	1.99E-04	1.95E-06	9.55E-07	7.57E-07	1.26E-06	4.81E-06	1.59E-05	3.96E-06	**2.70E-04**
Ecotoxicity	CTUe	2.07E-01	6.32E+01	2.82E-02	2.00E-04	9.07E-03	1.64E-02	2.32E-02	2.89E-02	7.28E-02	**6.36E+01**
Land Use	m^2a crop eq	3.66E-04	1.87E+00	3.03E-05	2.24E-05	4.72E-05	1.48E-05	5.66E-05	0.00E+00	0.00E+00	**1.87E+00**
Water Consumption	m^3	4.72E-04	4.87E-02	2.71E-05	8.06E-05	1.26E-06	7.90E-04	5.04E-06	0.00E+00	0.00E+00	**5.01E-02**
Cumulative Energy Demand	MJ	1.96E+00	4.71E+00	4.45E-01	6.88E-02	7.91E-03	1.31E-02	5.19E-02	5.33E-01	3.89E-01	**8.18E+00**

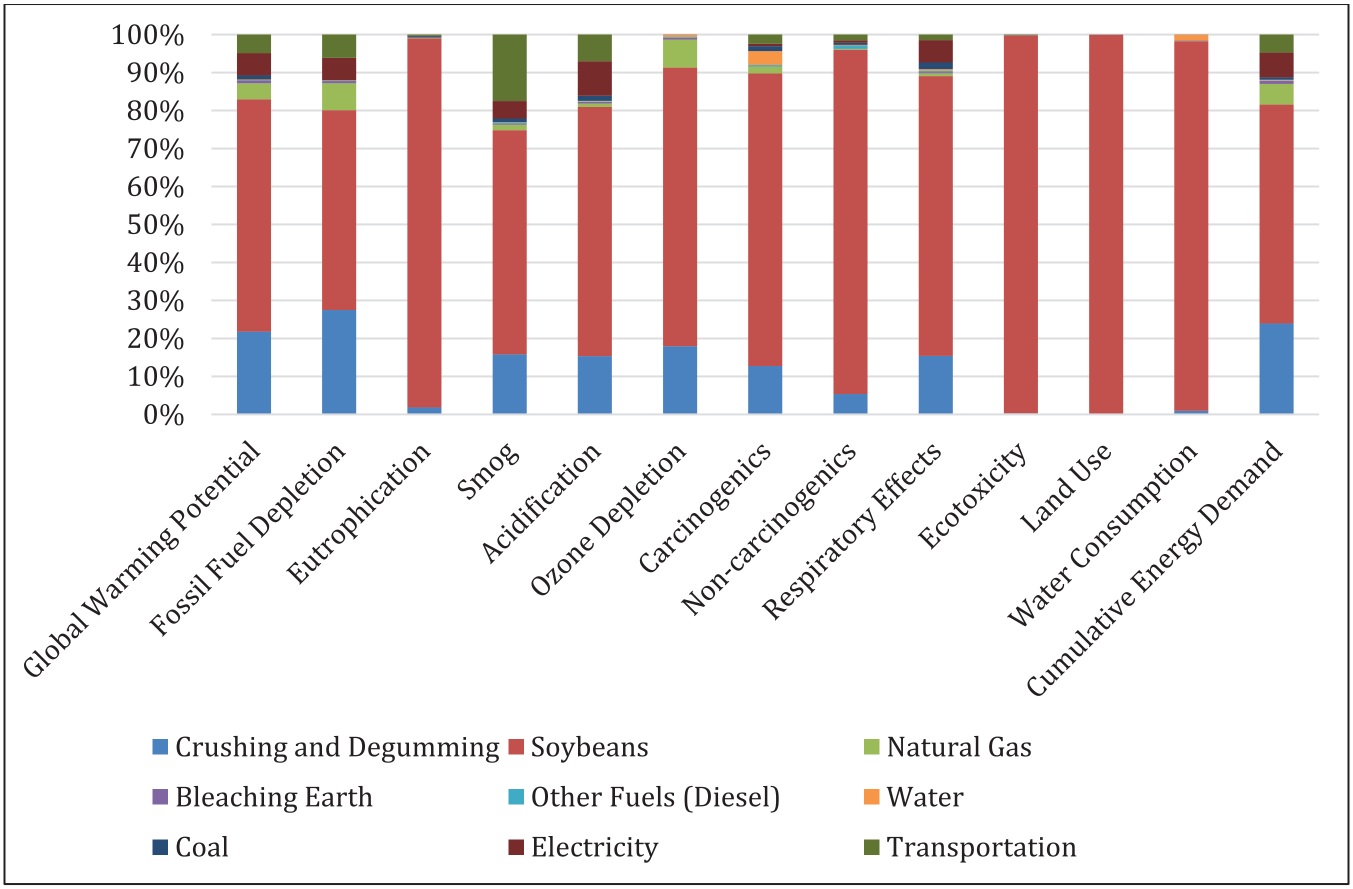


Figure 7.2 – Environmental Impacts of Refined Soybean Oil (TRACI Impact Assessment Methodology)

Overall, soybean cultivation and harvesting is the main driver of environmental impacts, with its contribution ranging from approximately 54% for GWP to almost 100% for land use.

Figure 7.2 shows that, similarly, to results for the crushing and degumming process to produce crude soybean oil, soybeans contribute a majority of the impact in most categories for refined soybean oil. The crushing and degumming process also has a slightly higher impact than oil refining. For eutrophication, human toxicity and ecotoxicity, the majority of the impacts occur also in the soybean agriculture stage, mostly due to the use of fertilizers and crop residue of nitrogen. Overall, environmental impacts of refined soybean oil have also declined overtime when compared to the results from the 2015 study, as shown in Figure A.4 in Appendix A.

8.0 Additional Analysis – Biofuels

Soybeans are 18-20% oil by mass and have fewer nutrient requirements than any other oilseed crop. Consequently, one of the primary uses for soy oil is as a renewable, plant-based feedstock in the production of biodiesel, renewable diesel and sustainable aviation fuel. In fact, U.S. Energy Information Agency data indicate that over 60 percent of U.S. biodiesel today is produced from soy oil.

Biofuels are vital in meeting U.S. transportation needs and climate policy objectives. For example, soy-based biodiesel offers a more sustainable energy source than fossil fuels, and has replaced billions of volumes of petroleum-based diesel under the U.S. Environmental Protection Agency's Renewable Fuels Program. According to the Clean Fuels Alliance America:

- For every unit of fossil energy it takes to produce biodiesel, as much as 3.5 units of renewable energy is returned, the best of any U.S. fuel.
- Compared to petroleum-based diesel, biodiesel lowers particulate matter pollution by 47%.
- Biodiesel combustion emits less greenhouse gases that can contribute toward GWP, compared to petroleum-based diesel, biodiesel can reduce hydrocarbon emissions by nearly 70%.

Increased production to meet market demands may impact water and air quality if facilities are not operated in accordance with environmental permitting requirements, agricultural development for oilseed cultivation in the U.S. may impact biodiversity in certain regions and can result in direct or indirect land use changes.

The effects of utilizing biodiesel, which is largely produced using soy oil feedstocks generated by the soybean processing companies that participated in this study, in different concentrations to replace diesel, gasoline, propane, and natural gas during soybean cultivation are illustrated in Figure 8.1 and detailed in Table 8.1. This sensitivity does not account for energy efficiency differences between the current fuels and biofuels, or practical limitations associated with the complete replacement of traditional petroleum-based fuels with biodiesel.

Table 8.1 – Environmental Impacts of Replacing Fossil Fuels with Biodiesel for Soybean Cultivation/Harvesting

Impact Category	Unit	0% Biodiesel	50% Biodiesel	100% Biodiesel
Global Warming Potential	kg CO_2 eq	3.41E-01	3.26E-01	3.11E-01
Fossil Fuel Depletion	MJ surplus	4.17E-01	3.86E-01	3.54E-01
Eutrophication	kg N eq	3.79E-03	3.81E-03	3.84E-03
Smog	kg O_3 eq	2.06E-02	2.55E-02	3.05E-02
Acidification	kg SO_2 eq	2.00E-03	2.13E-03	2.27E-03
Ozone Depletion	kg CFC-11 eq	3.11E-08	3.05E-08	2.99E-08
Carcinogenics	CTUh	1.16E-08	1.14E-08	1.12E-08
Non-Carcinogenics	CTUh	2.04E-07	2.03E-07	2.03E-07
Respiratory Effects	kg $PM_{2.5}$ eq	1.88E-04	1.91E-04	1.95E-04
Ecotoxicity	CTUe	5.97E+01	6.00E+01	6.03E+01
Land Use	m^2a crop eq	1.77E+00	1.78E+00	1.79E+00
Water Consumption	m^3	4.60E-02	4.63E-02	4.65E-02
Cumulative Energy Demand	MJ	4.46E+00	4.22E+00	3.99E+00

