Information Sheets

FOR PLANT SUPPLY CHAINS

Table of contents

7 *Summary Information Sheets for Plant Supply Chains*

7.1 *Guide to reading an information sheet*

Characteristics of the supply chain

- The plant resource supply chains are listed in order of their significance in France.
- Only biomass sources covered by the LCAs inventoried are listed.

Link between the plant supply chain and the fossil source(s) replaced

Product or application in the supply chain

PLANT SUPPLY CHAIN (FOSSIL CHAIN REPLACED)	PRODUCT	BIOMASS	PRIMARY USE
A	Structural components		
B	Particleboard		

Biomass or molecule used to produce the product in question

Most common use of the product in question

Table 6
Description of the supply chain

Environmental impacts: plant vs. fossil

PRODUCTS **IMPACT CATEGORY**	**Solid structural components**		**Glue-laminated structural components**		**Natural fibres and petrochemical polymers**	**Natural fibres and biopolymers**
Primary use	*Building structure*				*Parts used in the transportation industry (Pallets, cars)*	
Reference supply chain	**Concrete**	**Steel**	**Concrete**	**Steel**	**Fibreglass**	**Fibreglass**
Consumption of non-renewable energy	++	++	n.d.	+	+++	
Fossil greenhouse effect	++	+	n.d.	+	+	++

The various columns provide an indication of the range of the overall performance of the supply chain (impacts of the plant resource supply chain minus the impacts generated by the fossil supply chain).

Table 7
Environmental impact of the supply chain

The environmental balance sheet is assessed by functional unit, except in the case of surfactants because of the lack of available data.

A "benefit/cost" ratio is calculated relative to the corresponding reference fossil supply chain and synchronized among the various plant resource supply chains:

++	*very favourable*: impact avoided >> impact generated (difference of at least 50%)
+	*favourable*: impact avoided > impact generated (difference of 20 to 50%)
0	*no difference*: impact avoided essentially equal to impact generated (maximum difference of 20%)
-	*unfavourable*: impact avoided < impact generated (difference of 20 to 50%)
--	*very unfavourable*: impact avoided << impact generated (difference of at least 50%)
+/-	*result dependant on key parameters*: the sign (positive or negative) of the overall impact varies strongly with the parameters identified (e.g., choice of technology, etc.)
?	*no reliable data available*: the benefit or cost cannot be assessed because of the lack reliable knowledge in the area
n.d.	*(not defined) no data available*

Influencing parameters and areas for improvement

This section summarizes, in table form, the state of knowledge about the influence (strong, weak, indeterminate) of key parameters of the supply chain.

Whether a parameter exerts a strong influence or not on environmental performance is very difficult to ascertain and must be based on the definition of a relevant benchmark. The following rule was applied:

- ♦ A parameter is regarded as exerting a strong influence when the difference between the impact generated and the impact avoided is at least 20%.
- ♦ A parameter is regarded as having a weak influence when the difference between the impact generated and the impact avoided is at most 20%.
- ♦ The influence of a parameter is considered indeterminate when no data whatsoever is available or the data available is not reliable.

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT

Strong, weak or indeterminate influence

Impact categories most sensitive to a variation in the parameter

Table 8
Parameters exerting an influence on environmental balance sheet

Quality of studies selected

Six indicators of the state of current LCA knowledge, evaluated on a five-level scale (from very weak to very strong) generated a semi-quantitative assessment of LCA data available for a given supply chain.

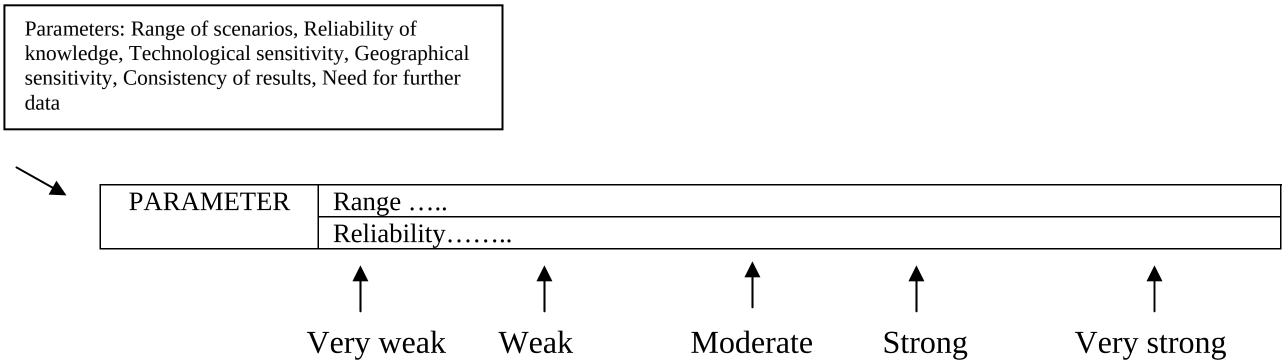

Table 9
Analysis of the bibliography

Range of scenarios studied:

The more varied the scenarios studied in an LCA, the higher the score. The following points were noted in particular:

- range of studies encountered,
- distribution of studies among sub-supply chains,
- significant state-of-the-art reviews.

Reliability of knowledge:

The more solid, complete and consistent the LCA knowledge, the higher the score assigned (based on the consistency of results from separate studies).

The quality of the sensitivity analyses, included in all the studies, is also a factor in the score.

Technological sensitivity:

Influence of the type of technology selected in the supply chain.

Geographical sensitivity:

Sensitivity of a supply chain to specific geographical conditions.

Consistency of results:

This indicator conveys whether the results of all the studies are consistent. Where a lack of consistency was noted, an effort was made to provide an explanation.

Need for further LCA data

The score indicates whether there is a need to expand the current knowledge base. Requirements for additional data were identified based on a critical analysis of a number of bibliographic references. In some cases, data are missing, in others, they are highly uncertain, for example, in the case of:

- inventory data,
- impact assessment data.

Quantified assessment of certain indicators

Where consistent results are available in the “consumption of non-renewable primary energy” and “greenhouse effect” impact categories, average values, or ranges in values for gains achieved are presented.

Discussion

A comprehensive discussion of a supply chain may highlight links between supply chains or areas for improvement. The following points may be addressed:

- state of LCA knowledge of the supply chain,
- key components of the supply chain and areas for improvement, and
- opportunities involving and links with other plant resource supply chains.

Bibliographic index

Based on the previously defined standards of quality (cf. Chapter 6), a summary was prepared of the references for the main studies analyzed. Table 10 summarizes the various studies that were selected and covered in the information sheets.

TITLE	DATE	MANDATED BY	CONDUCTED BY	REFEREED

Table 10
Bibliography of studies analyzed in the information sheets covering LCA studies

7.2 *Information sheets*

The 10 plant resource supply chains analyzed are detailed in the following information sheets. They are presented in order of the quantity of data available for each:

- agrimaterials
- ether alcohols (transportation biofuels)
- oil esters (transportation biofuels)
- forest biomass [bioenergy; heat & electricity]
- agricultural biomass [bioenergy; heat & electricity]
- biopolymers
- surfactants
- lubricants and hydraulic fluids
- solvents
- chemical and other intermediates

Agrimaterials

Agrimaterials comprise biomaterials that are blends of natural fibres and polymers; they include solid wood products used as structural building components (dwellings, industrial buildings, etc.). The production of furniture and other non-structural elements (windows, doors, flooring, etc.) is not included in this study.

1 *Characteristics of the supply chain*

PLANT SUPPLY CHAIN (FOSSIL CHAIN REPLACED)	**PRODUCT**	**BIOMASS (MOLECULE)**	**PRIMARY USE**
A	Solid structural components	Wood (fir, etc.)	Building components (beams, rafters, villas, houses, buildings, commercial and industrial buildings)
B	Glue-laminated structural components	Wood (spruce, Douglas fir)	Building components (beams, commercial and industrial buildings)
C	Particleboard	Wood industry co-products	Building components (commercial and industrial buildings, etc.)
D	Linoleum	. Jute (fibre) . Wood and/or cork (particleboard) . Flax (oil)	Floor coverings
E	Parts that are blends of natural fibres and petrochemical polymers	. Chinese reed (fibre) . Hemp (fibre) . Flax (fibre) . Sisal (fibre)	. Shipping pallets . Car parts
F	Parts that are blends of natural fibres and petrochemical polymers	. Chinese reed (fibre) . Cellulose (diacetate)	. Shipping pallets . Car parts
G	. Thermal insulating textiles . Plastic reinforced with hemp fibre	. Hemp . Grass (hay)	. Textiles . Insulation . Miscellaneous
REFERENCE FOSSIL FUEL SUPPLY CHAINS			
A/B	Steel structural components	-	Building components
A/B	Concrete structural components	-	Building components
E/F	Parts that are blends of fibreglass and petrochemical polymers	-	. Shipping pallets . Car parts
E/F	Parts made of petrochemical polymers	-	Car parts
E/F	Magnesium parts	-	Car parts

2 Environmental impacts – Plant vs. fossil

PRODUCTS IMPACT CATEGORY	**Solid structural components**		**Glue-laminated structural components**		**Natural fibres and petrochemical polymers**[4]	**Natural fibres and biopolymers**[1]
Primary use	*Building structure*				*Parts used in the transportation industry (pallets, cars)*	
Reference supply chain	**Concrete**	**Steel**	**Concrete**	**Steel**	**Fibreglass**	**Fibreglass**
Consumption of non-renewable energy	++	++	n.d.	+	+++	
Greenhouse effect	++	+	n.d.	+	+[1]	++[2]
Eutrophication	0	0	n.d.	0	-	- -
Acidification	?	?	n.d.	?	+	+
Destruction of the ozone layer	n.d.	n.d.	n.d.	n.d.	0[3]	n.d.
Photochemical pollution	?	?	n.d.	?	+	+
Terrestrial toxicity	?	?	n.d.	?	0[3]	0
Aquatic toxicity	++	++	n.d.	++	+[3]	+
Human health	n.d.	n.d.	n.d.	n.d.	+[3]	+

(1) *For this sub-supply chain, only one study is available on shipping pallets (Mayet, 2000) and one on a car part (Margand et al., 2003); both studies utilize the same base data.*

(2) *In terms of the greenhouse effect, the performance of the reference sectors (Rebitzer et al., 2003), which is highly dependent on end-of-life recovery, is superior. In the study in question, the various pallet components and the fibreglass car part are recycled, whereas the plant sector components are incinerated.*

(3) *Very few quantitative values are available (one or two studies).*

(4) *If the matrix of the component is also a product of the plant supply chain, the performance improves as a function of the environmental performance of the biopolymer used.*

Replacement of conventional products with products containing natural fibres can be very advantageous in terms of non-renewable primary energy and the greenhouse effect.

In the case of transportation-related applications, plant-source products (pallets, car parts, etc.) can be much lighter than their conventional fossil counterparts, which can result in an energy gain of up to several hundred gigajoules (GJ) of primary non-renewable energy per hectare of fibre crop. If the use phase is included, the gain can even exceed 1,000 GJ per hectare of crop.

In the case of these applications, indirect gain is achieved in two ways:

- the quantity of fibre used for a given function is smaller than in the case of conventional fibres because the physical characteristics of natural fibres are often superior;
- the lower weight promotes energy savings (e.g. fuel) during the use phase.

By comparison with fossil fuel supply chains, the performance of composite materials (natural fibres and biopolymers) and raw timber (used as building components) is the most favourable of all the sub-supply chains studied in terms of consumption of non-renewable primary energy and the greenhouse effect.

