Deutsches BiomasseForschungsZentrum
German Biomass Research Centre

Kurzexpertise zur Evaluierung der Studien “Life Cycle Impact of Soybean Production and Soy Industrial Products” und “Applying Recent US SoybeanDato to the EU Renwable Energy Sources Directive”

-Prüfung auf Konformität mit der EU RED

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Abkürzungsverzeichnis

Abkürzung	Erklärung
CH_4	Methan
CO_2	Kohlenstoffdioxid
DIN	Deutsches Institut für Normung
EU RED	European Renewable Energy Directive
ha	Hektar
IPCC	Intergovernmental Panel on Climate Change
ISO	Internationale Organisation für Normung
kg	Kilogramm
kWh	Kilowattstunde
l	Liter
LCA	Life cycle analyses
MJ	Megajoule
N_2O	Distickstoffoxid
THG	Treibhausgas
USB	United Soybean Board

1 Einleitung

1.1 Hintergrund und Zielstellung

Innerhalb der Richtlinie 2009/28/EG zur Förderung der Nutzung von Energie aus erneuerbaren Quellen (EU RED) [1] wird neben den Anforderungen an den Schutz natürlicher Flächen und eine nachhaltige landwirtschaftliche Bewirtschaftung, ein Mindest-Treibhausgasminderungspotential gefordert. Demnach müssen flüssige Biobrennstoffe und Biokraftstoffe zu bestimmten Zeitpunkten gegenüber einem definierten fossilen Referenzwert ein festgelegtes Treibhausgasminderungspotential aufweisen (z.B. 35 % Treibhausgasminderung ab Einführung der Richtlinie). Zur Berechnung dieses Treibhausgasminderungspotentials anhand tatsächlicher Werte gibt die Richtlinie eine Methodik vor. Des Weiteren besteht die Möglichkeit das Treibhausgasminderungspotenzial über die Verwendung von vorgegebenen Standardwerten zu ermitteln. Die entsprechend der vorgegebenen Methodik berechneten Standardwerte werden in regelmäßigen Abständen auf Basis neuer Erkenntnisse angepasst.

Die amerikanische United Soybean Board (USB) beauftragte Omni Tech International, im Rahmen der Studie „Life Cycle Impacts of Soybean Production and Soy Industrial Products“ [2] (im folgenden Omni Tech Studie 1 genannt) die nationalen Daten für die Produktion von Sojabohnen und Sojaöl, sowie die Konversion des Sojaöls zu sojabasierten Produkten, zu aktualisieren und die Prozesse ökologisch zu bewerten. Da der Default Wert der EU RED für Sojabiodiesel mit einem THG-Minderungspotential von 31 % die 35 % Vorgabe verfehlt, ließ der USB auf Basis der Daten der Omni Tech Studie 1 im Rahmen der Studie „Applying Recent US Soybean Data to the EU Renewable Energy Sources Directive“ [3] (im Folgenden Omni Tech Studie 2 genannt) die Treibhausgasemissionen für die Bereitstellung von Sojabiodiesel gemäß der Methodik der EU RED berechnen und fordert nun, diese Werte zu prüfen und gegebenenfalls die Default Werte anzupassen.

Demgemäß wurde zum Einen die Datenbasis der Omni Tech Studie 1 hinsichtlich ihrer Plausibilität typischen Daten gegenüberstellt und zum Anderen prüft, ob die Ergebnisse der Treibhausgasbilanzierung der Omni Tech Studie 2 geeignet sind, eine Anpassung des in der EU RED enthaltenen Standardwertes für Biodiesel auf der Basis von Soja herbeizuführen bzw. als Grundlage dienen können, einen gesonderten Default-Wert für den Soja-Anbau in den USA zu implementieren.

2 Evaluierung der verwendeten Datenbasis der Omni Tech Studie 1

2.1 Vorgehensweise

Um die Konformität der hinsichtlich der Vorgaben der EU RED zu prüfen, wurden die innerhalb der Studie „Life Cycle Impacts of Soybean Production and Soy Industrial Products“ getroffenen Annahmen und Daten hinsichtlich ihrer Plausibilität typischen Daten gegenübergestellt.

2.2 Produktion der Sojabohnen

Die Bilanzierung der Sojabohnenproduktion (Abbildung 1) enthält alle notwendigen Aufwendungen. Dazu zählen alle Emissionen und Aufwendungen aus der Produktion und Nutzung von Düngemitteln, Saatgut, Diesel und Pflanzenschutzmitteln und etwaiger Landnutzungsänderungen. Die Daten zur Bilanzierung der landwirtschaftlichen Prozesse der Sojabohnenproduktion im Rahmen der Omni Tech

Studie 1 wurden der Inventardatenbank U.S Life Cycle Inventory Database (U.S. LCI) [4] entnommen. Sie basieren auf Durchschnittswerten der U.S. Sojabohnenproduktion in den Jahren 2001 bis 2007.

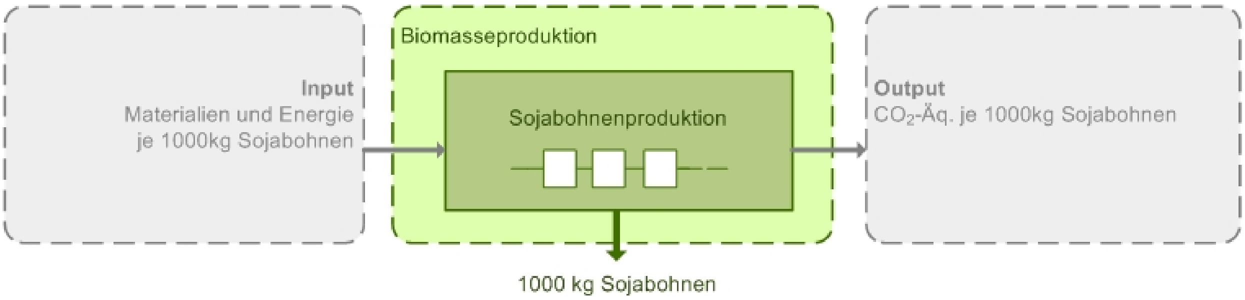

Abbildung 1 Prozess der Biomasseproduktion

Diese Daten wurden sowohl den Hintergrunddaten des Standardwertes der EU RED [5] als auch den Inventardaten der Datenbank Ecoinvent [6] für den Anbau von Sojabohnen vergleichend gegenübergestellt (Tabelle 1). Während sowohl die Ertragswerte als auch die Energieverbrauchswerte ähnliche Größenordnungen aufweisen, sind insbesondere im Bereich des Düngemitteleinsatzes deutliche Unterschiede zu verzeichnen.

Tabelle 1 Erträge und Verbrauchswerte für die Sojaproduktion im Vergleich

	Einheit	Omni Tech Studie 1	EU RED	Ecoinvent
Ertrag	kg/ha	2.766,00	2.798,00	2.641,00
Input je 1000kg Sojabohnen				
Energie				
Diesel	l	14,30	20,92	20,98
Elektrizität	MJ	25,00		
Benzin	l	4,50		
LPG	MJ	32,00		
Erdgas	MJ	48,00		
Energiebedarf Gesamt	MJ	763,00	750,00	752,00
Materialien				
Chemikalien	kg	0,52	0,96	0,47
N-Dünger (NH_4NO_3 als N)	kg	1,60	2,85	1,89
P-Dünger (TSP als P_2O_5)	kg	5,00	23,6	6,12
K-Dünger (K_2O)	kg	9,30	22,15	9,33
Kalk	kg	94,00	0,00	8,35

Insgesamt ist die im Rahmen der Omni Tech Studie verwendete Datenbasis für den Sojabohnenanbau aber sehr nah an den Hintergrunddaten des EU Default Wertes für den Sojabohnenanbau.

Feldemissionen

Die Werte für die Feldemissionen der Omni Tech Studie 1 und des Standardwertes der EU RED weichen deutlich voneinander ab (Tabelle 2). Obwohl laut Omni Tech Studie die Feldemissionen gemäß der Vorgaben der IPCC Guidelines von 2006 [7] berechnet wurden, scheint der Wert mit Unsicherheiten behaftet. Entsprechend der angegebenen Anbau- und Ertragsdaten ergab eine parallele Berechnung mit

Hilfe der Rechentabellen der Hintergrunddaten der Standardwerte [5] der EU RED einen deutlich höheren Wert.

Tabelle 2 Feldemissionen im Vergleich

Je 1000 kg Sojabohnen	Einheit	Omni Tech Studie 1	EU RED
Lachgasemissionen	kgN_2O	350	800
Lachgasemissionen validiert	kgN_2O	772	

Diese unterschiedlichen Eingangsparameter, für die in der Bilanz zu berücksichtigenden Lachgasemissionen, haben einen deutlichen Einfluss auf das Ergebnis. Der wesentlich geringere Wert der Omni Tech Studie 1 würde zu einem deutlich „besseren“ Wert für den Prozess der Sojabohnenproduktion führen. Bei Verwendung des validierten, bzw. parallel berechneten Wertes wäre ein Ergebnis in der Größenordnung des Default Wertes für die Sojabohnenproduktion zu erwarten.

2.3 Produktion Sojaöl

Die Daten für die Sojaölproduktion wurden von der National Oilseed Processors Association (NOPA) gesammelt und aggregiert. Der Prozess umfasst die Verarbeitung der Sojabohnen zu Sojarohöl in einer Ölmühle (Abbildung 2). Einbezogen sind der Energieaufwand und Betriebsmitteleinsatz der Mühle.

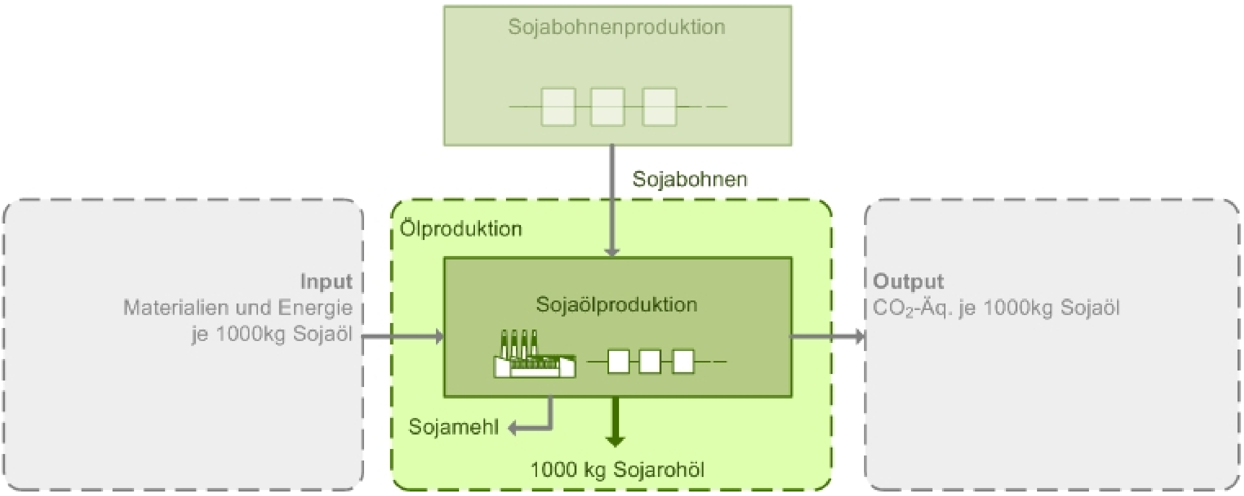

Abbildung 2 Prozess der Sojarohölproduktion

Die vergleichende Darstellung der betrachteten Daten zeichnet ein relativ homogenes Bild (Tabelle 3). Einzig in den Bereichen Dampf- und Hexanbedarf sind deutlichere Unterschiede festzustellen. Innerhalb der betrachteten Studie wurde für den Dampfbedarf der Sojaölproduktion ein wesentlich höherer Wert angenommen als im Hintergrundsystem des entsprechenden Default Wertes.

Tabelle 3 Verbrauchs- und Outputwerte für die Ölmühle im Vergleich

Inputs je 1000kg Sojaöl	Einheit	Omni Tech Studie 1	EU RED	Ecoinvent US
Energie				
Elektrizität	kWh	289	319	299
Dampf	MJ	6.290	5.319	5.202
Material				
Sojabohnen	kg	5.236	5.319	5.316
Hexan	kg	2,96	3,72	11,16
Output				
Sojamehl	kg	4.131	4.319	4.221
Sojaöl	kg	1.000	1.000	1.000

2.4 Produktion Sojabiodiesel

Die Daten stammen von der nationalen Biodiesel Vereinigung NBB (National Biodiesel Board), die eine Befragung ihrer Mitglieder, in den USA ansässige Biodiesel Produzenten, zu den prozessspezifischen Energie- und Materialflüssen durchführte. Der Prozess der Sojadieselproduktion (Abbildung 3) enthält Aufwendungen zur Raffination des Sojarohöls und der Umesterung des raffinierten Öls zu Sojabiodiesel. Energieaufwand und Betriebsmitteleinsatz der Konversionsanlage wurden berücksichtigt.

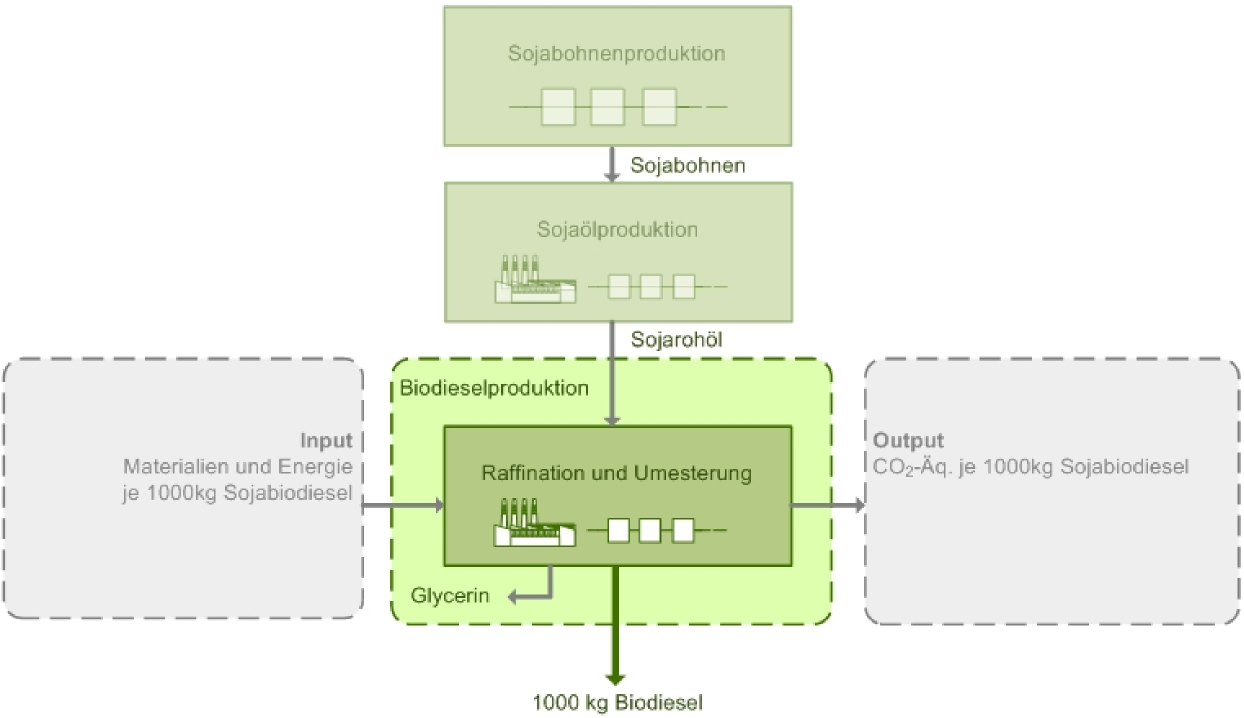

Abbildung 3 Prozess der Sojabiodieselproduktion

Der Vergleich der Daten mit den Daten des Standardwertes (Tabelle 4) zeigt, dass bis auf den Elektrizitätsbedarf die Verbrauchswerte stark voneinander abweichen. Insbesondere der Dampfbedarf ist gegenüber den Daten des Standardwertes der EU RED deutlich niedriger. Zu gering erscheint außerdem der Verbrauchswert für Methanol. Durch die Zugabe von Methanol erfolgt die schrittweise Umesterung pflanzlicher Fette. Zur Validierung des angegebenen Wertes wurde eine stöchiometrische Berechnung durchgeführt. Aufgrund fehlender Informationen bezüglich der spezifischen Eigenschaften des Rohöls wurde für die Berechnung auf Standardwerte (Verseifungszahl, molare Masse) [8] zurückgegriffen. Die Berechnung ergab einen Mindestzugabewert für Methanol von 10 Masseprozent des Rohölinputs. Für einen Input von 997 kg Rohöl würden somit mindestens 99,7 kg Methanol benötigt, die Omni Tech Studie 1 gibt einen Verbrauchswert von 91,65 kg Methanol an. Da die Reaktion von Triglyceriden und Methanol zu Pflanzenölfettsäuremethylester und Glycerin eine Gleichgewichtsreaktion ist, die zum Stillstand kommt wenn etwa zwei Drittel der Ausgangsstoffe reagiert haben, wird meistens mit einem Überschuss an Methanol gearbeitet, um das Gleichgewicht in die gewünschte Richtung zu beeinflussen [9]. Vor diesem Hintergrund, sollten die in der Omni Tech Studie 1 angegebenen Verbrauchswerte für Methanol hinterfragt werden.

Tabelle 4 Verbrauchs- und Outputwerte für die Prozesse Raffination und Umesterung im Vergleich

Je 1000kg Sojadiesel	Einheit	Omni Tech Studie 1	EU RED	Ecoinvent US
Inputs				
Sojaröhl	kg	997	1.019	1.027
Elektrizität	kWh	36	35	42
Dampf	MJ	874	2.856	920
Methanol	kg	92	109	113,16
Natriummethylat	kg	23		
Natriumhydroxid	kg	1	7	
Chlorwasserstoff	kg	44	20	4,6
Phosphorsäure	kg	0,64	1,7	1,13
Zitronensäure	kg	0,735		
Natriumcarbonat	kg		2,5	
Produkte				
Biodiesel	kg	1.000	1.000	1.000
Glycerin	kg	114	106	

2.5 Ergebnis der Evaluierung

Die Evaluierung der verwendeten Datenbasis ergab für die Prozesse Sojabohnenanbau, Rohöl- und Biodieselproduktion teilweise hohe Unterschiede zwischen den Werten der untersuchten Omni Tech Studie 1 und den Hintergrunddaten des EU RED Standardwertes. Einer möglichen Anpassung der Prozessdaten müsste eine ursächliche Überprüfung der Unstimmigkeiten vorausgehen.

3 Evaluierung der Ergebnisse der Treibhausgasbilanzierung der Omni Tech Studie 2

3.1 Vorgehensweise

Um die Konformität des Ergebnisses hinsichtlich der Vorgaben der EU Richtlinie zu prüfen, wurden die innerhalb der Omni Tech Studie 2 getroffenen Annahmen und die verwendete Methodik zur Treibhausgasbilanzierung mit der Methodik der EU RED verglichen.

3.2 Methodik

Im Allgemeinen kommt für die ökologische Bewertung das Instrument der Ökobilanzierung (auch Life Cycle Analysis, LCA) zum Einsatz. Für die Erstellung einer existierenden die international gültigen Normen ISO 14040 [10] und ISO 14044 [11]. Innerhalb einer LCA wird der Lebensweg des untersuchten Produkts von der Rohstoffgewinnung über die Produktion und Nutzung bis zur Entsorgung analysiert. Dabei werden alle von der Rohstoffbereitstellung bis zur Distribution verwendeten Hilfs- und Betriebsstoffe erfasst, bilanziert und die mit der Produktion dieser Hilfs- und Betriebsstoffe sowie der sonstigen Produkte und Dienstleistungen verbundenen Emissionen berücksichtigt.

Die Methodik der Ökobilanzierung nach DIN ISO 14040 kann grob in die folgenden vier Bestandteile (Abbildung 4) unterteilt werden: (i) Festlegung von Ziel und Untersuchungsrahmen (ii) Sachbilanz (iii) Wirkungsabschätzung (iv) Auswertung.

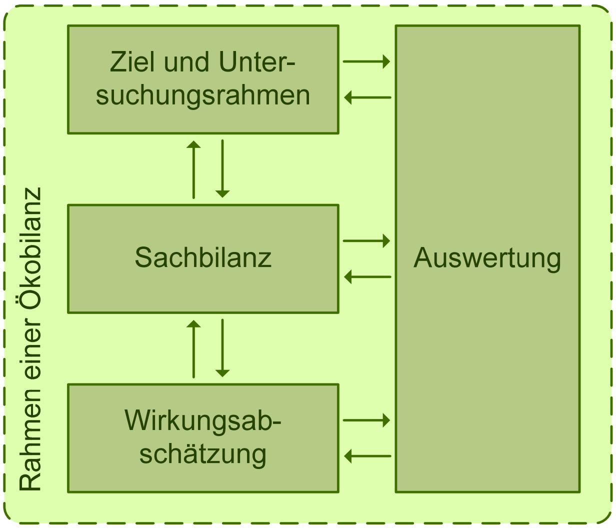

Abbildung 4 Methodischer Ansatz nach DIN ISO 14040

Der erste Schritt - Ziel und Untersuchungsrahmen - beschreibt u. a. die Bilanzgrenzen und definiert die funktionelle Einheit. Innerhalb der Sachbilanz werden alle Emissionen entlang der Prozesskette innerhalb des Bilanzierungsrahmens ermittelt und im Schritt der Wirkungsabschätzung sortiert, verdichtet und im Hinblick auf mögliche Umweltwirkungen ausgewertet. Der Schritt der Auswertung dient der Interpretation der Resultate aus Sachbilanz und Wirkungsabschätzung.
Die Methodik der EU RED orientiert sich im Wesentlichen an der DIN ISO 14040, schränkt allerdings die Freiheitsgrade der Bilanzierung stark ein.

3.3 Annahmen und Rahmenbedingungen der THG-Bilanzierung

3.3.1 Ziel und Untersuchungsrahmen

Der Bilanzierungsrahmen der betrachteten Studie umfasst entsprechend den Vorgaben der EU RED die Prozesskette von der Sojabohnenproduktion über Biodieselproduktion bis zur Kraftstoffnutzung „Well-to-wheel“ (Abbildung 5).