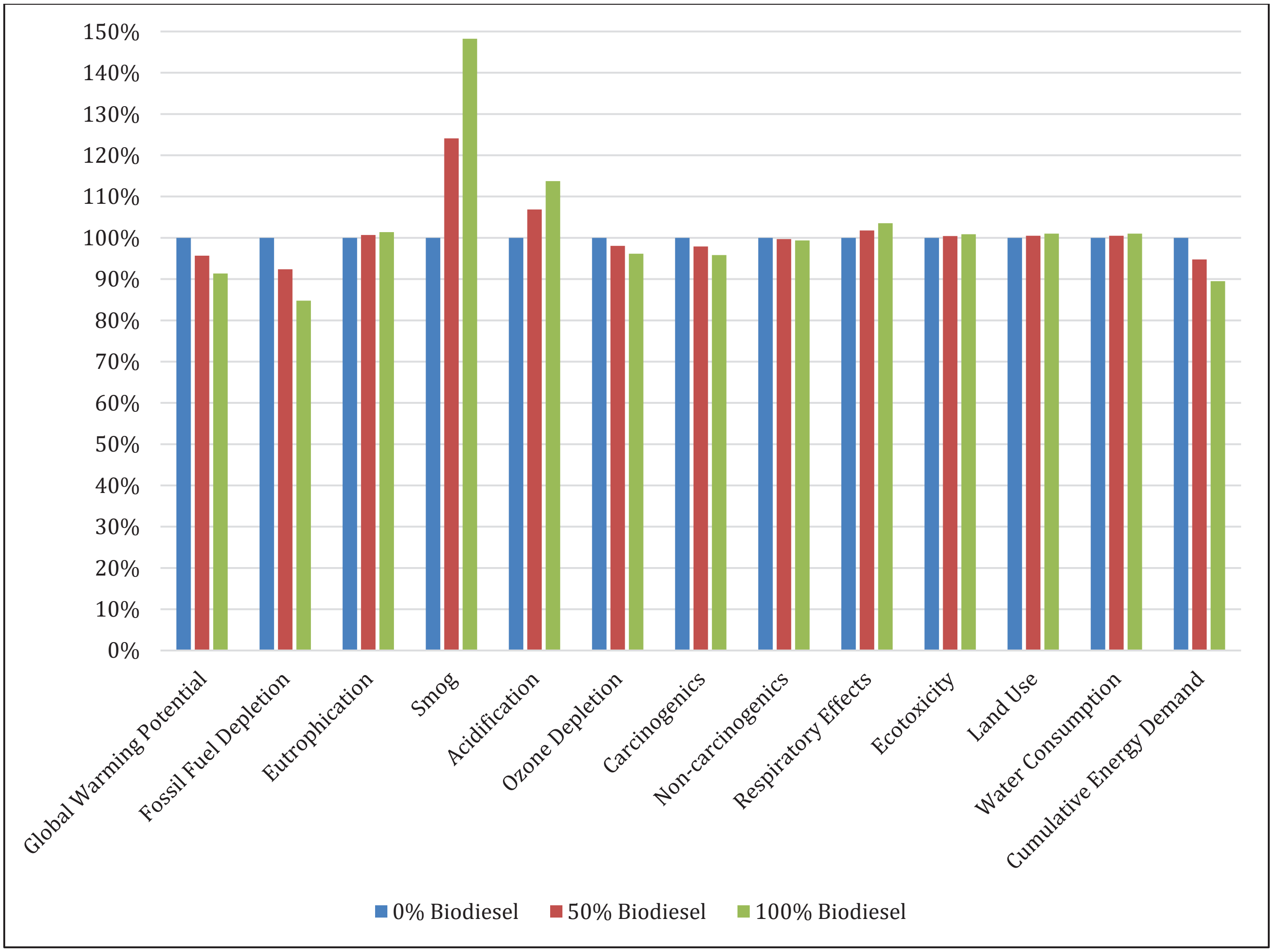


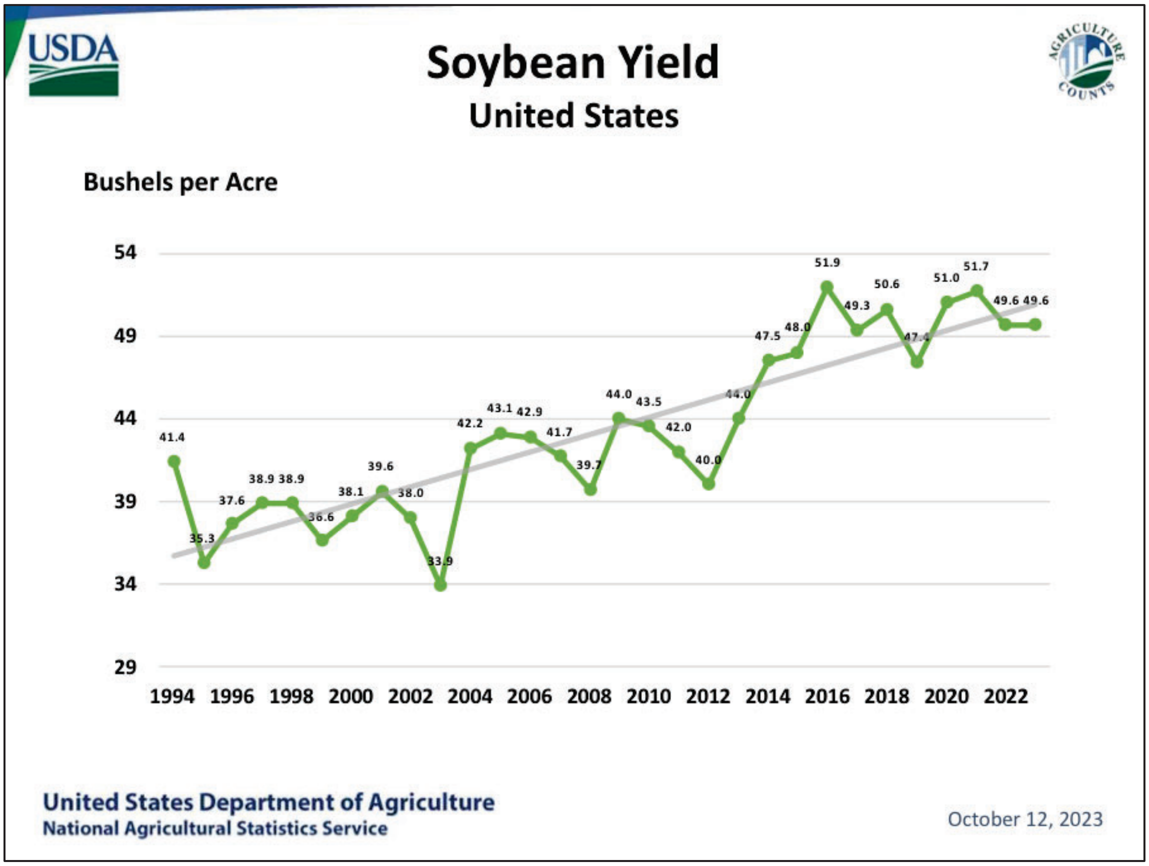
Figure 8.1 – Environmental Impacts of Replacing Fossil Fuels with Biodiesel for Soybean Cultivation/Harvesting

The most significant change is smog, which increases significantly because biodiesel combustion generates more smog than other fuel alternatives. Acidification also shows a visible increase when switching to biodiesel, but on a smaller scale than smog. While biodiesel has higher impact in those two categories, it also remains relatively the same in eutrophication, land use, and water consumption. Switching to biodiesels also shows considerable improvements in global warming potential, fossil fuel depletion, and to a lesser extent, ozone depletion.

9.0 Sensitivity Analysis

9.1 Harvest Yield

The most influential variable in the soybean farming operation was determined to be the harvest yield, characterized as bushels of soybeans per acre of farmed land. Soybean yields (bushels per acres) continue to improve as indicated by the USDA figure below. Improvements in seed quality and farmer practices drive more bushels per acre, as demonstrated by numerous reporting agencies. This is being done while reducing chemicals, passes through the fields, and increasing practices such as no till and cover crop expansion.



The average yield for all soybean farming in the United States is 51 bushels/acre (USDA 2020) which is the value applied to calculate the baseline results of the study. Soybean yields have been reported in the range of 40-70 bushels/acre (USDA 2020, farming survey). Lower yields of around 40 bushels per acre result from the use of organic farming techniques (USDA 2020). Lower yields can also occur under sub-optimal growing conditions (e.g., when crops don't receive sufficient water in drought conditions).

A value of 41 bushels/acre was selected as the low bound for sensitivity analysis. This value is consistent with the yield from the previous LCA carried out by Quantis and is near the lower limit for reported yields as described in the scenarios above. A value of 61 bushels/acre was selected for the upper bound. This value represents the average yield reported in the farming survey and is near the high average of 64 bushels/acre reported for fully irrigated soybean cultivation (USDA 2020). Impact results at the lower and upper bound of the soybean yields show approximately a 25% change over the baseline case. Figure 9.1 and Table 9.1 illustrate the result differences.

> *Note: This analysis only represents changes in yield data for the 2020-2021 years and not any other parameters that may influence yield, such as fertilizer application.*

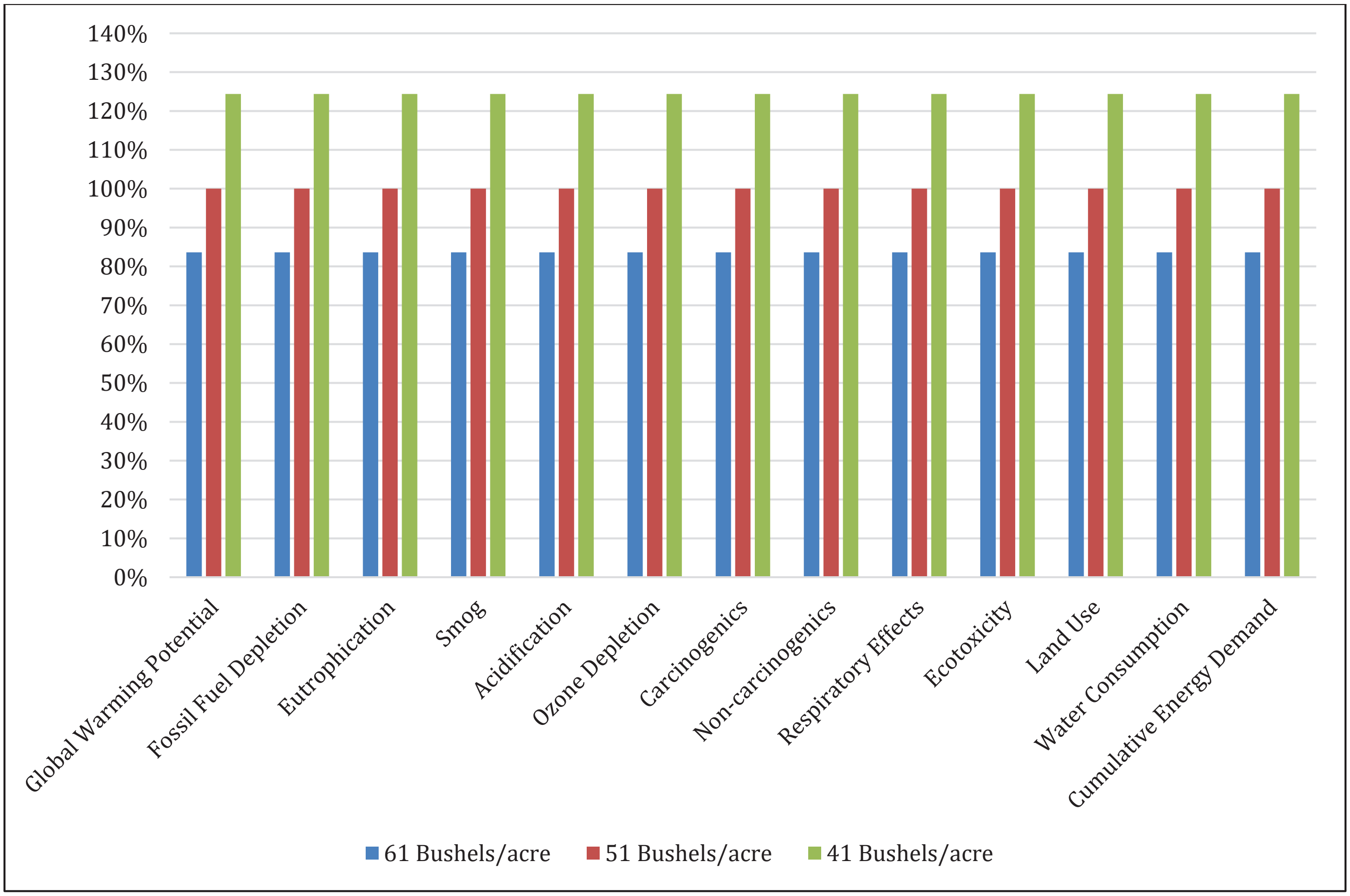


Figure 9.1 – Soybean Yield Sensitivity Analysis

Table 9.1 – Environmental Impacts of 1 kg of Soybeans with Different Harvest Yields

Impact Category	Unit	61 Bushels/acre	51 Bushels/acre	41 Bushels/acre
Global Warming Potential	kg CO_2 eq	2.85E-01	3.41E-01	4.24E-01
Fossil Fuel Depletion	MJ surplus	3.49E-01	4.17E-01	5.19E-01
Eutrophication	kg N eq	3.17E-03	3.79E-03	4.71E-03
Smog	kg O_3 eq	1.72E-02	2.06E-02	2.56E-02
Acidification	kg SO_2 eq	1.67E-03	2.00E-03	2.48E-03
Ozone Depletion	kg CFC-11 eq	2.60E-08	3.11E-08	3.86E-08
Carcinogenics	CTUh	9.73E-09	1.16E-08	1.45E-08
Non-Carcinogenics	CTUh	1.70E-07	2.04E-07	2.54E-07
Respiratory Effects	kg $PM_{2.5}$ eq	1.57E-04	1.88E-04	2.34E-04
Ecotoxicity	CTUe	4.99E+01	5.97E+01	7.43E+01
Land Use	m^2a crop eq	1.48E+00	1.77E+00	2.20E+00
Water Consumption	m^3	3.85E-02	4.60E-02	5.73E-02
Cumulative Energy Demand	MJ	3.72E+00	4.46E+00	5.54E+00

9.2 Diesel

Survey results suggest that farming practices require approximately 1.4 gallons of diesel per acre, which under the current yield assumptions results in approximately 0.001 gallons of diesel per kg of soybeans. However, previous studies had worked under the assumption that soybean farming requires approximately 5 to 6 gallons per acre, which under current yield assumptions corresponds to 0.0036 and 0.0043 gallons per kg, respectively. A sensitivity analysis tests the effects of higher diesel concentrations, comparing baseline survey results to 2.5 gallons per acre, 5 gallons per acre, and 6 gallons per acre. Results are shown Figure 9.2.

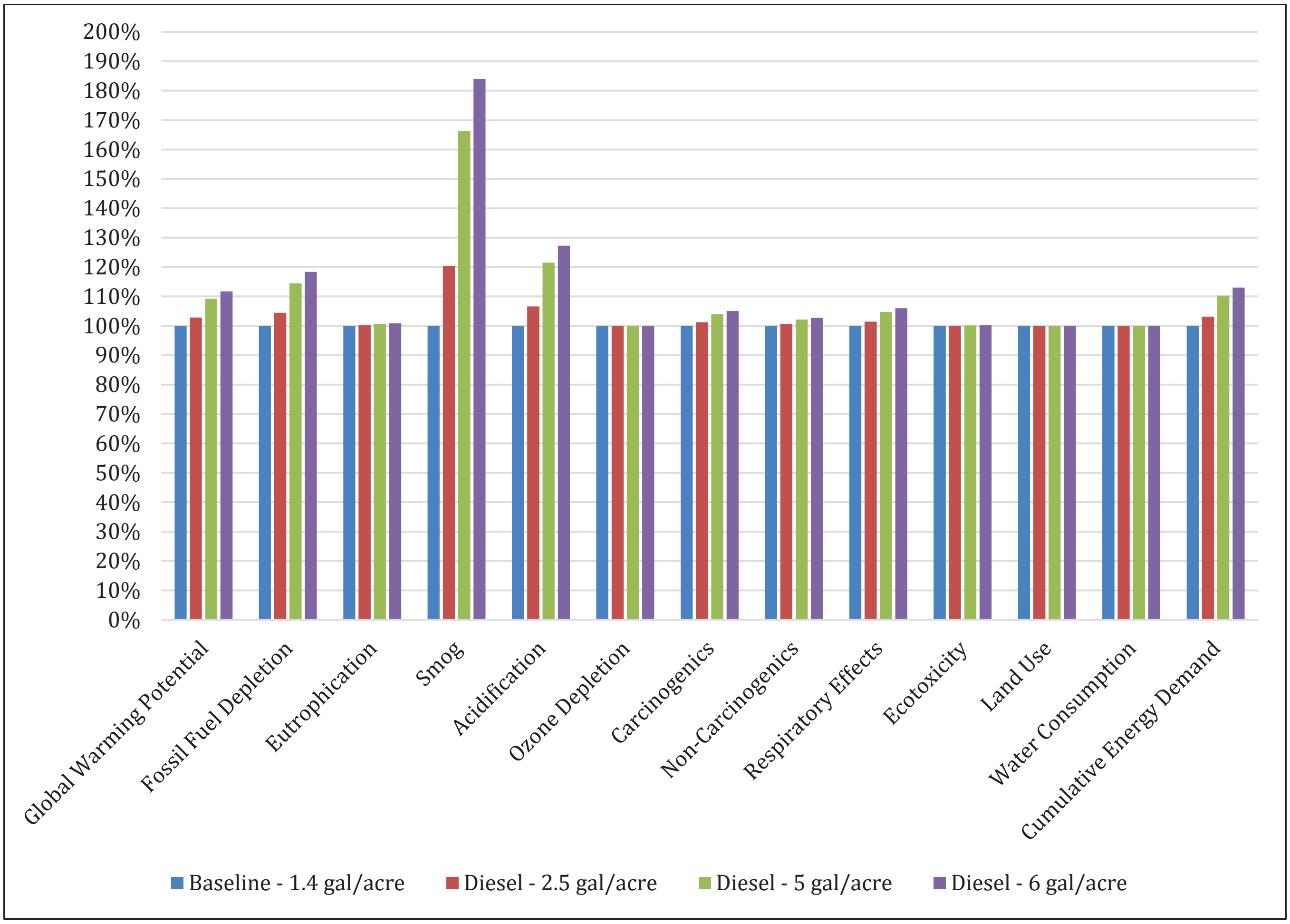


Figure 9.2 – Diesel Sensitivity Analysis, 1 kg of Soybeans

The effects of higher diesel concentrations remain relatively low in most impact categories except smog. This is due to the chemical reactions that take place when diesel is combusted. Overall impacts resulting from each of the different diesel quantities considered in this sensitivity analysis are included in Table 9.1 below.