3 *Influencing parameters and areas for improvement*

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT
STRONG	Useful life	All	All	Extend the useful life of biomaterials produced
	Type of use (thermal insulation or structures in the construction sector)	All	All wood and fibre components intended for use in construction	Emphasize applications in which the intrinsic performance of plant-based products is superior to that of fossil counterparts (better insulating power, etc.)
	Type of end-of-life recovery: either incineration or landfilling, or recycling	. Resource use . Greenhouse effect . All	. Car parts . Solid or glue-laminated structural components	Ensure that end-of-life recovery is appropriate and effective
	Type of use (weight of products in transportation-related applications)	. Resource use . Greenhouse effect . Human health	. Car parts . Shipping pallets	Emphasize applications in which the intrinsic performance of plant-based products is superior to that of fossil counterparts (weight, etc.)
	Choice of functional unit (quantity used per functional unit, as compared with conventional products)	All	Building components, particleboard	-
	Type of use (single-family dwelling, building, shed, etc.) and type of structure (horizontal, vertical)	All	Solid and glue-laminated structural components	Emphasize applications in which the intrinsic performance of plant-based products is superior to that of fossil counterparts (load-bearing capacity, etc.)
	Type of use (proportion of fibres in the final product)	. Resource use . Greenhouse effect . Toxicity to humans	. Car parts . Shipping pallets	Emphasize applications in which the intrinsic performance of plant-based products is superior to that of fossil counterparts (strength, etc.)
	Transportation (raw material)	. Resource use . Greenhouse effect	Solid or glue-laminated structural components	Limit transportation of raw material
	Production-phase technology: wood drying, use of related products (resins, etc.)	. Energy . Greenhouse effect	. Structural components . Particleboard	Improve the production phase (drying)
	Production-phase technology (cultivation and processing of fibres)	. Resource use . Eutrophication . Acidification . Aquatic toxicity	. Car parts . Shipping pallets	Improve fibre production and processing
	Use-phase technology (soil maintenance)	All	Linoleum	Include soil maintenance in the assessment of environmental impacts
INDETERMINATE	Production-phase technology (nature of pigments)	-	Linoleum pigments	Study the other linoleum components
	Raw material used (tree species)	-	Solid or glue-laminated structural components	Study the effect of the tree species used

Range of scenarios				**X**	
Reliability of studies		**X**			
Technological sensitivity				**X**	
Geographical sensitivity			**X**		
Consistency of results		**X**			
Need for further data				**X**	
	↑ Very weak	↑ Weak	↑ Moderate	↑ Strong	↑ Very Strong

A certain similarity is seen between transportation-related applications (fibres) and applications related to the construction of single and multiple-family dwellings (wood sub-supply chains). Several significant reviews were identified for this supply chain. The sub-supply chains related to wood material are well studied. Less work has been done on the sub-supply chains associated with fibre-based agrimaterials.

Reliability is acceptable where wood sub-supply chains are concerned, but fairly poor in the case of fibre sub-supply chains (developing technologies).

Technological sensitivity is fairly strong in the case of fibres, and moderate in the case of wood. Geographical sensitivity is moderate where fibres are concerned (agricultural phase) and moderately strong in the case of wood (method of production, climate, etc.).

In the case of fibres, no overall consistency of results is seen in the studies (fairly diverse applications). Conversely, consistency is fairly satisfactory in the case of wood.

Missing or highly uncertain data:

- agricultural-phase emissions: fibre crop cultivation, silviculture based on local tree species,
- production and processing of fibres: composite products, plant matrices, auxiliary products (surface coatings, pigments, etc.),
- emissions related to the end of life of materials: landfilling, incineration (various technologies), recycling,
- assessment of the environmental impact in terms of eutrophication, acidification, destruction of the ozone layer, photochemical pollution, ecotoxicity and human health.

5 Quantified assessment of certain indicators

In the case of lumber (raw timber, laminates, panels, etc.), environmental gain cannot be quantified because the units used to assess the environmental impact of the reference fossil fuels do not permit comparison.

The various studies on fibres reveal strong variations in environmental gain in the agrimaterials sector, depending on the type of application and the key parameters identified (cf. Chapter 3). In terms of the consumption of primary, non-renewable energy, the gain can be as high as several hundreds of GJ/ha, and in the case of the greenhouse effect, it can be several tens of tonnes CO_2 eq.

In the other impact categories, either few quantitative values are presented in the studies, or results are contradictory and therefore not presented in a quantified manner.

6 Discussion

The supply chain is fairly well understood in terms of LCA of wood sub-supply chains. Fibre sub-supply chains are not as extensively studied.

Useful life and end-of-life recovery are important parameters for all applications in the agrimaterials sector.

The use phase is important in wood-related applications (home heating and insulation, wood, etc.) and fibre (fuel consumption based on weight).

Although interesting results are seen in the agrimaterials supply chain, great potential exists for improvement. This is particularly true in the case of fibre because the technology has not yet been optimized.

The agrimaterials sector is the only plant resource supply chain studied that allows for indirect gain (an advantage in terms of vehicle weight provides a fuel advantage in the use phase). This gain is partly responsible for the sector’s environmental performance.

Agrimaterials must be developed in a manner that takes into consideration the development of their fossil counterparts. In order to avoid recycling problems, the two should not be mixed.

7 Bibliographic index

168 references inventoried, 99 studies identified, 12 studies selected

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
REBITZER G., SCHMIDT W.-P., *Design for Environment in the Automotive Sector with the Materials Selection Tool euroMat, Gate to EHS*	March 2003	Life Cycle Management - Design for Environment, vol. 17, pp. 1-4.	. Bundesministerium für Bildung und Forschung, Germany . Ford Motor Company, Germany	. Technische Universität Berlin, Germany . Ford Motor Company, Germany	No
BETZ M., COEN D., DEIMING S., KREISSIG J., *Thermische Verwertung von Holzprodukten Inputabhängige Modellierung der End-of-Life Prozesse von Holz* (heat recovery from wood-based products and their end-of-life modelling)	Sept. 2002	Deutsche Gesellschaft für Holzforschung, PE Europe GmbH.	. Deutsche Gesellschaft für Holzforschung (DGfH) . Holzabsatzfonds, Germany	PE Europe GmBH, Germany	No
BUCKET E., *Analyse de cycle de vie d'une poutre générique en bois lamellé collé* (life-cycle analysis of a standard glue-laminated beam)	June 2002	CTBA, 71 p.	Agence De l'Environnement et de la Maîtrise de l'Energie (ADEME) (environmental and energy management agency), France	Centre Technique du Bois et le l'Ameublement (CTBA), France	Yes
HASCH J., *Ökologische Betrachtungen von Holzspan und Holzfasenplatten* (ecological assessment of particleboard)	2002	Dissertation, Hamburg University	. Universität Hamburg . Bundeswirtschafts - ministerium, Germany	Universität Hamburg, Germany	Yes
POHLMANN C.M., *Ökologische Betrachtung für den Hausbau - Ganzheitliche Energieund Kohlendioxidbilanzen für zwei verschiedene Holzhauskonstruktionen* (ecological study of habitat – energy and CO_2 balance sheets for various wood building systems)	2002	Dissertation zur Erlangung des Doktorgrades an der Uni. Hamburg, Fachbereich Biologie, 274 p. (www.sub.uni-hamburg.de/disse/712/dissertation.pdf)	Universität Hamburg, Fachbereich Biologie, Germany	Universität Hamburg, Fachbereich Biologie, Germany	Yes

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
SCHARAI-RAD M., WELLING J., *Environmental and Energy Balances of Wood Products and Substitutes*	2002	Hamburg University, Federal Research Centre for Forestry and Forest Products (www.fao.org/DOCREP/ 004/Y3609E/ y3609e00.htm)	Food and Agriculture Organization of the United Nations (FAO), Italy	Hamburg University, Federal Research Centre for Forestry and Forest Products, Germany	No
GLOVER J., *Which is better? Steel, concrete or wood: a comparison of assessments on three building materials in the housing sector*	2001	Four year thesis, University of Sydney	University of Sydney, Australia	University of Sydney, Australia	No
BINZ M., ERB M., LEHMANN G., *Ökologische Nachhaltigkeit im Wohnungsbau, Eine Bewertung von Erneuerungsstrategien* (ecological monitoring of building construction, an assessment of renewal strategies)	April 200	Fachhochschule beider Basel, Institut für Energie, Muttenz, Bundesamt für Energie IKEAStiftung Migros- Genossenschafts - Bund Kantone Basel-Stadt und Basel-Landschaft	. Bundesamt für Energie . IKEA-Stiftung . Migros - Genossenschafts-Bund . Kantone Basel-Stadt und Basel-Landschaft, Switzerland	. Fachhochschule beider Basel, Institut für Energie . Zentrum für Energieund Nachhaltigkeit im Bauwesen (EMPA), Switzerland	Yes
GORREE M., GUINEE J.B., HUPPES G., VAN OERS L., *Environmental Life Cycle Assessment of Linoleum - final report*	2000	Leiden: Centre of Environmental Science, Leiden University, 56 p. (www.leidenuniv.nl/ interfac/cml/ssp/ publications/ lcalinoleum.pdf)	Forbo-Krommenie B. V., Netherlands	Forbo-Krommenie B. V., Netherlands	Yes
PAYET J., *Analyse de Cycle de Vie de biomatériaux d'emballage et méthode d'évaluation de l'impact sur les ecosystems* (life-cycle analysis of biological packing material and method of ecosystem impact assessment)	2000	Swiss Federal Institute of Technology Lausanne, ADEME 70 p.	Agence De l'Environnement et de la Maîtrise de l'Energie (ADEME), France	Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland	No
DIENER J., SIEHLER U., *Ökologischer Vergleich von NMT- und GMT-Bauteilen* (ecological comparison of NMT and GMT components)	1999	Die Angewandte Makromolekulare Chemie, vol. 272, n° 4744, pp. 121-127.	Daimler-Chrysler Corp., Germany	Daimler-Chrysler Corp., Germany	No
WÖTZEL K., WIRTH R., FLAKE M., *Life cycle studies on hemp fibre- reinforced components and ABS for automotive parts*	1999	Die Angewandte Makromolekulare Chemie, vol. 272, n° 4763, pp. 121 - 127.	Audi Corp., Germany	. Technische Universität Braunschweig, Germany . Seeber Systemtechnik, Germany	No

Ether alcohols (transportation biofuels)

Alcohols are transportation biofuels or energy biofuels (fuel cells) used in varying proportions in unleaded gasoline (ethanol, methanol) either as additives (less than 5% of the blend), components (5% or more of the blend), or complete fuels (100%). Their ethers are used in varying proportions in unleaded gasoline (ETBE) and diesel (DME).

1 Characteristics of the supply chain

PLANT SECTOR **(FOSSIL SOURCE REPLACED)**	**PRODUCT**	**BIOMASS** **(MOLECULE)**	**PRIMARY USE**
A	Bioethanol	. Beets, wheat, wood, sugar cane, grass, corn, millet, potato . Sugar cane bagasse, forest co-products, cereal, oilseed and rice straw, whey, waste paper,[1] wine	. Additive . Component . Transportation fuel . Energy fuel
B	Ethyl tertiary butyl ether (ETBE)	. Beets, wheat, wood, grass, corn . Straw, whey, waste paper[1]	. Additive . Component
C	Biomethanol	Wood	. Additive . Component . Transportation fuel . Energy fuel
D	Dimethyl ether (DME)	Wood	. Additive . Component
REFERENCE FOSSIL FUEL SUPPLY CHAINS			
A/B/C	Unleaded fuel	-	Transportation fuel
A[2]/D	Diesel	-	Energy fuel
C	Methanol	-	. Additive . Component . Transportation fuel . Energy fuel
B	Ethyl tertiary butyl ether (ETBE)	-	Additive

(1) Developing sector.
(2) As an additive.