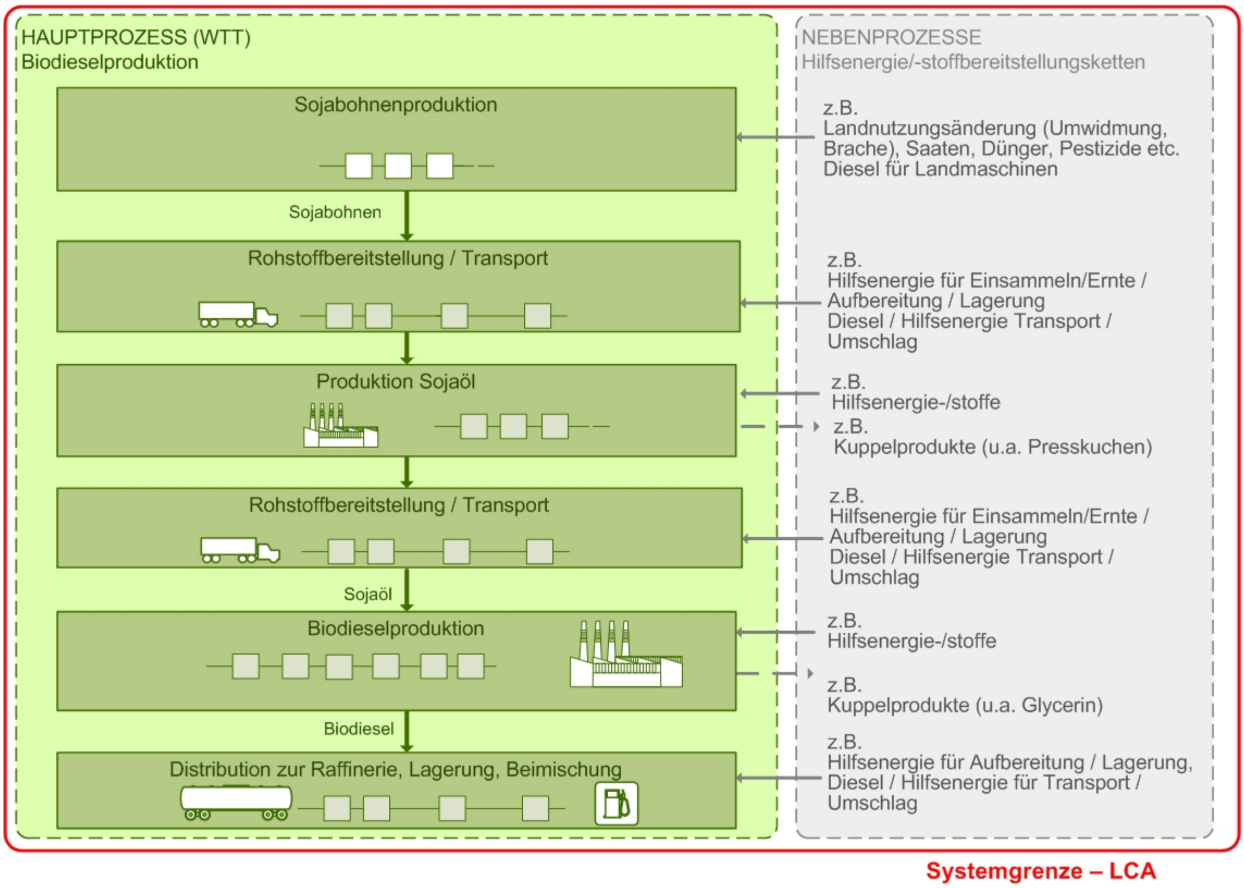

Abbildung 5 Bilanzierungsrahmen

Im Rahmen der Studie wurden dabei auf den jeweiligen Stufen der Prozesskette folgende Punkte berücksichtigt:

- Sojabohnenproduktion: Aufwendungen zur Produktion der Sojabohnen. Dazu zählen alle Emissionen und Aufwendungen aus der Produktion und Nutzung von Düngemitteln, Saatgut, Diesel und Pflanzenschutzmitteln und etwaiger Landnutzungsänderungen.
- Rohölproduktion. Aufwendungen zur Produktion von Sojarohöl. Dazu zählen alle Emissionen und Aufwendungen aus der Produktion und Nutzung von Elektrizität, Dampf, Hexan usw.
- Konversion zu Sojabiodiesel. Aufwendungen zur Produktion von Sojabiodiesel. Dazu zählen alle Emissionen und Aufwendungen aus der Produktion und Nutzung von Elektrizität, Dampf, Methanol usw.
- Distribution

Als funktionelle Einheit wurden 1 MJ Sojabiodiesel festgelegt.

3.3.2 Formel zur Berechnung der Treibhausgasemissionen

Die Berechnung der Treibhausgasemissionen erfolgte anhand der im Anhang V der EU RED angegebenen Formel.

3.3.3 Heizwerte für fossile Kraftstoffe und Biodiesel

Entsprechend den Vorgaben der EU RED wurde als Heizwert für fossile Kraftstoffe 42,8 MJ/kg und für Biodiesel 37,2 MJ/kg angenommen. In einer Sensitivitätsanalyse erfolgte die Berechnung des

Treibhausgasminderungspotentials unter Verwendung eines US-amerikanischen Wertes von 43,5 MJ/kg für den fossilen Komparator.

3.3.4 Allokation

Koppelprodukte wurden gemäß EU RED mittels Allokation nach dem unteren Heizwert berücksichtigt Das bedeutet, dass alle Aufwendungen und die damit verbundenen Emissionen und Energieaufwendungen die bis zur Erzeugung des Koppelproduktes anfallen zwischen dem Hauptprodukt und dem Koppelprodukt aufgeteilt werden.

3.3.5 Emissionsfaktor für fossile Kraftstoffe

Für die Berechnung des Treibhausgasminderungspotentials wurde der von der EU RED vorgegebene Referenzwert von 83,8 gCO2-Äq./MJ für die fossilen Komparatoren verwendet. Die wesentlichen Aspekte der verwendeten Berechnungsmethode sind den Aspekten der Methode der EU RED in nachfolgender Tabelle 5 vergleichend gegenübergestellt.

Tabelle 5 Wesentliche Aspekte der Berechnungsmethode

	Omni Tech Studie 2	**EU RED**
Systemgrenzen	„Well-to-wheel“	„Well-to-wheel“
Umgang mit Koppelprodukten	Nach unteren Heizwert	Nach unteren Heizwert
Lachgasemissionen	IPCC 2006	IPCC 2006
Berücksichtigung infrastruktureller Aufwendungen	Nein	nein
Funktionelle Einheit	1 MJ	1 MJ

3.4 Analyse der THG-Berechnungen der Omni Tech Studie 2

Auf der Grundlage der Methode der EU RED zur Treibhausgasbilanzierung wurden für die nachfolgend beschriebenen drei Szenarien Berechnungen der Treibhausgasemissionen durchgeführt.

- Szenario 1:Substitution des EU RED Default Wertes für Sojaanbau durch einen eigenen Wert für den Anbau von Soja in den USA, basierend auf den Werten der OMNI Tech Studie 1 und Transport der Sojabohnen von den USA nach Europa, nicht wie in der EU RED unterstellt, von Brasilien nach Europa.
- Szenario 2: Substitution der EU RED Default Werte für Sojaanbau und die Verarbeitung durch eigene Werte für den Anbau von Soja und die Verarbeitung zu Biodiesel in den USA, basierend auf den Werten der OMNI Tech Studie I
- Szenario 3: Berechnung des Treibhausgasminderungspotentials der Szenarien 1 und 2 mit Hilfe des amerikanischen Emissionsfaktors für fossile Kraftstoffe anstelle des in der EU RED vorgegebenen Wertes für fossile Komparatoren.

Die Ergebnisse der Treibhausgasbilanzierungen der zuvor beschriebenen Szenarien sind in Tabelle 6 dargestellt und werden in nachfolgenden Kapiteln analysiert und hinsichtlich der Methodenkonsistenz geprüft.

Tabelle 6 Treibhausgasemissionen der EU RED für Biodiesel aus Sojabohnen und der Omni Tech Studie 2

	Anbau	Konversion	Transport / Distribution	Ingesamt	THG-Minderungs-Potential
Einheit			gCO_2-Äq./MJ		%
EU RED typ. THG-Emissionen	19	18	13	50	40
EU RED Standard-THG-Emissionen	19	26	13	58	31
Szenario 1 typ. THG-Emissionen	**16**	18	**8,9**	43	48
Szenario 1 Standard-THG-Emissionen	**16**	26	**8,9**	51	39
Szenario 2 typ. THG-Emissionen	16	**16**	**4,7**	37	56
Szenario 2 Standard-THG-Emissionen	16	**22**	**4,7**	43	49
Szenario 3-1 typ. THG-Emissionen	16	18	8,9	43	52
Szenario 3-1 Standard-THG-Emissionen{Citation}	16	26	8,9	51	44
Szenario 3-2 typ. THG-Emissionen	16	16	4,7	37	59
Szenario 3-2 Standard-THG-Emissionen	16	22	4,7	43	52

3.4.1 Szenario 1

In diesem Szenario wurden die typischen Werte und Standardwerte der EU RED für die Prozesse Sojabohnenanbau und Transport/Distribution durch eigene Berechnungen der THG-Emissionen ersetzt. Die Basisdaten für den Sojabohnenanbau entstammen der Omni Tech Studie 1. Mit 16 g CO_2-Äq./MJ liegt der Wert ca. 15 % unter dem Default Wert der EU RED. Während die verwendete Berechnungsmethodik konform zur Methodik der EU RED ist, ergab eine Prüfung der Basisdaten deutliche Unterschiede gegenüber den Hintergrunddaten für den Default Wert der EU RED. Zum Einen liegen die Unterschiede im Düngemitteleinsatz und zum Anderen bei der Berechnung der aus dem N-Düngereinsatz resultierenden Feldemissionen (vgl.2.2.). Der zweite Ansatz dieses Szenarios betrifft den Transport der Sojabohnen nach Europa. Der Annahme folgend, dass die Sojabohnen, nicht wie dem Default Wert der EU RED unterstellt von Brasilien, sondern von den Vereinigten Staaten zum europäischen Festland transportiert werden, reduzieren sich laut Omni Tech Studie 2 die Überseetransportentfernungen (10.186 km von Brasilien, 6.350 km von USA) und somit die mit dem Prozess Transport/Distribution verbundenen Treibhausgasemissionen. Die Transportentfernungen innerhalb Europas blieben gegenüber den Hintergrunddaten zum Default Wert unverändert.

3.4.2 Szenario 2

Aufbauend auf Szenario 1 wurde in diesem Szenario der disaggregierte Default Wert für die Verarbeitung der Sojabohnen zu Biodiesel durch eigene Berechnungen ersetzt. Analog zu Szenario 1 entstammen auch hier die Basisdaten für die Berechnung der THG-Emissionen der Omni Tech Studie 1. Mit dem Verweis auf die Aktualität der Prozessdaten wurden die Treibhausgasemissionen für die Konversion der Sojabohnen zu Biodiesel berechnet und die Werte für die typischen THG-Emissionen und Standardemissionen (Erhöhung des typ. Wertes um 40 %) der EU RED ersetzt. Der Wert liegt ca. 15 % unter dem des Default-Wertes. Ähnlich wie bei der Berechnung der THG-Emissionen für Sojabohnenanbau in Szenario 1 liegen hier die Unsicherheiten nicht in der verwandten Methodik (Annahmen und Rahmenbedingungen entsprechen den Vorgaben der EU RED), sondern auf Seiten der Prozessdaten. Wie bereits beschrieben (vgl. 2.4) erscheint der Verbrauchswert für den Einsatz von Methanol zu gering und bedarf einer näheren Untersuchung. Des Weiteren wird angenommen, dass der Biodiesel nicht in Europa, sondern in den USA produziert und nach Europa exportiert wird. Dementsprechend reduzieren sich die Massenströme für den Transport und somit die mit dem Transport verbundenen THG-Emissionen.

Die in Szenario 1 und 2 beschriebene Substitution der disaggregierten Werte für die Prozesse Sojaanbau, Konversion und Transport/Distribution durch eigene Berechnungen der THG-Emissionen ergibt in Summe eine Wert der typischen Emissionen der mit einem Minderungspotential von 58 % (Tabelle 6) gegenüber der fossilen Referenz die Forderungen der EU RED deutlich erfüllt. Jedoch wurde bereits deutlich darauf hingewiesen, dass die genutzten Basisdaten mit einigen Unsicherheiten behaftet sind.

3.4.3 Szenario 3

Da die Berechnungen des Treibhausgasminderungspotentials für dieses Szenario von den Vorgaben der EU RED abweichen (geänderter fossiler Referenzwert), werden die Ergebnisse an dieser Stelle nicht weiter diskutiert.

3.5 Ergebnis der Evaluierung

Die zur Berechnung der Treibhausgasemissionen verwandte Methodik ist konform zu den Vorgaben der EU RED. Jedoch, und das sei an dieser Stelle noch einmal erwähnt, gibt es teilweise hohe Unterschiede zwischen den genutzten Basisdaten der Omni Tech Studie 1 und den Hintergrunddaten der EU RED, die im Falle einer möglichen Anpassung einer ursächlichen Überprüfung bedürfen.

4 Schlussfolgerungen

Die Evaluierung der verwendeten Datenbasis der Omni Tech Studie 1ergab für die Prozesse Sojabohnenanbau, Rohöl- und Biodieselproduktion teilweise hohe Unterschiede zwischen den Werten der untersuchten Studie und den Hintergrunddaten des EU RED Standardwertes. Einer möglichen Anpassung der Prozessdaten müsste eine ursächliche Überprüfung der Unstimmigkeiten vorausgehen.

Die im Rahmen der Omni Tech Studie 2 zur Berechnung der Treibhausgasemissonen für Sojabiodiesel genutzte Methodik entspricht in ihren Annahmen und Rahmenbedingungen 1:1 den Vorgaben der EU RED, jedoch sind die genutzten Basisdaten mit einigen Unsicherheiten behaftet und bedürfen einer näheren Prüfung. Entsprechend der Kritik der Omni Tech Studie 2, dass die verwendeten Hintergrunddaten des Default Wertes der EU RED für die Bereitstellung von Biodiesel aus Sojabohnen realitätsfern bzw. nicht aktuell und die damit verbundenen THG-Emissionen zu hoch sind und den daraus resultierenden Forderungen einer Anpassung des Default-Wertes für die Produktion von Biodiesel beziehungsweise die Implementierung eines Default-Wertes für den Anbau von Sojabohnen in den USA, wird an dieser Stelle auf folgende Sachverhalte hingewiesen:

- 1. Die Default-Werte der EU RED sind bewusst konservativ gerechnet worden, um zum Einen eine Erhöhung oder möglicherweise unrealistisch vorteilhafte Darstellung bestimmter Biokraftstoffe zu vermeiden und zum Anderen zielen sie darauf ab, einen möglichst breiten konservativen Durchschnitt der angewendeten Produktionsverfahren abzubilden.
- 2. Es besteht die Möglichkeit neben der Verwendung der Standardwerte bzw. disaggregierten Teilstandardwerte der EU RED die Lebenszyklustreibhausgasemissionen von Biokraftstoffen unter Verwendung tatsächlicher Werte gemäß der in Anhang V Teil C festegelegten Methodik der EU RED zu berechnen.

Die Studie zeigt beispielhaft, dass neben der Konformitätsprüfung der verwandten Methodik zur Berechnung der Treibhausgasemissionen, die Notwendigkeit einer Evaluierung der Quelldaten eine hohe Relevanz besitzt.

Abbildungsverzeichnis

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Literaturverzeichnis

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A.1 Anhang

Deutsches BiomasseForschungsZentrum
German Biomass Research Centre

DBFZ

Expertise for the publications "Life Cycle Impact of Soybean Production and Soy Industrial Products" and "Applying Recent US Soybean Data to the EU Renewable Energy Sources Directive"

-Evaluation of the conformity with EU RED

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July 2010

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Date: 24.06.2010
Project nb. DBFZ: 3514000

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Abbreviations

Abbreviations	Explanation
CH_4	Methane
CO_2	Carbon dioxide
DIN	Deutsches Institut für Normung
EU RED	European Renewable Energy Directive
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kg	Kilogramme
kWh	Kilowatt hour
l	Litre
LCA	Life cycle analyses
MJ	Mega joule
N_2O	Nitrous oxide
GHG	Greenhouse gas
USB	United Soybean Board

1 Introduction

1.1 Background and objectives

Within the EU Directive 2009/28/EG for the promotion of the use of energy from renewable sources (EU RED) [1], a future minimum greenhouse gas reduction potential for biofuels is required in addition to requirements for the protection of natural surfaces and a sustainable agricultural management. Bioliquids and biofuels have to proof a fixed greenhouse gas reduction potential in relation to a defined fossil reference value for different times. This greenhouse gas reduction has to be calculated on the basis of actual values and according to the methodology of the EU RED. Furthermore, there is the possibility to calculate the greenhouse gas emissions saving by using so called default values. These default values have been calculated according to the methodology of the EU RED und will be updated in regular intervals on basis of new cognitions.

The United Soybean Board (USB) commissioned Omni Tech International, within the study “Life Cycle Impacts of Soybean Production and Soy Industrial Products” [2] (hereinafter called Omni Tech Study 1), to perform an update of the data for soybean production and processing of soy feedstock for the purpose of calculating a life cycle assessment of soybean derived biodiesel.

Since the default value of soy biodiesel failed the target of 35 % GHG-mitigation the USB commissioned afresh Omni Tech International, within the study “Applying Recent US Soybean Data to the EU Renewable Energy Sources Directive” [3] (hereinafter called Omni Tech Study 2) to calculate GHG-emissions of soybean derived biodiesel according to the methodology of EU RED based an data of Omni Tech Study 1. The USB requires to examine this calculated value and to adapt the default values if necessary.

Accordingly the assumptions and data considered within the Omni Tech Study 1 have been compared with typical (literature) data. Furthermore, the used methodology to calculate the greenhouse gas balance within the Omni Tech Study 2 has been compared with the methodology of the EU RED. The goal of this survey is to examine, whether the result of the investigated study is suitable for an update of the EU default value for biodiesel on the basis of soy or whether it is suitable to specify and establish a default value for the national soybean production in the USA.

2 Evaluation of used data within Omni Tech Study 1

2.1 Approach

In order to examine the conformity with the guidelines of EU RED the assumptions and data considered within Omni Tech Study 1 have been compared as to plausibility with typical (literature) data.

2.2 Production of soybeans

The used Data for agricultural processes to produce soybeans within the Omni Tech Study 1 are based on average U.S. soybean production practices in the U.S. and are based mainly on the years 2001 to 2007. The soybean agriculture data within the Omni Tech Study 1 are an update of the existing soybean data that are currently published in the U.S. Life Cycle Inventory Database (U.S. LCI) [4].

The balance of soybean production (Figure 1) contains all necessary expenditures, all emissions and expenditures from production and use of fertilizers, seeds, diesel fuel and pesticides and any changes of land use.

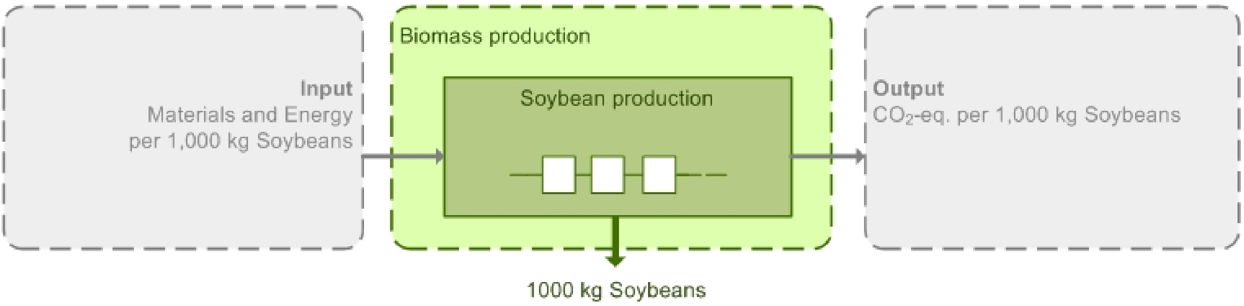

Figure 1 Soybean production unit process

These data for the soybean production were compared to the background data of the soybean biodiesel default value of the EU RED as well as to inventory data from the Ecoinvent database [6] for the cultivation of soybeans (Table 1).

While both the yield and the energy consumption values are nearly equal, there are clear differences within the range of the fertilizer application.

Table 1 Comparison of yield and input data for the process of soybean production

	Unit	Omni Tech Studie 1	EU RED	Ecoinvent
Yield	kg/ha	2766	2798	2641
Input per 1000kg Soybeans				
Energy				
Diesel	l	14.30	20.92	20.98
Electricity	MJ	25.00		
Gasoline	l	4.50		
LPG	MJ	32.00		
Natural gas	MJ	48.00		
Energy demand	MJ	763.00	750.00	752.00
Materials				
Chemicals	kg	0.52	0.96	0.47
N-fertilizer (NH_4NO_3 as N)	kg	1.60	2.85	1.89
P-fertilizer (TSP as P_2O_5)	kg	5.00	23.6	6.12
K-fertilizer (K_2O)	kg	9.30	22.15	9.33
Quick lime	kg	94.00	0.0	8.35

Altogether the used database for the cultivation of soy bean within the Omni Tech Study is very similar to the background data of EU RED default value.

Field emissions

The result of field emissions from the Omni Tech Study 1 and the background data of the default value from the EU RED clearly deviate from each other (Table 2). According to the Omni Tech Study 1 field emissions have been calculated in accordance with guidelines of IPCC 2006, but however, there are uncertainties. According to the yield and input data, a parallel calculation (with the help of the background data of the default values [5] of the EU RED) resulted in a clearly higher value.

Table 2 Comparison of field emissions' calculation

per 1000 kg soybeans	Unit	Omni Tech Study 1	EU RED
N_2O emissions	kgN_2O	350	800
N_2O emissions validated	kgN_2O	772	

These different initial parameters for field emissions have a clear influence on the overall result. The substantially smaller value of the Omni Tech Study 1 leads to a clearly "better" value for the process of soy bean production compared to the EU RED default value.

2.3 Soy crude oil production

The data for the soy crude oil production used within the Omni Tech Study 1 have been collected from the national Oilseed Processors Association (NOPA). The demand of energy and input of auxiliaries are included (Figure 2) in the calculations.

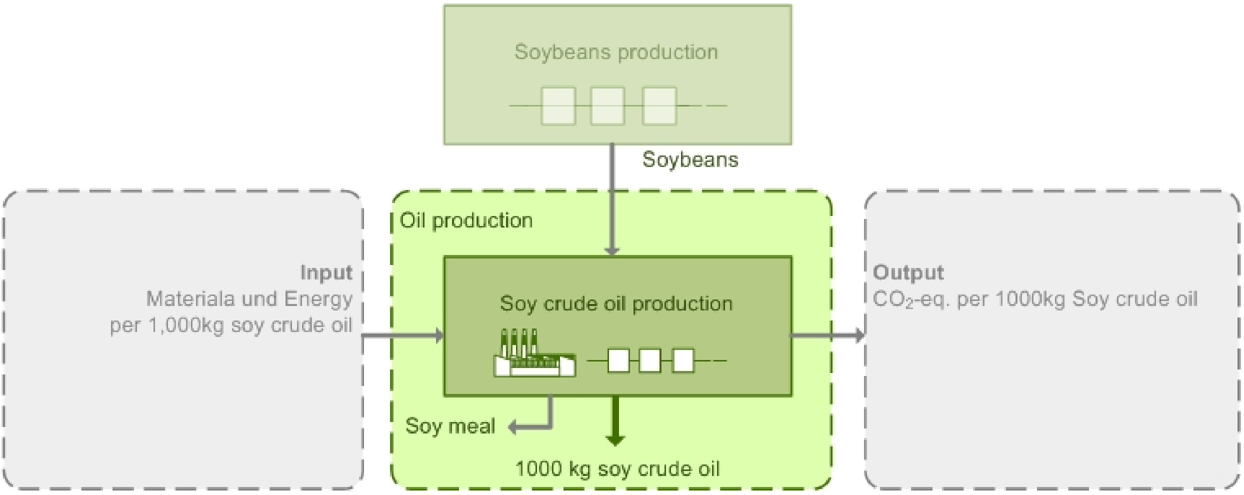

Figure 2 Process of soy crude oil production

Table 4 shows that the used database is comparable to the EU RED Ecoinvent data. Only the values for steam and hexane demand differ between the considered datasets.