Table 9.2 – Environmental Impacts of 1 kg of Soybeans with Different Diesel Concentrations

Impact Category	Unit	Baseline	2.5 gal/acre	5 gal/acre	6 gal/acre
Global Warming Potential	kg CO_2 eq	3.41E-01	3.50E-01	3.72E-01	3.81E-01
Fossil Fuel Depletion	MJ surplus	4.17E-01	4.36E-01	4.78E-01	4.94E-01
Eutrophication	kg N eq	3.79E-03	3.80E-03	3.81E-03	3.82E-03
Smog	kg O_3 eq	2.06E-02	2.48E-02	3.42E-02	3.79E-02
Acidification	kg SO_2 eq	2.00E-03	2.13E-03	2.42E-03	2.54E-03
Ozone Depletion	kg CFC-11 eq	3.11E-08	3.11E-08	3.11E-08	3.11E-08
Carcinogenics	CTUh	1.16E-08	1.18E-08	1.21E-08	1.22E-08
Non-Carcinogenics	CTUh	2.04E-07	2.05E-07	2.08E-07	2.09E-07
Respiratory Effects	kg $PM_{2.5}$ eq	1.88E-04	1.91E-04	1.97E-04	1.99E-04
Ecotoxicity	CTUe	5.97E+01	5.98E+01	5.98E+01	5.99E+01
Land Use	m^2a crop eq	1.77E+00	1.77E+00	1.77E+00	1.77E+00
Water Consumption	m^3	4.60E-02	4.60E-02	4.60E-02	4.60E-02
Cumulative Energy Demand	MJ	4.46E+00	4.60E+00	4.91E+00	5.04E+00

Since soybeans are the main drivers of impacts for soybean oil and meal, Figure 9.3 and Figure 9.4 show the impacts that result from these higher diesel concentrations. Table 9.3 and Table 9.4 detail the impact assessment results.

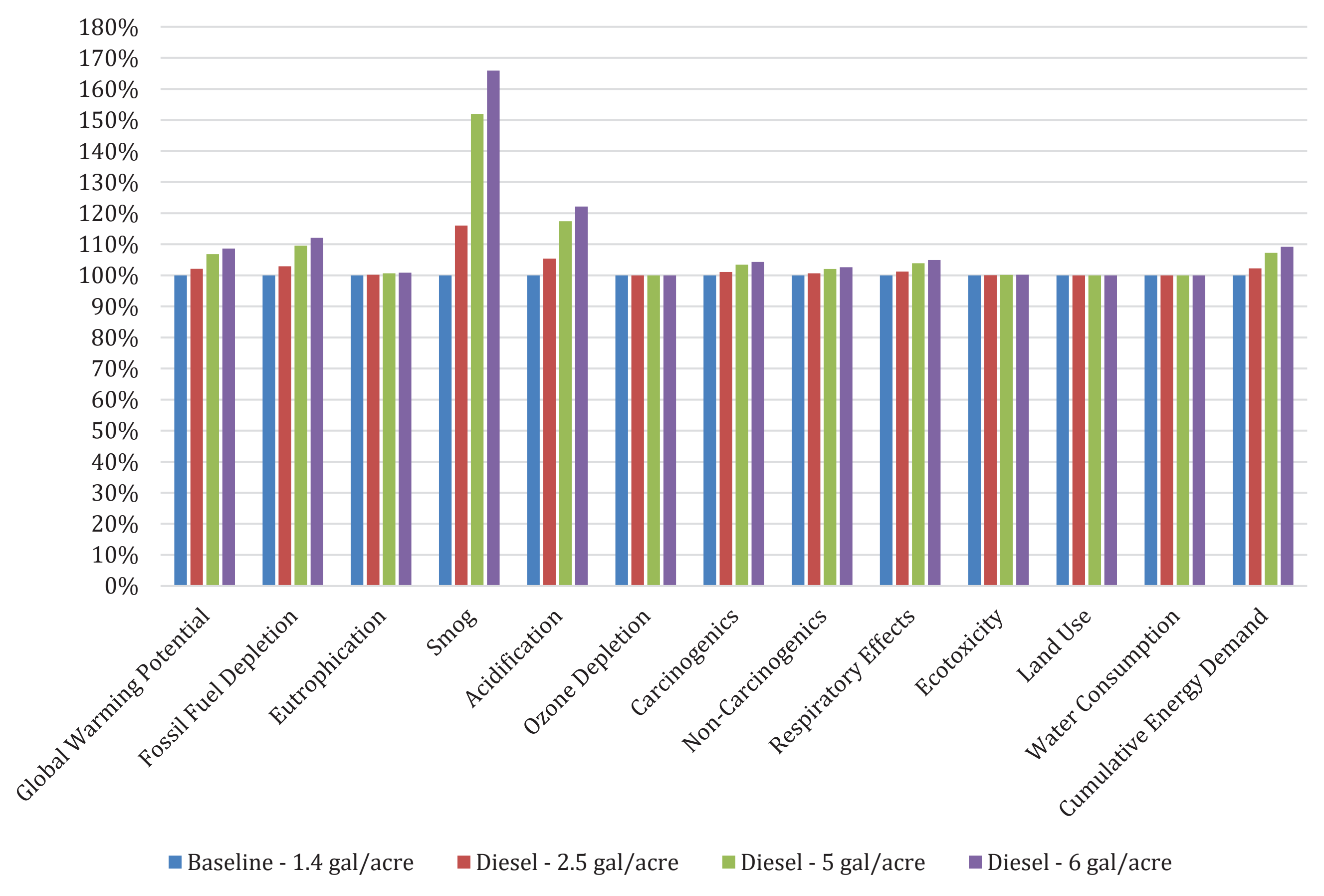


Figure 9.3 – Diesel Sensitivity Analysis, 1 kg of Crude Soy Oil or 1 kg of Soybean Meal

Table 9.3 – Environmental Impacts of 1 kg of Crude Soy Oil or Soybean Meal with Different Diesel Concentrations

Impact Category	Unit	Baseline	2.5 gal/acre	5 gal/acre	6 gal/acre
Global Warming Potential	kg CO_2 eq	4.78E-01	4.88E-01	5.11E-01	5.19E-01
Fossil Fuel Depletion	MJ surplus	6.57E-01	6.76E-01	7.19E-01	7.36E-01
Eutrophication	kg N eq	3.99E-03	4.00E-03	4.02E-03	4.02E-03
Smog	kg O_3 eq	2.71E-02	3.15E-02	4.12E-02	4.50E-02
Acidification	kg SO_2 eq	2.55E-03	2.68E-03	2.99E-03	3.11E-03
Ozone Depletion	kg CFC-11 eq	4.00E-08	4.00E-08	4.00E-08	4.00E-08
Carcinogenics	CTUh	1.40E-08	1.42E-08	1.45E-08	1.46E-08
Non-Carcinogenics	CTUh	2.23E-07	2.25E-07	2.28E-07	2.29E-07
Respiratory Effects	kg $PM_{2.5}$ eq	2.35E-04	2.38E-04	2.44E-04	2.47E-04
Ecotoxicity	CTUe	6.20E+01	6.20E+01	6.21E+01	6.21E+01
Land Use	m^2a crop eq	1.83E+00	1.83E+00	1.83E+00	1.83E+00
Water Consumption	m^3	4.81E-02	4.81E-02	4.81E-02	4.81E-02
Cumulative Energy Demand	MJ	6.52E+00	6.67E+00	6.99E+00	7.12E+00

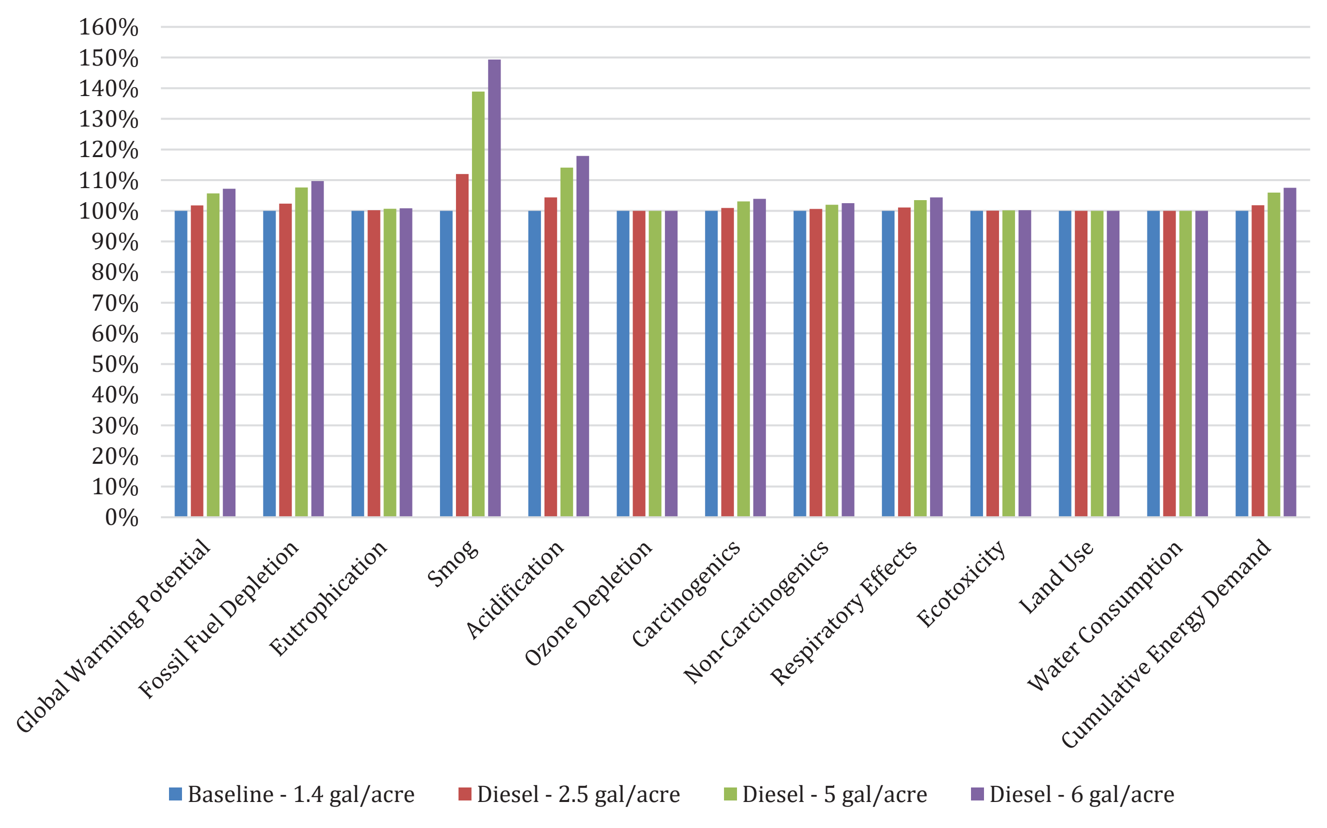


Figure 9.4 – Diesel Sensitivity Analysis, 1 kg of Refined Soy Oil

Table 9.4 – Environmental Impacts of 1 kg of Refined Soy Oil with Different Diesel Concentrations

Impact Category	Unit	Baseline	2.5 gal/acre	5 gal/acre	6 gal/acre
Global Warming Potential	kg CO_2 eq	5.88E-01	5.98E-01	6.21E-01	6.30E-01
Fossil Fuel Depletion	MJ surplus	8.37E-01	8.57E-01	9.01E-01	9.18E-01
Eutrophication	kg N eq	4.11E-03	4.12E-03	4.14E-03	4.15E-03
Smog	kg O_3 eq	3.70E-02	4.14E-02	5.13E-02	5.52E-02
Acidification	kg SO_2 eq	3.21E-03	3.35E-03	3.66E-03	3.79E-03
Ozone Depletion	kg CFC-11 eq	4.47E-08	4.47E-08	4.47E-08	4.47E-08
Carcinogenics	CTUh	1.59E-08	1.61E-08	1.64E-08	1.66E-08
Non-Carcinogenics	CTUh	2.37E-07	2.39E-07	2.42E-07	2.43E-07
Respiratory Effects	kg $PM_{2.5}$ eq	2.69E-04	2.72E-04	2.79E-04	2.81E-04
Ecotoxicity	CTUe	6.34E+01	6.34E+01	6.35E+01	6.35E+01
Land Use	m^2a crop eq	1.87E+00	1.87E+00	1.87E+00	1.87E+00
Water Consumption	m^3	4.99E-02	4.99E-02	4.99E-02	4.99E-02
Cumulative Energy Demand	MJ	8.16E+00	8.31E+00	8.64E+00	8.77E+00

The results are very similar to those for soybeans, with little to no significant change for most impact categories outside of diesel. However, as processing the soybeans or further processing the oil increases processing impacts, this results in lower overall changes when increasing the quantities of diesel used in farming.

9.3 Allocation Methods

Soybean meal and crude soybean oil are co-products during the soybean crushing and degumming stage. Energy and raw materials for this process were allocated to each product based on mass. This is consistent with the allocation method used in the 2015 Quantis LCA study, but other allocation methods, such as economic and by energy content, were also considered. Economic allocation consists of allocating energy and resources to each product based on their economic value in the market. This is a good alternative for allocation when products that would normally be considered waste streams are sold to other markets. This is also the allocation method recommended by EU Product Environmental Footprint Category Rules for Feed for Food Producing Animals. Allocation by energy content allocates materials and resources to each co-product based on their caloric content. This can be helpful when allocating for co-products that will be used to generate energy, such as oil. Figure 9.5 shows what percentage of the environmental impacts of each kg of processed soybeans are allocated to crude soy oil and to soybean meal according to each of the different allocation methods.