2 *Environmental impacts – Plant vs. fossil*

PRODUCTS **IMPACT CATEGORY**[7]	**Bioethanol**	**ETBE**	**Biomethanol**	**BioDME**
Primary use	*Transportation*			
Reference supply chain	**Gasoline**	**MTBE**	**Methanol**	**DME**
Consumption of non-renewable energy	++[1]	+	++	++
Fossil greenhouse effect	++[1]	+	++	+
Eutrophication	+/-[2]	+/-	-	+/-
Acidification	-	-	-	+/-
Destruction of the ozone layer	?[3]	?[3]	+/-	+/-
Photochemical pollution	+/-	+/-	-	+/-
Terrestrial toxicity	?[5]	?[5]	?[5]	?[3]
Aquatic toxicity	?[5]	?[5]	?[5]	?[3]
Human health	+/-[4]	?[5]	?[5 & 6]	?[3]

(1) *The gain from incorporating ethanol in gasoline is greater than the gain from incorporating ethanol in diesel. Producing ethanol from cellulose appears to have the most favourable environmental performance.*

(2) *With regard to this impact category, production of ethanol becomes unfavourable when intensive cultivation replaces the use of a co-product.*

(3) *Study results differ widely.*

(4) *Environmental performance varies according to several parameters (emissions during the combustion phase, incorporation of ethanol in gasoline or diesel, type of vehicle). It also differs if carcinogenic or respiratory effects on human health are considered.*

(5) *Studies provide very few or no values for these impact categories.*

(6) *A certain amount of information is available on the direct toxicity of methanol, but assessing the toxicity of its life cycle as a fuel is problematic and results are open to debate.*

(7) *Environmental impact results vary depending on whether a functional unit measures distance, energy or weight. Results presented in this information sheet are based on a 5 to 10% inclusion rate for the biofuel and the megajoule of useful energy as a functional unit.*

Ethanol is the most studied sub-supply chain, followed by the ethers and methanol. With regard to cellulose ethanol, incorporation of ethanol in diesel, the use of methanol as a fuel (fuel cell) and the use of DME, results remain weak, for two reasons:

- relatively few studies have been carried out of these sub-supply chains;
- process and technologies associated with these sub-supply chains are in the developmental stages, and significant uncertainties remain.

In a general sense, the environmental performance of sub-supply chains that utilize agricultural co-products is very often more favourable than that of sub-supply chains that utilize dedicated agricultural products.

3 Influencing parameters and areas for improvement

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT
STRONG	Use-phase technology (efficiency, emissions)	All	. Ethanol . ETBE . Methanol . DME	Improve efficiency and combustion phase
	Raw material used (co-product, agricultural crop)	. Resource use . Greenhouse effect . Acidification . Eutrophication	. Ethanol . ETBE	Encourage the use of co-products
	Raw material used (isobutene)	. Resource use . Greenhouse effect	ETBE	Optimize the production of isobutene or find another resource
	Production-phase technology (type of process and energy used in production)	. Resource use . Greenhouse effect	. Ethanol from corn, wheat and beets . Cellulose ethanol . DME . Methanol	. Optimize energy consumption of processes, particularly lignocellulose processes . Use renewable energies
	Allocation of emissions associated with co-products (financial value and effective recovery)	All	Ethanol from grass	Ensure market opportunities for co-products
	Fertilizer use and emissions from the agricultural phase	. Resource use . Greenhouse effect . Acidification	Ethanol and ETBE from beets, wheat and corn	Encourage a rational agricultural phase
	Emissions allocation method (allocation among the co-products of emissions from the crop or product concerned)	. Resource use . Greenhouse effect	. Naphta . Ethanol from corn and grass	-
WEAK	Infrastructure (agricultural production)	. Resource use . Greenhouse effect	Ethanol from wheat and beets	-
	Carbon storage (agricultural phase)	Greenhouse effect	. Ethanol . ETBE	-
INDETERMINATE	Type of agricultural production (extensive, intensive	All	All	Study the effect of type of cultivation (extensive, intensive)
	Type of use (inclusion rate for the biofuel)	All	All	Study the effect of vehicle performance as a function of biofuel inclusion rate

4 *Quality of studies selected*

Range of scenarios		X			
Reliability of studies			X		
Technological sensitivity					X
Geographical sensitivity			X		
Consistency of results				X	
Need for further data				X	
	↑ Very weak	↑ Weak	↑ Moderate	↑ Strong	↑ Very Strong

A certain similarity is noted among the supply chains studied. However, not all the studies cover the combustion phase. Several significant reviews were identified for this supply chain.

Reliability is acceptable where amylaceous and sacchariferous crops are concerned, but fairly poor in the case of lignocellulose crops (developing technologies).

The technological sensitivity makes the comparison of certain studies difficult.

Satisfactory consistency of results is seen once studies are made comparable.

Missing or highly uncertain data:

- production and use (naphta, MTBE, lignocellulose supply chains, fuel cells),
- use of transportation biofuels (efficiencies, emissions, etc.) at different rates,
- data on Esterol (ethanol incorporated in biodiesel),
- assessment of the environmental impact on the ozone layer, ecotoxicity and human health.

5 *Quantified assessment of certain indicators*

In the case of the ether alcohol plant supply chain, environmental gain reported in the various studies ranges from 0.1 to 1 MJ/MJ for consumption of primary non-renewable energy, and from 0.02 to 0.08 kg CO_2 eq/MJ useful energy for the greenhouse effect.

The gain per hectare of cultivated land ranges from 44 to 78 GJ for consumption of primary non-renewable energy, and from 44 to 78 GJ for the greenhouse effect.

In the other impact categories, either few quantitative values are provided in the studies, or results are contradictory and therefore not presented in a quantified manner.

6 Discussion

The ether alcohol sector is fairly well understood in terms of the cereal (wheat, corn) and sugar (sugar cane and sugar beet) sub-supply chains. The lignocellulose (wood, straw, grass, etc.) sub-supply chains are far less well studied.

The biofuel-energy conversion phase is an important parameter for the ether alcohol supply chain.

Environmental gain in the case of lignocellulose sub-supply chains looks interesting, particularly since they make use of co-products that are not yet well utilized (forest waste, pulp and paper, agricultural and municipal co-products). Because data are contradictory, this gain remains to be validated.

The production of hydrogen from ethanol and methanol for fuel cells may offer an attractive alternative to the impact of reference fossil fuels. However, the toxicity of methanol may be a constraint.

Improvement in the environmental performance of ether alcohols may be possible through pairing with other plant supply chains (agricultural biomass, etc.).

7 Bibliographic index

213 references inventoried, 145 studies identified, 9 studies selected

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
ECOBILAN SA, *Bilans énergétiques et gaz à effet de serre des filières de production de biocarburants en France* (energy and greenhouse gas performance of transportation biofuel production chains in France)	Sept. & Nov. 2002	ADEME / DIREM: Summary note and final report	. Direction de l'Agriculture et des Bioénergies de l'ADEME (agriculture and bioenergies branch of the ADEME), France . Direction des Ressources Energétiques et Minérales (energy and minerals resources branch) (DIREM) of the Ministère de l'Economie, des Finances et de l'Industrie (economy, finance and industry department), France	Ecobilan SA	No
LB SYSTEMTECHNIK GMBH, *GM well-to-wheel analysis of energy use and greenhouse gas emissions of advanced fuels/vehicle systems, a European study*	2002	European Study, 137 p. - Annex: Full background report: methodology, assumptions, descriptions, calculations, results, 412 p. - Annex to chapter 3: annex full background report, 53 p.	General Motors Corporation, U.S.A.	LB Systemtechnik GmbH, Germany	Yes
SARLOS G., GNANSOUNOU E., DAURIAT A., *Etude comparative de carburants par leur analyse de cycle de vie* (comparative life-cycle-analysis study of fuels)	Dec. 2002	Alcosuisse, Reference 415.105: Summary –Final report, 66 p. - Annexes	Alcosuisse, Switzerland	Ecole Polytechnique Fédérale de Lausanne (EPFL) (federal polytechnical school of Lausanne), Switzerland	No
EUROPEAN COMMISSION, *Bioenergy for Europe: Which ones fit the best? A comparative analysis for the community*	Nov. 2000	FAIR V program, contract CT 98 3832, IFEU, Heidelberg: Final report, 162 p. - External annex, 82 p.	European Commission, European Union	IFEU - Germany	No

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
FROMENTIN A., BIOLLAY F., DAURIAT A., LUCASPO R TA H., MARCHAND J.D., SARLOS G., *Caractérisation de filières de production de bioéthanol dans le contexte énergétique suisse* (characterization of bioethanol production chains in the Swiss energy context)	Mar. 2000	Programme de recherche biomasse, Office Fédéral de l'Energie (federal energy office), Contract n°69809: Final report, 99 p. – Annexes	Office Fédéral de l'Energie, Switzerland	. Alcosuisse, Switzerland . Carbotech AG, Switzerland . Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland . Office Fédéral pour l'Approvisionnement Economique (OFAE) (federal economic supply office), Switzerland	Yes
REINHARDT G.A., ZEMANEK G ., *Ökobilanz Bioenergieträger . Basisdaten, Ergebnisse, Bewertungen* (LCA of transportation biofuels: base data, results, assessments)	2000	Initiativen zum Umweltschutz 17, Schriftenreihe der Deutschen Bundesstiftung Umwelt, Erich Schmidt Verlag, Berlin	Deutschen Bundesstiftung Umwelt, Germany	Institut für Energie und Umweltforschung (IFEU), Germany	Yes
NETHERLANDS AGENCY FOR ENERGY AND THE ENVIRONMENT, *Analyse en evaluatie van gave-ketens* (analysis and assessment of GAVE program fuel supply chains)	Dec. 1999	GAVE program: Final report, GAVE rapport 9909, deel 2 van 3, 225 p. - Appendices, GAVE rapport 9910, deel 3 van 3, 132 p.	Netherlands Agency for Energy and the Environment (NOVEM), Netherlands	Arthur D. Little International Inc., U.S.A.	No
STELZER T., *Biokrafstoffe im vergleich zu konventionellen kraftstoffen – lebensweg analysen von Umweltwirkungen* (comparison of energy biofuels and fossil fuels – life-cycle analysis of their impacts on the environment)	1999	Forschungbericht, Universität Stuttgart, Institut für Energiewirtschaft und rationelle Energieanwendung, ISSN 0938-1228	Universität Stuttgart, Institut für Energiewirtschaft und rationelle Energieanwendung, Germany	Universität Stuttgart, Institut für Energiewirtschaft und rationelle Energieanwendung, Germany	Yes
ECOBILAN GROUP, *Ecobilan de l'ETBE de betteraves - Comparaison avec le MTBE* (environmental balance sheet for ETBE from beets – comparison with MTBE)	Mar. 1996	Confédération Générale des Planteurs de Betteraves (general beet growers confederation) – Syndicat National des Producteurs d'Alcools Agricoles (national union of agricultural alcohol producers), 166 p.	. Confédération Générale des Planteurs de Betteraves (CGB) . Syndicat National des Producteurs d'Alcools Agricoles (SNPAA), France	Ecobilan SA, France	No

Oil esters (transportation biofuels)

Vegetable oils and their esters (VOMEs) are transportation biofuels used in varying proportions in diesel, either as additives (less than 5% of the blend), components (5% or more of the blend), or complete fuels (100%). Vegetable oils are derived from oilseed crops. Their corresponding esters are obtained by esterification of the oils with an alcohol (methanol).