Table 3 Comparison of input and output data for the process of soy crude oil production

Inputs per 1000kg soy oil	unit	Omni Tech Study 1	EU RED	Ecoinvent US
Energy				
Electricity	kWh	289	319	299
Steam	MJ	6290	5319	5202
Materials				
Soybeans	kg	5236	5319	5316
Hexane	kg	2.96	3.72	11.16
Outputs				
Soy meal	kg	4131	4319	4221
Soy crude oil	kg	1000	1000	1000

2.4 Production of soy derived biodiesel

The data used to calculate emissions from the biodiesel production process have been taken from the national biodiesels combination NBB (national biodiesel board). The NBB asked its members, (commercial biodiesel production plants located in the U.S), to specify process specific energy and material use data. The calculations for the process of the soy biodiesel production (Figure 3) contain expenditures for the refining of soy crude oil and the transesterification of the refined oil to soy biodiesel. The demand of energy and input of auxiliaries are included.

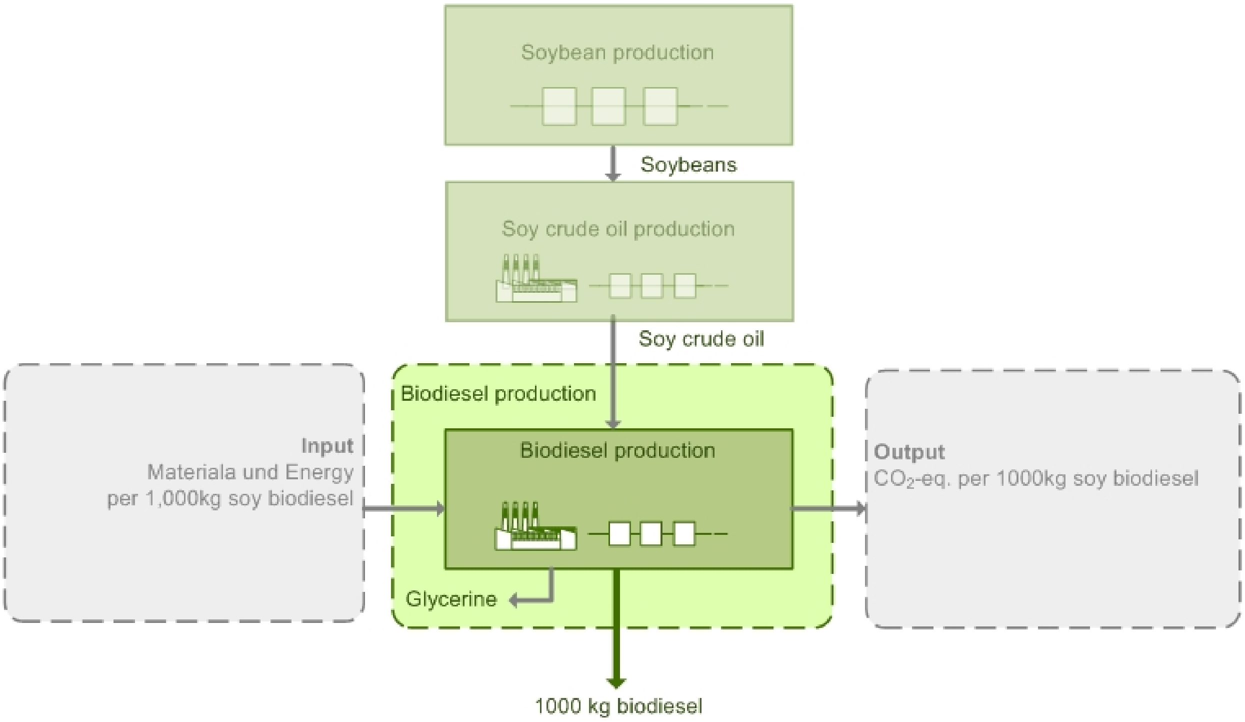

Figure 3 Process of biodiesel production

The comparison of the datasets (Table 4) shows, with the exception of the electricity demand, strong differences. In particular, the demand of steam within the investigated study is clearly smaller in relation to the default value data of the EU RED. The consumption value for methanol seems too small. The step by step transesterification of vegetable fats takes place due to the addition of methanol. For the validation of the indicated value, a stoichiometric calculation has been carried out. Due to missing information regarding the specific characteristics of the used crude oil, standard values (saponification number, molecular mass) [8] have been used for calculation. The calculation resulted in a minimum addition value of 10 mass per cent methanol per crude oil input. For an Input of 997 kg crude oil at least 99.7 kg methanol are needed. The Omni Tech Study 1 indicates a methanol consumption value 91.65 kg. Since the reaction from triglycerides and methanol to vegetable oil fatty acid methyl ester and glycerine is an equilibrium reaction, which is stopped if about two third of the basic materials reacted, mostly a surplus on methanol is used to affect the equilibrium in the desired direction [9]. Against this background, the values for methanol consumption indicated in the Omni Tech Study 1 should be questioned.

Table 4 Comparison of input and output data for the process of soy biodiesel production

Per 1000kg soy biodiesel	unit	Omni Tech Study 1	EU RED	Ecoinvent US
Inputs				
Soy crude oil	kg	997	1019	1027
Electricity	kWh	36	35	42
Steam	MJ	874	2856	920
Methanol	kg	92	109	113.16
Sodium methylate	kg	23		
Sodium hydroxide	kg	1	7	
Hydrochloric acid	kg	44	20	4.6
Phosphoric acid	kg	0.64	1.7	1.13
Citric acid	kg	0.735		
Sodium carbonate	kg		2.5	
Outputs				
Biodiesel	kg	1000	1000	1000
Glycerine	kg	114	106	

2.5 Results of data evaluation

The evaluation of the used data base resulted in partial high differences between the values of the examined Omni Tech Study 1 and the background data of the EU RED, in particular in the range of field emissions and the demand of steam for the conversion processes. Both, the field emissions and the steam demand have a substantial influence on the overall biodiesel greenhouse gas balance. Prior to a potential adjustment of the process data, a causal examination of the discrepancies should be conducted.

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3 Evaluation of used methodology within Omni Tech Study 2

3.1 Approach

In order to examine the conformity of the study with the guidelines of the EU RED, the assumptions and the methodology to calculate the greenhouse gas balance considered within the Omni Tech Study 2 have been compared with the methodology of the EU RED.

3.2 Methodology

Generally, a Life cycle assessment (LCA) is used for the environmental assessment. The LCA methodology is defined within the ISO 14040 and 14044 standards. The LCA of products or services includes environmental aspects of the whole product system, from the production of raw material to the final disposal of the product after the use phase. The analysis covers the complete product life cycle including all upstream products and used energy carriers.

According to ISO 14040, the methodology consists of four main aspects (Figure 4), namely: (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation.

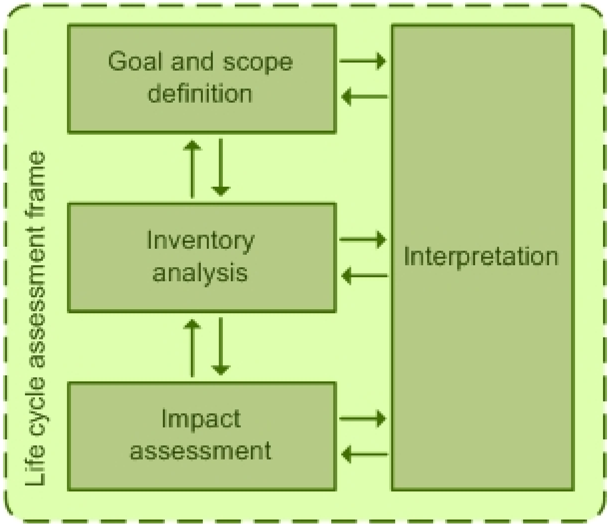

Figure 4 Methodology of a life cycle assessment according to ISO

The goal and scope definition describes, among others, the underlying questions of the case study, the considered system boundaries and defines the functional unit. In the life cycle inventory analysis (LCI), the inputs of resources, materials, and energy as well as the outputs of products, waste and emissions are investigated and listed. This phase also defines the procedure for the consideration of possible by-products. Within the phase of the life cycle impact assessment (LCIA), the results of the inventory analysis are associated to specific potential environmental impact categories. Within the interpretation part, the results of the LCI and the LCIA are discussed and conclusions are drawn. The method defined in EU RED is based on ISO 14040.

3.3 Assumptions within the Omni Tech Study 2

3.3.1 Goal and scope definition

According to the guidelines of EU RED the system boundary of the investigated assessment covers the process chain for the production of soybean biodiesel from soybean production to biodiesel distribution (Figure 5).

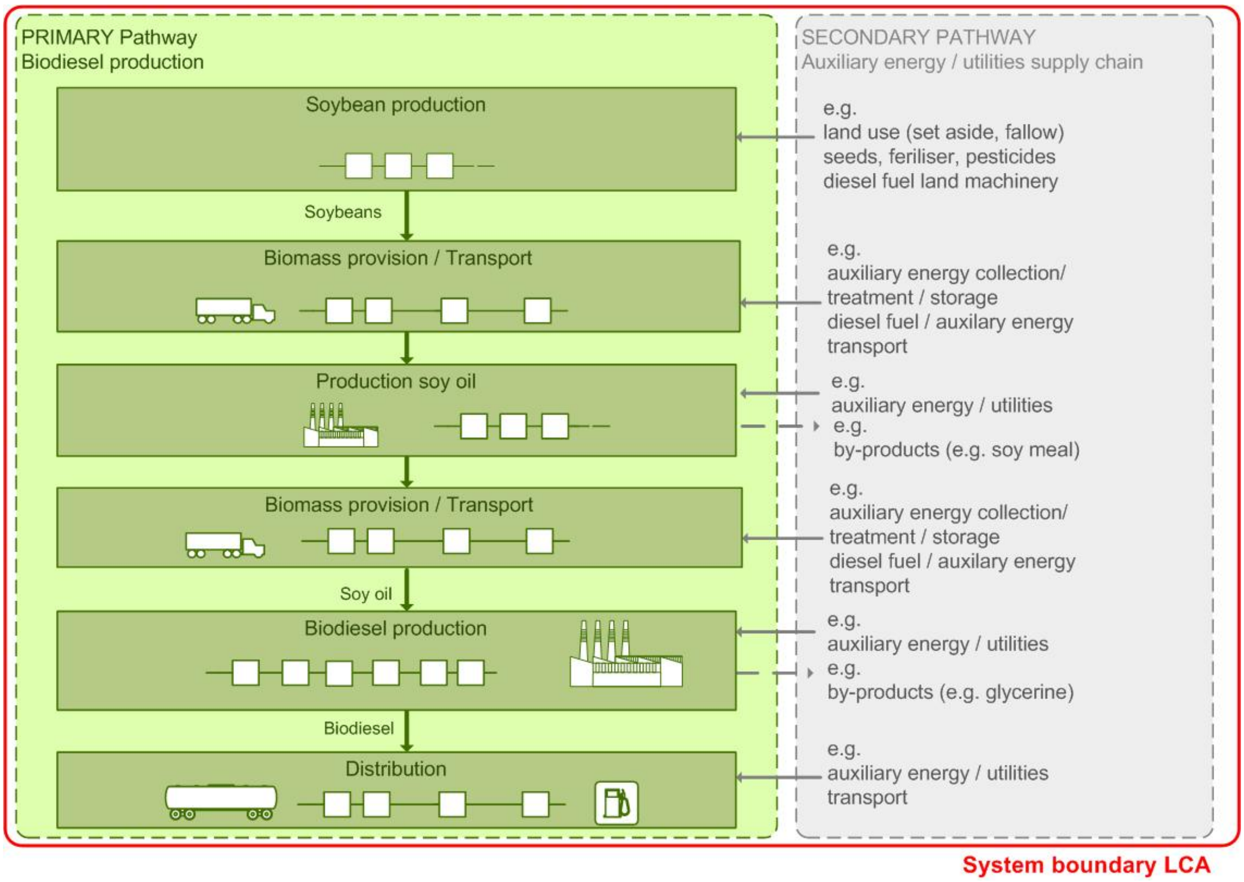

Figure 5 System boundaries

For the calculation of GHG emissions, within the investigated Omni Tech Study 2 the following points were considered:

- Soybean production: All expenditures to produce soybeans, including all emissions and expenditures from the production and use of fertiliser, seeds, diesel fuel and pesticides.
- Soy oil production. All expenditures to produce soy oil, including all emissions and expenditures from the production and use of electricity, steam, hexane etc.
- Conversion to soy biodiesel. All expenditures to produce soy biodiesel, including all emissions and expenditures from the production and use of electricity, steam, methanol etc.
- Distribution

The functional unit is the energy content of fuel, expressed in 1 MJ.

3.3.2 Formula for calculating GHG emissions

For the calculation of GHG emissions the formula given in Annex V of EU RED has been applied.

3.3.3 Energy content for fossil fuel and biodiesel

According to the guidelines of EU RED the following energy content of the final fuels has been used.

- Fossil fuel energy content: 42.8 MJ/kg
- Biodiesel fuel energy content: 37.2 MJ/kg

3.3.4 Allocation

The produced by-products have been considered by allocation with respect to lower heating value. Allocation means that all expenditures and the associated emissions up to the production of the by-product have been divided (allocated) between the main and the by-product.

3.3.5 Emissions factor for fossil fuel

The EU fossil fuel EF emission factor of 83.8 g CO_2-eq/MJ has been used to obtain the GHG reduction potential for soybean biodiesel.

Table 5 Main aspects of the GHG calculation of the considered methods

	Omni Tech Study 2	EU RED
System boundaries	„Well-to-wheel"	„Well-to-wheel"
Consideration of by-products	Allocation based on lower heating value	Allocation based on lower heating value
N_2O emissions	IPCC 2006	IPCC 2006
Consideration of Infrastructural expenditures	no	no
Functional unit	1 MJ	1 MJ

3.4 Analysis of GHG calculation of Omni Tech Study 2

Using the methodology of EU RED the following scenarios has been examined within the Omni Tech Study 2:

- Scenario 1: Substitution of EU RED default value for soybean cultivation with US soybean cultivation data based on Omni Tech Study 1 and substitution of transport of the soybeans from Brazil to Europe with transport from the US.
- Scenario 2: Substitution of EU RED default values for soybean cultivation and processing with US soybean cultivation and US processing data based on Omni Tech Study 1.
- Scenario 3: Using US emission factor for fossil fuels for calculation the GHG mitigation potential of scenarios 1 and 2.

The results of GHG calculation are shown in Table 6 and discussed in the following chapter.

Table 6 Comparison of results GHG calculation

	Cultivation	Conversion	Transport / distribution	Total	GHG savings
Unit		gCO_2-eq/MJ			%
EU RED typ. GHG emissions	19	18	13	50	40
EU RED default GHG emissions	19	26	13	58	31
Scenario 1 typ. GHG emissions	**16**	18	**8.9**	43	48
Scenario 1 default GHG emissions	**16**	26	**8.9**	51	39
Scenario 2 typ. GHG emissions	16	**16**	**4.7**	37	56
Scenario 2 default GHG emissions	16	**22**	**4.7**	43	49
Scenario 3-1 typ. GHG emissions	16	18	8.9	43	52
Scenario 3-1 default GHG emissions	16	26	8.9	51	44
Scenario 3-2 typ. GHG emissions	16	16	4.7	37	59
Scenario 3-2 default GHG emissions	16	22	4.7	43	52

3.4.1 Scenario 1

Within this scenario the typical and default values for the processes of soybean cultivation and transport/distribution have substituted with own calculations of GHG emissions. The base data for soybean cultivation emanate from Omni Tech Study 1. With 16 g CO_2-eq/MJ the value is approximately 15 % under the default value of the EU RED. While the used methodology for calculating GHG emissions is consistent with the methodology of EU RED, the evaluation of the base data resulted in clear differences compared to the background data for the default value of the EU RED. Main differences are the N-fertilizer application and the calculation of field emissions caused by N-fertilizer application (cf. 2.2.). The second approach of this scenario concerns the transport of soybeans to Europe. The soybeans will not be transported to Europe from Brazil but from US. To that effect, the oversee shipment distances are reduced (10186 km from Brazil, 6350 km from USA) and so are the GHG-emissions caused by transport.

3.4.2 Scenario 2

Based on scenario 1 the disaggregated default values for conversion of soybeans to biodiesel have been replaced with own calculations based on data from Omni Tech Study 1. The Value is approximately 15 % under the default value. Similar to scenario 1 there are several uncertainties concerning process data. As mentioned before (cf. 2.4) the consumption of methanol seems too small.

Furthermore it is considered that the biodiesel is produced not in Europe, but in USA and exported to Europe. Accordingly the mass flows for transport and thus the GHG emissions connected with transport are reduced.

The described substitution of the disaggregated values for cultivation, conversion and transport/distribution with own calculations of GHG emissions results in an GHG mitigation potential of 56 % for biodiesel (Table 6) compared to the fossil reference, which meets the target of 35 % GHG mitigation required in EU RED. However, it was pointed out that the used base data contain some uncertainties.

3.4.3 Szenario 3

Since the calculations of GHG mitigation potential differ from guidelines of EU RED, the results have been not discussed.

3.5 Results of evaluation

The methodology used for the calculation of GHG emissions is consistent with the guidelines of EU RED. However, there are areas where high differences between the used base data of the Omni Tech Study 1 and the background data of the EU RED are reported, which require a further examination in case of a possible adaptation.

4 Conclusions

The evaluation of the used database resulted in partially high differences between the values of the examined study and the background data of the RES-D default value for the cultivation of soy bean and the crude soy oil and biodiesel production. Prior to a potential adaption of the process data, an explanation of the discrepancies should be conducted.

The methodology used for the calculation of GHG emissions within the Omni Tech Study 2 is conform to the guidelines of EU RED. However Omni Tech Study 2 criticises that the used background data of EU RED default value for provision of soy biodiesel are out of date and unrealistic and that the GHG emissions caused by provision are too high and requires an adaptation of the default value for soy bio diesel. According to this criticism two points should be highlighted.

- 1. The default values of the EU RED were calculated consciously conservatively, on the one hand to avoid an unrealistically favourable representation of certain biofuels and on the other hand to present a conservative average of applied production procedures.
- 2. In addition to the use of default values or disaggregated default values of EU RED there is the possibility to calculate the GHG emissions with the help of actual values in accordance with the methodology defined in Annex V part C of EU RED.

This survey points out that a possible adaption of default values concerning the calculation of GHG balances requires the examination of the conformity of the used methodology to EU RED and the critical evaluation of the data base.

Figures

Tables

Literature

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A.1 Annex

Life Cycle Impact of Soybean Production and Soy Industrial Products

Released February 2010

Prepared for

The United Soybean Board

By

Omni Tech International

Additional data tables as well supplemental technical information are available on request.
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Introduction

Objectives

The past decade has witnessed an increased consumer and government interest in replacing petroleum based products with those made from or with biobased resources. As the array of biobased products has increased, so too has the interest in evaluating the energy and environmental impacts of these products. One common method of measuring those impacts is to conduct a life cycle assessment (LCA).

To conduct a credible LCA, it is critical to use good quality, current data on all raw materials, energy, and processing aids used as well as the environmental outputs associated with producing a product because this information becomes the platform for performing the life cycle inventories (LCIs) which are the basis for the LCA. The existing databases for soybean agriculture and processing were, in many cases, over 10 years old and no longer representative of current energy use or raw material production processes.

The United Soybean Board[1] commissioned Omni Tech International, Ltd. to perform an update of the data for soybean production and processing and soy feedstocks for the purpose of calculating LCAs and for other life cycle related tools. The LCA modeling was performed by Four Elements Consulting, LLC. The main objective of the project was to update the cradle-to-gate data for soybean production and conversion of soybean oil and meal into key soy-derived feedstocks (methyl soyate, soy lube base stock, soy polyol, and soy resin) used in fuel and industrial products in order to calculate life cycle inventories (LCIs).

These updated data sets are now available and will be placed into the U.S. Life Cycle Inventory (U.S. LCI) Database, which is managed by the Department of Energy's National Renewable Energy Laboratory (NREL). Until now, only soybean production data have been included in the U.S. LCI Database; as a result of this study, data on soybean processing, refining, and conversion into key soy-derived feedstocks can be added to the Database.

Standards Used

This study has been conducted in accordance with the International Standards Organization (ISO) standards on LCA, including:

- ISO 14040:2006, the International Standard of the International Standardization Organization, Environmental management. Life cycle assessment. Principles and framework.

[1] The United Soybean Board (USB) is made up of 68 farmer-directors who oversee the investments of the soybean checkoff on behalf of all U.S. soybean farmers. As stipulated in the Soybean Promotion, Research and Consumer Information Act, USDA's Agricultural Marketing Service has oversight responsibilities for USB and the soybean checkoff.

- ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

Peer Review

The study has been peer reviewed by a group of international reviewers to verify that the project was performed in accordance with ISO 14040 and 14044 standards to ensure credibility and objectivity of the data and results. Reviewers included: Dr. Martin Patel of Utrecht University (chairperson) and Michael Levy of the American Chemistry Council.

Scope Definition and Methodology

General System Overview

The following table summarizes the system components of the study:

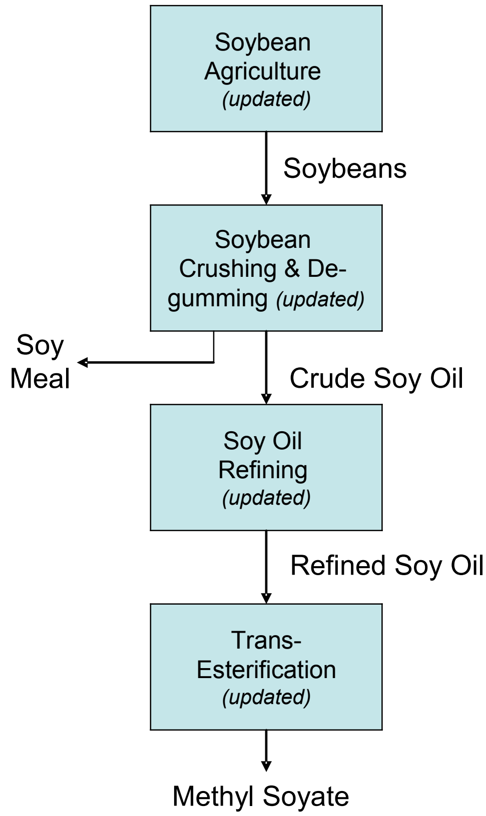
Table 1 Systems Studied

Soy-related unit processes (cradle-to-gate LCIs produced)	Soy agriculture
	Soy crude oil and soy meal production (crushing)
	Soy oil refining
	Methyl soyate (biodiesel)[2]
Comparisons (cradle-to-gate LCIs and LCIAs produced)	Soy biodiesel vs. Petroleum diesel
	Soy-based oil for lubricant vs. Petroleum-based oil for lubricant
	Soy-based polyol vs. Petroleum-based polyol
	Soy-based resin vs. Petroleum-based resin

ISO defines a unit process as the “smallest element of a product system for which data are collected when performing a life cycle assessment.”[3] The unit processes updated for this study include: soybean growing/agriculture, crushing into crude soybean oil and meal, refining, and methyl soyate production by transesterification, shown in the figure below. Transportation aspects for each unit process are included. Unit processes to represent the manufacturing of other soy-based products and intermediate materials for other product/material comparisons in this study have also been built. For each analysis, some or all of these unit process stages are linked together to form the basis of the LCIs and Life Cycle Impact Assessments (LCIAs) for soy-based products and intermediate materials. Diagrams representing each system studied are presented in each of the respective sections in the Modeling & Assumptions section of this report.

[2] Methyl soyate and biodiesel are being used interchangeably in this study.
[3] ISO 14040, Sec 3.45.

Figure 1 Unit Process Stages Updated



Cut-Off Criteria: Inclusion in the System Boundaries

ISO 14044 requires a cut-off criterion to be defined for the selection of materials and processes to be included in the system boundary. Several criteria are used in LCA practice to decide which inputs are to be studied, including mass, energy and environmental relevance.[4] The mass criterion was applied, and a cut-off goal of 99% of material inputs was defined.