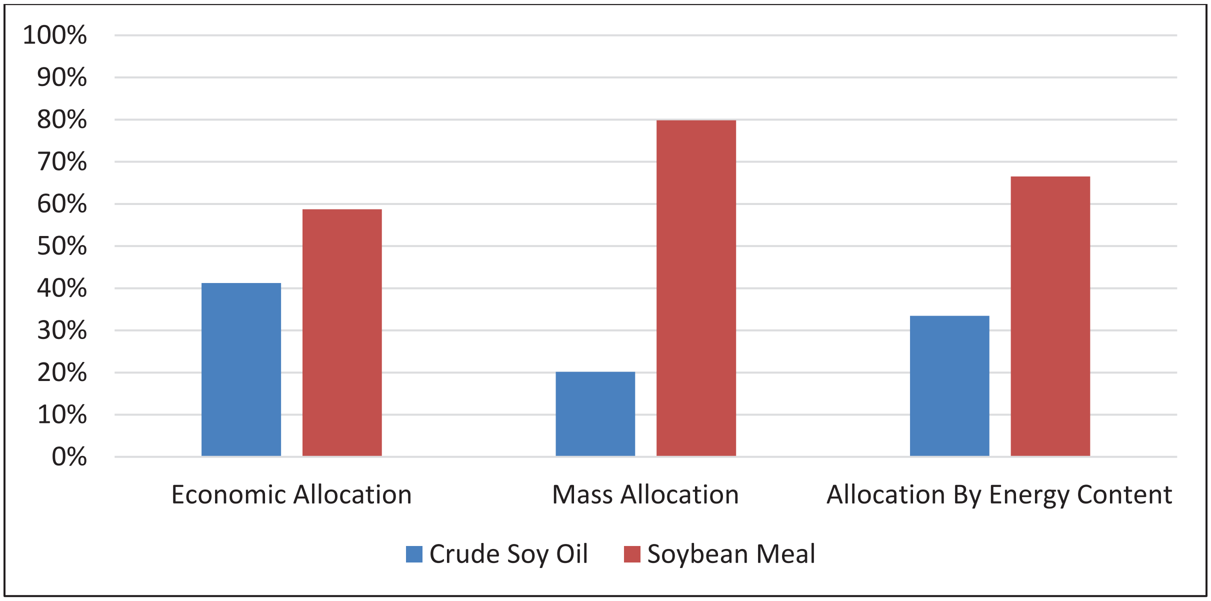


Figure 9.5 – Soybean Allocation Sensitivity Analysis – per kg of Soybeans

Soybeans are approximately 20% oil by mass, and the rest is turned into soymeal. Since soymeal is about 80% of the product, it has a higher allocation of impacts regardless of which method is used. Overall, the gap between their respective shares of impacts decreases with economic and energy content allocations: 20% oil/80% meal for mass allocation, 33% oil/67% meal for allocation by energy content, and 41% oil /59% meal for economic allocation. This happens because crude soy oil has a higher energy content than soybean meal, and it is significantly more expensive. Figure 9.6 portrays what percentage of impacts are allocated to soybean meal in proportion to those allocated to crude soy oil on a per-kilogram of each product basis.

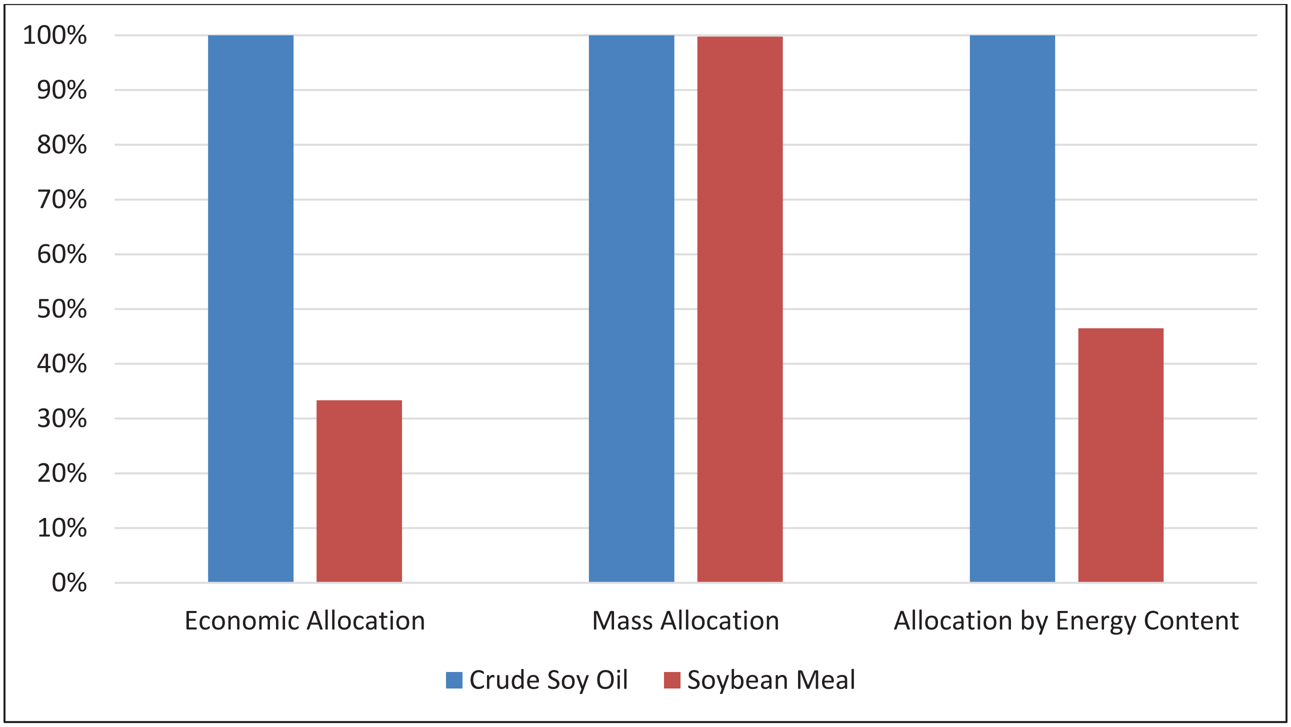


Figure 9.6 – Soybean Allocation Sensitivity Analysis – per kg of Product

10.0 Limitations

All energy and waste data for the soybean cultivation and harvesting were obtained directly from U.S. soybean farmers through collaboration with a third-party survey organization. The data for water usage and soil management practices were obtained from publicly available USDA surveys. Transportation distances and modes were collected directly from publicly available data published by the Soy Transportation Coalition. All processing and transportation data were collected and provided directly from NOPA. Fertilizer data were obtained from USDA. Efforts were made to check the data for internal consistency and to verify data with organization personnel.

The findings in this research are limited by the inherent uncertainty of creating a representative model through LCA. Many assumptions were made in modeling the product system with representative processes and datasets. The authors addressed the uncertainty in modeling decisions by conducting a mass balance and sensitivity analysis as the LCI model was being constructed (data verification/validation relative to cut-off criteria and study goals).

Geography, soil, and rainfall are just some of the key variables that influence soybean cultivation. This study attempts to capture the average case for soybean cultivation in the United States. The results for individual farming practices will differ based on their unique operations. Approaches such as organic farming result in different emissions profiles but may have lower yields, resulting in different impact profiles per unit produced. During the period of this study, organic soybeans represented 0.3% of the entire U.S. soybean production, thus, organic soybeans were excluded from the scope of this study. Additionally, crop rotation is a method commonly used in soybean cultivation to utilize the benefits of soil nutrients leftover from crop cultivation. This study allocated the field operation inventory based on harvest acreage; however, there are more nuances and complexities behind this system that makes this an oversimplified allocation. This was the most feasible way to account for the crop rotations but should be noted as a limitation of the study. While the farming survey is believed to be representative of the average soybean cultivation and harvesting practices, any additional data collection on soybean agricultural activity would strengthen the study. Similarly, yield and field applications are known to have a direct correlation on the environmental impact of agricultural products. A sensitivity analysis was conducted to evaluate how yield would affect the results presented; however, field application rates were not adjusted accordingly due to the complexity of soil nutrient maintenance. This is an opportunity for improvement of the study.

There exists limitation within the secondary data used for the material processes. One of these limitations is the reliance on assumptions, as established in Section 5.1, Section 6.1, and Section 7.1. Another limitation is from the methodology for obtaining primary data. The methodology relied on responses from many different farmers who were not instructed on how to specifically measure the data points. This approach can inherently carry some uncertainty based on the method of measurement. Due to the volume of responses collected, it was not feasible to host individual sessions on how to measure data; however, SSC conducted a thorough screening of the survey responses to eliminate any data points that were inconsistent with traditionally expected ranges. The ideal solution to this limitation would be to employ a single team to go to each survey site and measure the data points of interest using a pre-established methodology. This solution would require a multi-year planning and implementation procedure to collect all the necessary data for a production year, and thus would risk the temporal relevance of the study data. Due to this limitation, the data collection survey was not capable of including fertilizer application rates which have a direct correlation to the yield of production.

Additionally, primary data for this study were based on survey responses from 454 U.S. farmers across 16 states, which might not fully represent the entire soybean industry in the U.S. Attempts were made to expand the field of the survey by inviting 60,000 farmers across all soybean growing states; although, the third-party was unable to obtain responses from the larger sample set in the required timeline. This represents an opportunity for improvement in the study; however, given the temporal and geographic relevance of the data utilized, the study data are still deemed relevant. Similarly, these survey data represent two years of farm practices, but farm practices vary significantly based on numerous factors such as climate, crop rotations, and more. An opportunity for improvement of this study is to utilize three to five years' worth of data in future studies to strengthen the background datasets and mitigate these effects.

The method of data aggregation detailed in Section 6.1 and Section 7.1 present opportunities for improvement of the study in future iterations. Data aggregation based on weight of soybeans processed will eliminate misalignments in the processing mass balance that will improve the results of the study.

An additional opportunity for improvement for this study is the inclusion of soil carbon sequestration in the inventory. This study does not account for soil carbon sequestration due to the complexities of accounting for the carbon mass balance; however, accounting for soil sequestration that results from no-till and cover crop practices, as well as additional agricultural techniques, represents an opportunity to reduce the environmental footprint of the U.S. soybean farming practices.

The EU Product Environmental Footprint Category Rule (PEFCR) and the Global Feed LCI Institute recommend using economic allocation, rather than a mass-based allocation which was used in this study. This is acknowledged as a limitation to the study's applicability to European markets, however, this study is intended for North American markets, so a mass allocation was used to remain consistent with previous studies. Evaluating an economic allocation approach is recommended as an opportunity for improvement in future studies.

A quantitative uncertainty analysis was not conducted as it is only required for statements of comparative assertion per ISO 14044. Only the data quality assessment described in Section 3.0 to evaluate the uncertainty in use of inventory data has been carried out. The characterization models used to calculate midpoint and endpoint results also introduce uncertainty; however, there is currently no way to quantify this uncertainty in the software tools being used. Therefore, the overall uncertainties will be necessarily underestimated due to this uncharacterized uncertainty in the characterization models.

11.0 Conclusions

Soybean yields have trended upwards since 2010, from around an average return of 41 bushels per acre planted to 51 bushels per acre. This 24% increase is the result of improved farming practices that allow for more efficient use of land. As yields continue to increase, the environmental impacts for soybeans and soybean products will look more favorable on a per mass basis.

Based on the analysis and findings presented above, the soybean meal, crude soy oil, and refined soy oil life cycle impacts are strongly driven by the cultivation and harvesting of soybeans. More specifically, field operations, fertilizer, and herbicides. Further increasing yields, decreasing chemical applications, and reducing energy consumption would be the best way to reduce overall environmental impacts.

Higher soybean yields resulted in increased soybean meal and soy oil production during the same period from around 41 bushels/acre in 2010 to 51 bushels/acre in 2021. This 24% increase in production is also tied to increased global demand for U.S. soy-based feedstocks used in the manufacturing of food, feed, biofuels, and industrial products. Despite experiencing increased production, NOPA member companies have implemented numerous improvements to plant operations based on the latest technology available, plant design and U.S. regulatory requirements, which have resulted in overall process improvements between 2010 and present day.

As discussed in Section 3.0 the data used in this LCA was deemed to be as accurate as possible for quantifying a national average; however, there was high uncertainty in primary data as it pertains to the range of variation in survey responses. USB survey responses accounted for 0.45% of the total U.S. soybean production in 2020 and 2021 but were deemed to be a good representation of the U.S. soybean process as the majority of respondents were from the highest producing geographical regions. NOPA data were gathered from 52 (crushing and degumming) facilities and 27 (oil refining) co-located facilities, representing the vast majority of the U.S. soybean processing industry. SSC recommends utilizing three to five years of data in future iterations of this study in order to improve the quality of the data and reduce the uncertainty of primary data.

Based on the analysis and findings presented above, the life cycle impacts are strongly driven by energy inputs (e.g., electricity), transportation (e.g., rail, truck, barge), and raw material inputs (e.g., soybeans). Any opportunity to reduce energy consumption during the manufacturing process, as well as impacts resulting from the transportation of raw materials and final goods, would have a direct reduction in environmental impacts. Implementation costs and permitting restrictions may impact operational costs and consumers.

12.0 Recommendations

This information can prepare USB and NOPA for future sustainable supply chain requirements and can form the basis of marketing literature focused on environmental benefits. This LCA can also assist USB and NOPA members with greenhouse gas modeling and evaluating their own green product claims.