1 Characteristics of the supply chain

PLANT SECTOR (FOSSIL SOURCE REPLACED)	**PRODUCT**	**BIOMASS (MOLECULE)**	**PRIMARY USE**
A	Oils	Rapeseed, palm, soy, sunflower	. Additive . Component . Fuel
B	Vegetable oil methyl esters (VOMEs)	Rapeseed, palm, coconut, soy, sunflower	. Additive . Component . Fuel
REFERENCE FOSSIL FUEL SUPPLY CHAINS			
A/B	Diesel	-	Fuel

2 Environmental impacts – Plant vs. fossil

PRODUCTS IMPACT CATEGORY[4]	Oils	VOME
Primary use	*Transportation*	
Reference supply chain	**Diesel**	
Consumption of non-renewable energy	++[1]	+
Fossil greenhouse effect	++	++
Eutrophication	- -	- -
Acidification	-	- -
Destruction of the ozone layer	- -	- -
Photochemical pollution	-	0
Terrestrial toxicity	?[2]	?[2]
Aquatic toxicity	?[3]	?[2]
Human health	+/-[3]	+/-[3]

(1) *Production of sunflower seed oil and soybean oil appears to have the most favourable energy balance.*

(2) *Study results vary widely.*

(3) *The studies provide few or no values for these impact categories.*

(4) *The results presented in the oil esters information sheet are based a 5 to 10% inclusion rate for the transportation biofuel and the megajoule of useful energy as a functional unit.*

With regard to the “primary non-renewable energy” and “greenhouse effect” aspects, in the oil esters supply chain, the oil sub-supply chain is of greater interest than the VOME sub-supply chain.

The most studied sub-supply chains are those represented by oil and VOME production from rapeseed, sunflower and soy. With regard to oils and VOMEs derived from palm and coconut, results are fairly weak because of the lack of data.

In a general sense, the environmental performance of sub-supply chains that utilize agricultural co-products is very often more favourable than that of sub-supply chains that utilize dedicated agricultural products.

3 Influencing parameters and areas for improvement

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT
STRONG	Use-phase technology (efficiency and quality of the combustion phase)	All	All	Improve the combustion phase
	Production-phase technology (production process): 1. esterification, production of methanol 2. release of methane	1. Resource use, greenhouse effect 2. Greenhouse effect	1. Rapeseed VOME 2. Palm VOME	Optimize production processes
	Raw material used (rapeseed, sunflower, palm)	. Resource use . Greenhouse effect . Eutrophication	VOME	Encourage the most effective crops
	Allocation of emissions associated with co-products: financial value and effective recovery (pulp, cakes, glycerine)	. Resource use . Greenhouse effect	Rapeseed VOME	Ensure market opportunities for co-products
	Fertilizer use and emissions from the agricultural phase	. Resource use . Greenhouse effect . Acidification	VOME	Encourage a rational agricultural phase
	Type of use: degree of refining as a function of how the oil is used (automobile fuel or heat production)	All	Rapeseed oil and VOME	Encourage uses that require the least amount of energy in order to make the product available
WEAK	Energy recovery from oilseed straw	All	Rapeseed VOME	-
	Emissions allocation method used	All	Rapeseed VOME	-
INDETERMINATE	Type of use (inclusion rate for the biofuel)	. Resource use . Greenhouse effect	All	Study the effect of vehicle performance as a function of biofuel inclusion rate

4 *Quality of studies selected*

Range of scenarios		**X**			
Reliability of studies			**X**		
Technological sensitivity				**X**	
Geographical sensitivity			**X**		
Consistency of results				**X**	
Need for further data				**X**	
	↑ Very weak	↑ Weak	↑ Moderate	↑ Strong	↑ Very Strong

A certain similarity is noted among the supply chains studied. However, not all the studies cover the combustion phase. Several significant reviews were identified for this supply chain.

Reliability is acceptable in the case of rapeseed, soy and sunflower crops, but fairly poor for palm oil and coconut crops (developing technologies).

The technological sensitivity makes comparison of certain studies difficult.

Satisfactory consistency of results is seen once studies are made comparable.

Missing or highly uncertain data:

- agricultural-phase emissions: pesticides and N_2O in the case of rapeseed and sunflower, respectively,
- soybean farming and processing in Europe,
- use of transportation biofuels (efficiencies, emissions, etc.) at different rates,
- assessment of the environmental impact on ecotoxicity and human health.

5 *Quantified assessment of certain indicators*

As observed in the various studies, the environmental gain offered by the oil esters supply chain ranges from 0.2 to 0.9 MJ/MJ useful energy for consumption of primary non-renewable energy, and from 0.01 to 0.04 kg CO_2 eq/MJ useful energy for the greenhouse effect.

The gain per hectare of cultivated land ranges from 33 to 115 GJ for consumption of primary non-renewable energy, and from 1.7 to 8.9 GJ for the greenhouse effect.

In the other impact categories, either few quantitative values are provided in the studies, or results are contradictory and therefore not presented in a quantified manner.

6 *Discussion*

Oil esters are fairly well understood in terms of the VOME-based sub-supply chains (rapeseed, soy, sunflower). The lignocellulose (wood, straw, grass, etc.) sub-supply chains are far less well studied.

The biofuel-energy conversion phase is an important parameter for the oil esters supply chain.

Possibilities exist for pairing of the oil esters supply chain with other plant resource supply chains (agricultural biomass, etc.) that could improve its environmental performance.

7 Bibliographic index

201 references inventoried, 125 studies identified, 8 studies selected

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
ECOBILAN SA, *Bilans énergétiques et gaz à effet de serre des filières de production de biocarburants* (energy and greenhouse gas performance of transportation biofuel production chains)	Sept. & Nov. 2002	ADEME / DIREM: Summary note and final report	. Direction de l'Agriculture et des Bioénergies de l'ADEME (agriculture and bioenergies branch of the ADEME), France . Direction des Ressources Energétiques et Minérales (energy and minerals resources branch) (DIREM) of the Ministère de l'Economie, des Finances et de l'Industrie (economy, finance and industry department), France	Ecobilan SA	No
LB SYSTEMTECHNIK GMBH, *GM well-to-wheel analysis of energy use and greenhouse gas emissions of advanced fuels/vehicle systems, a European study*	2002	European Study, 137 p. - Annex: Full background report: methodology, assumptions, descriptions, calculations, results, 412 p. - Annex to chapter 3: annex full background report, 53 p.	General Motors Corporation, U.S.A.	LB Systemtechnik GmbH, Germany	Yes
EUROPEAN COMMISSION, *Bioenergy for Europe: Which ones fit the best? A comparative analysis for the community*	Nov. 2000	FAIR V program, Contract CT 98 3832, IFEU, Heidelberg: Final report, 162 p. - External annex, 82 p.	European Commission, European Union	Institut für Energie und Umweltforschung (IFEU), Germany	No

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
HEINZER L., GAILLARD G., DUX D., STELLER C., *Ökologische und Ökonomische Bewertung von Bioenergieträgern, Vergleichende Untersuchungen von Stückholzheizung, Rapsmethylester und Fernwärme aus Heu* (economic and ecological assessment of bioenergy resources, comparative study of wood heating, rapeseed methyl ester, and district heating with straw)	2000	Eidgenössichen Forschungsanstalt für Agrarwirtschaft und Landtechnik (FAT): Schriftenreihe n° 52 – Schriften-riheTänikon, Schweiz	Bundesamt für Berufsbildung und Technologie, Switzerland	Eidgenössiche Forschungsanstalt für Agrarwirtschaft und Landtechnik (FAT), Switzerland	No
REINHARDT G.A., ZEMANEK G ., *Ökobilanz Bioenergieträger . Basisdaten*, *Ergebnisse*, *Bewertungen* (LCA of transportation biofuels: base data, results, assessments)	2000	Initiativen zum Umweltschutz 17, Schriftenreihe der Deutschen Bundesstiftung Umwelt, Erich Schmidt Verlag, Berlin	Deutschen Bundesstiftung Umwelt, Germany	Institut für Energie und Umweltforschung (IFEU), Germany	Yes
. ECOBILAN SA, *Analyse de cycle de vie du diester, Evaluation comparée des filières gazole et diester* (LCA of diester fuel, comparative analysis of diesel and diester fuels) . ECOBILAN SA, *Actualisation de l'écobilan du diester* (update of the environmental performance of diester fuels) . ECOBILAN SA, *Ecobilan du diester et éléments d'analyse de la filière gazole* (environmental performance of diester fuels and fundamentals of diesel fuels analysis)	1993 1999	Ecobilan SA, 22 p. Ecobilan SA, 3 p. Ecobilan SA, Volume 1: Results, ONIDOL final report, 147 p. - Volume 2 : Annexe, 74 p.	Omnidol, France	Ecobilan SA, France	No

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
NETHERLANDS AGENCY FOR ENERGY AND THE ENVIRONMENT, *Analyse en evaluatie van gave-ketens* (analysis and assessment of GAVE program fuel supply chains)	Dec. 1999	GAVE program: Final report, GAVE rapport 9909, deel 2 van 3, 225 p. - Appendices, GAVE rapport 9910, deel 3 van 3, 132 p.	Netherlands Agency for Energy and the Environment (NOVEM), Netherlands	Arthur D. Little International Inc., U.S.A.	No
STELZER T., *Biokrafstoffe im vergleich zu konventionellen kraftstoffen – lebensweg analysen von Umweltwirkungen* (comparison of biogenic fuels and fossil fuels – life-cycle analysis of their impacts on the environment)	1999	Forschungbericht, Universität Stuttgart, Institut für Energiewirtschaft und rationelle Energieanwendung, ISSN 0938-1228	Universität Stuttgart, Institut für Energiewirtschaft und rationelle Energieanwendung, Germany	Universität Stuttgart, Institut für Energiewirtschaft und rationelle Energieanwendung, Germany	Yes

Forest biomass

Energy biofuels derived from forest biomass comprise all examples of energy recovery from this type of biomass (production of heat, electricity etc.). They are divided into three sub-supply chains: fuels from dedicated crops (short or very-short rotation coppice willow, eucalyptus, poplar, etc.), fuels from co-products (pellets, sawdust, etc.), and fuels from slash (billets, chips, etc.). Energy recovery from waste wood is not covered in this study.

1 Characteristics of the supply chain

PLANT SECTOR (FOSSIL SOURCE REPLACED)	**PRODUCT**[2]	**BIOMASS (MOLECULE)**	**PRIMARY USE**[1]
A	Fuels from dedicated crops	Short rotation coppices (SRC) (poplar, etc.)	. Production of heat: combustion (medium to large scale) . Production of electricity: combustion (large scale) – co-combustion (large scale) - pyrolysis, gasification (large scale) . Production of steel: co-combustion of charcoal (large scale)
B	Fuels from co-products (pellets, sawdust, etc.)	Co-products from logging, forest maintenance, etc.	. Production of heat: combustion (small scale) . Co-generation: combustion (medium scale)
C	Slash (billets, chips)	Standing wood (oak, beech, softwood, etc.) (crown, clear cutting, thinning, etc.)	. Production of heat: combustion (small scale) . Production of electricity: combustion (large scale)
REFERENCE FOSSIL FUEL SUPPLY CHAINS			
A/B/C	Gas	-	. Production of heat (small scale) . Production of electricity (large scale)
A/B/C	Fuel oil	-	. Production of heat (small to large scale) . Production of electricity (large scale)
A	Coal	-	Production of steel (large scale)
B	Coal	-	Production of electricity (large scale)

(1) Small scale: 1 to 300 kW: medium scale: 300 kW to 3 MW; large scale: over 3 MW.

(2) Only one study of common industrial wastes could be included (Betz et al., 2002).

2 Environmental impacts – Plant vs. fossil

PRODUCTS IMPACT CATEGORY	**Fuels from dedicated crops**	**Fuels from co-products**	**Slash**		
Technology	*SRC (large scale)*	*Pellets (small scale)*	*Billets, chips (small scale)*		*Chips (large scale)*
Primary use	*Electricity*	*Heat*	*Heat*	*Heat*	*Electricity*
Reference supply chain	**coal**	**fuel oil**	**gas**	**fuel oil**	**coal**
Consumption of non-renewable energy	++	++	++	++	++
Fossil greenhouse effect	++	++	++	++	++
Eutrophication	- -	-	-	-	n.d.
Acidification	+/-	0	-	0	n.d.
Destruction of the ozone layer	n.d.	+	- -	+	n.d.
Photochemical pollution	n.d.	-	- -	-	n.d.
Terrestrial toxicity	n.d.	+	?[1]	+	n.d.
Aquatic toxicity	n.d.	+	0	+	n.d.
Human health[2]	n.d.	+/-	- -	+/-	n.d.