Detailed information on the materials required for each unit process stage were collected, and every effort was made to include life cycle data for the production of these materials or to find suitable surrogate data (i.e., if data on that material was not included). Despite a defined cut-off criteria based on mass, an attempt was still made to collect all materials and energy inputs to the systems, regardless of mass contribution, in order to capture all materials that may be environmentally relevant.

Exclusion of Data from the System Boundaries

The scope and boundaries exclude impacts for human activities associated with production of the feedstocks and products that are outside the facility boundaries, such

[4] ISO 14044, Section 4.2.3.3.

as employee travel to and from work. Impacts for facility construction and capital equipment are also excluded, as these impacts typically are negligible when allocated over the total quantity of product manufactured over the life cycle of the facilities and equipment.[5] Packaging of the final products has also been excluded since it is assumed that the products are packaged similarly and net differences in the results would therefore be small.

Function and Functional Unit

In order to conduct a proper LCA under the ISO guidelines, product results are run based on a unit summarizing their function or service. This allows for the comparison of different industrial products performing the same function. The cradle-to-gate unit process data on soy feedstocks are modeled on a mass basis since these data are used as building blocks to other LCA systems. All results are run based on 1000 kg of output.

The function of the product comparisons is the use of soy-based products and their petroleum-based alternatives in fuel and industrial products. The comparisons have been run on 1000 kg of each, with the assumption that the materials compared perform generally the same on an equivalent weight basis. It should be noted that for some of the products compared, while they generally can be used interchangeably in many applications, the precision of this one-to-one replacement in terms of actual performance is difficult to assess since every formulation using such materials may have different requirements and functions. It is out of the scope of this work to evaluate each product on the basis of very precise applications. So users of the results should understand that this is a limitation in the results, and that decisions made for the use of these products should be based on appropriateness and applicability of each material as well as the trade-offs of the environmental impacts being evaluated.

Allocation

Mass allocation was used as the main allocation rule for the baseline analysis in this study. However, the data used to build the LCIs are available in unallocated form and these are the data that will be submitted to the U.S. LCI database. This will allow the LCA practitioner or other data user to decide upon an allocation rule appropriate for his/her study.

In LCA, when allocation is necessary, the key to robust modeling is to determine the basis for the allocation (e.g., based on mass, economic value, etc.). It was decided for this study that allocation based on the mass of the products and coproducts would be made for the baseline results. There is a careful rationale behind this methodological decision. Physical partitioning was done because it made the most sense and had the least set of uncertainties. The economics of soy oil and soy meal values are volatile, requiring data to be updated frequently. Also using system boundary expansion was found not to be a viable option for this analysis. Finally, mass allocation has been used for the LCAs performed on biobased products evaluated for the Federal BioPreferred Program. Nonetheless, a sensitivity analysis was conducted using economic allocation. The results of the sensitivity analysis as well as more information on the allocation

[5] Note that capital equipment is included where data sets in the software do contain that information.

decision rationale are found in Appendix A (Allocation Determination and Economic Sensitivity Analysis).

Modeling Tools

The LCA model was built in SimaPro 7, a commercially available LCA software product.[6] This software contains U.S. and European databases on a wide variety of materials in addition to an assortment of European- and U.S.-developed impact assessment methodologies.

Data Categories and Life Cycle Impact Assessment

Life Cycle Inventory (LCI)

Cradle-to-gate life cycle models for the intermediate and final products were constructed in SimaPro and LCI results were generated

Life Cycle Impact Assessment (LCIA)

LCI results for the product comparisons are classified into impact categories, that is, categories in which a set of related flows may contribute to impacts on human or environmental health. The Building for Environmental and Economic Sustainability (BEES) set of impacts were used for the following reasons:

- BEES has adopted the U.S. EPA-developed Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI)[7], a set of peer-reviewed U.S.-based LCIA methods;
- BEES has a comprehensive set of impacts to meet ISO's requirements for a range of impact categories;
- BEES has a recognized and accepted methodology to ensure a level playing field in terms of its methodological approach; and
- The BEES framework and impact categories are used for other government programs, such as the USDA's BioPreferred program.[8]

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[6] PRé Consultants: *SimaPro 7.0 LCA Software*. 2006. The Netherlands.

[7] U.S. Environmental Protection Agency, Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI): User's Guide and System Documentation, EPA/600/R-02/052, U.S. EPA Office of Research and Development, Cincinnati, OH, August 2002.

[8] See http://www.bfrl.nist.gov/oae/software/bees/please/USDA/bees_please.html.

The following table presents the LCIA categories included.

Table 2 LCIA Categories

Impact Category	**Units**
Global Warming	CO_2 equivalents
Acidification	H^+ equivalents
Eutrophication	N equivalents
Fossil Fuel Depletion	MJ surplus energy
Water Intake notes 1,2	liters of water
Criteria Air Pollutants	microDALYs
Smog	NO_x equivalents
Ecological Toxicity	2,4-D equivalents
Ozone Depletion	CFC-11 equivalents
Human Health – Cancer	C_6H_6 equivalents
Human Health – NonCancer	C_7H_8 equivalents
Total Fuel Energy notes 3,4	MJ

Note 1: Total water usage is specific to BEES and is not included in TRACI.
Note 2: For example: water used in agriculture is from irrigation (rainfall would not be included in this figure). Water intake for other process stages means water used for all process steps including steam generation and cooling where applicable.
Note 3: fuel energy values are based on lower heating values.
Note 4: Total fuel energy is all energy related to what was used as fuel in the whole system. The fossil fuel depletion category accounts for only the coal, natural gas, and crude oil in the system.

LCIA has limitations, and users of this study must understand these limitations:

1. Spatial and temporal resolution is lost in an LCA. When emissions are put in terms of a functional unit, the system becomes a snapshot in time and space. So all temporal and geographical characteristics which are needed to assess local environmental impacts, i.e., human and/or ecological health-related, are lost. LCA results do not distinguish between emissions released instantaneously and locally and those released over a large geographical area over a long period of time. Also, amplifying and/nor attenuating effects of toxic chemicals may not be taken into account.

2. Threshold effects are lost in an LCA. LCA is based on a linear extrapolation of mass loadings with the assumption that this loading contributes to an environmental effect. This is contrary to threshold-driven environmental and toxicological mechanisms. Thus, while the linear extrapolation of mass loadings is a reasonable approach for more global and regional impact categories such as GWP and acidification, it is not as appropriate a measure for human health- and toxicity- related impacts.

In addition, readers should recognize that human health- and toxicity-related impacts do not include all toxic chemicals at this time. In light of these limitations, LCA results for human health- and toxicity- related impacts, such as human cancer and non-cancer potentials and ecotoxicity, should be used with caution. Results for these categories should be understood to be more limited than some other categories.

Modeling & Assumptions

Data and Energy Used

Both primary data (collected from a manufacturing plant) and secondary data (publicly-available, literature sources) can be used for LCAs. This study contains a mix of primary and secondary data, and this is detailed below in the specific modeling and data quality sections.

All energy data in this study comes from the U.S. LCI database. Unless otherwise specified, the average U.S. electricity grid is used, containing 53% coal, 16% natural gas, 20% nuclear, 3% heavy fuel oil, 7% hydropower, and 1% other biomass renewables)[9]. A line loss factor of 9.91% which represents the difference between electricity generated and electricity sold is accounted for. All power quantities provided in the data tables in this study come from the electricity grid and not facility-specific combined heat and power (CHP) units. Steam is generated from natural gas unless otherwise specified.

Note that except where specified, the air emissions outputs in the data tables below are process-related, and not related to energy use. The emissions resulting from energy use/combustion are accounted for in upstream data sets.

Accounting for Carbon Sequestration

In this cradle-to-gate study, the sequestration of carbon is taken into account, based on the quantity of biomass carbon embedded in each of the final products (see Table 13). In the results, the biomass carbon content, in terms of its quantity in CO2, is subtracted from the GWP total. It should be noted that this accounting of embodied carbon is the same, regardless of choice of allocation used.

The reader should be reminded that the carbon sequestered in feedstocks may or may not be released during use or the end-of-life phase of the end product (depends on the end-use application).

Soybean Growing/Agriculture

Data for the agricultural processes to produce soybeans is based on average U.S. soybean production practices in the U.S., and data are based mainly on the years 2001 through 2007. These soybean agriculture data are an update of the existing soybean data that are currently published in the U.S. LCI database.[10]

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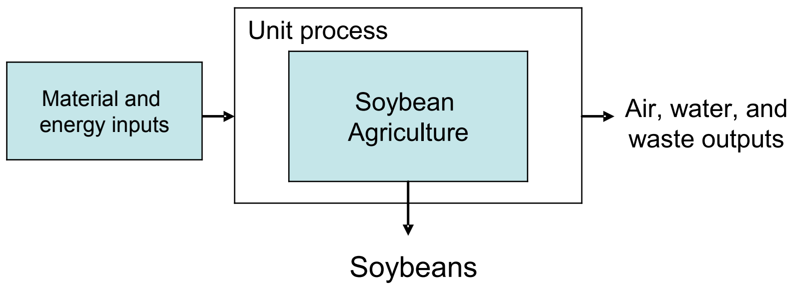
[9] U.S. LCI Database process information for the U.S. average electricity grid. Found at http://www.nrel.gov/lci/database/default.asp.

[10] The U.S. LCI current data comes from the soybean growing data in National Renewable Energy Laboratory's (NREL's) LCA study on biodiesel use in an urban bus, some of which was updated by Omni Tech International and other experts in 2003. The NREL study, hereinafter referred to as "Biodiesel Report", is cited as follows: Sheehan, J. et al*.,* **Life Cycle Inventory of Biodiesel and Petroleum Diesel**

The soybean agriculture data are provided as a single unit process (see figure below), and include:

- Use of farm tractors;
- Irrigation (only consumptive use taken into account);
- Use of nitrogen, phosphorous, and potash fertilizers and air emissions and water effluents associated with those inputs. Note: the influence of a previous year crop has been taken into account through the actual quantities of fertilizer/pesticide used in the current year;
- Use of pesticides and herbicides and air emissions and water effluents associated with those inputs;
- Other energy and materials requirements, including energy to grow seedlings; and
- Transportation of the material inputs to the farm.

Figure 2 Soy Agriculture Unit Process



The updated information is summarized below. Where there was no change in data from the original soy agriculture data set ("NC"), refer to the documentation on the U.S. LCI database website.

Table 3 Updated Soy Agriculture Inputs

Inputs	Quantity per 1000 kg soybeans[Note 1]	Source
Energy inputs[11]		
Diesel (farm tractor) (l)	14.3	5
Electricity (MJ elec.)	25	5
Gasoline (farm tractor) (l)	4.5	5
LPG (MJ)	32	5
Natural gas (MJ)	48	5
Material inputs		
Agrochemicals (kg)	0.52	1
Nitrogen Fertilizer (NH4NO3 as N) (kg)	1.6	1
Phosphorous Fertilizer (TSP as P2O5) (kg)	5.0	1
Potash Fertilizer (K2O) (kg)	9.3	1
Quick lime (kg)	94	2,3

for Use in an Urban Bus, NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

[11] Note that the energy in this and other tables in this report is reported as unit process energy, and not, for example, for energy related to material inputs (that energy is captured upstream).

Water (from river) (l)[note 2]	15855	4
Water (from well) (l)[note 2]	34725	4
Land use information		
Cropland (Conservation Tillage) (m2.yr)	2034	NC
Cropland (Conventional Tillage) (m2.yr)	850	NC
Cropland (Reduced Tillage) (m2.yr)	723	NC

Note 1: The average yield of soybeans for the years 2004 through 2007 was 1120 kg/acre. U.S. soybean data from United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) database found at www.nass.usda.gov, and US soybean seed data from USDA/Economic Research Service (ERS) Crop Production Practices database, found at www.ers.usda.gov.
Note 2: A report that has recently been published contains irrigation data consistent with that in the table (The Keystone Center, "Environmental Resources Indicators for Measuring Outcomes of On-Farm Agricultural Production in the United States", First Report, January 2009, p.44, found at http://keystone.org/files/file/SPP/Field-to-Market_Environmental -Indicator_First_Report_with_Appendices_01122009.pdf)

Source 1: USDA NASS Agricultural Chemical Usage Field Crops Summary Reports for 2006, 2005, 2004, 2002 and 2001, found at www.nass.usda.gov.
Source 2: Agricultural Resources & Economic Indicators, 2006 edition/EIB-16/Economic Research Services/USDA, p. 97. Based on 2002 survey by the Economic Research Services of the USDA, approximately 80% of the soybean acres in the 10 major producing states use corn-soybean rotation. The average lime application rate was allocated to soybeans based on the ratio of soybean and corn usage.
Source 3: Personal communication (email), James Duffield to James Pollack, September 9, 2008 with attachment "devLime data published.doc".
Source 4: USDA Farm & Ranch Irrigation Survey reports for 1994, 1998, and 2003, found at www.agcensus.usda.gov.
Source 5: Argonne National Lab report ANL/ESD/08-02, pp. 14-17. Specifically, the data was retrieved from USDA, 2007b, Data Sets: Commodity Costs and Returns, available at http://www.ers.usda.gov/Data/CostsAndReturns/Fuelbystate.xls, accessed Nov. 2007. Current data was pulled from Ag resource and management survey (ARMS), Economic Research Service, USDA, for year 1997.

Transportation of materials to the field has been accounted for, and an average distance of 300 miles is used, and the materials are transported by truck. For modeling in SimaPro of this and all the input data for this study, data for energy and transportation come from the U.S. LCI database. Data for materials are from secondary sources from the following databases (in order of preference and data availability): the U.S. LCI database, the EcoInvent database,[12] and the SimaPro database which contains data sets with varying levels of data quality in terms of representativeness of technology, age of data, and geography of the processes.

[12] Generally reputed to be current, representative data on processes and chemicals, the EcoInvent database is a for-purchase database developed by the Swiss Center for Life Cycle Inventories. EcoInvent is used in conjunction with other databases in the SimaPro software. More information can be found at www.ecoinvent.org.

The output data from soybean production includes biomass CO2 (-1,560,995 grams per 1,000 kg soybeans[13]), nitrous oxide (350 grams per 1,000 kg soybeans[14]), and air and water emissions associated with fertilizer, agrochemicals, and other agriculture activities. This full data set will be available as part of the submission to the U.S. LCI database.

Some components of soybean agriculture were excluded either due to general LCA practice or lack of available data, including:

- Capital equipment for farm machinery and buildings
- Farmer-related impacts, such as production and consumption of food
- Micronutrients
- Nitrification inhibitors

Soybean Processing to Produce Soy Crude Oil and Meal

The data for soybean processing were collected and aggregated by the National Oilseed Processors Association (NOPA).[15] To the degree possible, NOPA has provided updated data for specific energy and material "inputs" and "outputs" set forth in a May 1998 Final Report issued by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) entitled "Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus."

The data in the 1998 NREL Report were obtained from a single soybean processing plant. These data were not representative of either other individual soybean processing plants or the soybean processing industry as a whole.

NOPA's data, obtained by surveying its 15 member companies in mid-December 2008 for data reflective of each company's most recent fiscal year, do not reflect the performance of any single soybean processing plant. Rather, the data reflect company-supplied data that NOPA received on 50 of the 60 soybean processing plants that it represents, and are broadly reflective of energy and material inputs and outputs for soybean processing plants similar in general design and processes to the plant that was evaluated in the 1998 Report. The data that NOPA received were provided as full-facility inputs and outputs on a per-soybean input basis, and cover soybean processing via solvent extraction through crude oil degumming.

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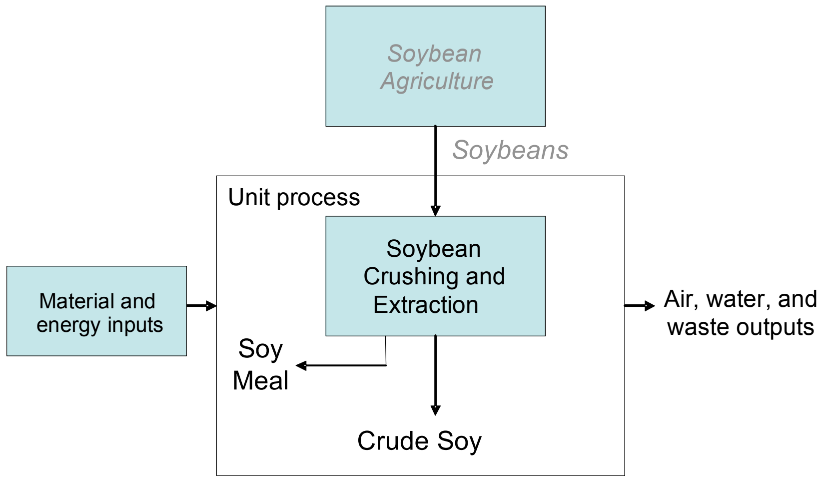
[13] Calculated based on soybean carbon content of 42.6%.

[14] Calculated using 2006 **IPCC Guidelines** and **U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005,** DAYCENT and CENTURY models, Global Change Program Office, Office of the Chief Economist, USDA, 2008.

[15] David Ailor, Vice President of Regulatory Affairs for the National Oilseed Processors Association, Washington, D.C., provided the aggregated data in January 2009, following a data collection effort that he undertook in December 2008 and January 2009 via NOPA's "Technical and Research, Environmental, Security, and Safety, Health & Loss Prevention" (TESH) Committee.

Figure 3 Soybean Crushing and Extraction Process



The updated soybean processing data are summarized in the table below.

Table 4 Soybean Processing Updated Data (per 1000 kg Oil)

Inputs	Biodiesel Study	NOPA Updates	Notes
Energy inputs			
Electricity (kWh)	410	289	
Natural Gas (kcal)	1,569,000	---	
Steam (kcal)	1,296,000		
% NG (NOPA)	---	65%	Fuel types were not broken down this specifically in Biodiesel study
% #2 FO (NOPA)	---	0.5%	
% #6 FO (NOPA)	---	1%	
% Coal (NOPA)	---	32%	
% Biomass (NOPA)	---	1%	
% LF gas (NOPA)	---	0.5%	
Total kcal of heat	*2,865,000*	*1,502,729*	NOPA data do not include data from six plants that do not produce steam onsite.
Material inputs			
Soybeans (kg)	5,891	5,236	NOPA note: 1000 bushels of soybeans
Hexane (kg)	11.9	2.96	See **note 1** below.
Water (kg)	19.4	2,547	See **note 2** below.
Outputs			
Products (kg)			
Soy Meal Produced (% by mass)	4,478 (82%)	4,131 (80.5%)	Based on five-year (2003-2007) average yields that NOPA has provided to USDA. Also see **note 3** below.
Soybean Oil Produced (% by mass)	1000 (18%)	1000 (19.5%)	
Air Emissions (kg)			
Hexane	10.15	2.96	See **note 1** below.
Water Effluents (kg)			
Water	453	1,383	For NOPA: the difference between the water input and output is primarily evaporation losses.

Fats, oils, and grease	5.0	<0.14	
Triglycerides	4.9	---	Not broken out by NOPA
Unsaponifiable Matter	0.08	---	
Free Fatty Acids	0.04	---	
Nonhaz. solid waste (kg)	46	8.7	

Note 1: NOPA's hexane input and air emissions numbers are based on EPA's Vegetable Oil MACT limit of 0.2 gallon of hexane lost/ton of soybeans processed with an assumed specific gravity of hexane of 5.65 pounds/gallon. The MACT limit is a "total loss" limit that reflects total hexane disappearance, the vast majority of which is via air emissions.
Note 2: NOPA data reflect individual facility metered water use, which includes water used in cooling towers, steam production, and other process-related equipment. NOPA believes the current data are more accurate than the water use data contained in the 1998 lifecycle inventory.
Note 3: In 1998 it took 5,891 kilograms of soybeans to produce 1,000 kilograms of oil, but the new data show only 5,236 kilograms of soybeans needed to produce 1,000 kilograms of oil, representing an 11% increase in efficiency. In 1998, 1,316 kilograms of soybeans produced 1,000 kilograms of meal but the new data show only 1,267 kilograms of soybeans needed to produce 1,000 kilograms of meal, representing a 4% increase in efficiency.

Soybeans are modeled as being transported 75 miles to the crushing facility.[16] The products from soybean crushing/processing include degummed soy oil and soybean meal.

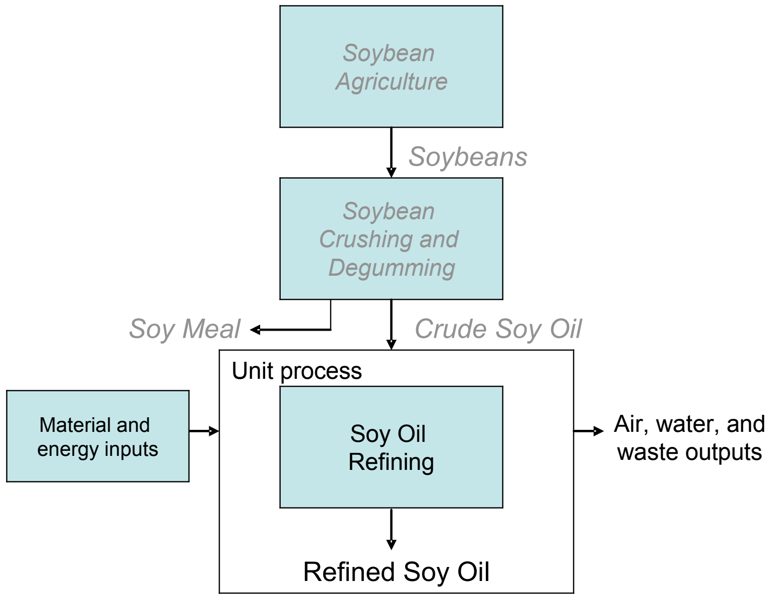
It is important to note that the data in Table 4 are unallocated data. Because there are multiple product outputs (or coproducts), the process inputs and outputs have to be divided or allocated among all products in order to fairly assign environmental impacts to each product. In LCA, when allocation is necessary, the key to robust modeling is to determine how an allocation is to be made (e.g., based on mass, economic value, etc.). It was decided for this study that allocation based on the mass of the products and coproducts would be made for the baseline results.

Crude Soy Oil Refining

Soy oil refining is modeled using the alkaline refining process. **[Note: If one is planning to model methyl soyate go to the next section.]** For this process, caustic soda is added to degummed crude oil, which reacts with the free fatty acids (FFA) to form soap stock. The oil/soap mixture is separated using a centrifuge, and filtration may be done to further clarify the oil from the soap. According to the Biodiesel study, 0.72% of total crude oil input is lost as FFA,[17] and a mass allocation has been made on refined soy oil and soap stock. For the economic allocation for sensitivity, the oil was given an allocation percentage of 100 since soap stock has a minimal value, especially relative to oil. The refining unit process relative to upstream production is as follows:

[16] Biodiesel Report, Sec. 5.2.1.
[17] Biodiesel study, Table 88.

Figure 4 Soy Oil Refining Unit Process



For this model, typical soy oil refining electrical and steam energy were provided by a large agro-processor in the U.S.[18] The other data used for soy oil refining were extrapolated from the Biodiesel report since it contained information on the alkaline refining processes occurring prior to transesterification into biodiesel.[19] The table below summarizes the inputs and outputs associated with production of refined soy oil.

Table 5 Refining Crude Soybean Oil

	Input or Output	Quantity per 1000 kg refined soy oil
Inputs	Crude, degummed soy oil (kg)	1042
	Caustic soda (kg)	2.3
	Water (l)	156
	Electrical energy (Btu)	15,223
	Steam energy (Btu)	56,644
Outputs	Refined soybean oil (kg)	1000
	Soap stock (kg)	7.4
	Wastewater (kg)	123
	- Water (kg)	*90.1*
	- Unsaponifiable matter and lost glycerides (kg)	*14.9*
	- Saponifiable oils and fats (kg)	*18.0*

Bleaching and deodorizing refined soybean oil is only done to produce food grade oil and these steps are not included in this model. Transportation of materials to the refining facility has been accounted for, and 200 miles by truck has been assumed for

[18] Company name not released for confidentiality purposes.
[19] Biodiesel report, Section 5.5.