Opportunities to improve the relative impacts of U.S. soybeans, soybean meal, and soy oil production include:

- Enhancing seed quality to improve soybean yields and protein content to maximize value of U.S. soybean products.
- Guiding farmers to adopt sustainable growing practices through implementation of climate-smart technologies.
- Reducing consumption of high-carbon fuels (e.g., coal, petroleum-based diesel, kerosene).
- Modifying equipment and revising operating procedures, where practicable, to improve energy efficiency at processing facilities and refineries.

At this time, SSC recommends the publication of this study and corresponding data for U.S. soybean, soybean meal and soy oil; and for future use by USB and NOPA as the basis for sharing LCA data if market conditions, government requirements, or customers require public release of the data.

13.0 References

ISO 14040/Amd1:2020, Environmental management - Life cycle assessment – Principles and framework. *International Standards Organization*. 2020.

ISO 14044:2006/Amd1:2017/Amd2:2020, Environmental management - Life cycle assessment – Requirements and guidelines. *International Standards Organization*. 2020.

Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) – TRACI version 2.1 – User's Guide. *United States Environmental Protection Agency* 2012.

IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

ReCiPe 2016 v1.1 – A harmonized life cycle impact assessment method at midpoint and endpoint level – Report I: Characterization. *National Institute for Public Health and the Environment*. 2016.

Frischnecht R., Jungbluth, et.al. (2003) Implementation of Life Cycle Assessment Impact Assessment Methods. Final report ecoinvent 2000. *Swiss Centre for LCI*. Duebendorf, CH. V1.11. 2018.

SimaPro Life Cycle Assessment version 9.2.0.2 (software). *PRe Sustainability.* Accessed: 2023.

"U.S. Life Cycle Inventory Database." (2012). *National Renewable Energy Laboratory*, 2012. Accessed: 2023. https://www.lcacommons.gov/nrel/search.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. *The International Journal of Life Cycle Assessment*. [online] 21(9), pp.1218–1230. Accessed: 2023. http://link.springer.com/10.1007/s11367-016-1087-8.

Quick Stats. United States Department of Agriculture – National Agricultural Statistics Service. Accessed: 2022. https://quickstats.nass.usda.gov/.

Life Cycle Impact of Soybean Production and Soy Industrial Products. *United States Soybean Board – Omni Tech International*. 2010.

Update of Soybean Life Cycle Analysis. *United States Soybean Board – Quantis – New Earth - AGECO*. 2016.

National Emission Standards for Hazardous Air Pollutants: Solvent Extraction for Vegetable Oil Production [40 CFR 63.2840]. *Code of Federal Regulations – Title 40*. 2023.

Farm to Market – A Soybean's Journey from Field to Consumer. *Informa Economics*. 2016.

GREET – Updated N2O Emissions for Soybean Fields. *Argonne National Laboratory*. 2015.

Appendix A: Comparison to Previous Study[8]

The analysis presented in this appendix is focused on evaluating the environmental impact differences between the two studies. Impact categories for comparison were limited to what was reported in the 2015 study, so the only impact categories evaluated in this section were TRACI impacts. Data collection and allocation the two studies were similar in respect to methodology. The methodological consistencies between the recent studies were intentionally kept similar where relevant and appropriate to ensure a level of comparability exists between studies. USB and NOPA intend to use this study internally to evaluate the effect of organizational changes that have been implemented geared toward reductions in environmental impacts. The comparison of the results cannot be entirely attributed to the organizational improvements that USB and NOPA have implemented, due to the improvements in LCA datasets and methodologies, as well as the differences in the LCA methods employed by the LCA practitioners; however, the impact of these changes should not be understated and are considered to have a considerable contribution to the comparison.

The main driving factors for each study stayed consistent. In both studies:

- Field operations and chemical application were the main impact drivers for soybean production.
- Soybean cultivation was the main impact driver for the production of soybean meal, crude soy oil, and refined soy oil.

A.1 Soybean Comparison: 2015 and 2021

A comparison of TRACI environmental impacts of soybean agriculture from 2015 and 2021 is illustrated in Figure A.1 below.

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[8] The processing data in the 2015 study were collected in 2010 and reevaluated in 2015 with no changes. The 2015 dataset for refined soybean oil leveraged existing databases and publicly available information; including, the Ecoinvent v3 dataset for soybean oil and meal, and the Omnitech 2010 study for soybean processing.

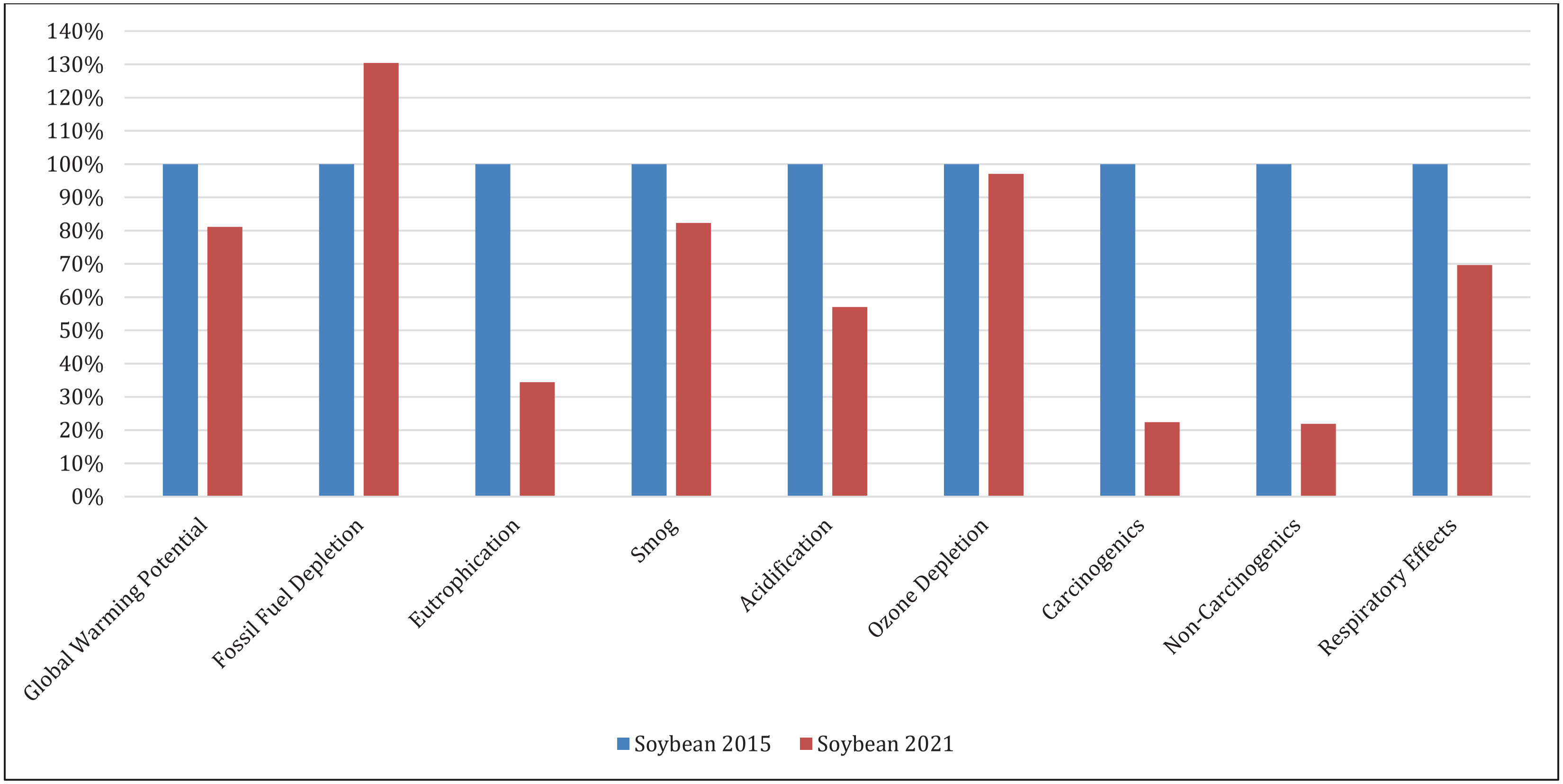


Figure A. 1 – 2021 Values Compared to 2015 Values

The figure above demonstrates that, in general, impacts of soybean production have decreased over the last 5 years. This is due to more efficient farming equipment and farming practices, as well as increasing yields. Yields went from 41 bushels per acre in 2015 to 51 bushels per acre in 2021, which significantly contributed towards impact reduction. Changes in farming practice to use lower impact fuels, such as natural gas, and reduction in pesticide use reduced impacts when compared with the previous study. Overall energy consumption decreased by around 10% per acre, further contributing to the reductions observed. The one exception to this trend is Fossil Fuel Depletion (FFD), in which the impact increased slightly. This is because the use of natural gas for the soybean drying process increased to replace other fossil fuels, such as propane. There are fewer natural gas reserves, which drives FFD up, but since natural gas is a cleaner fossil fuel, it is still better for the environment and reduces overall emissions.

A.2 Soybean Meal and Crude Soy Oil Comparison: 2015 and 2021

The impacts of soybean processing for crude soy oil and soybean meal are illustrated in Figure A.2 and Figure A.3 respectively.