(1) Study results vary widely.
(2) Performance depends on several parameters (emissions during the combustion phase).

By comparison with fossil sub-supply chains (electricity, gas, fuel oil, coal), the performance of the corresponding plant resource sub-supply chains (billets, chips, pellets) is very favourable in the “primary non-renewable energy” and “greenhouse effect” impact categories.

With respect to the other impact categories, the performance of plant resource supply chains is either not well known or unfavourable, particularly in the processing and combustion phases. The emission of other airborne pollutants during the combustion phase produces additional impacts in terms of:

- acidification (NOx),
- human health (dioxins, benzene, NOx, particulates, etc.),
- photochemical pollution (VOCs).

The sub-supply chain with the most favourable performance appears to be the simultaneous production of electricity and heat (cogeneration). However, there are few in-depth studies of this sub-supply chain or of new technologies such as pyrolisis and gasification.

3 *Influencing parameters and areas for improvement*

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT
STRONG	Use-phase technology (efficiency and quality of the combustion phase)	. Resource use . Greenhouse effect . Acidification . Human health	All	Improve the combustion phase
	Raw material used (dedicated crop, co-product)	. Resource use . Greenhouse effect	All	Encourage the use of co-products
	Agricultural practices (fertilizer) and emissions from the agricultural phase	. Resource use . Greenhouse effect	Short-rotation coppices	Encourage a rational agricultural phase
	Transportation (shipment of raw materials by road)	. Resource use . Greenhouse effect	. Chips . Wood residues	Reduce shipping distances
	Production-phase technology (performance of the logging equipment and level of mechanization)	. Resource use . Greenhouse effect	Slash (billets, chips)	Improve production equipment performance
	Production-phase technology: packaging (plastic wrapping)	. Resource use . Greenhouse effect	Billets	Improve production technology
	Use-phase technology (fuel oil for start-up of 5-30 MW plant)	. Resource use . Greenhouse effect	Chips	Improve use technology (power plant start up/shutdown)
WEAK	Type of production: biomass development (industrial, small-scale)	. Resource use . Greenhouse effect	Chips	-
	Transportation: finished product, by boat and train (long distances)	. Resource use . Greenhouse effect	Pellets	-
	Use-phase technology: power and size of the facility (low and moderate power)	. Resource use . Greenhouse effect	All	-
INDETERMINATE	Raw material used	All	Billets, charcoal	Study the effect of the type of raw material used
	Transportation (logistics supply chains)	All	All	Study the effect of transportation
	Use-phase technology (type of combustion technology)	All	All	Study optimization of the conditions of energy recovery (combustion technology)

4 *Quality of studies selected*

Range of scenarios				**X**	
Reliability of studies			**X**		
Technological sensitivity				**X**	
Geographical sensitivity			**X**		
Consistency of results				**X**	
Need for further data				**X**	
	↑ Very weak	↑ Weak	↑ Moderate	↑ Strong	↑ Very Strong

The wide diversity of studies reflects the diversity of the supply chain (resource, applications, scales). The small-scale production of heat is the most studied sub-supply chain. Knowledge of a supply chain is closely tied to the technological expertise associated with it. Several significant reviews of forest biomass were identified.

Reliability is fairly good in the case of small and medium-scale heating facilities, but relatively poor with regard to the remaining sub-supply chains (with the exception of energy and greenhouse effect).

The technological sensitivity of the forest biomass sector is strong, particularly with regard to the impact of combustion on human health.

Aside from energy and the greenhouse effect, consistency of results is fairly weak, except in the case of small and medium-scale heating facilities.

Missing or highly uncertain data:

- emissions for certain crops under European conditions (eucalyptus, SRCs, etc.),
- air emissions during combustion at heating facilities (particularly VOCs, NM, dioxins).
- data on carbon storage in forest soil,
- data on (small, medium and large-scale) co-generation facilities that use fuels derived from forest biomass,
- data on the various combustion technologies for wood-based products (pyrolysis, gasification, combustion, etc.),
- impact of transportation activities on the supply chain,
- assessment of the environmental impact in all impact categories other than energy and greenhouse effect.

5 Quantified assessment of certain indicators

As observed in the various studies, the environmental gain offered by the forest biomass supply chain ranges from 0.05 to 0.3 MJ/MJ useful energy for consumption of primary non-renewable energy, and from 0.006 to 0.045 kg CO_2 eq/MJ useful energy for the greenhouse effect.

The gain per hectare of cultivated land ranges from 33 to 161 GJ for consumption of primary non-renewable energy, and from 2.5 to 11.6 GJ for the greenhouse effect.

In the other impact categories, either few quantitative values are provided in the studies, or results are contradictory and therefore not presented in a quantified manner.

6 Discussion

LCA knowledge of the forest biomass supply chain is fairly poor, with the exception of the “energy” and “greenhouse effect” impact categories. The co-generation sub-supply chains are the least well studied. Small-scale heat production is the most thoroughly studied.

The biofuel-energy conversion phase is an important parameter for the supply chain.

Improvement of the environmental performance of the forest biomass supply chain is highly dependent on technological improvement (combustion).

Possibilities exist for pairing of the forest biomass supply chain with other plant resource supply chains (transportation biofuels, agrimaterials, etc.) that may improve its environmental performance.

7 Bibliographic index

114 references inventoried, 75 studies identified, 9 studies selected

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
MICHEL E., DEVES A., LABOUZE E., MOULAY L., *Bilan environnemental de différents modes de chauffage domestique* (environmental performance of various domestic heating options)	Nov. 2002	ADEME, Contract No. 01 01 013: Final report, 121 p. - Annexes – Summary note, 10 p.	Agence De l'Environnement et de la Maîtrise de l'Energie (ADEME) (environmental and energy management agency), France	Ecobilan SA	No
RAKOS C., TRETTER H., *Vergleich der Umwelt-auswirkungen einer Pelletheizung mit denen konventioneller Energiebereitstellungs-systeme am Beispiel einer 400 kW Heizanlage* (comparison of the environmental impacts of a wood pellet heating system with those of conventional systems, e.g. a 400-kW heating system)	Feb. 2002	Energieverwentungs agentur, Wien	Stadt Wien, Austria	Energieverwertungsagentur, Austria	No
JUNGBLUTH N., FRISCHKNECHT R., FAIST M., *Ökobilanz für die Stromerzeugung aus Holzbrenn-stoffen und Altholz* (environmental balance sheet for the production of electricity from wood and used-wood-based fuels)	2002	In Jahresversammlung der IG Altholz. Kaiseraugst - Schlussbericht , Forschungs-und P+D Programm Biomasse, Projekt 41458, Vertrag n°81427, ESU-services for Bundesamt für Energie, Uster	Bundesamt für Energie, Switzerland	ESU-services, Switzerland	Yes
BETZ M., COEN D., DEIMING S., KREISSIG J., *Thermische Verwertung von Holzprodukten Inputabhängige Modellierung der End-of-Life Prozesse von Holz* (heat recovery from wood-based products and their end-of-life modelling)	Sept. 2002	Deutsche Gesellschaft für Holzforschung, PE Europe GmbH.	. Deutsche Gesellschaft für Holzforschung (DGfH) . Holzabsatzfonds, Germany	PE Europe GmBH, Germany	No

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
EUROPEAN COMMISSION, *Bioenergy for Europe: Which ones fit the best? A comparative analysis for the community*	2000	FAIR V program, contract CT 98 3832, IFEU, Heidelberg: Final report, 162 p. - External annex, 82 p.	European Commission, European Union	Institut für Energie und Umweltforschung (IFEU), Germany	No
REINHARDT G.A., ZEMANEK G ., *Ökobilanz Bioenergieträger . Basisdaten, Ergebnisse, Bewertungen* (LCA of transportation biofuels: base data, results, assessments)	2000	Initiativen zum Umweltschutz 17, Schriftenreihe der Deutschen Bundesstiftung Umwelt, Erich Schmidt Verlag	Deutschen Bundesstiftung Umwelt, Germany	Institut für Energie und Umweltforschung (IFEU), Germany	Yes
KESSLER F.M., KNECHTLE N., FRISCHKNECHT R., *Heizenergie aus Heizöl, Erdgas oder Holz ; Ökobilanzen von Heizungen für Ein-und Mehr-familienhäuser mit 10kW bzw. 50 bis 100kW* (heating energy from fuel oil, natural gas or wood; environmental balance sheets for 10kW and 50-100 kW heating for single houses and groups of houses)	2000	Schriftenreihe Umwelt Nr. 315, Bundesamt für Umwelt, Wald und Landschaft (BUWAL)	Bundesamt für Umwelt, Wald und Landschaft (BUWAL), Switzerland	. Basler & Hofmann (Switzerland) . ESU Services, Switzerland	Yes
HEINZER L., GAILLARD G., DUX D., STELLER C., *Ökologische und Ökonomische Bewertung von Bioenergieträgern, Vergleichende Untersuchungen von Stück-holzheizung, Rapsmethylester und Fernwärme aus Heu* (economic and ecological assessment of bioenergy resources, comparative study of wood heating, rapeseed methyl ester, and district heating with straw)	2000	Schriftenreihe der Eidgenössichen Forschungsanstalt für Agrarwirtschaft und Landtechnik, n°52, Eidgenössiche Forschungsanstalt für Agrarwirtschaft und Landtechnik (FAT), SchriftenreiheTänikon, Schweiz	Bundesamt für Berufsbildung und Technologie, Switzerland	Eidgenössiche Forschungsanstalt für Agrarwirtschaft und Landtechnik (FAT), Switzerland	No

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
STELZER T., *Biokrafstoffe im vergleich zu konventionellen kraftstoffen – lebensweg analysen von Umweltwirkungen* (comparison of biogenic fuels and fossil fuels – life-cycle analysis of their impacts on the environment)	1999	Dissertation am Institut für Energiewirtschaft und Rationelle Energieanwendung der Universität Stuttgart (IER), Forschungsbericht IER Band 57	Institut für Energiewirtschaft und Rationelle Energieanwendung der Universität Stuttgart, Germany	Institut für Energiewirtschaft und Rationelle Energieanwendung der Universität Stuttgart (IER), Germany	Yes

Agricultural biomass

Energy biofuels derived from agricultural biomass comprise all examples of energy recovery from this type of biomass (generation of heat, electricity etc.). They are divided into two sub-supply chains: fuels based on dedicated crops (short or very-short rotation coppice willow, eucalyptus, poplar, etc.), and fuels from co-products (pellets, sawdust, etc.), and fuel from slash (chips, billets, etc.). Energy recovery from waste wood is not covered in this study.

1 Characteristics of the supply chain

PLANT SECTOR **(FOSSIL SOURCE REPLACED)**	**PRODUCT**[2]	**BIOMASS** **(MOLECULE)**	**PRIMARY USE**[1]
A	Fuels from dedicated crops	Wheat, hemp, grasses (Bermuda grass, hay, reed canary grass, switchgrass), Chinese reed (Miscanthus sinensis), kenaf, corn, barley, rye, triticale	. Production of heat: combustion (large scale) – co-combustion (large scale) – pyrolysis, gasification (large scale) . Production of electricity: combustion (large scale) – co-combustion (large scale) - pyrolysis, gasification (large scale) . Cogeneration: combustion (medium to large scale)
B	Fuels from co-products	Sugar cane bagasse, straw (wheat, rapeseed, barley, rye, etc.), rice husk, etc.	. Production of heat: combustion (medium to large scale) – co-combustion (large scale) . Production of electricity: combustion (large scale) – co-combustion (large scale) – pyrolysis, gasification (large scale) - Co-generation: combustion (medium to large scale)
REFERENCE FOSSIL FUEL SUPPLY CHAINS			
A/B	Gas	-	Production of heat: combustion (medium to large scale)
A/B	Fuel oil	-	Production of heat: combustion (medium to large scale)
A/B	Coal	-	Production of electricity: combustion (large scale)

(1) Small scale: 1 to 300 kW: medium scale: 300kW to 3 MW; large scale: over 3 MW.