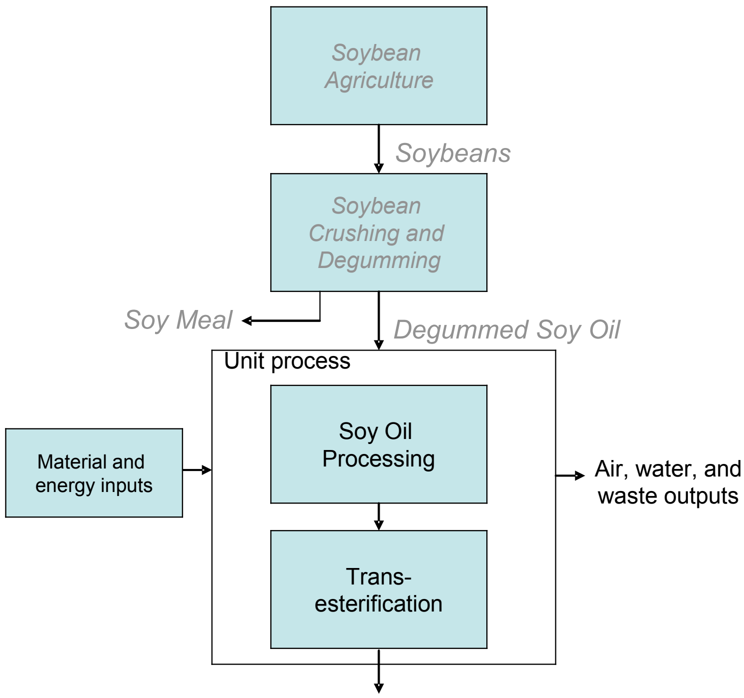
the caustic soda. It is important to note that the data in Table 5 are unallocated data. For this study, mass allocation was made for oil (99.3%) and the soap stock (0.7%).

NOTE: Table 6 for methyl soyate (biodiesel production) below includes the soy oil processing (refining) data. Therefore, when modeling methyl soyate, use the data in Table 6 in lieu of data in Table 5 to avoid double counting.

Methyl Soyate (Biodiesel) Production

For this model, methyl soyate is produced by transesterification, in which a simple alcohol is reacted with the triglycerides in soybean oil to produce methyl soyate and glycerin. The following figure presents the cradle-to-gate system boundaries for methyl soyate. The "unit process" box represents the biodiesel production data described in this section.

Figure 5 Methyl Soyate Production Unit Process



Responding to requests for biodiesel production data from academic institutions and government agencies such as the US Department of Agriculture, the National Biodiesel Board (NBB), the trade association representing the US biodiesel industry, surveyed 2008 energy and material use data from its member companies' commercial biodiesel production plants located in the U.S. NBB developed a survey that was sent to its entire membership, including 230 biodiesel producing companies. In order to design a survey instrument capable of accurately capturing the most relevant data, NBB sought input from organizations such as Argonne National Laboratories, developer of the GREET life cycle model.

According to NBB, 2008 was a record year for the volume of biodiesel production in the U.S., reaching nearly 700 million gallons.[20] The survey data returned by U.S. producers represents 37% of that volume, and as such, this is the first survey of biodiesel production primary data that represents such a substantial volume. Also, due to the good participation rate in this survey, the values represent an excellent cross section of biodiesel plant size, biodiesel production technologies, and biodiesel feedstocks.

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[20] From http://www.biodiesel.org/resources/faqs/. Data originates from the Energy Information Administration.

One obstacle to acquiring this type of process-specific data is the reluctance of private companies to reveal trade secrets in a highly competitive market. Previous estimates of the energy used during biodiesel production had to rely on process modeling and data from a very small number of plants using older technology. The results reported from the NBB survey include no modeling and represent actual energy consumption measured and materials used at operating biodiesel facilities. For this reason, this updated, primary information is considered to be excellent quality and timely for this study.

The table below presents the industry-weighted average of energy and material inputs and products and other outputs. The data reported here were weighted against actual 2008 production volumes.[21]

Table 6 Biodiesel Production

	Input or Output	Quantity per 1 gal. Biodiesel
Inputs		
Feedstock	Virgin oil (lb)[note 1]	7.3285
Energy	Electricity (kWh)	0.12
	Natural Gas (Btu)[note 2]	2,763
Materials	Methanol (lb)	0.6735
	Sodium Methylate (lb)	0.1712
	Sodium Hydroxide (lb)	0.0072
	Hydrochloric Acid (lb)	0.3214
	Phosphoric Acid (lb)	0.0047
	Citric Acid (lb)	0.0054
	Water Usage (gal)[note 3]	0.30
Outputs		
	Biodiesel (gal)[note 4]	1.0
	Glycerin (lb)	0.8881
	Wastewater (gal)	0.0426
	Fatty Acids in w. water (lb)	0.0153

Note 1: Data here represents Biodiesel plants' data for both canola and soybean oils. According to NBB, very little variation was found between plants that used virgin oils, and that canola and soybean oil required similar energy inputs.
Note 2: Natural gas input is 2.69 standard cubic feet (SCF), with 1027 Btu per SCF
Note 3: This value comes from the Biodiesel study. The water use data from the surveys was not reported consistently enough with which to declare a new industry average. For example, some sites included only process water, while others included process and cooling water, etc.
Note 4: Assumed density: 7.4 pounds per gallon.

[21] Note from NBB documentation: weighting by actual plant production provides the most accurate representation of real-world production and provides a realistic estimate of energy use that can be expected as existing plants increase production volume. New plants and new technology implemented at existing plants can be expected to improve energy efficiency, just as has been demonstrated in recent years. No estimates for future energy improvements are included in this analysis.

It is important to note that the data in Table 6 are unallocated data. For this study, a mass allocation was made on the biodiesel and glycerin (89% and 11%, respectively).

Most of the facilities reported their incoming soy feedstock as general feedstock and did not distinguish between already refined oil, crude oil, or degummed crude oil. However, it was found that the difference in plant energy usage for plants reporting crude vs. refined was small (averaging to 170 Btu/gal). For plants that also crush beans and share a steam generation plant for both facilities, the steam going to the biodiesel plant was measured and then back-calculated to come up with the amount of natural gas consumed for biodiesel only. This was needed to be done for only a few facilities, and it was done to keep the biodiesel plant system boundaries consistent. The industry average does not include energy used to refine glycerin to pharmaceutical grade done at some plants. Transportation of materials is included in the model. All materials except crude soy oil are assumed to be transported 100 miles by diesel truck. The soy oil is assumed to be transported 570 miles by diesel locomotive, the same assumption used in the Biodiesel Study.

In terms of robustness of the data, each survey was reviewed by NBB's Professional Engineer. When necessary, clarifying questions were asked of the producers via phone or email to verify that all the data was reported consistently, and that the data accurately represent the actual energy used to produce the reported volume for each plant. In terms of precision, the range of numbers reported was relatively narrow. Wherever a potential outlier was identified, numbers, units, and/or measurements were double checked, and an explanation was requested. When the explanation was reasonable and numbers had been checked, the data point was kept.

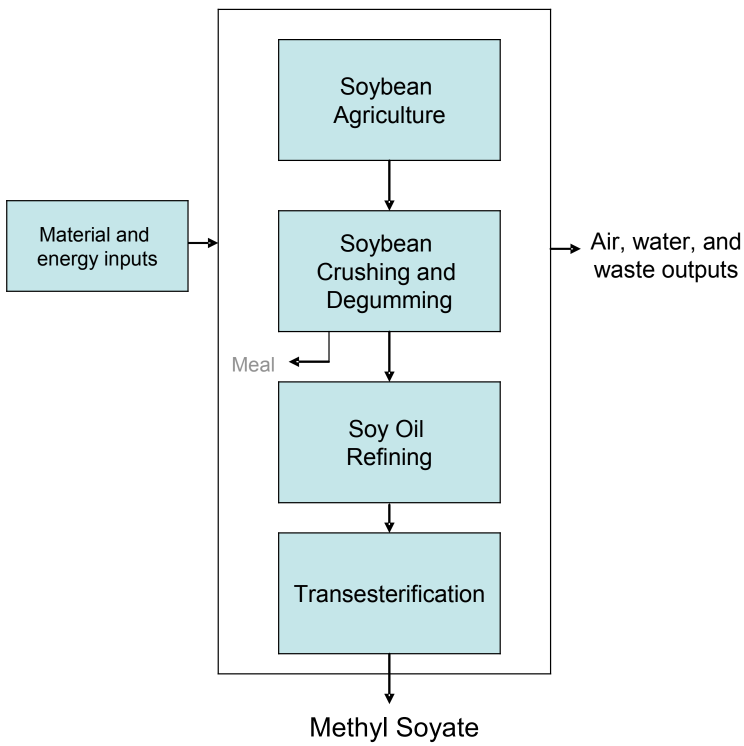
Product Comparisons

Diesel Comparison

Methyl Soyate Production

The main processes to produce methyl soyate have been described above – with all the above unit processes linked together to produce the LCA model, as shown in the figure below:

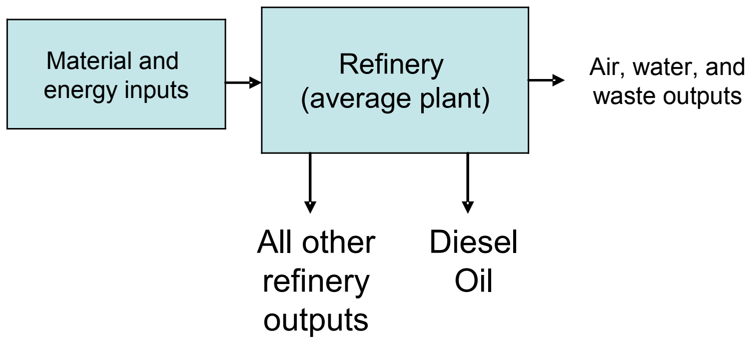
Figure 6 Methyl Soyate System Boundaries



Petroleum Diesel Oil Production

The data for diesel oil production comes from the U.S. LCI database on North American average refinery operations, which convert crude oil into petroleum products using physical and/or chemical processing technology. System boundaries of the diesel production data are as follows:

Figure 7 Diesel Oil System Boundaries



The petroleum refining data in the U.S. LCI database is based on production of 1000 pounds of general refinery product, and is summarized as follows:

Table 7 Inputs and Outputs of Petroleum Refining

	Input or Output	Quantity per 1000 lbs refined petroleum	Source
Inputs	**Raw materials**		
	Crude oil	1034 lbs	3
	Process energy		
	Electricity	64.9 kWh	1
	LPG	0.14 gal	1
	Natural Gas	178 cu-ft	1
	Residual Oil	3.26 gal	1
	Water (process and cooling)	249 gal	5
Outputs	**Air emissions**		
	Aldehydes	0.042 lbs	1,3
	Ammonia	0.021 lbs	1,3
	Carbon monoxide	13.3 lbs	1,3
	Carbon tetrachloride	1.2E-08 lbs	1,3
	CFC12	1.2E-07 lbs	1,3
	Hydrocarbons (other than methane)	2.03 lbs	1,3
	Methane	0.071 lbs	1,2,3
	NOx	0.33 lbs	1,3
	Particulates (unspecified PM)	0.24 lbs	1,3
	SOx (unspecified)	2.35 lbs	1,3
	Trichloroethane	9.7E-08 lbs	1,3

	Water effluents		
	BOD5	0.034 lbs	1
	COD	0.23 lbs	1
	Chromium (hexavalent)	3.7E-05 lbs	1
	Chromium (unspecified)	5.7E-04 lbs	1
	Nitrogen (as ammonia)	0.015 lbs	1
	Oil and Grease	0.011 lbs	1
	Phenolic Compounds	2.3E-04 lbs	1
	Sulfide	1.9E-04 lbs	1
	Total Suspended Solids	0.028 lbs	1
	Solid Waste		
	Solid waste (unspecified)	5.60 lbs	4

Source 1: Energy and Environmental Profile of the U.S. Petroleum Industry. U.S. Department of Energy Office of Industrial Technologies. December 1998.
Source 2: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000. Table 2-29: CH4 Emissions from Petroleum Systems. U.S. EPA Office of Atmospheric Programs, Washington, DC. April 15, 2002.
Source 3: Energy Information Administration, Annual Energy Review 2001, Table 5.8: Refinery Input and Output
Source 4: Estimating Externalities of Oil Fuel Cycles, Oak Ridge National Laboratory and Resources for the Future, August 1996.
Source 5: Water in refining process - 1 to 2.5 gal range per refined fuel. From U.S. DOE Dec 2006, Energy Demands on Water Resources: Rpt to Congress on the Interdependency of Energy and Water, page 20. Report says refinery use of water for processing and cooling is about 1 to 2.5 gallons of water for every gallon of product (Gleick, 1994).

Data for crude oil production comes from the U.S. LCI database. Transportation of crude oil and process fuels to the refinery is also included in the refinery model. Other sources of data for the refinery include personal communication with industry experts, U.S. EPA,[22] Worldbank Group,[23] and Association of Oil Pipelines.[24]

Data for specific refinery outputs, including diesel fuel, were obtained by allocating the overall refinery inputs and outputs to specific refinery outputs. Allocation has been made on a mass basis, based on the percent by mass of each product produced at the refinery. The following table provides the percent by mass of the refinery outputs:[25]

[22] AP-42, Chapter 5, Petroleum Refining, U.S. Environmental Protection Agency, January 1995.
[23] Petroleum Refining, Pollution Prevention and Abatement Handbook, WORLD BANK GROUP, 1998.
[24] Association of Oil Pipelines Annual Report 2000.
[25] US LCI Database: Data Module Report on Petroleum Refining, February 2004, specifically: Energy Information Administration, **Annual Energy Review 2001**, Table 5.8: Refinery Input and Output.

Table 8 Production (by Mass Percent) of Refinery Products

Fuel / Refinery product	Percent mass of refinery output
Gasoline	42.1 %
Diesel (distillate fuel oil)	21.9 %
Kerosene (jet fuel)	9.1 %
Petroleum coke	6.0 %
Residual fuel oil	4.9 %
Still Gas	4.5 %
Asphalt	3.7 %
LPG	2.7 %
Lubricant[26]	1.3 %
Other refinery outputs	3.9 %
Total	**100 %**

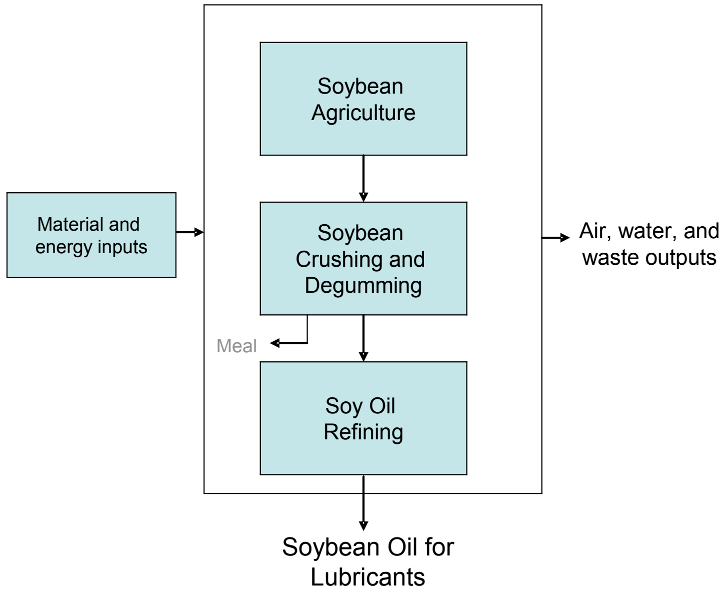
Oil for Lubricants Comparison

Soybean Oil for Lubricants

A soybean-based oil for lubricants is a high oleic soybean oil, which is produced from soybeans whose seeds have been genetically modified to have increased levels of oleic acid, and decreased levels of linoleic and linolenic acid. According to soybean GMO testing done by the DuPont Company, Pioneer, high oleic soybean was found to be no different than conventional soybean for both "yield and agronomic and other relevant characteristics."[27] The soybean growing model already factors in an energy consumption of growing seed, but no data were available to account for producing these GM seeds. Despite that, it is assumed that most of the energy is accounted for in the conventional soybean growing model. Thus, the conventional model is used to produce the soy oil for lubricants, presented in the figure below:

[26] Note: in the U.S. LCI documentation, lubricants are included in the "other outputs" category. The 1.3% for lubricants comes form the Biodiesel study, which provides a more detailed list of refinery outputs.
[27] Butzen, Steve and Steve Schnebly, *High-Oleic Soybean*, from the Pioneer®, a DuPont Company, website, at: http://www.pioneer.com/web/site/portal/menuitem.666b80f644978322a0030d05d10093a0/.

Figure 8 Soybean Oil for Lubricants System Boundaries

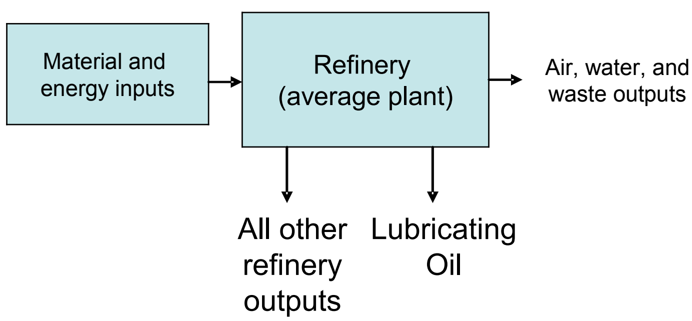


These data include the production of base oil only, and not further downstream material.

Lubricant Production

Because petroleum-based lubricant is produced at a refinery, the same model for diesel fuel (described above) has been applied. The exception to this is the allocation factor for these refinery outputs (see Table 8).

Figure 9 Petroleum Oil for Lubricants System Boundaries



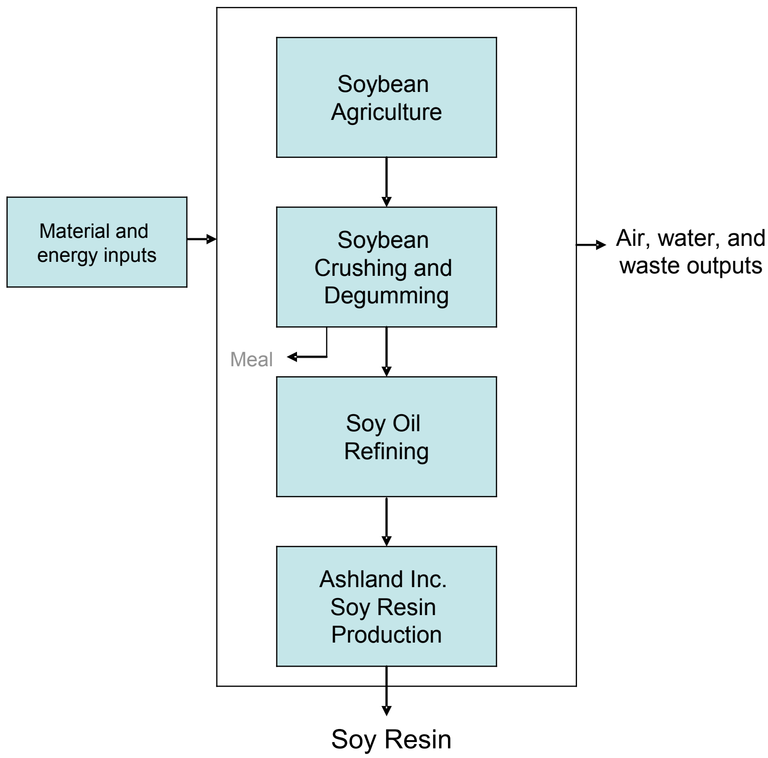
Resin Comparison

Soy Resin Production

Soy resin production data was provided by Ashland Composite Polymers. Specifically, Ashland provided process energy and formulation data to produce their ENVIREZ 1807 soy-based resin product, an intermediate material used by customers to make end-products such as John Deere combine panels. ENVIREZ 1807 is an unsaturated polyester resin (UPR); this resin has a double bond available to use as a reaction (cross-link) site.

The soy resin is produced by reacting refined soybean oil, ethanol, and other materials to produce the resin.[28] Water and ethanol distillates produced in the process are burned through an oxidizer. The reacted resin is then diluted in styrene to produce the mixture as sold to customers. The only other process input is water for cooling, and total make-up water amounts to 0.01 gal/lb resin. No air emissions, solid waste, or other by-products are produced. The following figure represents the soy resin LCA model:[29]

Figure 10 Soy Resin System Boundaries



Both electrical and natural gas energy are used to manufacture the resin at Ashland's plant, and these data were provided by Ashland. The reported energy is net energy consumed – and includes fuel to run the thermal oxidizers and their heat recovery, plus any on-site utility energy consumption such as that used by the cooling tower. The following table provides the electrical and natural gas requirements for the soy resin production at Ashland's facility (the final unit process stage in the figure above):

[28] For confidentiality purposes, the names and quantities for all materials in this product are omitted from this report.
[29] Note: for confidentiality purposes, results are fully aggregated and life cycle stages (e.g., unit processes) and not broken down.

Table 9 Soy resin production energy

Energy sources	Quantity per lb of resin
Electricity	0.117 kWh
Natural gas boiler	1497 Btu

The formulation for ENVIREZ 1807 is current and assumed to be representative of a soy resin. However, it is uncertain how representative this product is amongst all soy resins of this nature available in the marketplace. Data are based on 2008 figures.

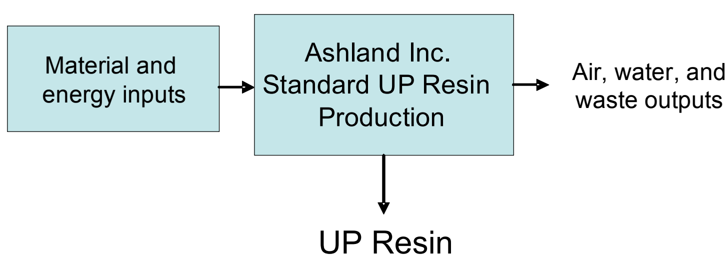
The soy resin model includes transportation of refined soy oil and other materials to Ashland's resin manufacturing plant. Packaging of the final product is not included, nor is transportation to downstream customers or any transportation of the resin into the final end-use product.

Standard Unsaturated Polyester (UP) Resin Production

The data for an alternate unsaturated polyester resin, the petroleum-based alternative to the soy resin, were provided by Ashland Composite Polymers company. Specifically, Ashland provided process energy and formulation data to produce their propylene glycol maleate.

The PG maleate is produced by reacting maleic anhydride, propylene glycol, and other additives to produce the resin.[30] Water as a distillate is burned through an oxidizer. The reacted resin is then diluted in styrene to produce the mixture as sold to customers. The only other process input is water for cooling, and total make-up water amounts to 0.01 gal/lb resin. No air emissions, solid waste, or other by-products are produced. The following figure represents the standard UP resin LCA model:

Figure 11 Standard Resin System Boundaries



Both electrical and natural gas energy are used to manufacture the resin, and this data was provided by Ashland. On-site utility energy consumption, including the cooling tower, was included in Ashland's total energy figures. The following table provides the electrical and natural gas requirements for the standard UP resin production at Ashland's facility (the main unit process stage in the figure above, not including the material and energy inputs):

[30] For confidentiality purposes, the names and quantities for all materials in this product are omitted from this report.