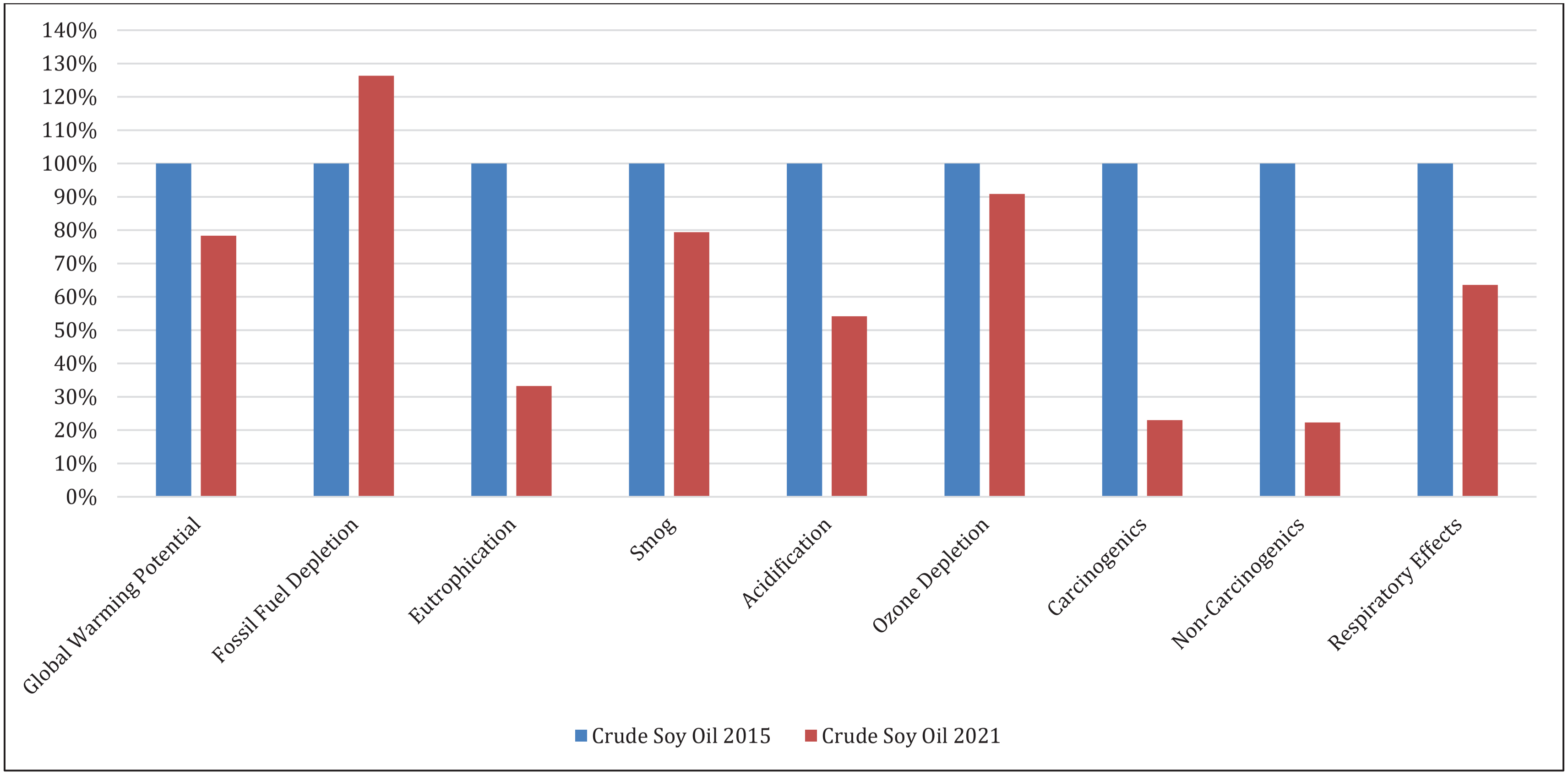


Figure A. 2 – Crude Soy Oil in 2015 vs 2021

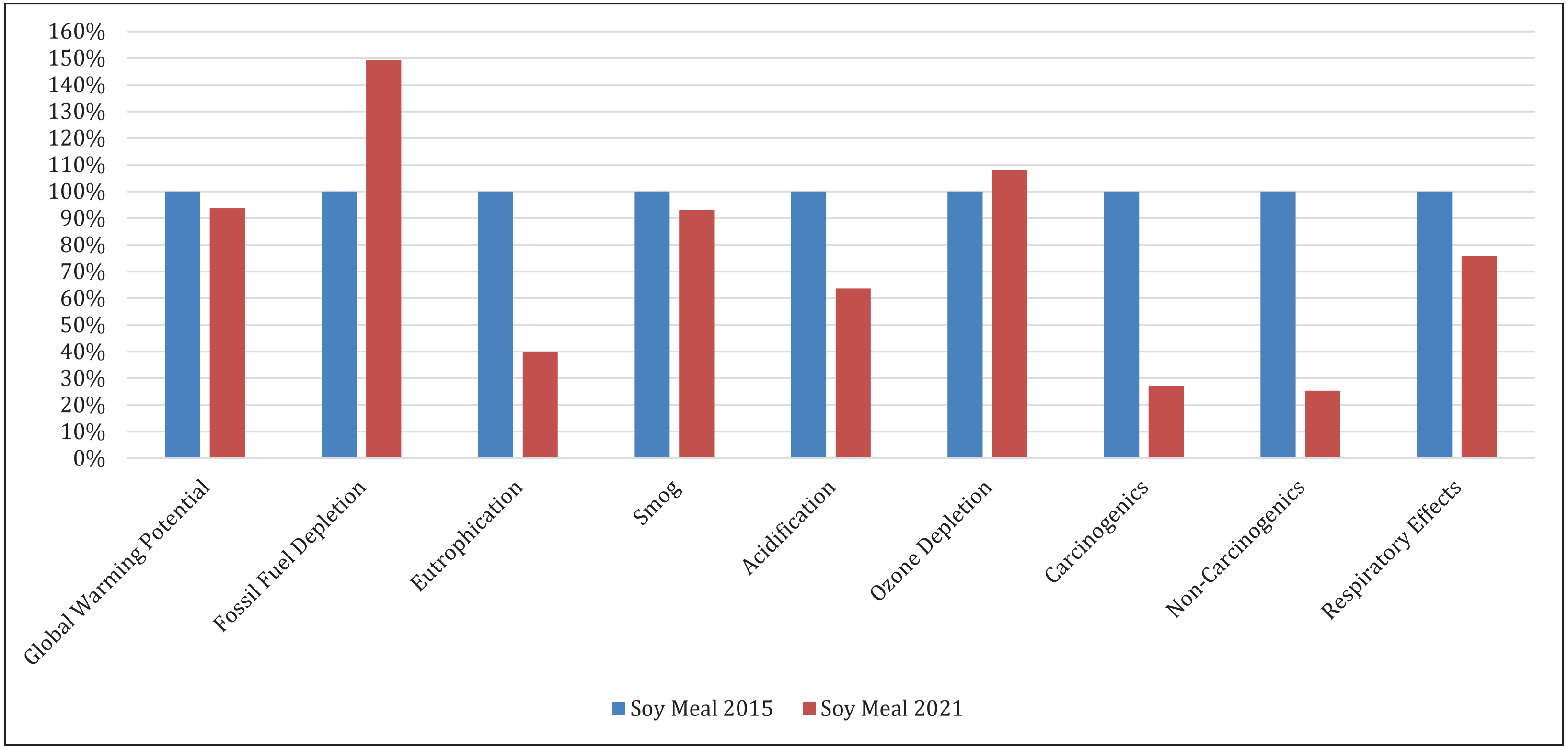


Figure A. 3 – Soybean Meal in 2015 vs 2021

Overall, impacts have decreased throughout most categories, closely following the results from comparing 2015 soybean agriculture to 2021 soybean agriculture. This is partially due to the embodied impacts of the soybeans that have declined over the last several years, and partially because soybean processing technologies have been improving and becoming more efficient. The one exception is fossil fuel depletion, which is a result of the shift to natural gas as a fuel source in farming practices.

A.3 Soy Oil Refining Comparison: 2015 and 2021

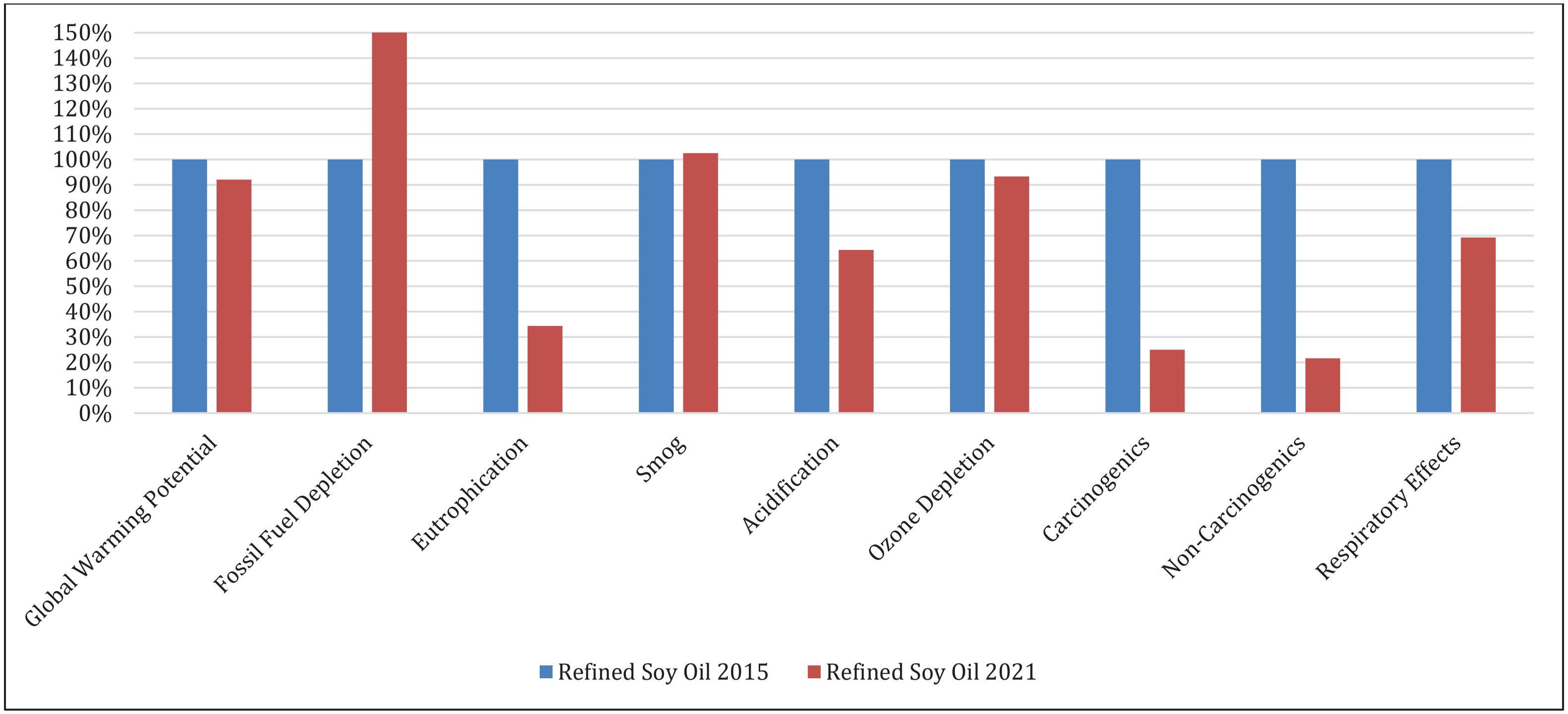


Figure A. 4 – Refined Soy Oil in 2015 vs 2021

Following suit with the soybean product trends described previously, there is a reduction of impacts across the spectrum of impact categories, again with the exception of fossil fuel depletion. The explanation for the previous trends holds true for refined soy oil, since it is downstream of the process flow. In addition, improvements in the refining process contribute to more significant reductions observed in Figure A. 4.

Note: 2015 LCA data was not exclusive to co-located refineries.

Quantified comparative values can be found in Table A. 1.

A.3 Soybean Products Comparison Table: 2015 and 2021

Table A. 1 – Comparison to Previous Study

		Soybeans		Crude Soy Oil		Soy Meal		Refined Soy Oil	
Impact Category	**Unit**	**2015**	**2021**	**2015**	**2021**	**2015**	**2021**	**2015**	**2021**
Global Warming Potential	kg CO_2 eq	4.20E-01	3.41E-01	6.10E-01	4.78E-01	5.10E-01	4.78E-01	6.40E-01	5.89E-01
Fossil Fuel Depletion	MJ surplus	3.20E-01	4.17E-01	5.20E-01	6.57E-01	4.40E-01	6.57E-01	5.50E-01	8.39E-01
Eutrophication	kg N eq	1.10E-02	3.79E-03	1.20E-02	3.99E-03	1.00E-02	3.99E-03	1.20E-02	4.12E-03
Smog	kg O_3 eq	2.50E-02	2.06E-02	3.40E-02	2.70E-02	2.90E-02	2.70E-02	3.60E-02	3.69E-02
Acidification	kg SO_2 eq	3.50E-03	2.00E-03	4.70E-03	2.55E-03	4.00E-03	2.55E-03	5.00E-03	3.22E-03
Ozone Depletion	kg CFC-11 eq	3.20E-08	3.11E-08	4.40E-08	4.00E-08	3.70E-08	4.00E-08	4.80E-08	4.48E-08
Carcinogenics	CTUh	5.20E-08	1.16E-08	6.10E-08	1.40E-08	5.20E-08	1.40E-08	6.40E-08	1.60E-08
Non-Carcinogenics	CTUh	9.30E-07	2.04E-07	1.00E-06	2.23E-07	8.80E-07	2.23E-07	1.10E-06	2.38E-07
Respiratory Effects	kg $PM_{2.5}$ eq	2.70E-04	1.88E-04	3.70E-04	2.35E-04	3.10E-04	2.35E-04	3.90E-04	2.70E-04

Appendix B: Data Quality Tables

Table B. 1 – Data Quality Table for Soybean Cultivation

Component	Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type
Fertilizer	inorganic potassium fertiliser, as K2O {RoW}| nutrient supply from potash salt | Cut-off, U	Ecoinvent 3	2020	Rest of World	Supply of nutrients from ''potash salt'' for fertiliser use	Secondary
	inorganic nitrogen fertiliser, as N {RNA}| nutrient supply from urea | Cut-off, U	Ecoinvent 3	2020	North America	Supply of nutrients from ''urea'' for fertiliser use.	Secondary
	Sulfur {GLO}| market for | Cut-off, U	Ecoinvent 3	2020	Global	This activity starts at the gate of the activities that produce sulfur within the geography of this dataset, with the product ready for transportation. This activity ends with the supply of 1 kg of sulfur to the consumers of this product.	Secondary
	inorganic phosphorus fertiliser, as P2O5 {RoW}| nutrient supply from triple superphosphate | Cut-off, U	Ecoinvent 3	2020	Rest of World	Supply of nutrients from ''triple superphosphate'' for fertiliser use.	Secondary
Field	Occupation, annual crop, conventional tillage	Inputs from Nature	N/A	N/A	N/A	Secondary
	Heat, district or industrial, natural gas {GLO}| market group for | Cut-off, U	Ecoinvent 3	2020	Global	The module includes fuel input from high pressure (RER) network, infrastructure (boiler), emissions to air and water, and electricity needed for operation.	Secondary

Component	Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type
	Electricity, at grid, US/US 2020	USLCI	2020	United States, excluding Alaska and Hawaii	Representative of year 2000 mix of fuels used for utility electricity generation in the U.S. Fuels include coals, fuel oil, nuclear, hydroelectric, and unconventional energy sources. Data are weighted according to percent share of consumption. Includes line loss factor of 9.91%, which represents the difference between electricity generated and electricity sold. SSC modified to represent the average US grid mix in 2020 based on EPA data	Secondary
	Diesel, combusted in industrial equipment/US	USLCI	2015	United States	Diesel combustion in industrial applications such as mobile refrigeration units, generators, pumps, and portable well-drilling equipment	Secondary
	Gasoline, combusted in equipment/US	Sustainable Solutions	2019	United States	Gasoline combustion in equipment such as mobile refrigeration units, generators, pumps, and portable well-drilling equipment.	Secondary
	Propane, burned in building machine {GLO}| market for | Cut-off, U	Ecoinvent 3	2020	Global	The module describes the use of liquid propane fuel extracted for natural gas to provide the service of burning 1 MJ in a building machine.	Secondary

Component	Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type
	irrigation {US}| irrigation, surface | Cut-off, U	Ecoinvent 3	2020	United States	Surface irrigation is the application of water by gravity flow to the surface of the field.	Secondary
Fungicide	Fungicide, at plant/RER Mass	Agri-footprint 5	1987	N/A	Fungicide production. Dataset was the only available option.	Secondary
Herbicide	Glyphosate {RoW}| production | Cut-off, U	Ecoinvent 3	2020	Rest of World	Production of glyphosate including materials, energy uses, infrastructure and emissions.	Secondary
	Atrazine {RoW}| production | Cut-off, U	Ecoinvent 3	2020	Rest of World	Production of atrazine	Secondary
	Metolachlor {RoW}| production | Cut-off, U	Ecoinvent 3	2020	Rest of World	Production of metolachlor including materials, energy uses, infrastructure and emissions.	Secondary
	Alachlor, at plant/RER Mass	Agri-footprint	2017	RER	Pesticide Production	Secondary
	Trifluralin, at plant/RER Mass	Agri-footprint	2017	RER	Pesticide Production	Secondary
	Herbicide, at plant/RER Mass	Agri-footprint	2017	RER	Pesticide Production	Secondary
	Dicamba, at plant/RER Mass	Agri-footprint 5	2017	RER	Pesticide Production	Secondary
	Paraquat, at plant/RER Mass	Agri-footprint 5	2017	RER	Pesticide Production	Secondary

Component	Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type
	Pendimethalin {RoW}| production | Cut-off, U	Ecoinvent 3	2020	Rest of World	Production of pendimethalin including materials, energy uses, infrastructure and emissions.	Secondary
Insecticide	Insecticide, at plant/RER Mass	Agri-footprint		RER	Pesticide Production	Secondary