2 *Environmental impacts – Plant vs. fossil*

PRODUCTS **IMPACT CATEGORY**	**Fuels from dedicated crops**			**Fuels from co-products**		
Technology	*Combustion (med & large scale)*	*Gasification (large scale)*	*Co-combustion (large scale)*	*Combustion (med & large scale)*	*Gasification (large scale)*	*Co-combustion (large scale)*
Primary use	*Heat*	*Heat*	*Electricity*	*Heat*	*Heat & El*	*Electricity*
Reference supply chain	**gas, fuel oil**	**gas, fuel oil**	**coal**	**gas, fuel oil**	**gas, fuel oil**	**coal**
Consumption of non-renewable energy	++	++	++	++	++	++
Fossil greenhouse effect	++	++	++	++	++	++
Eutrophication	- -	n.d.	- -	- -	n.d.	- -
Acidification	- -	n.d.	-	-	n.d.	0
Destruction of the ozone layer	- -	n.d.	- -	- -	n.d.	- -
Photochemical pollution	- -	n.d.	- -	- -	n.d.	- -
Terrestrial toxicity	?[1]	n.d.	?[1]	?	n.d.	?[1]
Aquatic toxicity	?[1]	n.d.	?[1]	?	n.d.	?[1]
Human health[2]	- -	n.d.	-	- -	n.d.	?[1]

(1) Study results vary widely.
(2) The studies provide few or no values for these impact categories

By comparison with fossil sub-supply chains, the performance of the corresponding plant resource sub-supply chains is very favourable in “primary non-renewable energy” and “greenhouse effect” impact categories.

With respect to the other impact categories, the performance of plant resource supply chains is either not well known or unfavourable (in the processing and combustion phases). In addition, less is known about these other categories than in the case of the forest biomass supply chain.

The performance of sub-supply chains dedicated to production of electricity is more favourable than that of sub-supply chains dedicated to the production of heat. However, in the case of the production of electricity, this result is a function of the fossil fuel replaced, i.e. coal.

3 Influencing parameters and areas for improvement

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT
STRONG	Use-phase technology (efficiency and quality of the combustion phase)	. Resource use . Greenhouse effect . Acidification . Human health	All	Improve the combustion phase
	Use of fertilizers (containing nitrogen, for dedicated crops)	. Resource use . Greenhouse effect	Grasses, Chinese reed, etc.	Encourage a rational agricultural phase
	Allocation of emissions associated with co-products (emissions from the crop concerned allocated among the various co-products)	. Resource use . Greenhouse effect	Straw	Ensure market opportunities for co-products
	Agricultural practices (extensive, intensive)	. Resource use . Greenhouse effect . Ecotoxicity . Human health	Grasses, Chinese reed	Encourage a rational agricultural phase
	Production-phase technology: method of harvesting and management (ensiling, drying, etc.)	. Resource use . Greenhouse effect	Chinese reed	Improve production technology (harvesting and management)
	Use-phase technology (fuel oil for start-up of 5-30 MW plant)	. Resource use . Greenhouse effect	Chips from short rotation coppice	Improve use technology (power plant start-up/shutdown)
INDETERMINATE	Transportation (raw material)	All	All	Study the effect of shipping the raw material
	Raw material used (dedicated crop or co-product)	All	All	Study the effect of the type of raw material used
	Use-phase technology (power of combustion plants, type of combustion technology)	All	All	Study optimization of the conditions of energy recovery (combustion technology)

4 *Quality of studies selected*

Range of scenarios					**X**
Reliability of studies	**X**				
Technological sensitivity					**X**
Geographical sensitivity				**X**	
Consistency of results		**X**			
Need for further data					**X**
	↑ Very weak	↑ Weak	↑ Moderate	↑ Strong	↑ Very Strong

The wide diversity of studies reflects the diversity of the supply chain (resource, applications, scales). Knowledge of a supply chain is closely tied to the technological expertise associated with it. One significant review of agricultural biomass was identified.

With the exception of the impact on energy and the greenhouse effect, reliability is fairly poor (weak and diverse studies).

Technological sensitivity is very strong, particularly with regard to the production of energy biofuels and their combustion (impact on human health).

Aside from energy and the greenhouse effect, consistency of results is fairly poor.

Missing or highly uncertain data:

- impact of transportation activities on the supply chain,
- impact of raw material used,
- data on the growth and processing of certain energy energy biofuels (triticale, Chinese reed, hemp, etc.),
- data on (small, medium and large-scale) co-generation facilities that use energy biofuels,
- data on the various combustion technologies used on agricultural biomass-based products (pyrolysis, gasification, combustion, co-combustion, etc.) to produce heat and electricity,
- assessment of the environmental impact in all impact categories other than energy and greenhouse effect.

5 *Quantified assessment of certain indicators*

As observed in the various studies, the environmental gain offered by the agricultural biomass supply chain ranges from 0.02 to 0.2 MJ/MJ useful energy for consumption of primary non-renewable energy, and from 0.01 to 0.03 kg CO_2 eq/MJ useful energy for the greenhouse effect.

The gain per hectare of cultivated land ranges from 87 to 220 GJ for consumption of primary non-renewable energy, and from 6.3 to 16 GJ for the greenhouse effect.

In the other impact categories, either few quantitative values are provided in the studies, or results are contradictory and therefore not presented in a quantified manner.

6 *Discussion*

Because of the diverse nature of the agricultural biomass supply chain, LCA knowledge of the chain is fairly poor. Medium-scale heat production is the most thoroughly studied sub-supply chain. The co-generation sub-supply chains are the least well studied.

The biofuel-energy conversion phase is an important parameter for the supply chain.

Improvement of the environmental performance of the agricultural biomass supply chain is highly dependent on technological improvement (combustion).

Possibilities exist for pairing the agricultural biomass supply chain with other plant resource supply chains (transportation biofuels, etc.) that may improve its environmental performance.

7 Bibliographic index

75 references inventoried, 54 studies identified, 5 studies selected

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
BULLARD M., METCALFE P., *Estimating the energy requirements and CO_2 emissions from production of the perennial grasses Miscanthus, switchgrass and reed canary grass*	2001	UK Department of Trade and Industry, 2001, report ETSU B/U1/00645/REP, 94 p.	UK Department of Trade and Industry, program ETSU, United Kingdom	ADAS Consulting Ltd., United Kingdom	No
EUROPEAN COMMISSION, *Bioenergy for Europe: Which ones fit the best? A comparative analysis for the community*	Nov. 2000	FAIR V program, contract CT 98 3832, IFEU, Heidelberg: Final report, 162 p. - External annex, 82 p.	European Commission, European Union	Institut für Energie und Umweltforschung, Germany	No
REINHARDT G.A., ZEMANEK G., *Ökobilanz Bioenergieträger . Basisdaten, Ergebnisse, Bewertungen* (LCA of transportation biofuels: base data, results, assessments)	2000	Initiativen zum Umweltschutz 17, Schriftenreihe der Deutschen Bundesstiftung Umwelt, Erich Schmidt Verlag	Deutschen Bundesstiftung Umwelt, Germany	Institut für Energie und Umweltforschung (IFEU), Germany	Yes
HEINZER L., GAILLARD G., DUX D., STELLER C., *Ökologische und Ökonomische Bewertung von Bioenergieträgern, Vergleichende Untersuchungen von Stück-holzheizung, Rapsmethylester und Fernwärme aus Heu* (economic and ecological assessment of bioenergy resources, comparative study of wood heating, rapeseed methyl ester, and district heating with straw)	2000	Schriftenreihe der Eidgenössichen Forschungsanstalt für Agrarwirtschaft und Landtechnik, n°52, Eidgenössiche Forschungsanstalt für Agrarwirtschaft und Landtechnik (FAT), SchriftenreiheTänikon, Schweiz	Bundesamt für Berufsbildung und Technologie, Switzerland	Eidgenössiche Forschungsanstalt für Agrarwirtschaft und Landtechnik (FAT), Switzerland	No

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
STELZER T., *Biokrafstoffe im vergleich zu konventionellen kraftstoffen – lebensweg analysen von Umweltwirkungen* (comparison of biogenic fuels and fossil fuels – life-cycle analyses of their environmental impacts)	1999	Dissertation am Institut für Energiewirtschaft und Rationelle Energieanwendung der Universität Stuttgart (IER), Forschungsbericht IER Band 57	Institut für Energiewirtschaft und Rationelle Energieanwendung der Universität Stuttgart, Germany	Institut für Energiewirtschaft und Rationelle Energieanwendung der Universität Stuttgart (IER), Germany	Yes

Biopolymers

Biopolymers are natural polymers from renewable plant, algae or animal sources. These polymers are grouped into three main families: polysaccharides (starch, cellulose, chitosan, pullulan), proteins (collagen, gelatine, casein, etc.) and lignin. They can also be produced by industrial synthesis processes (polymerization) from natural monomers or monomers that are identical to natural monomers. This study covers only biopolymers from the plant resource supply chain.

1 Characteristics of the supply chain

PLANT SECTOR (FOSSIL SOURCE REPLACED)	**PRODUCT**[2]	**BIOMASS (MOLECULE)**	**PRIMARY USE**[1]
A	Natural polymers	. Cereals (starch) . Potato (starch)	Cushioning material
B	Mixed polymers (produced from biopolymers and polymers from petrochemical sources)	. Corn (starch) . Potatoes (starch) . Wood (lignin)[1]	. Cushioning material . Compostable bags . Films . Printed circuits
C	Synthetic biopolymers: lactic acid polymers (PLA)	. Cereals (starch) . Corn (starch)	. Packaging . Milk bottles . Baby diapers
D	Bacterial polymers: polyhydroxyalkanoates (PHA)[2]	Corn residues or seeds (starch)	. Polyethylene (PE) replacement in numerous products . Packaging in the food sector
REFERENCE FOSSIL FUEL SUPPLY CHAINS			
A/B/C/D	. Polyethylene (PE): low and high-density polyethylene (LDPE, HDPE) . Polyethylene terephthalate (PET)	-	. Packaging . Films . Baby diapers
A/B	Polystyrene (PS): expanded polystyrene (EPS)	-	Cushioning material
B	Epoxy/dicyandiamide	-	Printed circuits

(1) Co-products of paper manufacturing.
(2) Developing supply chain.

PRODUCTS / IMPACT CATEGORY[7]	**Natural polymers**	**Mixed polymers**	**Synthetic biopolymers**[1]	**Bacterial polymers**[1]
Primary use	*Cushioning material*	*Cushioning material, bags, films, printed circuits*	*Packaging, bottles, diapers*	*Packaging*
Reference supply chain	**EPS**	**EPS, PS, epoxy/dicyandiamide**	**PE and PP**	**PE**
Consumption of non-renewable energy	+[2], ++	+, ++[3]	+/-[4]	+/-
Fossil greenhouse effect	+[2], ++	+, ++[3]	+/-[4]	+/-
Eutrophication	+/-[2]	+/-	-	+/-
Acidification	- -	-	-	n.d.
Destruction of the ozone layer	0	0	-	n.d.
Photochemical pollution	?	?	-	n.d.
Terrestrial toxicity	n.d.	n.d.	n.d.	n.d.
Aquatic toxicity	n.d.	n.d.	n.d.	n.d.
Human health	n.d.	n.d.	n.d.	n.d.