Table 10 Standard UP Resin Production Energy

Energy sources	Quantity per lb of resin
Electricity	0.048 kWh
Natural gas boiler	612 Btu

The formulation for the standard resin is current and can probably be assumed to be representative of other UP resins in the marketplace. Data are based on 2008 figures.

The model includes transportation of input materials to Ashland's resin manufacturing plant. Packaging of the final product is not included, nor is transportation to downstream customers or any transportation of the resin into the final end-use product.

Polyol Comparison

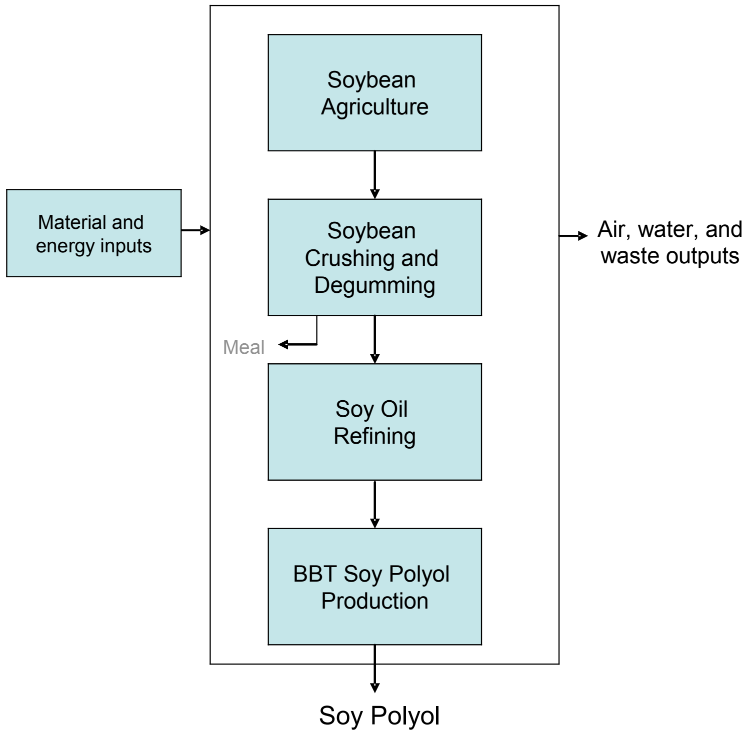
Soy Polyol Production

Soy polyol production data was provided by Biobased Technologies, LLC (BBT). Specifically, BBT provided process energy and formulation data to produce their Agrol soy-based polyol product. To produce Agrol, refined soy oil and acidified oxidant[31] are charged to a clean reactor under an inert atmosphere. The reactor contents are heated to reflux with agitation and aged for a specified period of time. After completing the aging step, the reaction mixture is treated to remove impurities and excess of raw materials that are recycled back into the subsequent batch. The pure polyol is then cooled, filtered and stored in a dry inert atmosphere. This is sold to customers.

Other process inputs include water for cooling and nitrogen used for blanketing. Wastewater and air emissions associated with water and material use have been accounted for in the model. There are no coproducts produced in this process. The following figure represents the soy polyol LCA model:[32]

[31] For confidentiality purposes, the names and quantities for all materials in this product are omitted from this report.
[32] Note: for confidentiality purposes, results are fully aggregated and life cycle stages (e.g., unit processes) and not broken down.

Figure 12 Soy Polyol System Boundaries



Both electrical and natural gas energy are used to manufacture Agrol, and these data were provided by BBT on a total batch basis. Energy consumption for the on-site utilities has been included in BBT's total energy figures. The following table provides the electrical and natural gas requirements for Agrol at BBT's facility (the final unit process stage in the figure above):

Table 11 Soy Polyol Production Energy

Energy sources	Quantity per lb of polyol
Electricity	0.188 kWh
Natural gas boiler	957 Btu

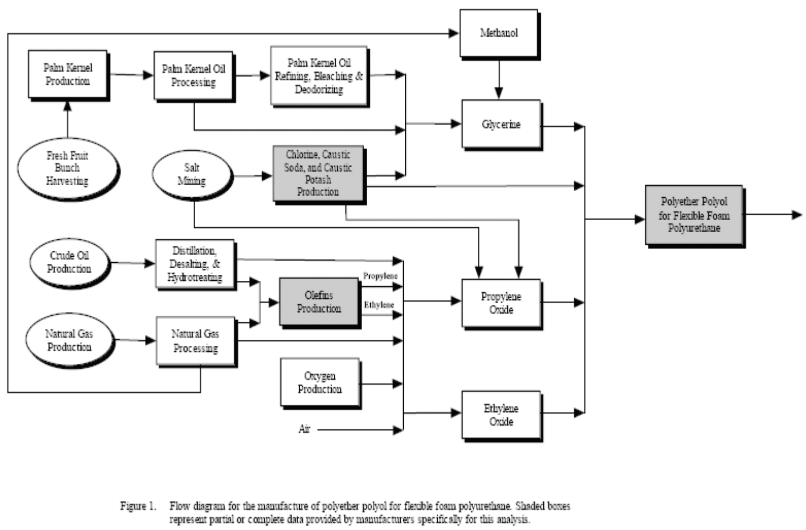
The formulation for Agrol is current and may be assumed to be representative of soy polyol production. However, it is uncertain how representative this product is amongst all soy polyols produced in the marketplace. Data are based on 2009 figures.

The soy polyol model includes transportation of refined soy oil and other materials to BBT's plant. Packaging of the final product is not included, nor is transportation to downstream customers.

Petroleum-Based Polyol

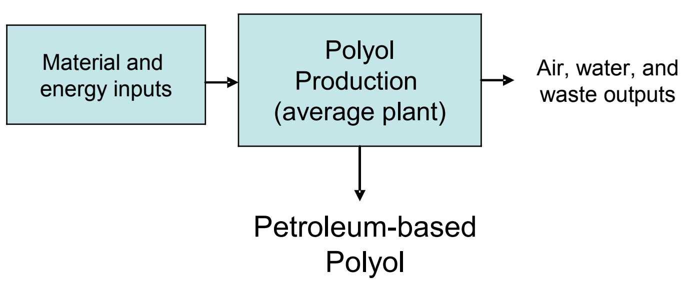
The manufacture of polyether polyol begins with the introduction of a potassium hydroxide catalyst to a polyol initiator, such as a triol. This solution is reacted with propylene oxide and ethylene oxide to form an intermediate. Water is then added to this intermediate. A solvent is introduced, which absorbs the polyol from the water/catalyst. The density difference between the aqueous & organic phases is used to separate the two phases. Finally, the polyol is purified of solvent, side products and water through distillation.[33] Its detailed process flow diagram is provided below:[34]

Figure 13 Detailed polyol production flowchart



Data for the petroleum polyol, specifically polyether polyol used for flexible foam polyurethane, came from the U.S. LCI database. The figure below presents the polyether polyol unit process flowchart as it is modeled for this study.

Figure 14 Petroleum Polyol System Boundaries



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[33] From the "Data Module Report for Polyether Polyol for Flexible Foam Polyurethanes", dated April 18, 2007, found at http://www.nrel.gov/lci/ (hereinafter referred to as "Polyol for Flexible Foam Polyurethane Data Module Report")

[34] Flexible Foam Polyurethane Data Module Report, page 2.

The main material and process energy inputs to polyol production are as follows (gate-to-gate):

Table 12 Inputs to Petroleum-based Polyol Production

Inputs	Quantity per 1000 kg Polyol
Raw Materials	
Propylene oxide (kg)	856
Ethylene oxide (kg)	113
Glycerine (kg)	26
Caustic Potash (kg)	4
Water (as process water) (liter)	451
Energy	
Electricity (grid) (GJ)	0.26
Electricity (cogeneration) (GJ)	0.77
Natural gas (GJ)	2.57

Solid waste, air emissions, and water effluents were also reported in the data sets, and these can be found in the U.S. LCI database.

The US LCI database also provides the transportation needed for the full *cradle-to-gate* production, as follows, for 1000 kgs polyol:

Diesel barge transportation: 11 ton-miles
Residual oil barge transportation: 37 ton-miles
Diesel ocean freighter transportation: 111 ton-miles
Residual oil ocean freighter transportation: 995 ton-miles
Pipeline-petroleum products: 665 ton-miles
Pipeline-natural gas: 697 ton-miles
Diesel combination truck transportation: 187 ton-miles
Diesel single unit truck transportation: 2 ton-miles
Diesel Locomotive transportation: 90 ton-miles

According to the Polyol for Flexible Foam Polyurethane Data Module Report, primary (site-specific) data were provided by five producers (5 plants) in North America and represent the years 2003 and 2005. As of 2002, it is estimated that for all polyurethane applications, there were 7 polyether polyol producers and 9 polyether polyol plants in the U.S. The polyether polyol data collected represents a majority of the total North American production of polyether polyol for flexible foam polyurethane. Additionally, the polyol producers who provided data for this module verified that the characteristics of their plants are representative of a majority of the North American production. The final, averaged dataset was reviewed and accepted by all polyether polyol data providers.[35] Data quality for the collection methods, technology, industry representation, time period, and geography were extensively assessed. Note that since the data that were collected from the producers represented a good sample size, it is likely that the submitted data represent a wide range of molecular weights, creating truly an industry-wide average polyol.

[35] Polyol for Flexible Foam Polyurethane Data Module Report; The Resin Review. The Annual Statistical Report for the U.S. Plastics Industry. American Plastics Council. 2003, backed by research by Franklin Associates on each polyol producing companies' website.

The upstream material and energy data for polyol inputs come from secondary sources, namely the U.S. LCI database, EcoInvent, and the SimaPro database. Glycerine is a co-product of palm oil methyl ester production, according to the same data source as the polyol production data (Franklin Associates Limited), and these FAL data were used.[36] Upstream palm kernel production comes from EcoInvent.

Results and Interpretation

Results tables are presented in this section of the report and are based on 1000 kg of each output (e.g., soybeans, lubricant, polyol, etc.). It is important to remind the reader that the *application* of these products has not been evaluated. These results are cradle-to-gate, so depending on the use and end of life phases of the products, results could change.

In terms of understanding the tables, readers should be aware that most impact categories are independent from one another so the data in the tables should be read across rather than down. It is not appropriate to compare results for one impact category to a different category, e.g., to directly compare GWP impacts with acidification impacts.

Carbon Sequestration in the Results

As mentioned previously, for the GWP category, the sequestration of carbon is taken into account based on the quantity of biomass carbon embedded in each of the soybean-based final products, as shown in the table below..[37] In the results, the following carbon contents are subtracted from the GWP total

Table 13 Biobased carbon content in 1000 kg of each output

Product or output	% carbon	Biomass carbon (kg)	Corresponding biomass CO2 (kg)
Crude soy oil	77%	770	2823
Meal	48%	480	1760
Refined oil	80.6%	806	2955
Biodiesel	77%	770	2823
Soy oil used for lubricants	80.6%	806	2955
Soy-based polyol (oil is 91% of product)	80.6% * 91% = 73.4%	733	2689
Soy-based resin (oil is 12% of product)	80.6% * 12% = 9.7%	97	355

[36] Franklin Associates, Revised Final Appendices: Cradle-to-Gate LCI of Nine Plastic Resins and Two Polyurethane Precursers prepared for Plastics Division of ACC, December 2007, Tables L-5 and L-6.
[37] Carbon contents for the refined oil, biodiesel, polyol, and resin were calculated by an Omni Tech chemical engineer, based on the molecular formulas for each output. Crude oil was estimated based on oil content and "impurities" in the crude that are non-carbon in nature. The meal carbon content has been estimated.

Soybean Production Results

Table 14 Soybean Production (1000 kg output)

Impact category	Unit	Total Soybean Production
Global warming potential	kg CO2 eq	-1.2 E+03
Acidification Potential	milmole H+eq	9.4 E+04
Eutrophication Potential	kg N eq	2.9 E+00
Fossil Fuel Depletion	MJ Surplus	1.9 E+02
Water Intake	Liters	5.1 E+04
Criteria Air Pollutants	microDALYs	2.5 E+01
Ozone Depletion Potential	kg CFC-11 eq	8.0 E-07
Smog Formation Potential	g NOx eq	2.0 E+03
Total Fuel Energy	MJ	1.8 E+03
Ecotoxicity	g 2,4-D eq	1.1 E+04
Human Toxicity - Cancer	g C6H6 eq	1.9 E+02
Human Toxicity - Noncancer	g C7H8 eq	3.8 E+05

Product comparisons

The next tables present the comparisons of soy-based products to petroleum-based products. In the first two data columns, the tables present the overall result for each impact category. The third data column presents the ratio of the petroleum-based product to the soy product. As noted by the color key with each table, when values are within 10% (+/-) of each other, the results are considered equivalent. Ratios above 1 are better for soy and ratios below 1 are worse for soy. For example, 0.30 means the petroleum product's impact value is 30% of that of the soy product.

When the results are negative numbers, as they are with global warming potential (GWP) for three of the soy-based products, ratios cannot be used. Instead, comparing the absolute values for GWP shows the differences between the alternatives. Thus, "N/A" is shown in the tables in place of a ratio.

Some general remarks about these results:

- Application/use of the end products are not accounted for: These results are cradle-to-gate, so depending on the use and end of life phases of the products, the results could change.

- Limited impact categories: In light of the limitations of very localized types of impact categories, the ecological toxicity potential and two human health potential sets of results should be used with caution (see previous discussion for more detail). In addition, for both soy-based and petroleum-based products, the ozone depletion potential numbers are extremely small.

Diesel Comparison Results

Table 15 Methyl Soyate vs. Petroleum-based Diesel (1000 kg output)

Impact category	Unit	Methyl Soyate Total	Petroleum-based Diesel Oil Total	Petro to soy ratio
Global warming potential	kg CO2 eq	-2.1 E+03	6.6 E+02	N/A
Acidification Potential	milmole H+eq	4.1 E+05	5.0 E+05	1.20
Eutrophication Potential	kg N eq	2.8 E+00	4.5 E-01	0.16
Fossil Fuel Depletion	MJ Surplus	1.5 E+03	7.3 E+03	5.00
Water Intake	Liters	4.8 E+04	2.2 E+03	See Note
Criteria Air Pollutants	microDALYs	1.1 E+02	1.1 E+02	0.95
Ozone Depletion Potential	kg CFC-11 eq	1.8 E-06	1.7 E-07	0.09
Smog Formation Potential	g NOx eq	5.0 E+03	1.0 E+04	2.04
Total Fuel Energy	MJ	8.7 E+03	8.1 E+03	0.93
Ecotoxicity	g 2,4-D eq	1.4 E+04	4.9 E+03	0.35
Human Toxicity - Cancer	g C6H6 eq	7.5 E+02	1.9 E+03	2.59
Human Toxicity - Noncancer	g C7H8 eq	1.0 E+06	1.4 E+06	1.40

"equivalent" (+/- 10%)
soy is better than petroleum
soy is worse than petroleum

Note: Incomplete water usage data for crude oil exploration and production prevents a meaningful comparison for this impact category.

Oil for Lubricants Comparison Results

Table 16 Soy-based Oil for Lubricant vs. Petroleum-based Oil for Lubricant (1000 kg output)

Impact category	Unit	Soy-based Lubricant Total	Petroleum-based Diesel Oil Total	Petro to soy ratio
Global warming potential	kg CO2 eq	-2.4 E+03	6.6 E+02	N/A
Acidification Potential	milmole H+eq	1.8 E+05	5.0 E+05	2.82
Eutrophication Potential	kg N eq	3.1 E+00	4.5 E-01	0.14
Fossil Fuel Depletion	MJ Surplus	4.3 E+02	7.3 E+03	16.99
Water Intake	Liters	5.4 E+04	2.2 E+03	See Note
Criteria Air Pollutants	microDALYs	4.9 E+01	1.1 E+02	2.23
Ozone Depletion Potential	kg CFC-11 eq	1.9 E-06	1.7 E-07	0.09
Smog Formation Potential	g NOx eq	3.0 E+03	1.0 E+04	3.42
Total Fuel Energy	MJ	4.3 E+03	8.1 E+03	1.90
Ecotoxicity	g 2,4-D eq	1.3 E+04	4.9 E+03	0.37
Human Toxicity - Cancer	g C6H6 eq	2.9 E+02	1.9 E+03	6.62
Human Toxicity - Noncancer	g C7H8 eq	7.5 E+05	1.4 E+06	1.86

"equivalent" (+/- 10%)
soy is better than petroleum
soy is worse than petroleum

Note: Incomplete water usage data for crude oil exploration and production prevents a meaningful comparison for this impact category.

Polyol Comparison Results

Table 17 Soy-based Polyol vs. Petroleum-based Polyol (1000 kg output)

Impact category	Unit	Soy-based Polyol Total	Petro-based Polyol Total	Petro to soy ratio
Global warming potential	kg CO2 eq	-1.4 E+03	4.1 E+03	N/A
Acidification Potential	milmole H+eq	5.1 E+05	1.5 E+06	3.04
Eutrophication Potential	kg N eq	3.0 E+00	1.1 E+01	3.80
Fossil Fuel Depletion	MJ Surplus	1.7 E+03	1.1 E+04	6.50
Water Intake	Liters	6.8 E+04	7.6 E+04	See Note
Criteria Air Pollutants	microDALYs	1.4 E+02	4.3 E+02	3.06
Ozone Depletion Potential	kg CFC-11 eq	1.4 E-05	4.0 E-06	0.28
Smog Formation Potential	g NOx eq	5.6 E+03	1.6 E+04	2.81
Total Fuel Energy	MJ	1.6 E+04	5.5 E+04	3.48
Ecotoxicity	g 2,4-D eq	1.4 E+04	6.8 E+04	4.87
Human Toxicity - Cancer	g C6H6 eq	7.9 E+02	2.1 E+03	2.63
Human Toxicity - Noncancer	g C7H8 eq	1.3 E+06	1.2 E+07	9.55

"equivalent" (+/- 10%)
soy is better than petroleum
soy is worse than petroleum

Note: Incomplete water usage data for crude oil exploration and production prevents a meaningful comparison for this impact category.

Resin Comparison Results

Table 18 Soy-based Resin vs. Petroleum-based Resin (1000 kg output)

Impact category	Unit	Envirez Resin Total	Standard Resin Total	Petro to soy ratio
Global warming potential	kg CO2 eq	4.1 E+03	5.2 E+03	1.28
Acidification Potential	milmole H+eq	1.6 E+06	1.7 E+06	1.03
Eutrophication Potential	kg N eq	6.8 E+00	7.0 E+00	1.04
Fossil Fuel Depletion	MJ Surplus	1.1 E+04	1.2 E+04	1.11
Water Intake (see note)	liters	4.4 E+04	4.9 E+04	See Note
Criteria Air Pollutants	microDALYs	4.2 E+02	4.4 E+02	1.03
Ozone Depletion Potential	kg CFC-11 eq	1.7 E-06	1.7 E-06	0.99
Smog Formation Potential	g NOx eq	5.6 E+04	2.0 E+04	0.36
Total Fuel Energy	MJ	4.3 E+04	4.7 E+04	1.08
Ecotoxicity	g 2,4-D eq	2.2 E+04	2.8 E+04	1.28
Human Toxicity - Cancer	g C6H6 eq	3.3 E+03	3.3 E+03	1.01
Human Toxicity - Noncancer	g C7H8 eq	4.3 E+06	6.2 E+06	1.46

"equivalent" (+/- 10%)
soy is better than petroleum
soy is worse than petroleum

Note: Incomplete water usage data for crude oil exploration and production prevents a meaningful comparison for this impact category.

Data Quality Requirements and Evaluation

Overview of ISO Data Quality

This LCA adheres to the ISO standards on data quality to help ensure consistency, reliability, and clear-cut evaluation of the results. The following aspects of the study's data quality are described in accordance with ISO 14044.[38]

- **Representativeness** of the data in the study, which includes an assessment of the temporal, geographical, and technological coverage of the model;
- **Consistency** – the qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis;
- **Reproducibility** – the qualitative assessment of the extent to which information about the methodology and data values allows an independent practitioner to reproduce the results reported in the study;
- **Precision** – the measure of the variability of the data values for each data category expressed;
- **Completeness** – the percentage of flow that is measured or estimated;
- **Sources of data**; and
- **Uncertainty of information**.

Data Quality as Applied to this Study

Representativeness

Representativeness includes the following:

- Time/temporal coverage – describes the age of data and the minimum length of time (e.g., one year) over which data are collected;
- Geographical coverage – describes the geographical area from which data for unit processes are collected to satisfy the goal of the study; and
- Technological coverage – describes the technology mix of the data sets, which may include weighted average of the actual process mix, best available technology, or worst operating unit.

Table 19 provides a detailed analysis of the temporal, geographical, and technological coverage for all aspects of this study.

[38] ISO 14044 Section 4.2.3.6

Table 19 Temporal, Technological, Geographical Coverage & Data Sources

	Temporal Information	Technological coverage	Type of data	Geographical coverage	Source of data
Data sets for input materials in each unit process and product	Data sets range primarily from mid-1990s through the 2000s. No data older than 1990 is used (if any).	For generic materials, the most representative technology is used wherever possible. Most data sets represent average technologies	Secondary data	U.S. data is preferable, but where U.S. data are not available or if the quality is low, European data sets are used (**see note below**)	U.S. LCI database, elements of the SimaPro and EcoInvent databases.
Energy and fuel data sets	2000s	The most representative technologies	Secondary data	U.S. data, average US grid mix.	U.S. LCI database
Transportation data sets	2000's data	Average technologies	Secondary data	Represents U.S. production	U.S. LCI database
Soybean agriculture	2000's data	Industry average technologies	Secondary data	Represents U.S. production	Various sources; see body of the report
Soybean processing	Mid 2000's data, some 2007 data	Industry average technologies	Primary data	Represents U.S. production	NOPA
Soybean oil refining	2000's data	Industry average technologies	Secondary data	Represents U.S. production	Various sources; see body of the report
Biodiesel production	2008	Industry average technologies	Primary data	Represents U.S. production	NBB
Soy-based polyol production	2009	BBT technologies	Primary data	BBT U.S. production	BBT
Soy-based resin production	2008	Ashland Composite Polymers technologies	Primary data	Ashland Composite Polymers U.S. production	Ashland Composite Polymers

Petroleum diesel production	2000's	Average technologies	Secondary data	North America	U.S. LCI Database
Petroleum-based lubricant production	2000's	Average technologies	Secondary data	North America	U.S. LCI Database
Petro-based polyol production	2000's	Average technologies	Primary data from several producers that has been made public	North America	American Plastics Council; U.S. LCI Database
Petro-based resin production	2008	Ashland Composite Polymers technologies	Primary data	Ashland Composite Polymers U.S. production	Ashland Composite Polymers

Note on geographical coverage of the data sets: In LCA it is quite common to use a mix of data sets from different geographical locations, for several reasons. First, data for all materials are not always available for all geographies. Also, available data from a preferred geographical location may be very poor in quality (may be outdated, based on faulty emissions factors, based on old or non-representative technologies, based on one plant or a non-representative sample, etc.). Finally, an alternative geography or data set is used because it is better than no data at all. In order to minimize an LCA's margin of error associated with data based on a different geographical location, it is Four Elements' practice to customize the data sets to the preferred geographical location. For example, instead of using a European data as-is, the energy, fuels, and transportation data, all European, are replaced by the corresponding U.S. data sets from the U.S. LCI database, ensuring more U.S. related emissions factors.

Consistency

Consistency is a qualitative understanding of how uniformly the study methodology is applied to the various components of the study. Consistency was maintained in the data collection and modeling of all of the components in the study. The OTI and Four Elements team shared responsibilities which enabled consistent modeling – one set of consultants collected, reviewed and validated the data before life cycle modeling in the software, and then the data were modeled and cross-checked.