Component	Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type
Rail	Transport, train, diesel powered/US	USLCI	2015	United States	Combustion of diesel in a locomotive.	Secondary
Truck	Transport, combination truck, average fuel mix /US	USLCI	2015	United States	Mixing process for combination truck, assuming 100% diesel and 0% gasoline	Secondary
Barge	Transport, barge, average fuel mix/US	USLCI	2015	United States	Mixing process for barge transport (78% residual and 22% diesel)	Secondary

Table B. 2 - Data Quality Table for Soybean Meal and Crude Soy Oil Manufacturing

Component	Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type
Natural Gas	Heat, district or industrial, natural gas {GLO}| market group for | Cut-off, U	Ecoinvent 3	2020	Global	The module includes fuel input from high pressure (RER) network, infrastructure (boiler), emissions to air and water, and electricity needed for operation.	Secondary
Coal	Heat, district or industrial, other than natural gas {RoW}| heat production, at coal coke industrial furnace 1-10MW | Cut-off, U	Ecoinvent 3	2020	Rest of World	Combustion of coke coal in an industrial furnace is modeled based on an combustion of hard coal in an industrial boiler in early 1990s. Stoker boiler used as reference technology.	Secondary
Biomass	Heat, onsite boiler, softwood mill average, NE-NC/MJ/RNA	USLCI	2006	United States	Steam and Air-Conditioning Supply. Average technology.	Secondary
Other Fuels	Diesel, burned in agricultural machinery {GLO}| diesel, burned in agricultural machinery | Cut-off, U	Ecoinvent 3	2020	Global	1 MJ (0.0222 kg) diesel burned for running a tractor with a trailer. The inventory represents heavy road transport with tractor and 2 tyre-trailers of max. 8 t loading capacity each. Mean velocity when loaded = 15 km/h. Mean velocity when empty = 25 km/h. Empty return over the same distance included.	Secondary
Water	Tap water {RoW}| market for | Cut-off, U	Ecoinvent 3	2020	Rest of World	This activity starts from tap water, under pressure, at tap water treatment plant and fed into the tap water distribution network. This activity ends	Secondary

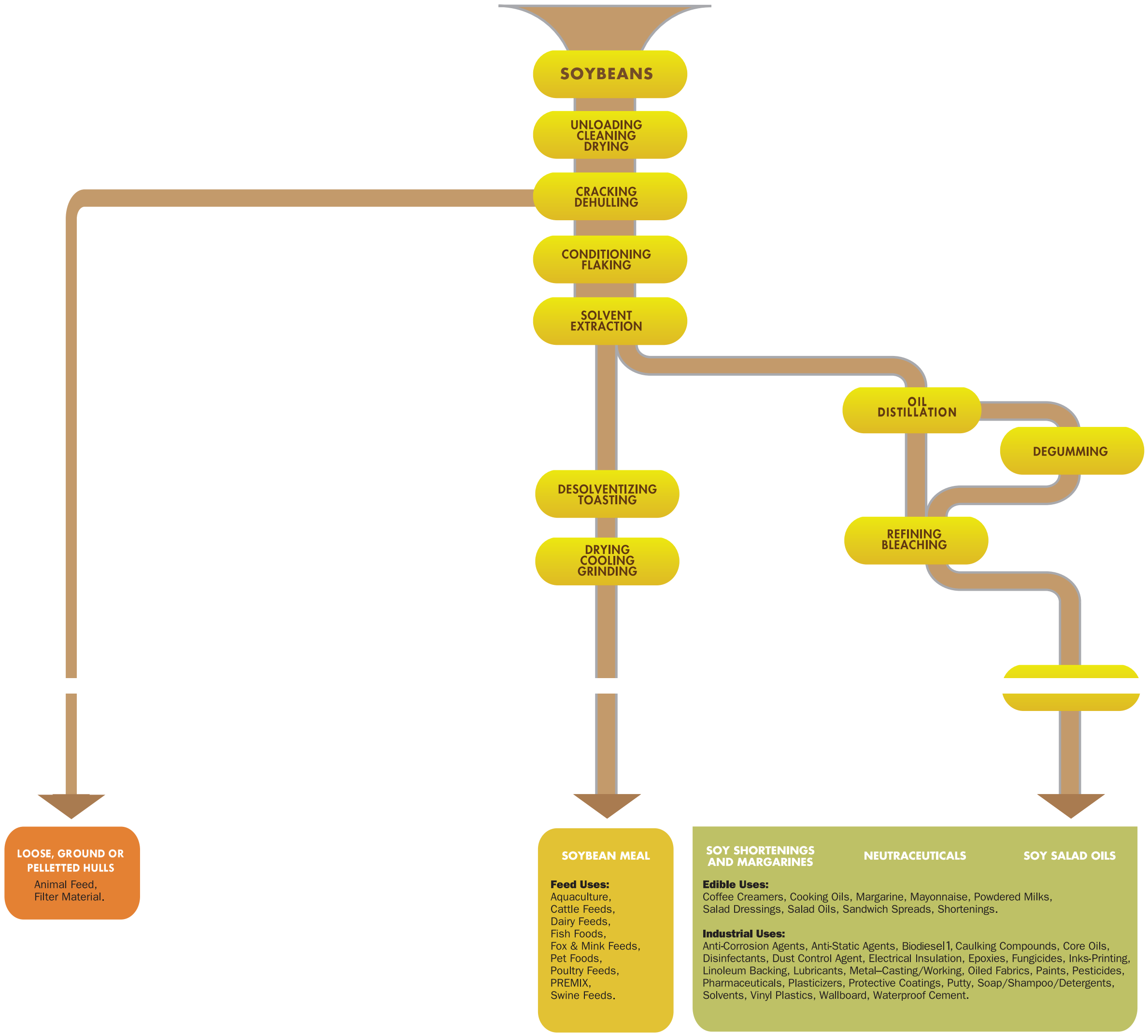
Component	Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type
					with 1 kg of water at consumer (industrial or household).	
Electricity	Electricity, at grid, US/US 2020	USLCI	2020	United States, excluding Alaska and Hawaii	Representative of year 2000 mix of fuels used for utility electricity generation in the U.S. Fuels include coals, fuel oil, nuclear, hydroelectric, and unconventional energy sources. Data are weighted according to percent share of consumption. Includes line loss factor of 9.91%, which represents the difference between electricity generated and electricity sold. SSC modified to represent the average US grid mix in 2020 based on EPA data	Secondary
Purchased Steam	Heat, from steam, in chemical industry {RoW}| steam production, as energy carrier, in chemical industry | Cut-off, U	Ecoinvent 3	2020	Rest of World	Production of 1 MJ of steam used for heating in the chemical and petrochemical industry. The inventory represents the average fuel mix used for steam production in the chemical and petrochemical industry.	Secondary
Purchased Steam from Natural Gas	Process steam from natural gas, heat plant, consumption mix, at plant, MJ, EU-27 S System - Copied from ELCD	Agri-footprint 5	2015	EU-27	The process steam is produced in a natural gas specific heat plant. Provision of 1 MJ of process steam at heat plant for final consumers.	Secondary

Table B. 3 - Data Quality Table for Refined Soy Oil

Component	Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type
Sodium Hydroxyde	Sodium hydroxide	Inputs from nature	N/A	N/A	N/A	Secondary
Bleaching Earth	Bleaching earth, at plant/RER Mass	Agri-footprint 5	2009	N/A	Bleaching earth production. Dataset was the only available option.	Secondary
Electricity	Electricity, at grid, US/US 2020	USLCI	2020	United States, excluding Alaska and Hawaii	Representative of year 2000 mix of fuels used for utility electricity generation in the U.S. Fuels include coals, fuel oil, nuclear, hydroelectric, and unconventional energy sources. Data are weighted according to percent share of consumption. Includes line loss factor of 9.91%, which represents the difference between electricity generated and electricity sold. SSC modified to represent the average US grid mix in 2020 based on EPA data	Secondary
Natural Gas	Heat, district or industrial, natural gas {GLO}| market group for | Cut-off, U	Ecoinvent 3	2020	Global	The module includes fuel input from high pressure (RER) network, infrastructure (boiler), emissions to air and water, and electricity needed for operation.	Secondary

Component	Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type
Coal	Heat, district or industrial, other than natural gas {RoW}| heat production, at coal coke industrial furnace 1-10MW | Cut-off, U	Ecoinvent 3	2020	Rest of World	Combustion of coke coal in an industrial furnace is modeled based on an combustion of hard coal in an industrial boiler in early 1990s. Stoker boiler used as reference technology.	Secondary
Other Fuels	Diesel, burned in agricultural machinery {GLO}| diesel, burned in agricultural machinery | Cut-off, U	Ecoinvent 3	2020	Global	1 MJ (0.0222 kg) diesel burned for running a tractor with a trailer. The inventory represents heavy road transport with tractor and 2 tyre-trailers of max. 8 t loading capacity each. Mean velocity when loaded = 15 km/h. Mean velocity when empty = 25 km/h. Empty return over the same distance included.	Secondary
Water	Tap water {RoW}| market for | Cut-off, U	Ecoinvent 3	2020	Rest of World	This activity starts from tap water, under pressure, at tap water treatment plant and fed into the tap water distribution network. This activity ends with 1 kg of water at consumer (industrial or household).	Secondary

Appendix C: Soybean Meal and Soybean Oil Process Flow Diagram



NOTE: The National Oilseed Processors Association (NOPA) represents the U.S. soybean, canola, flaxseed, sunflower seed and safflower seed crushing industries. This flowchart is an illustrative diagram of standardized steps employed in the processing of soybeans. The steps employed may vary from plant to plant and from oilseed to oilseed.

Figure C. 1 – Process Flow Diagram for Soybean Processing

Appendix D: Adjusted Crude Soy Oil and Soybean Meal LCI

Table D. 1 - Crude Soy Oil and Soybean Meal LCI Adjusted for 58.6 lbs./bushel

Energy Inputs	Unit	Quantity per kg of Soybean Meal or Crude Soy Oil
Electricity	kWh	3.90E-02
Natural Gas	mmbtu	6.71E-04
Coal	mmbtu	5.55E-05
Biomass	mmbtu	5.18E-06
Other Fuels	mmbtu	8.13E-06
Purchased Steam	mmbtu	5.20E-04
Material Inputs	**Unit**	**Quantity per kg of Soybean Meal or Crude Soy Oil**
Soybeans	kg	1.00E+00
Hexane	kg	5.52E-04
Water	**Unit**	**Quantity per kg of Soybean Meal or Crude Soy Oil**
Inflow	L	3.54E-01
Wastewater	L	1.41E-01
Evaporated Water	L	2.13E-01
Transportation	**Unit**	**Quantity per kg of Soybean Meal or Crude Soy Oil**
Truck	kgkm	7.01E+01
Rail	kgkm	4.69E+01
Barge	kgkm	2.15E+01
Emissions	**Unit**	**Quantity per kg of Soybean Meal or Crude Soy Oil**
Hexane	kg	5.52E-04
Note: Soybean meal and crude oil are co-products resulting from crushing operations. Consequently, inventory data was unable to be allocated to product specific processes and the product values are the same.		

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January 21, 2024

Marquis Miller
Sustainable Solutions Corporation
155 Railroad Plaza, Suite 203
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Enclosure: Review Table

Critical Review Statement: "Life Cycle Assessment of U.S. Soybeans, Soybean Meal, and Soy Oil"

This memo serves as a Review Statement for the critical review of the study performed by Sustainable Solutions Corporation for United Soybean Board and the national Oilseed Processors Association.

The Scope of the Critical Review

As the LCA does not involve a product comparison and will not be used to support a comparative assertion, based on ISO 14044 recommendations, a review by a single external expert was deemed sufficient. The reviewer had the task to assess whether:

- the methods used to carry out the LCA are consistent with ISO 14044:2006 and ISO/TS 14071: 2014
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The review of the study was performed to demonstrate conformance with the following standards:

- International Organization for Standardization. (2006). *Environmental management -- Life cycle assessment – Principles and framework* (ISO 14040:2006).
- International Organization for Standardization. (2006). *Environmental management -- Life cycle assessment -- Requirements and guidelines* (ISO 14044:2006).
- International Organization for Standardization. (2014). *Environmental management -- Life cycle assessment -- Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006*. (ISO/TS 14071:2014).

The independent third-party critical review was conducted by Marty Heller, PhD, AgResilience Consulting, LLC

REVIEW SCOPE

The intent of this review was to provide an independent third-party external critical review of a LCA study report in conformance with the aforementioned ISO standards. This review did not include an assessment of the Life Cycle Inventory (LCI) model; however, it did include a critical review of the general approach to complete the study and consideration of the individual datasets applied.

REVIEW PROCESS

The critical review process of the LCA study was conducted to ensure conformance to the International Organization for Standardization (ISO) 14040/44 LCA standards following the review processes and procedures per ISO 14071. The primary task of the review process per ISO 14044 review requirements is to ensure the general requirements for conducting LCA studies are met:

- *Are methods used to carry out the LCA consistent with ISO 14040/14044 standards?*
- *Are methods used to carry out the LCA scientifically and technically valid?*
- *Are data used appropriate and reasonable in relation to the goal of the study?*
- *Do interpretations reflect limitations identified and the goal of the study?*
- *Was the study report transparent and consistent?*

The review process involved the review of all requirements set forth by the applicable ISO standards, cataloged in a comprehensive review table along with editorial comments. There were two rounds of comments by the reviewer submitted to the LCA practitioner. Responses by the LCA practitioner to each issue raised were resolved and acknowledged by the reviewer to have been satisfactorily addressed.