(1) *A number of studies compare conventional products with products of the plant resource supply chain on the basis of the kilogram rather than on the basis of a functional unit.*
(2) *Depending on the key parameters and the raw materials used to produce the conventional product, the environmental performance can also be unfavourable in the case of cushioning material derived from the plant resource supply chain (Würdinger et al., 2002).*
(3) *In terms of non-renewable energy and greenhouse gases, the performance of films derived from the plant resource supply chain compares very favourably with that of conventional products.*
(4) *The most recent study, which was conducted by Cargill Dow, a producer of lactic acid polymers, shows a gain in the "energy" and "greenhouse effect" impact categories (Vink, 2003). However, the study on PLA-based diapers reports a greater environmental impact in all impact categories for the product derived from the plant resource supply chain (Hakala et al., 1997).*

Except in the case of bacterial polymers, studies report positive performances for plant resource sub-supply chains as compared with corresponding fossil sub-supply chains (PE, PS, epoxy/dicyandiamide).

In certain impact categories, performance is:

- not defined because of a lack of data or because of conflicting data (ecotoxicity, human health), or
- unfavourable for plant resource supply chains, in impact categories related to agricultural production-phase emissions (e.g. eutrophication).

Of all the sub-supply chains studied, the performance of natural polymers compares the most favourably with that of the reference fossil supply chains.

3 *Influencing parameters and areas for improvement*

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT
STRONG	Raw material used (dedicated crop or co-products, crop yield)	All	. Lignin . PHA . Cushioning material	Encourage co-products or high-yield crops
	Choice of functional unit (quantity of material used per functional unit as compared with conventional products)	All	Cushioning material	-
	Production-phase technology (source of electrical power for biopolymer production)	. Resource use . Greenhouse effect . Ecotoxicity . Human health	. Biopolymers and fibres . Cushioning material . PLA	Reduce production-phase energy consumption
	Type of end-of-life recovery (recycling, composting, incineration, landfilling) and substitution-related assumptions (electricity, heat, fertilizer, raw material)	All	All	Ensure that end-of-life recovery is appropriate
	Agricultural practices (intensive, extensive)	All	All	Encourage a rational agricultural phase
	Agricultural-phase emissions (fertilizer used for corn cultivation)	. Destruction of the ozone layer . Eutrophication . Acidification	PLA, products derived from corn	Encourage a rational agricultural phase
WEAK	Biodegradability	. Ecotoxicity . Human health	Products that are not environmentally degradable	-
INDETERMINATE	Allocation of emissions associated with co-products	All	-	Study the co-products and ensure their market opportunities

4 Quality of studies selected

Range of scenarios					X
Reliability of studies			X		
Technological sensitivity					X
Geographical sensitivity		X			
Consistency of results				X	
Need for further data			X		
	↑ Very weak	↑ Weak	↑ Moderate	↑ Strong	↑ Very Strong

The diversity of studies reflects the diversity of the supply chain (production processes, products). One significant review of biopolymers was identified.

Reliability is moderate for all studies (incomplete, lack of objectivity, technological development). Only one source is used for the reference fossil supply chains.

Technological sensitivity is strong, making it difficult to compare certain studies with reference fossil supply chains.

Consistency of results is reasonably satisfactory on a per kilogram biopolymer basis. However, few comparisons are available on a functional unit basis (results open to distortion).

Missing or highly uncertain data:

- production and use of polyvinyl alcohol,
- data on the various end-of-life supply chains for biopolymers (incineration, recycling, composting, landfilling) in the case of synthetic and bacterial polymers,
- environmental impact assessment, based on the correct functional unit (weight differences, etc.),
- assessment of the environmental impact on eutrophication, acidification, destruction of the ozone layer, photochemical pollution, ecotoxicity and human health.

5 Quantified assessment of certain indicators

As observed in the various studies, the environmental gain offered by the biopolymer supply chain is approximately 55 MJ/MJ per kilogram of natural polymer pellets for consumption of primary non-renewable energy, and approximately 3.5 kg eq CO_2/kg for the greenhouse effect. In the case of mixed polymers, the gain decreases in proportion to fossil material content. Not all available LCA studies report gains in the case of synthetic and bacterial polymers.

The gain per hectare of cultivated land ranges from 39 to 525 GJ (1.9 and 34 t CO_2 eq/ha, respectively), except for synthetic polymers and bacterial polymers. Certain studies of these polymers estimate a higher consumption of primary non-renewable energy and a greater potential greenhouse effect than in the case of conventional fossil products.

In the other impact categories, either few quantitative values are provided in the studies, or results are contradictory and therefore not presented in a quantified manner.

6 Discussion

LCA knowledge of the biopolymer supply chain is moderate (strong diversity, uncertainties). The synthetic and bacterial sub-supply chains are the least well studied.

The natural polymer sub-supply chain has the best environmental performance in terms of energy and greenhouse effect.

End-of-life recovery of biopolymers and the choice of products replaced are important parameter for the supply chain.

Biopolymer biodegradability can be an asset or a liability, depending on the end-of-life option chosen for the product.

Development of biopolymers must not interfere with the recycling of their fossil counterparts.

Despite the uncertainties revealed, the studies analysed show that the environmental performance of biopolymers is favourable relative to that of petrochemical supply chains. Given the rapid development of the biopolymer supply chain, future environmental gains may be more significant thanks to mass production and improved production technologies.

7 Bibliographic index

40 references inventoried, 27 studies identified, 9 studies selected

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
VINK E.T.H., RABAGO K.R., GLASSNER D.A., GRUBER P.R., *Applications of life cycle assessment to NatureWorks polylactide (PLA) production*	2003	Polymer Degradation and Stability, vol. 80, pp. 403-419.	Cargill Dow, U.S.A.	Cargill Dow, U.S.A.	No
WUERDINGER E., WEGENER A. ET AL., *Kunststoffe aus nachwachsenden Rohstoffen - Vergleichende Oekobilanz für Loosefill_Packmittel aus Stärke bzw. aus Polystyrol* (renewable resource-based plastics - comparative environmental balance sheet for starch and polystyrene-based cushioning materials)	2002	Bayrisches Institut für Anngewandte Umweltforschung und -technik (BIFA GmbH), Institut für Energie- und Umweltforschung (IFEU), Flo-Pak BmbH, 488 p (www.bifa.de - www.ifeu.de).	Deutsche Bundesstiftung Umwelt, Germany	. Bayrisches Institut für angewandte Umweltforschung und -technik (BIFA) . Institut für Energie und Umweltforschung (IFEU) . Flo-Pak GmbH, Germany	Yes
AKIYAMA M., TSUGE T., DOI Y., *Environmental life cycle comparison of polyhydroxyalkanoates produced from renewable carbon resources by bacterial fermentation*	2002	Nagatsuta: Department of Innovative and Engineered Materials, Tokyo Institute of Technology. Endbericht, DBU-Az. 04763	? Japan	Tokyo Institute of Technology, Japan	No
KURDIKAR D., FOURNET L., SLATER S. ET AL., *Greenhouse gas profile of a plastic material derived from a genetically modified plant*	2001	Journal of Industrial Ecology, vol. 4, n° 3, pp. 107-121.	? U.S.A	Monsanto Company . Ecobalance Inc. . Cereon Genomics . Dartmouth College, U.S.A.	No
ESTERMANN R., *Life Cycle Assessment of Mater-Bi and EPS Loose Fills*	2000	Study prepared by Composto, Olten, Switzerland, 43 p.	Novamont SpA, Italy	Composto, Switzerland	Yes
KOSBAR L.L., GELORME J.D. ET AL., *Introducing biobased materials into the electronics Industry: developing a lignin-based resin for printed wiring boards*	2000	Journal of Industrial Ecology, vol. 4, n°3, pp. 93-105. (www.mitpress.mit.edu/ cata log/item)	IBM, U.S.A.	Franklin Associates, U.S.A.	No

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFERE ED
ESTERMANN R., SCHWARZWAEDLER B., GYSIN B., *Life Cycle Assessment of Mater-Bi bags for the collection of compostable waste*	1998	Study prepared by Composto, Olten, Switzerland, 53 p.	Novamont SpA, Italy	Composto, Switzerland	Yes
HAKALA S., VIRTANEN Y ET AL., *Life-cycle assessment, comparison of biopolymer and traditional diaper systems*	1997	Finland: Technical Research Centre of Finland (VTT), 92 p.	Neste Group et Tekes Biopolymers Programme, Finland	Technical Research Centre of Finland (VTT), Finland	No
DINKEL F., POHL C., ROS M., WALDECK B., *Ökobilanz stärkehaltiger Kunststoffe* (environmental balance sheet for starch-based plastics)	1996	Bern, Schweiz, Bundesamt für Umwelt und Landschaft (BUWAL) n°271: vol. 1, pp.1- 188 - vol 2, pp. 189- 536.	Office Fédéral de l'environnement, de la forêt et du paysage (OFEFP) (federal environment, forest and landscape office), Switzerland	Carbotech SA, Switzerland)	Yes

Surfactants

Surfactants are amphiphilic biomolecules that possess emulsifying, softening, wetting or detergent characteristics, depending on their structure. The lipophile group can come from oleochemical raw materials derived from rapeseed, sunflower or palm plants. The hydrophilic component can come from co-products of the starch or sugar industries (sugar beets, derivatives of corn or other grain crops).

1 *Characteristics of the supply chain*

PLANT SECTOR **(FOSSIL SOURCE REPLACED)**	**PRODUCT**[2]	**BIOMASS** **(MOLECULE)**	**PRIMARY USE**[1]
A	Surfactants derived from coconut oil . Alcohol sulphate (AS) . Alcohol ethoxylate sulphate (AES) . Alcohol ethoxylate (AE) . Alkyl polyglucoside (APG)	. Coconut (coconut oil) (CNO) . Corn (glucose)	Washing and cleaning, chemical processes, etc.
B	Surfactants derived from palm oil . Alcohol sulphate (AS) . Alcohol ethoxylate sulphate (AES) . Alcohol ethoxylate (AE) . Alkyl polyglucoside (APG)	. Palm (palm oil) (PO) . Palm (palm kernel oil) (PKO) . Corn (glucose)	Washing and cleaning, chemical processes, etc.
C	Surfactants derived from rapeseed oil: Alcohol ethoxylate (AE)	Rapeseed (oil)	Washing and cleaning
REFERENCE FOSSIL FUEL SUPPLY CHAINS			
A/B/C	Petrochemical (Pc) surfactants: . Linear alkylbenzene sulphonate (LAS) . Alcohol sulphate (AS) . Alcohol ethoxylate sulphate (AES) . Alcohol ethoxylate (AE) . Soap . Secondary alkane sulphonate (SAS)	-	Washing and cleaning, chemical processes, etc.

(1) Because studies were based on weight (kilogram) rather than surfactant property, only the following combinations can be used to compare the various surfactants (Stalmans et al., 1995):

. AS-PKO, AS-CNO, AS-Pc

. *AE_3-PKO, AE_3-CNO, AE_3-Pc*

. *AE_7-PKO, AE_7-CNO, AE_7-Pc*

. *AE_3S-PKO, AE_3S-CNO, AE_3S-Pc*

. *APG-PKO, APG-CNO, APG-Pc*

PRODUCTS IMPACT CATEGORY[7]	**Surfactants derived from coconut oil (CNO)**	**Surfactants derived from palm oil (PO)**	**Surfactants derived from rapeseed oil[1]**
Primary use	*Washing and cleaning*		
Reference supply chain	**Fossil surfactants**		
Consumption of non-renewable energy	++	++	+
Fossil greenhouse effect	++	++	+
Eutrophication	?[2]	?[2]	- -
Acidification	+[3]	+[3]	0[3]
Destruction of the ozone layer	n.d.	n.d.	n.d.
Photochemical pollution	0[3]	0[3]	0[3]
Terrestrial toxicity	0[3]	0[2]	- -[3]
Aquatic toxicity	+[3]	0[3]	- -[3]
Human health	+/-[3]	+/-[3]	?[3]

(1) This column presents the results of a single study (MAFF, 1999).
(2) Study results are conflicting (Keller et al., 1996) (MAFF, 1999).
(3) Weak data.