Reproducibility

All of the data in this report used for life cycle modeling have been made available. So the level of detail and transparency provided in this report allow the results of this study to be reproduced by another practitioner as long as the production datasets are similar.

Precision

Precision represents the degree of variability of the data values for each data category. Areas where there is data variability are in the use of average data, including average soybean production, average soybean crushing and refining, and some of the average data sets in the U.S. LCI database, including the petroleum-based products. Most of these values have been obtained on a weighted average basis, so while there is variability in the data, it has been averaged on a production-output basis. There may be a high level of variability in the petroleum production data, as the data are older and are not very specific.

Completeness

ISO 14044, section 4.2.3.6 defines completeness as the "percentage of flow that is measured or estimated."[39] This study can be considered complete since much of the data was based on measured or estimated data. In many cases, data were provided by multiple producers. In terms of inclusion of production data of the raw materials, the cut-off criteria of 99% was exceeded, based on what was understood to be inputs to the systems.

[39] ISO 14044:2007, Section 4.2.3.6.

Sources of Data

Both primary and secondary data are used in the modeling. Primary data are the preferred, highest quality data for life cycle modeling. Primary data were gathered from the BBT facility, the Ashland facility, soybean crushing processors, biodiesel producers, and polyether polyol producers. Secondary data including published literature and theoretical models were used for other comparisons. All these have been detailed in the modeling and assumptions sections.

From a practical standpoint it is impossible to collect actual process data for each of the hundreds or thousands of unit processes included in a complete life cycle model, so the use of secondary data in an LCI is normal and necessary. Secondary data have been applied to production of material inputs, production and combustion of fuels used for process energy, and transportation energy throughout the life cycle. Wherever possible, the LCA used the best data that were available, including energy, fuels, transportation, and basic materials from the U.S.-based, recent data from the U.S. LCI database.

Limitations and Uncertainty

General use limitations. It should be borne in mind that LCA, like any other scientific or quantitative study, has limitations and is a far from perfect tool for assessing the environmental impacts and attributes associated with product systems. There is inherently a margin of error due to various limitations such as data quality differences and/or unavailability of potentially relevant data. *Should claims or assertions be made on the environmental performance of the product, the public should be informed of these inherent limitations.*

Product performance. It should be reminded that while generally these materials can be used interchangeably in probably most applications, the precision of this one-to-one replacement in terms of actual performance is difficult to assess. It was out of the scope of this work to evaluate each product on the basis of very precise applications. So users of the results should understand that this is a limitation and that decisions made for the use of these products should be based on appropriateness and applicability of each material as well as the trade-offs of the environmental impacts being evaluated.

Petroleum-based crude oil extraction. The data for petroleum-based crude oil extraction can be considered outdated, especially since even as recently as five to 10 years ago, oil flow was better in some of the North American operations, requiring less inputs into the wells to get the oil out. Now, more energy, water, and equipment are needed to get the same unit quantity of oil of the ground. This is an area that needs to be researched.

Also, more research may be necessary to update the quantity of brine water produced per unit output, other sources of water or other inputs including hot water/steam that is used to extract oil from oil sands and any contamination associated with these (that is released into the environment).

Uncertainty

Both primary and secondary data are used in modeling the materials. Because the quality of secondary data are not as good as primary data, the use of secondary data becomes an inherent limitation to the study. Secondary data may cover a broad range of technologies, time periods, and geographical locations. Because hundreds of data sets are linked together and because it is often unknown how much the secondary data used deviate from the specific system being studied, quantifying data uncertainty for the complete system becomes very challenging. As a result, it is not possible to provide a reliable quantified assessment of overall data uncertainty for the study.

It should be added that wherever possible, this LCA used the best data that were available, including energy, fuels, transportation, and basic materials from the U.S.-based, recent data from the U.S. LCI database. The U.S. LCI database is considered the best quality data for U.S.-based studies, however, there are limitations to the use of these data for all processes as discussed earlier.

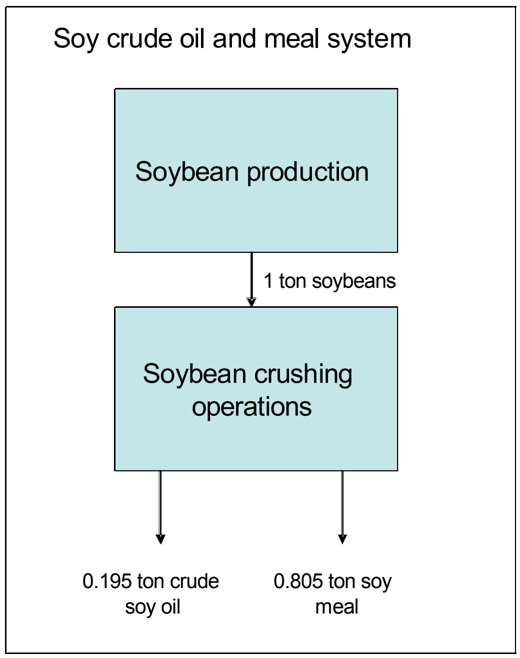
Appendix A

Allocation Determination and Economic Sensitivity Analysis

Allocation Determination

The products from soybean crushing/processing include degummed soy oil and soybean meal, both marketable and useful coproducts, and allocating these has been an ongoing debate. In LCA, when allocation is necessary, the key to robust modeling is to determine the basis for the allocation (e.g., based on mass, economic value, etc.). It was decided for this study that allocation based on the mass of the products and coproducts would be made for the baseline results, and a sensitivity analysis would be performed on their economic value. The below discussion provides the rationale behind this methodological decision. Figure A-1 presents the unallocated production of soy crude oil and soy meal.

Figure A-1 Unallocated Production of Soy Crude Oil and Soy Meal



ISO's preferred approach to allocation is as follows:[40]

1. Wherever possible, allocation should be <u>avoided</u> by:
   1) dividing the unit process to be allocated into two or more subprocesses and collecting the input and output data related to these subprocesses;
   2) expanding the product system to include the additional functions related to the co-products.

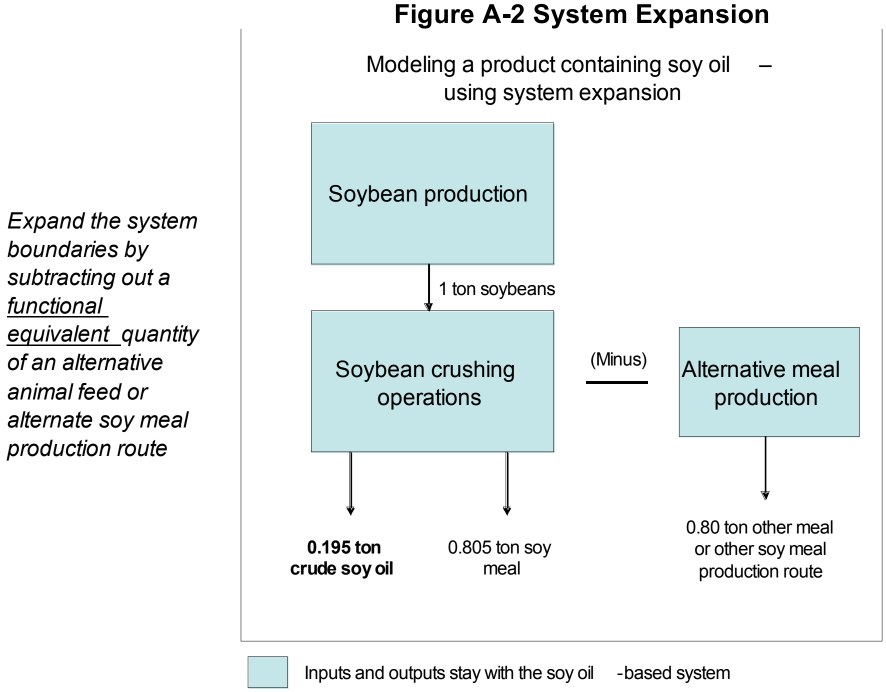
2. Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them.

[40] ISO 14044:2006, Section 4.3.4.2.

3. Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between coproducts in proportion to the economic value of the products.

When LCA practitioners are faced with processes having coproducts, they defer to ISO's first preference, i.e., dividing the multiple output process into two or more subprocesses and avoiding allocation altogether. In the case of soybean crushing, this is nearly impossible to do since soybean crushing is quite an integrated process and data is not available to model separately the energy, inputs, and outputs to produce soy meal and crude soy oil. ISO's second preference for dealing with coproducts would be to expand the system boundary, as shown in the figure below.

Figure A-2 System Expansion



Using system expansion was found to be not a viable option for this analysis for the following reasons:

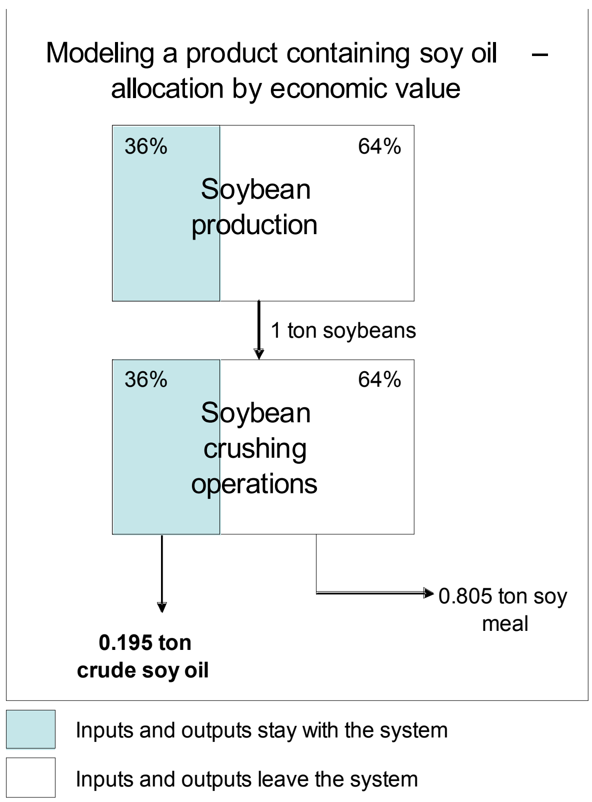
1. No data on an alternate *soy* meal process were available to use for system expansion, so alternate *animal or other vegetable meals* could be used. The composition of common feed rations varies based on species (poultry, swine, fish, beef, dairy etc.), age of species (starter rations, growth rations, finishing rations) and cost of ingredients. Alternative protein sources, if looking at just protein, include other protein meals (canola meal, DDGS, corn steep water, animal by-product meals such as dairy, feather or fish meals, etc.). For these reasons, choosing the most appropriate alternate meal over another would have been a complex process.
2. Some of the alternate meal sources would have made the soy-based polyol option have even lower GHG emissions, because of the N2O and CH4

associated with the animal husbandry. This in itself becomes a decision with a bias toward the soy-based polyol;

3. The data quality on the various alternate meals may not be as high as the other data in this study, so it would not have yielded as robust a set of results; and
4. Often with system expansion, the process data for the alternative product being subtracted out is higher than the process data for the coproduct, resulting in net negative, and very non-intuitive, results. This was the case here, and therefore it was decided that system expansion would not be used.

If avoiding allocation altogether or expanding the system boundary are not practicable, then the inputs and outputs should be allocated based on some sort of other basis, such as market value or physical partitioning. Figure A-3 presents the *economic* value of the coproducts, based on December 2008 price projections.

Figure A-3 Economic Allocation

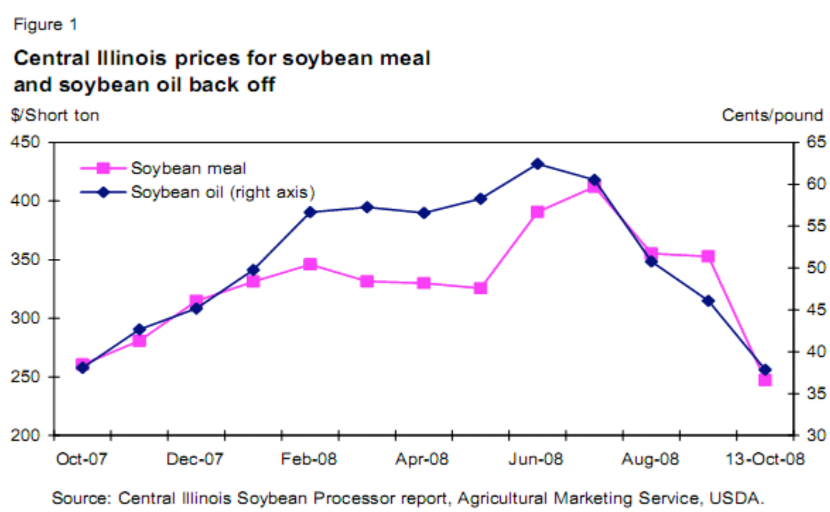


However, allocation based on the economic value of the products is also not a hard and fast choice. As shown in Table A-1 and Figure A-4 the economics of soy oil and soy meal are volatile. It is fairly common to update an LCA or data contained in an LCA every 4 to 6 years. But using allocation based on value would require the LCA to be updated very frequently, which is cost- and time- prohibitive and would not hold water for marketing purposes or for economic programs such as a carbon credit trading system. Economic allocation, nonetheless, is a defensible choice, and many in the LCA field feel that it is a preferred choice. For these reasons, those using this study or data should put a lot of consideration into the allocation choice.

Table A-1 Soy Oil and Meal Economic Data[41]

Allocation basis	Output	Portion of each output from 1 kg of soybean	Economic value for each output ($/kg)	Total $ in the system	Final allocated value
Economic, 2004 pricing	crude oil	0.195	$0.45	$0.09	36%
	meal	0.805	$0.19	$0.16	64%
Economic, 2005 pricing	crude oil	0.195	$0.46	$0.09	33%
	meal	0.805	$0.23	$0.19	67%
Economic, 2006 pricing	crude oil	0.195	$0.63	$0.12	40%
	meal	0.805	$0.23	$0.18	60%
Economic, 2007 pricing	crude oil	0.195	$1.01	$0.20	39%
	meal	0.805	$0.39	$0.31	61%
Economic, 2008 pricing	crude oil	0.195	$0.68	$0.13	34%
	meal	0.805	$0.32	$0.26	66%
Economic, June 2008	crude oil	0.195	$1.45	$0.28	43%
	meal	0.805	$0.46	$0.37	57%
Economic, Dec '08 pricing	crude oil	0.195	$0.78	$0.15	38%
	meal	0.805	$0.30	$0.24	62%
Economic, July 2009	crude oil	0.195	$0.75	$0.15	30%
	meal	0.805	$0.42	$0.34	70%

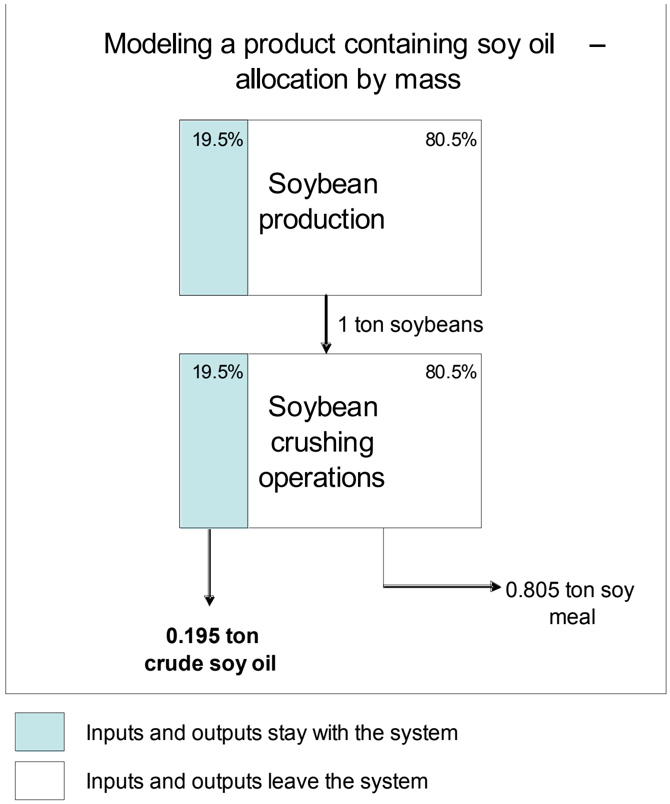
Figure A-4 Soy Oil and Meal Economic Data[42]



[41] Data from Chicago Board of Trade and Wall Street Journal.
[42] Taken from Ash, Mark and Erik Dohlman, **Oil Crops Outlook**, October 14, 2008. Found at www.ers.usda.org.

Finally, an allocation choice based on physical partitioning can be done. Figure A-5 presents the allocation by mass percent of the two coproducts.

Figure A-5 Mass Allocation



The physical breakdown of the quantities of oil and meal coming from soybeans is probably not going to vary more than a few percentage points, so in general, this is uncontested. Since a physical partitioning allocation choice seems to have the least set of uncertainties, this analysis uses mass allocation, and a sensitivity analysis is made using economic allocation. To sum up the decision on allocating coproducts,

1. For this analysis, physical partitioning was done because it made the most sense and was least contentious.
2. The economics of many product systems, including soy oil and soy meal, may be very volatile, and the numbers in Figure A-4 and Table A-1 demonstrate this well.
3. Mass allocation has been used for the LCAs performed on biobased products evaluated for the Federal BioPreferred Program.
4. Results for system expansion may not be intuitive for the user. Also one needs to have good data for the alternative production for system expansion, and data on alternate meal that is comparable to other data in the study.

It should be reminded that the soybean processing data (soy oil and meal production) will be submitted to the U.S. LCI database on an unallocated basis so that LCA practitioners can run results based on goals and scope of their studies.

Sensitivity Analysis: Use of Economic Allocation

The following tables present an analysis on the affect of the mass allocation decision. The value used for the economic sensitivity analysis was 38.5% allocated to oil (the higher end of the range). The petroleum-to-soy ratios have been presented in these tables to evaluate the differences of the ratios of the mass and economic allocation results.

Overall remark: for products that do not contain a significant amount of soy based material (such as resin), the allocation choice does not make as much of a difference. However, for products that contain a significant amount of soy-based material, the allocation choice does make more of a difference.

Diesel Economic Allocation Sensitivity Results

The table below presents the soy biodiesel results using mass allocation, vs. the soy biodiesel results using economic allocation (the petroleum results do not change).

Table A-2 Soy Biodiesel – Mass vs. Economic Allocation

Impact Category	Unit	Methyl Soyate (Mass)	Methyl Soyate (Econ)	Economic to Mass ratio
Global warming potential	kg CO2 eq	-2.1 E+03	-1.5 E+03	0.73
Acidification Potential	milmole H+eq	4.1 E+05	6.2 E+05	1.51
Eutrophication Potential	kg N eq	2.8 E+00	6.1 E+00	2.17
Fossil Fuel Depletion	MJ Surplus	1.4 E+03	2.0 E+03	1.38
Water Intake	liters	4.8 E+04	1.0 E+05	2.16
Criteria Air Pollutants	microDALYs	1.1 E+02	1.7 E+02	1.51
Ozone Depletion Potential	kg CFC-11 eq	1.8 E-06	3.8 E-06	2.14
Smog Formation Potential	g NOx eq	5.0 E+03	8.3 E+03	1.67
Total Fuel Energy	MJ	8.6 E+03	1.3 E+04	1.56
Ecotoxicity	g 2,4-D eq	1.4 E+04	2.8 E+04	2.02
Human Toxicity - Cancer	g C6H6 eq	7.5 E+02	1.1 E+03	1.48
Human Toxicity - Noncancer	g C7H8 eq	1.0 E+06	1.8 E+06	1.80

In all categories, the results for the economic allocation increase. This makes sense, since the crushing and soybean production impacts increased from a nearly 20% allocation to nearly 40%. The GWP category is lower; much of the GWP value stems from the carbon embedded in the product. Thus, the allocation change only affects the non-biomass CO_2 impacts. Table A-2 above presents soy biodiesel vs. petroleum-based diesel using economic allocation. But in order to effectively demonstrate how the change in allocation rule affects the overall comparative results, Table A-3 and the subsequent tables present the *ratios* calculated between the mass allocation comparison results and the economic allocation comparison results.

Table A-3 Diesel Comparison Using Economic Allocation

Impact category	Unit	Methyl Soyate Total	Petroleum-based Diesel Oil Total	Petro to soy ratio
Global warming potential	kg CO2 eq	-1.5 E+03	6.6 E+02	**N/A**
Acidification Potential	milmole H+eq	6.3 E+05	5.0 E+05	**0.79**
Eutrophication Potential	kg N eq	6.1 E+00	4.5 E-01	**0.07**
Fossil Fuel Depletion	MJ Surplus	2.0 E+03	7.3 E+03	**3.61**
Water Intake	liters	1.0 E+05	2.2 E+03	**See Note**
Criteria Air Pollutants	microDALYs	1.7 E+02	1.1 E+02	**0.63**
Ozone Depletion Potential	kg CFC-11 eq	3.8 E-06	1.7 E-07	**0.04**
Smog Formation Potential	g NOx eq	8.4 E+03	1.0 E+04	**1.22**
Total Fuel Energy	MJ	1.4 E+04	8.1 E+03	**0.59**
Ecotoxicity	g 2,4-D eq	2.8 E+04	4.9 E+03	**0.18**
Human Toxicity - Cancer	g C6H6 eq	1.1 E+03	1.9 E+03	**1.75**
Human Toxicity - Noncancer	g C7H8 eq	1.8 E+06	1.4 E+06	**0.77**

"equivalent" (+/- 10%)
soy is better than petroleum
soy is worse than petroleum

Note: Incomplete water usage data for crude oil exploration and production prevents a meaningful comparison for this impact category.

Table A-4 Economic Allocation: Soy-based Diesel vs. Petroleum-based Diesel

Impact category	Unit	Mass Allocation - petro to soy ratio	Economic Allocation - petro to soy ratio
Global warming potential	kg CO2 eq	N/A	N/A
Acidification Potential	milmole H+eq	1.20	0.79
Eutrophication Potential	kg N eq	0.16	0.07
Fossil Fuel Depletion	MJ Surplus	5.00	3.61
Water Intake	Liters	See Note	See Note
Criteria Air Pollutants	microDALYs	0.95	0.63
Ozone Depletion Potential	kg CFC-11 eq	0.09	0.04
Smog Formation Potential	g NOx eq	2.04	1.22
Total Fuel Energy	MJ	0.93	0.59
Ecotoxicity	g 2,4-D eq	0.35	0.18
Human Toxicity - Cancer	g C6H6 eq	2.59	1.75
Human Toxicity - Noncancer	g C7H8 eq	1.40	0.77

"equivalent" (+/- 10%)
soy is better than petroleum
soy is worse than petroleum

Note: Incomplete water usage data for crude oil exploration and production prevents a meaningful comparison for this impact category.

Remarks: In general, because the allocation went from 20% to nearly 40%, the ratio decreased for many of the categories, so the soy results are not as favorable when using the economic allocation. Where the soy product was considered equivalent to the petro product in the mass allocation (criteria pollutants and fuel energy), now the soy results are worse than the petroleum results. The GWP ratio increased slightly.