The following summarizes the key comment topics raised by the reviewers that were deemed important for appreciating the nuances and complexities of the study:

- Early rounds of review identified incomplete accounting of nitrous oxide emissions associated with anthropogenic additions of nitrogen to soil. These were sufficiently addressed and updated by the practitioner.
- Primary data used in the LCA were based on a survey of US growers with limited response rate and based on only two years of farm practices. In addition, the survey covered only a portion of the data necessary for the LCA, with the remainder supplemented by USDA statistics, introducing a potential disconnect between the survey population responses and dependent data such as yield. These limitations have been acknowledged in the report.
- The mass allocation method chosen to allocate impacts between co-products of crushing (soybean meal and soybean oil) are not aligned with recommendations from the EU Product Environmental Footprint Category Rule for Feed from Food Producing Animals and the Global Feed LCI Institute. Therefore, care must be taken in making comparisons with results aligned with these international standards. This limitation has been acknowledged in the study.

CRITICAL REVIEW STATEMENT

Based on the independent critical review objectives, the final report, LIFE CYCLE ASSESSMENT OF U.S. SOYBEANS, SOYBEAN MEAL, AND SOYBEAN OIL, dated January 12, 2024, was determined to be in conformance with the applicable ISO standards. The plausibility, quality, and accuracy of the LCA-based data and supporting information are confirmed.

I confirm that I have sufficient scientific knowledge and experience of agricultural processes and the applicable ISO standards to carry out this critical review.

Sincerely,

Marty Heller

Marty Heller

Managing Director
AgResilience Consulting, LLC

NOPA
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PROCESSORS ASSOCIATION

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February 20, 2024

Carolyn Lozo
Chief, Transportation Fuels Branch
California Air Resources Board
1001 "I" Street
Sacramento, CA 95814

Via electronic submission

Re: Proposed Low Carbon Fuel Standard Amendments

Transportation Fuels Branch Chief Lozo:

Thank you for the opportunity to comment in response to the California Air Resources Board's (CARB) "Proposed Low Carbon Fuel Standard Amendments." The National Oilseed Processors Association (NOPA) appreciates being able to share our observations. NOPA members have a vital interest in these issues.

NOPA appreciates CARB's analysis and recognition that consideration of a cap or limitation on crop-based oil feedstocks is unwarranted and would increase fossil diesel use resulting in higher costs for consumers and greater greenhouse gas (GHG), PM2.5 and NOx emissions. CARB should simultaneously promote sustainability and maintain the cost and health benefits afforded by Biomass-Based Diesel (BBD) by recognizing that fuels certified under the federal Renewable Fuel Standard (RFS) meet CARB's newly proposed sustainability criteria.

Background

Organized in 1930, NOPA represents the U.S. soybean, canola, flaxseed, safflower seed, and sunflower seed-crushing industries. NOPA's membership includes 15 members that are engaged in the processing of oilseeds for meal and oil that are utilized in the manufacturing of food, feed, renewable fuels, and industrial products. NOPA member companies operate a total of five softseed and 62 solvent extraction plants across 21 states. Collectively, NOPA members process 95 percent of all soybeans in the U.S. which accounts for approximately 2 billion bushels annually.

NOPA members' oilseed processing operations yield protein-rich meal for human and animal nutrition, as well as vegetable oil that is used as an ingredient in food manufacturing and as a feedstock for renewable fuels such as biodiesel, renewable diesel and sustainable aviation fuel (SAF). These sustainably produced biofuels help reduce carbon dioxide equivalent (CO_2e) greenhouse gas emissions and the carbon intensity of transportation fuels in use today. NOPA is uniquely qualified to respond to CARB's proposed sustainability criteria for crop-based biofuels given the number of markets that NOPA members serve, including the food, feed, fuel, and industrial markets.

NOPA supports California's Low Carbon Fuel Standard (LCFS) which drives demand for biodiesel, renewable diesel and SAF, and encourages investment in low carbon feedstocks and value-added agricultural opportunities. BBD is the largest domestically produced and commercially available fuel to meet the U.S. EPA's definition of an advanced biofuel under the RFS and provides one of the best carbon-reduction strategies for diesel engines available with today's vehicle technologies.

Sustainable Oilseed Processing Feedstocks and Investments

NOPA members are committed to producing sustainable feedstocks. Many of our members have made sustainability commitments and net-zero deforestation pledges. NOPA and the United Soybean Board (USB) published a study which demonstrates the following carbon reductions since 2015:

- 19% decrease for U.S. Soybean cultivation
- 6% decrease for U.S. Soybean Meal production
- 22% decrease for U.S. Crude Soy Oil production
- 8% decreased for U.S. refined soy oil production

NOPA members are also making significant investments to produce sustainable vegetable oil supplies to meet all the demands of biofuel, feed, and food customers. As critical feedstock suppliers to the renewable fuels industry, our industry has announced well over $6 billion in soybean crushing capacity investments since 2021 encompassing some 20 or more expansions or new facilities. These projects are currently on track to increase soybean crush capacity by over 30% between 2023-2026. Collectively, these projects will provide enough additional feedstock to support a 1-billion-gallon increase in BBD capacity over the next several years, **without impacting food or land use**.

This increased capacity will be largely supported by improving the yields from existing acreage already farmed with oilseed crops, increasing the amount of oil produced by such crops and regenerative farming practices, such as cover crops, which reduce the carbon intensity of agricultural practices.

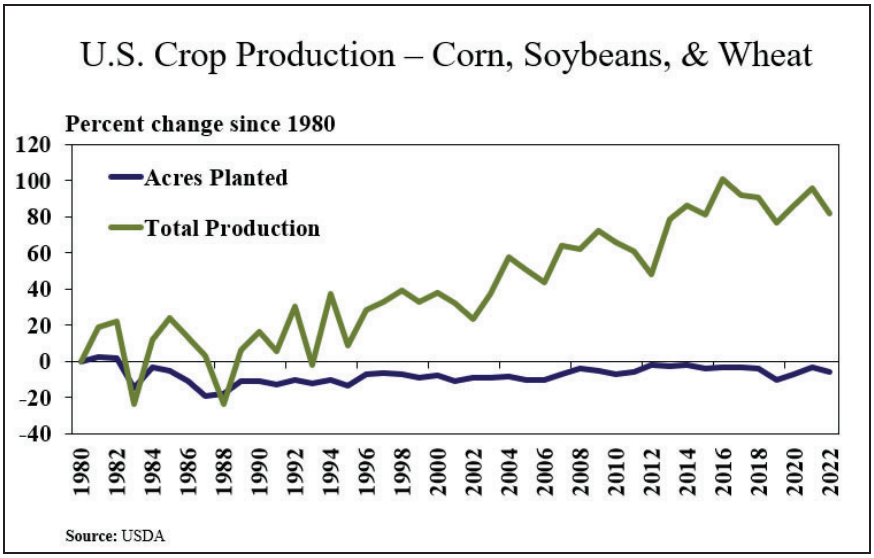
CARB's Proposed Crop-Based Biofuels Sustainability Criteria

As previously mentioned, NOPA appreciates CARB's analysis and recognition that its previous consideration of a cap or limitation on crop-based oil feedstocks is unwarranted and would increase fossil diesel use resulting in higher costs for consumers and greater GHG, PM2.5 and NOx emissions.

While CARB's newly proposed sustainability criteria does afford time for market participants to comply, NOPA would urge CARB to adopt a more risk-based approach to addressing deforestation by recognizing the sustainability requirements already provided for under the RFS. By not recognizing that the RFS already requires certification of all the sustainability criteria proposed by CARB, it would have the unintended consequence of disadvantaging regions of crop-based feedstock production with low-risk of deforestation (U.S. and Canada) at the expense of feedstocks produced in regions with a significantly higher risk of deforestation where segregated supply chains are more prevalent due to those risks.

As noted in Figure 1, total U.S. agricultural land use today is lower than it was in 1980; lower than it was when the RFS was created; and lower than it was when the LCFS was created. And total crop production has increased on roughly the same amount of land by over 80%.

Figure 1



Source: USDA

Not only is U.S. agriculture producing more with less and on fewer acres, it continues to do so at the lowest costs due to its comparative advantage in the world through our efficient bulk commodity, aggregation and transportation system. Layering additional cost and segregation on U.S. producers could have the effect of increasing demand for feedstocks from regions with the highest risk of deforestation.

NOPA also continues to remind CARB staff that it has already overly accounted for land use impacts in the development of the LCFS through the incorporation of indirect land use change penalties (iLUC) – values which continue to be significantly overestimated, and by default provide additional guardrails which CARB staff identified as motivation for additional sustainability criteria.

RFS Compliance with Proposed Sustainability Criteria

NOPA urges CARB to recognize that fuels produced and certified under the RFS meet CARB's newly proposed sustainability criteria. As demonstrated below, the RFS already meets the sustainability requirements proposed under the LCFS amendments:

Proposed Feedstock Sustainability Requirements	RFS Feedstock Sustainability Requirements
Must not be sourced on land forested after Jan. 1, 2008	Must not be sourced from agricultural land cleared or forested after December 19, 2007
Maintain continuous certification	Maintain continuous certification
Certification system must be recognized by an international, national, or state/provincial government for at least 24 months.	The RFS was approved by the U.S. Congress on, and has been in effect since, December 19, 2007
Certification system must consider environmental, social and economic criteria	Factors addressed by U.S. EPA during annual rulemakings to establish Renewable Volume Obligations (RVOs) under the RFS include: • Impact on the environment • Impact on cost to consumers and cost to transport goods, and job creation

	• Soil Quality • Environmental Justice
Certification system standard-setting process is participatory, and consensus driven – convening groups of economic, environmental and social stakeholders in both formal and informal manners; and creates a representative steering committee technical working group(s) and advisory group(s)	The passage of the RFS through Congress was by definition consensus driven, which allowed for the input by all stakeholders as afforded during the legislative process. EPA's annual rulemakings to establish RVOs allow for public comment by all stakeholders, both formal and informal. This process includes input from EPA's Clean Air Scientific Advisory Committee (CASAC) – an independent advisory group of non-EPA scientists, engineers, economists and social scientists.
The certification system must have clear, accessible, and transparent processes;	The development of the implementing regulations for the RFS and each subsequent rulemaking to establish RVOs went through a transparent and public comment process before finalization.
The certification system must publish procedures, guidance, certificates and audit report summaries on its website;	All RFS regulations, certificates, and compliance reports are available at https://www.epa.gov/renewable-fuel-standard-program
The certification system must be science based, provide clear targets to reach, and support demonstrable means of evaluation;	The development of the implementing regulations for the RFS and each subsequent rulemaking to establish RVOs by U.S. EPA go through a transparent and public comment process before finalization, based on specific scientific criteria and evaluation.
The certification system must demonstrate that requirements that are additional to the requirements of this sub article are vetted via a multi-stakeholder process to mitigate potential stakeholder bias;	The passage of the RFS through Congress was by definition consensus driven, which allowed for the input by all stakeholders as afforded during the legislative process. EPA's annual rulemakings to establish RVOs also allow for public comment by all stakeholders, both formal and informal. This process includes input from EPA's Clean Air Scientific Advisory Committee (CASAC) – an independent advisory group of non-EPA scientists, engineers, economists and social scientists.
The certification system must maintain an effective auditor training program to ensure auditor competency;	The RFS compliance and audit program is maintained by U.S. EPA and can be found at https://www.epa.gov/renewable-fuel-standard-program/compliance-overview-renewable-fuel-standard-program
The certification system must include an effective grievance mechanism to ensure that problems are resolved;	EPA's annual rulemakings to establish RVOs also allow for public comment by all stakeholders, both formal and informal. A petition process is also afforded under the RFS, which has been utilized by stakeholders. https://www.epa.gov/renewable-fuel-

	standard-program/other-requests-under-renewable-fuel-standard
The certification system must include sanction mechanisms for participating feedstock suppliers and auditing bodies to ensure conformance with its system requirements; and	The RFS compliance and audit program is maintained by U.S. EPA and can be found at https://www.epa.gov/renewable-fuel-standard-program/compliance-overview-renewable-fuel-standard-program. The RFS and Clean Air Act also establish penalties for non-compliance.

As demonstrated, the RFS already complies with CARB's proposed sustainability criteria and should be explicitly recognized as a compliant certification system under the LCFS amendments.

Ensuring Integrity of Imported Feedstocks

NOPA notes that imports of Used Cooking Oil (UCO) and other low carbon feedstocks have significantly increased since 2022 for LCFS compliance. While we recognize and support the need for low carbon and waste-based feedstocks, NOPA encourages CARB to undergo additional scrutiny and monitoring of imported feedstocks. Such actions will ensure continued program confidence and compliance.

Acknowledgement and Appreciation for Additional CARB Steps on Sustainability Requirements: NOPA notes that in the amendments to the LCFS, the proposed Sustainability Requirements released on December 19 was the first time stakeholders had any opportunity to review these provisions or its concept. Given the precedent-setting nature of this program in the U.S., and the potential for significant cost and compliance burden to stakeholders, NOPA was pleased to see CARB indicate on February 14 that it will take additional time to allow stakeholders to properly vet the intent, impact, and implications of the proposed sustainability requirements.

Conclusion

The body of CARB analysis, and market and scientific data collectively demonstrate that consideration of a cap or limitation on crop-based oil feedstocks is unwarranted. Further, doing so at this point would undercut the investments that are being made and are needed for low carbon feedstocks from the industry expansion.

A vibrant U.S. oilseed sector, and the advanced biofuels produced from oilseeds, are critically important to lowering the GHG emissions in the U.S. and California's fuel supply. Efforts to undercut current policies regarding eligible feedstocks will significantly and negatively impact investments being made in lower carbon feedstocks and fuels.

NOPA is eager to continue working with CARB to support the role of agriculture in diversifying the fuel supply through more sustainable feedstocks and thereby supporting cleaner fuel options in California and beyond. On behalf of America's soybean processors, we appreciate this opportunity to comment, and look forward to collaborating with CARB and other relevant stakeholders to enact policies that will address climate change while expanding the use of soy-based biofuels and market opportunities for soybean farmers.

Sincerely,

Kailee Tkacz Buller

Kailee Tkacz Buller
President & CEO
NOPA