Oil for Lubricants Economic Allocation Sensitivity Results

Table A-5 Economic Allocation: Soy Oil for Lubricant vs. Petroleum-based Oil for Lubricant

Impact category	Unit	Mass Allocation - petro to soy ratio	Economic Allocation - petro to soy ratio
Global warming potential	kg CO2 eq	N/A	N/A
Acidification Potential	milmole H+eq	2.82	1.44
Eutrophication Potential	kg N eq	0.14	0.07
Fossil Fuel Depletion	MJ Surplus	16.99	8.72
Water Intake	liters	See Note	See Note
Criteria Air Pollutants	microDALYs	2.23	1.14
Ozone Depletion Potential	kg CFC-11 eq	0.09	0.04
Smog Formation Potential	g NOx eq	3.42	1.73
Total Fuel Energy	MJ	1.90	0.97
Ecotoxicity	g 2,4-D eq	0.37	0.19
Human Toxicity - Cancer	g C6H6 eq	6.62	3.37
Human Toxicity - Noncancer	g C7H8 eq	1.86	0.95

"equivalent" (+/- 10%)
soy is better than petroleum
soy is worse than petroleum

Note: Incomplete water usage data for crude oil exploration and production prevents a meaningful comparison for this impact category.

Remarks: A couple of the categories where soy was better than the petroleum product (e.g., fuel energy and human toxicity non-cancer), are now equivalent to the petroleum product. Beside that, the overall outcomes did not change.

Polyol Economic Allocation Sensitivity Results

Table A-6 Economic Allocation: Soy-based Polyol vs. Petroleum-based Polyol

Impact category	Unit	Mass Allocation - petro to soy ratio	Economic Allocation - petro to soy ratio
Global warming potential	kg CO2 eq	N/A	N/A
Acidification Potential	milmole H+eq	3.04	2.34
Eutrophication Potential	kg N eq	3.80	1.96
Fossil Fuel Depletion	MJ Surplus	6.50	5.35
Water Intake	liters	See Note	See Note
Criteria Air Pollutants	microDALYs	3.06	2.34
Ozone Depletion Potential	kg CFC-11 eq	0.28	0.25
Smog Formation Potential	g NOx eq	2.81	1.92
Total Fuel Energy	MJ	3.48	2.83
Ecotoxicity	g 2,4-D eq	4.87	2.64
Human Toxicity - Cancer	g C6H6 eq	2.63	1.98
Human Toxicity - Noncancer	g C7H8 eq	9.55	6.29

"equivalent" (+/- 10%)
soy is better than petroleum
soy is worse than petroleum

Note: Incomplete water usage data for crude oil exploration and production prevents a meaningful comparison for this impact category.

Remark: while the ratios have still gone down (with the exception of GWP), overall, the majority of impacts for the soy product are still better than those for the petroleum product.

Resin Economic Allocation Sensitivity Results

Table A-7 Economic Allocation: Soy-based Resin vs. Petroleum-based Resin

Impact category	Unit	Mass Allocation - petro to soy ratio	Economic Allocation - petro to soy ratio
Global warming potential	kg CO2 eq	1.28	1.26
Acidification Potential	milmole H+eq	1.03	1.02
Eutrophication Potential	kg N eq	1.04	0.98
Fossil Fuel Depletion	MJ Surplus	1.11	1.10
Water Intake (see note)	liters	See Note	See Note
Criteria Air Pollutants	microDALYs	1.03	1.02
Ozone Depletion Potential	kg CFC-11 eq	0.99	0.87
Smog Formation Potential	g NOx eq	0.36	0.36
Total Fuel Energy	MJ	1.08	1.07
Ecotoxicity	g 2,4-D eq	1.28	1.19
Human Toxicity - Cancer	g C6H6 eq	1.01	1.00
Human Toxicity - Noncancer	g C7H8 eq	1.46	1.43

"equivalent" (+/- 10%)
soy is better than petroleum
soy is worse than petroleum

Note: Incomplete water usage data for crude oil exploration and production prevents a meaningful comparison for this impact category.

Remark: with this product, more categories are equivalent when the economic analysis is performed.

Applying Recent US Soybean Data

to the

EU Renewable Energy Sources Directive

December 2009

Prepared for the United Soybean Board
by
Omni Tech International, Ltd.
with
Four Elements Consulting, LLC

Applying Recent US Soybean Data to the

EU Renewable Energy Sources Directive

I. Introduction and Background

In 2009 the European Union adopted a Renewable Energy Sources Directive (2009/28/EC) that incorporates minimum GHG emission targets for biofuels. Starting in 2010, biofuels produced in new plants shall offer a minimum 35% GHG emission reduction compared with fossil fuels. On 1 January 2017, a reduction of 50% shall be required. Plants built in 2018 or later must show a further GHG reduction of 60%. [1]

To establish a benchmark for current biofuel production GHG emission reductions, the European Commission used the life cycle modeling from a CONCAWE Well-to-Wheel study conducted by the European Commission's Joint Research Centre (JRC) for establishing the emissions reductions levels.[2] CONCAWE is the European association of oil companies committed to addressing issues related to the refining of crude oil and the distribution of petroleum products. For soy based biodiesel, this modeling was based on soybeans grown in Brazil, overseas transport of the soybeans to Europe, and conversion of the soybeans into biodiesel in European processing plants. The European Commission took the basis of these results and established both "typical" and "default" values for various steps within the set life cycle boundary conditions. The modeling resulted in a 31% GHG emission reduction for soy based biodiesel when using the *default* value results (see Table 2), thus failing to satisfy the 35% GHG emission reduction minimum.

In 2008, the United Soybean Board (USB) commissioned a project to update the LCIs of all phases of the soybean through the feedstock chain.[3] The work done for this analysis includes recreating the GHG emission reduction numbers by applying the USB study life cycle inventory (LCI) data on US soybean cultivation and production, crude soybean oil production, and transesterification into biodiesel. This study uses the same methodology and modeling that the European Commission used to arrive at its reduction numbers.

A key highlight of the USB project was the gathering of actual operating data for soybean crushing and conversion of the crude oil into biodiesel. To our knowledge, prior publicly

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[1] DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (hereinafter referred to as the RES Directive). Found at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF.

[2] CONCAWE, European Council for Automotive R&D (EUCAR), European Commission Directorate General, Joint Research Centre (JRC): Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context; Well-to-Wheels Report, Version 2b, May 2006 and Version 3, October 2008; http://les.jrc.ec.europa.eu/WTW

[3] This project, completed in November 2009, underwent a rigorous ISO 14040/44 peer review process by an international review team led by Dr. Martin Patel of Utrecht University in the Netherlands. The project work was conducted by Omni Tech International, Ltd. and Four Elements Consulting, LLC and is referred to in this report as the "USB study".

available data for the crushing and transesterification steps were modeled based on theoretical process data. The new data shows energy usage for crushing and transesterification was reduced by 45% and 35%, respectively, from the publicly available data sets.[4,5] These reductions were not unexpected, as we believe that the increase in energy costs over the past several years provided much incentive for producers to audit and implement energy reduction practices.

With regards to "default" vs. "typical" values, the European Commission based the final GHG reduction numbers on the "default" value of the biofuel, not the "typical" value. It is our understanding (simply based on access we had to the background RES Directive Excel files) that the only difference between default and typical was a 40% increase in the processing step in the default values.[6] Thus, with this new USB primary data now available, we argue that adding 40% to the "typical" value is unnecessary. The European Commission is welcome to examine this data and potentially use it to update its process data. Because even though the processing data comes from US plants, we would assume that European processing plants would have implemented similar energy reduction programs at their facilities for the same economic reasons. Nonetheless, in our analysis we keep the typical and default values intact, including keeping the 40% increase for the default value.

We performed several analyses using the European Commission methodology as a basis:

- **Analysis 1**: Substitution of US soybean agriculture data for Brazilian data, and transport of US soybeans to Europe for conversion into biodiesel. The GHG reduction factor is calculated using the European emission factor (EF) for petroleum diesel. We chose to use the US soybean cultivation and production data as it is fully updated. Also, we want to show that using shorter transportation distances from the US lowers the overall carbon footprint, Note that we did not examine the Brazilian data – we accepted the GHG pathway numbers as face value.
- **Analysis 2**: Substitution of Brazilian soybean agriculture data with US data and European processing data with US data and transport of the finished biodiesel to Europe. The GHG reduction factor is calculated using the European EF for petroleum diesel.
- **Analysis 3**: Sensitivity analysis using US EF for petroleum diesel instead of the European EF for Analysis 1 and 2 above.

The results of these analyses show that the GHG emission reductions of each of these scenarios do exceed the 35% minimum requirement, even when using the default values, and

[4] For more information on the reduced energy usage for crushing, please see the USB study. Reduced energy usage for biodiesel is based on a comparison between the 2008 data from National Biodiesel Board (see the USB study) and USDA - ARS data: Haas, M.J., A.J. McAloon, W.C. Yee, et al., 2006, "A Process Model to Estimate Biodiesel Production Costs," Bioresource Technology, 97: 671–678.
[5] The mass balances for these respective processes can be found in the USB study which accompanies this report.
[6] Source: JRC background material for RES directive development. 2008."Updated figures communicated - Update on Data on pathways for RES Directive.xls", Tab entitled: Updated figures communicated.

can range to almost 60% depending on the option selected. A description along with assumptions used in each scenario is provided later in the report.

II. Review of European Commission Modeling and Methodology

We first examined the main methodology that was used to arrive at calculating the total GHG savings as compared to petroleum diesel. To be consistent with the modeling approach used by the European Commission, we did the following:

1. Followed the formula for what was included in the RES Directive biofuel pathway;
2. Used the same energy contents for petroleum diesel and soy-based biodiesel;
3. Used the same allocation basis (i.e., energy); and
4. Utilized the European GHG EF for petroleum diesel to obtain the default and typical GHG savings results.

Each of these is explained in more detail below.

1. Formula for the biofuel pathway

The following formula provides the emission sources used in the JRC model and RES Directive.[7] Each part is defined and discussed in terms of the USB model's variance from the European model:

$$E = e(ec)+e(l)+ e(p)+e(td)+e(u)-e(sca)-e(ccs)-e(ccr)-e(ee)$$

Formula part	Definition (from Annex V)	USB Model
E	Total emissions from the use of the fuel	Same
e(ec)	Emissions from the extraction or cultivation of raw materials	Same
e(l)	Annualised emissions from carbon stock changes caused by land-use change	GHG emissions from land use change not included since USDA reports that soy acreage may increase and decrease annually but very little new land is cleared for row crops.[8] Furthermore, PAS 2050, a well-accepted carbon footprinting standard states that, "where it can be demonstrated that the land use change occurred more than 20 years prior to the assessment being carried out in accordance with this PAS, no emissions from land use change should be included in the assessment as all emissions resulting from the land use change would be assumed to have occurred prior to the application of the PAS."[9]

[7] RES Directive, Annex V Part C.
[8] Major Uses of Land in the United States, 1997. M. Vesterby and K. Krupa, Resource Economics Division, Economic Research Service, USDA, Statistical Bulletin No. 973.
[9] PAS 2050:2008, British Standards Institute, Specification for the assessment of life cycle GHG emissions of goods and services, Section 5.5.

e(p)	Emissions from processing	Same
e(td)	Emissions from transport and distribution	Same
e(u)	Emissions from fuel use	Same
e(sca)	Emission savings from soil carbon accumulation via improved agricultural management	We did not take this factor into account thus there is less C uptake in our model
e(ccs)	Emission saving from carbon capture and geological storage	Did not include because not applicable
e(ccr)	Emission saving from carbon capture and replacement	Did not include because not applicable
e(ee)	Emission saving from excess electricity from cogeneration	We did not include this potential saving even though a few US crushing plants do employ cogeneration. We assumed that the cogeneration was not enough to warrant including the model.

It should also be noted that we used the same GHG CO2-e factors when calculating the updated pathways: CO_2 = 1, N_2O = 296, CH_4 = 23.

2. Use of same energy content for petroleum diesel and soy-based biodiesel.

The European Commission analysis normalized the per kilogram fuel carbon dioxide equivalent (CO2e) emissions on a per MJ of energy of the final fuel, as follows:

EU Fossil fuel energy content – 42.8 MJ/kg

EU Biodiesel fuel energy content - 37.2 MJ/kg

We used the same to be consistent. Note: we considered running the analysis using energy contents based on US figures[10] but determined that there was not enough of a difference to warrant sensitivity analysis:

US Fossil fuel energy content – 43.5 MJ/kg

US Biodiesel fuel energy content – 37.5 MJ/kg

[10] 1998 NREL Biodiesel study, NREL/SR-580-24089, www.nrel.gov/docs/legosti/fy98/24089.pdf

3. Use of same energy allocation for soybean processing.

In determining the biofuel pathway, energy allocation was used wherever applicable, consistent with the European Commission approach.[11] It should be noted that while the USB study did not use energy allocation (it used mass allocation and economic allocation), for this analysis, the model was re-run using energy allocation.[12] The following table presents the energy allocation percentages used to run the results:

Table 1 Energy Allocation Percentages used by the European Commission

	Soybean Crushing (Processing)
Crude soybean oil	**36%**
Soy meal	64%
	Biodiesel Production
Biodiesel	**94%**
Glycerin	6%

4. Utilization of the European GHG EF (EF) for petroleum diesel to obtain the default and typical results for calculating GHG savings.

The EU petroleum diesel EF of 83.8 g CO2e per MJ of diesel is used to obtain the final GHG reduction percentages for soybean biodiesel.[13] Because this resulting percentage is the determining factor as to whether or not the biofuel can meet the minimum requirements set by the Directive, it is probably one of the most critical pieces of data in this study. We used the 83.8 g CO2/MJ for the calculations in our analyses yet performed a sensitivity analysis using the EF calculated with data from the USB study.

[11] RES Directive, Annex V, Section C, no. 17.

[12] Note: because a different allocation basis was used, results in the USB study are different than what was arrived at here. Also, we acknowledge that JRC used system expansion to arrive at its biofuel pathway results; we did not do this modeling as it was outside the scope of this work.

[13] RES Directive, Annex V, Section C, no. 19.

III. Analyses

The table below presents the biofuel pathway and resulting GHG savings as they occur in RES Directive documentation.[14,15] We present the results to our analysis in the same format.

Table 2 EU Biofuel Pathway and Results for Typical and Default Values

Each value in biofuel pathway (g CO2e per kg soybean biodiesel) was divided by biodiesel's energy density of 37.2 MJ/kg to arrive at these numbers

EU Pathway (from RES)

Biofuel production pathway	Cultivation	Processing	Transport & distribution	Total	Updated % GHG savings
TYPICAL GHG emitted (g CO2eq/MJ)	19	18	13	**50**	**40%**
DEFAULT GHG emitted (g CO2eq/MJ)	19	26	13	**58**	**31%**

Default values: all the same except processing, where 40% was added (for all the biofuels, not just soy biodiesel)

Updated GHG savings calculated by taking the percentage of the biofuel pathway total divided by the EU petro diesel EF of 83.8 MJ/kg. E.g.: [1-(50/83.8)]

Analysis 1: Substitution of US soybean agriculture data and transport of soybeans to Europe for conversion into biodiesel

For our first analysis, we substituted the European Commission soybean cultivation numbers with the USB study soybean cultivation data and substituted transport of the soybeans to Europe from Brazil with transport from the US. For detailed information on soybean cultivation, refer to the USB study's modeling and assumptions section(s). The assumptions made for transport of soybeans from the US to Europe are provided in the table below. The data used for Brazilian transport are summarized as well for reference. According to individuals in the U.S. soybean market, soybeans transported to Europe from the US are primarily from the Gulf Coast so leave from southeast ports like Savannah, GA or Jacksonville, FL. Thus, most of the beans for that export market are grown from Missouri southward and from the southeastern states. Arkansas was chosen since it is a soybean producing state in the middle of the more southern soy-producing states.

[14] From Excel file: "Updated figures communicated - Update on Data on pathways for RES Directive.xls", Tab entitled: Updated figures communicated, Row 15.

[15] The 40% and 31% also are listed in the RES Directive, Annex V, Part A.

Table 3 Transport to Europe Assumptions

Summary of US Transport assumptions (US soybeans to EU)
Field to elevator: 80 km truck Arkansas to port at Jacksonville, FL: 1280 km rail Ocean freighter port at Jacksonville to Brest, France port: 3430 nautical miles (6350 km)
Mainland EU transport of Biodiesel
Biodiesel: 150 km to depot, 150 km from the depot to the refuelling station
Summary of EU Transport assumptions (Brazilian soybeans to EU)
Road transport, 700 km truck Ocean freighter: 5500 nautical miles (10186 km) to a port in the EU
Mainland EU transport of Biodiesel
Biodiesel: 150 km to depot, 150 km from the depot to the refuelling station

A summary of results of this first analysis is found in the table below:

Table 4 Results for Analysis 1

US Pathway (US SOYBEAN prod, transport)

Biofuel production pathway	Cultivation	Processing	Transport & distribution	Total	% GHG savings
TYPICAL GHG emitted (g CO2eq/MJ)	16	18	8.9	**43**	**48%**
DEFAULT GHG emitted (g CO2eq/MJ)	16	26	8.9	**51**	**39%**

Note: carbon sequestration is not counted here, consistent with the Brazilian cultivation model.

Using the data from the USB report provides a GWP of 606 grams CO2e/kg from cultivating and harvesting soybeans and applying the biodiesel energy content of 37.2 MJ/kg yields a value of 16.3 gCO2e/MJ for the cultivation phase, a reduction of approximately 3 g CO2e/MJ compared to Brazilian soybean production. The GHG emission values of 18 and 26 g CO2e/MJ, respectively, for processing the soybeans in Europe are the same as the EU scenario since we left these intact.

The transportation variables for shipping soybeans from the US to Europe vs. shipping soybeans from Brazil to the Europe consist of different distances for land and marine transport. We accepted the modes and distances of soybean transport from Brazil to Europe as presented and only modeled transport from the US. Overall, the total transport distance from Arkansas to Europe is shorter than the distance assumed for Brazilian bean transport by over 3,000 km. The transportation provides a GWP of approximately 330 grams CO2e/kg, and applying the biodiesel energy content yields a value of 8.9 g CO2e/MJ for US to Europe vs. approximately 13 g CO2e/MJ for Brazil to Europe. Overall, substituting soybean cultivation and transport from the US results in reductions of 48% and 39%, respectively, for typical and default values.

Analysis 2: Substitution of US agriculture, processing and transport modeling of biodiesel to Europe

In this scenario, we used the same methodology to recreate the European Commission total GHG reduction percentages, also using US soybean processing and biodiesel production, with transport of biodiesel to the EU. We acknowledge that this analysis strays from the original scope in which the imported soybeans are processed in Europe, but we provide this analysis to show the reduced GHGs that can result when good quality, primary data on soybean crushing (crude soy oil extraction) and biodiesel production are used. As mentioned before, we used actual operating data for both soybean crushing and biodiesel production plants. To our knowledge, this is the first time such data has been collected in primary form. Past publicly available data were based on theoretical models; the respective trade organizations which collected this data from their member companies stated that the energy and materials usage data is based on actual measurements rather than assumptions so we believe the data to be of high quality. Please see the USB Study for details on these data sets. As shown in the table below, using the US processing data and applying the European Commission energy allocation values, we obtained final GHG emission values of 16 and 22 g CO2e/MJ for the processing steps, reductions of 2 and 4 g CO2e/MJ, respectively, from the RES figures.

Table 5 Results for Analysis 2

US Pathway (US BIODIESEL prod, transport)

Biofuel production pathway	Cultivation	Processing	Transport & distribution	Total	% GHG savings
TYPICAL GHG emitted (g CO2eq/MJ)	16	16	4.7	**37**	**56%**
DEFAULT GHG emitted (g CO2eq/MJ)	16	22	4.7	**43**	**49%**

Soybean cultivation and transportation routes were modeled the same as in Analysis 1, with the exception of the quantity transported: in Analysis 1, almost 2 kg soybeans were transported to produce the one kg of biodiesel in the EU, while for this analysis, one kg of finished biodiesel is transported to Europe. This explains the approximately 50% reduction in transportation for Analyses 2 from Analysis 1.

Analysis 3: Sensitivity analysis using the US EF for petroleum diesel in Analysis 1 and 2

This discussion presents a sensitivity analysis using the US petroleum diesel EF per MJ of fuel instead of the EU EF. The EU petroleum diesel EF of 83.8 g CO2e per kg was obtained by dividing diesel's total life cycle CO2e (approximately 3587 g CO2e, which was a European calculated value) by diesel's energy content (42.8 MJ/kg). The diesel EF that we calculated was 3845 g CO2e. This was obtained by adding a diesel combustion EF to our cradle to gate of diesel production, as follows:

Table 6 Diesel EF Calculation

	Diesel EF (g CO2e / kg)	Source
Diesel production	663	USB study
Diesel combustion EF	3182	GHG Protocol, Efs for the Revised Mobile Tool (April 03).xls[16]
Total →	**3845**	
EF per MJ diesel fuel →	**89.8 g CO2e / MJ diesel**	**Calculated using 42.8 MJ/kg**

The USB study provides the detailed calculations for petroleum diesel production. Since the US EF is higher than the EU factor, using the former improves the overall GHG emission reductions for soy biodiesel. The following table presents the biofuel pathway reduction percentages with the US diesel EF applied.

Table 7 Results for Analysis 3

US Pathway (US SOYBEAN prod, transport)					Analysis 1	Analysis 3
					EU Diesel EF	US Diesel EF
Biofuel production pathway	Cultivation	Processing	Transport & distribution	**Total**	**% GHG savings**	**% GHG savings**
TYPICAL GHG emitted (g CO2eq/MJ)	16	18	8.9	**43**	**48%** →	**52%**
DEFAULT GHG emitted (g CO2eq/MJ)	16	26	8.9	**51**	**39%** →	**44%**
US Pathway (US BIODIESEL prod, transport)					**Analysis 2**	**Analysis 3**
					EU Diesel EF	**US Diesel EF**
Biofuel production pathway	Cultivation	Processing	Transport & distribution	**Total**	**% GHG savings**	**% GHG savings**
TYPICAL GHG emitted (g CO2eq/MJ)	16	16	4.7	**37**	**56%** →	**59%**
DEFAULT GHG emitted (g CO2eq/MJ)	16	22	4.7	**43**	**49%** →	**52%**

For this analysis, we are not insisting that you utilize the US emission factor but request that you recognize that this is quite a sensitive parameter.

[16] Found at: http://www.ghgprotocol.org/

IV. Summary and recommendations

The results are summarized in the table below in terms of GHG reduction percentages.

Table 8 Summarized Results

	EU Results	**Analysis 1**: US soybeans, EU EF & Alloc	**Analysis 2**: US biodiesel, EU EF & Alloc	**Analysis 3**: US soybeans, US EF, EU Alloc	**Analysis 3**: US biodiesel, US EF, EU Alloc
TYPICAL GHG Reduction %s	40%	48%	56%	52%	59%
DEFAULT GHG Reduction %s	31%	39%	49%	44%	52%

Our analysis examined the methodology used by the European Commission in calculating biofuels' GHG emissions and their relative percentages compared to petroleum diesel. We found that substituting recently developed soybean production and processing data and transporting it from the US instead of South America resulted in different and higher GHG emission reduction values. These GHG emission reductions ranged from 39% to 59% depending on the scenario tested.

In developing this analysis, we used many of the same assumptions as the European Commission study to allow for a consistent comparison. These assumptions included fuel EFs, fuel density values, and energy allocation. We were also consistent with the transportation modeling.

The substitution of actual operating data for soybean processing in place of default GHG emission data for processing has the greatest impact on the final GHG emission reduction results, as shown in Table 5. This is not to say that we are encouraging the production and export of biodiesel in the US. Rather, it is our opinion that this primary data now eliminates the need to use default data with the 40% multiplication factor. It also bolsters the argument to utilize more biodiesel since it does meet the targets for minimum emissions for soy biodiesel. We do believe, though, that import of US soybeans in lieu of Brazilian soybeans does reduce the overall carbon footprint due to shorter transportation distances and based on our updated soybean cultivation data.

We welcome your review and examination of the new USB data and to consider its use for updating EU process data (i.e., even to customize the upstream data sets to European energy production and combustion). If more elaboration of our analysis and/or methodology is desired, we would be pleased to further discuss our findings and answer any questions.