By comparison with petrochemical surfactants, in the "non-renewable primary energy" and "greenhouse effect" impact categories, the performance of plant resource sub-supply chains is generally favourable. However, performance in the other impact categories is not defined because of either:

- a lack of data, or
- conflicting data, specifically data on the three toxicity impact categories (human, terrestrial, aquatic).

Comparison among the sub-supply chains is difficult and delicate because the three available LCA studies are not based on functional units that reflect the function of surfactants (quantities used, etc.).

3 *Influencing parameters and areas for improvement*

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT
STRONG	Raw material used (coconut oil, palm oil, rapeseed)	. Resource use . Greenhouse effect . Eutrophication	All	Optimize the choice of raw material
	Production-phase technology (source of energy for production of oil: co-products of the production of oil or fossil resource)	. Resource use . Greenhouse effect	Surfactants for which co-products of crops can be used as energy sources	Encourage the use of co-products as energy sources for the production phase
	Agricultural-phase emissions (use of fertilizers and plant protection products)	. Resource use . Greenhouse effect	Pesticides for the production of vegetable oils	Encourage a rational agricultural phase
	Production-phase technology: procedures involved in the production and extraction of vegetable oils (size of the facility)	Greenhouse effect	Palm oils (methane emitted during anaerobic digestion)	Recover the methane emitted during production
WEAK	Transportation (raw materials)	. Resource use . Greenhouse effect	All	-
INDETERMINATE	Performance and quantity of surfactants used per functional unit, as compared with conventional products	All	All (depending on the application and the interaction with the other components of the final product)	Improve the intrinsic performance of surfactants
	Agricultural practices (sustainable farming practices, specifically palms in Asia)	-	Palm or coconut oil-based surfactants	Study the effect of sustainable agriculture in producing regions

4 Quality of studies selected

Range of scenarios	**X**				
Reliability of studies			**X**		
Technological sensitivity				**X**	
Geographical sensitivity			**X**		
Consistency of results			**X**		
Need for further data				**X**	
	↑ Very weak	↑ Weak	↑ Moderate	↑ Strong	↑ Very Strong

All the studies were based on the same inventory, conducted in 1995. No significant reviews were identified for this supply chain.

Reliability is moderate because of the single source of data, which was provided by the producers.

Technological sensitivity is linked to oil extraction.

The consistency of results reflects the fact that the vast majority of the studies are based on the same basic data, i.e. the 1995 inventory.

Missing or highly uncertain data:

- update of the inventory published in 1995,
- integration of use and end-of-life phases into the LCA studies,
- study of the sustainability of oil-palm farming (deforestation, etc.),
- assessment of environmental impact in all impact categories.

5 Quantified assessment of certain indicators

As observed in the various studies, the environmental gain offered by the surfactant supply chain is approximately 30 MJ/kg for consumption of primary non-renewable energy, and approximately 2 kg CO_2 eq/kg for the greenhouse effect. Surfactants derived from palm oil are an exception, providing up to ten times more gain because of superior per hectare yield.

Similarly, while the gain per hectare of cultivated land ranges from 18 to 44 GJ for consumption of primary non-renewable energy, and from 0.3 to 2.8 t CO_2 eq for the greenhouse effect, it can be ten times higher in the case of palm oil-based surfactants.

In the other impact categories, either few quantitative values are provided in the studies, or results are contradictory and therefore not presented in a quantified manner.

6 Discussion

Only three studies cover the complete surfactant life cycle (use and end-of-life, in particular). In addition, LCA data for this supply chain are based on a single source (Hirsinger et al., 1995 - Stalmans et al., 1995).

A functional-unit-based comparison is essential.

In contrast to the other plant resource supply chains, surfactant technology is well developed.

LCA analyses of this supply chain can be based on studies conducted for other plant resource supply chains that also utilize vegetable oils (lubricants and hydraulic fluids, solvents, oil esters).

7 Bibliographic index

26 references inventoried, 13 studies identified, 6 studies selected

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
PATEL M., THEISS A., WORRELL E., *Surfactant production and use in Germany: resource requirements and CO_2 emissions*	1999	Resources, Conservation and Recycling, vol. 25, p. 61-78.	Ministère allemand pour l'éducation, la science, la recherche et la technologie (German department of education, science, research and technology) (BMBF), Germany	. Frauenhofer Institute for Systems and Innovation Research (ISI) . Institut für Energie und Umweltforschung (IFEU), Germany	Yes
PATEL M., REINHARDT G., ZEMANEK G., *Vegetable oils for biofuels versus surfactants: an ecological comparison for energy and greenhouse gas*	1999	Fett/Lipid, vol. 101, n°9, p. 314-320.	Ministère allemand pour l'éducation, la science, la recherche et la technologie (BMBF), Germany	. Frauenhofer Institute for Systems and Innovation Research (ISI) . Institut für Energie und Umweltforschung (IFEU), Germany	No
MAFF, *Cost-benefit analysis, including life-cycle assessment, of oils produced from UK-grown oilseed compared with mineral oil*	1999	Maff project code: NF 0305, Reading: Centre for Agricultural Strategy, 26 p.	Ministery of Agriculture, Fisheries and Food, United Kingdom	Center for Agricultural Strategy, University of Reading, United Kingdom	No
HIRSINGER F., *Ecoprofiles of Surfactants, Comparing Oleochemical and Petrochemical Raw Materials*	1999	CTVO-net - First Workshop on Surfactants, 30/9 and 1/10, 1998, Gülzow, Germany (www.dainet.de/fnr/ctvo/surfact/Hirslang.doc)	Henkel SA, Germany	Henkel SA, Germany	No
STALMANS M., BERENBOLD H., BERNA J.L. ET AL., *European Life-Cycle Inventory for Detergent Surfactants Production*	1995	Tenside Surfactants Detergents, vol. 32, n° 2, p 84-109.	European LCI Surfactant Study Group (CEFIC/ECOSOL), Europe	Franklin Associates Ltd. (Europe, U.S.A.)	Yes
HIRSINGER F., SCHICK K.-P., *A life-Cycle Inventory for the Production of Oleochemical Raw Materials*	1995	Tenside Surfactants Detergents, vol. 32, n° 2, p. 420-432.	European LCI Surfactant Study Group (CEFIC/ECOSOL), Europe	Franklin Associates Ltd., Europe, U.S.A.	Yes

Lubricants and hydraulic fluids

Lubricants include biomolecules that possess lubricating properties, i.e. the capacity to reduce friction and wear, to make a surface smooth and to prevent adherence to it, i.e. to improve the performance of an apparatus. Hydraulic fluids are related to this category. Lubricants and hydraulic fluids are generally obtained from oleochemical raw materials derived, for example, from rapeseed.

1 Characteristics of the supply chain

PLANT SECTOR (FOSSIL SOURCE REPLACED)	**PRODUCT**[2]	**BIOMASS (MOLECULE)**	**PRIMARY USE**[1]
A	Plant-based lubricants and hydraulic fluids	. Rapeseed (seeds) . Coconut (coconut oil) . Corn (seeds)	. Lubricant for chainsaw chains . Hydraulic fluid for forestry machines and road-cleaning vehicles . Metallurgy (fluid for metal working)
B	. Mixed hydraulic fluids . Synthetic esters (petrochemical component: synthetic polyalcohol - polyol)	Rapeseed (seeds)	Hydraulic fluid for forestry machines
REFERENCE FOSSIL FUEL SUPPLY CHAINS			
A/B	Mineral lubricants and hydraulic fluids	-	. Lubricant for chainsaw chains . Hydraulic fluid for forestry machines and road-cleaning vehicles . Metallurgy (fluid for metal working)

2 Environmental impacts – Plant vs. fossil

PRODUCTS **IMPACT CATEGORY[7]**	**Rapeseed oil-based lubricants**	**Plant-based hydraulic fluids**		**Mixed hydraulic fluids**
Primary use	*Chainsaw chains*	*Road cleaning vehicles[4&3]*	*Forestry machines (cutting and transportation)*	*Forestry machines*
Reference supply chain	**Petrochemical-based lubricants and hydraulic fluids**			
Consumption of non-renewable energy	++	0	++	++
Fossil greenhouse effect	++	0	++	+
Eutrophication	- -[1]	0	- -	n.d.
Acidification	0[1]	0	[2]	+[3]
Destruction of the ozone layer	0[3]	0	0[3]	n.d.
Photochemical pollution	0[1]	0	- -	n.d.
Terrestrial toxicity	n.d.	0	0	n.d.
Aquatic toxicity	n.d.	n.d.	n.d.	n.d.
Human health	n.d.	0	0	n.d.

(1) The assessment is based on English data. The study also presents findings on mineral lubricants based on Danish data, which give results that are 55 to 80% lower.

(2) The results of the two studies are conflicting.

(3) The assessment is based on only one study.

(4) The functional unit comprises the entire life cycle of a road-cleaning vehicle that consumes very little hydraulic fluid (154 litres over four years). As a result, the environmental impact is essentially the same whether plant-based or mineral hydraulic fluids are used.

Plant-based lubricants used in open systems (e.g. chainsaw chains) seem to offer the greatest environmental benefit. However, available LCA studies do not provide any information on impacts in terms of terrestrial or aquatic toxicity or human health.

3 Influencing parameters and areas for improvement

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT
STRONG	Choice of functional unit (quantities of lubricant used per functional unit)	All	In comparison with mineral lubricant, 40% less vegetable lubricant for the same volume of wood cut with chainsaws	Improve intrinsic performance for a given quantity
	Useful life	All	Triglyceride hydraulic fluids based on rapeseed oil (higher frequency of replacement than mineral hydraulic fluids)	Extend useful life
	Choice of allocation method (co-products of the production of rapeseed; no allocation; mass, financial or energy-based allocation)	. Resource use . Greenhouse effect . Terrestrial and aquatic toxicity . Eutrophication	. Rapeseed-based lubricants for chainsaw chains . Vegetable oil	-
	Loss of lubricant and hydraulic fluids into the environment	. Terrestrial toxicity . Aquatic toxicity	Lubricants and hydraulic fluids	Reduce direct emissions into the environment
	Production process and method (oil extraction, local or centralized pressing)	. Greenhouse effect . Photochemical pollution	Rapeseed oil	Optimize the production process
WEAK	Transportation of raw materials and the finished product	. Energy . Greenhouse effect	Rapeseed oil	-
INDETERMINATE	Type of raw material used (sunflower, rapeseed)	-	All	Study the effect of the type of raw material used
	Use-phase technology (reduction of leaks during use)	All	Hydraulic fluids	Study the effect of losses into the environment

4 *Quality of studies selected*

Range of scenarios			**X**		
Reliability of studies		**X**			
Technological sensitivity					**X**
Geographical sensitivity			**X**		
Consistency of results		**X**			
Need for further data				**X**	
	↑ Very weak	↑ Weak	↑ Moderate	↑ Strong	↑ Very Strong

No significant reviews were identified for this supply chain.

Reliability is fairly weak because few external reviews are available and studies are sometimes incomplete.

Technological sensitivity is very strong (fluid losses, production processes, product performance and useful life); geographical sensitivity is moderate (agricultural phase).

Consistent results are seen in the case of the "primary non renewable energy" and "greenhouse effect" impact categories. Consistency is much less evident in the other impact categories.

Missing or highly uncertain data:

- quantities of vegetable products needed to replace fossil solvents (with the same function),
- data on lubricant and hydraulic fluid additives,
- data on hydraulic oils and fluids based on mixtures of esters obtained from oleic sunflower oil,
- data on systems that release significant direct emissions into the environment (losses),
- assessment of the environmental impact in terms of eutrophication, destruction of the ozone layer, photochemical pollution, ecosystem toxicity and human health.

5 Quantified assessment of certain indicators

As observed in the various studies, the environmental gain offered by the lubricants and hydraulic fluids supply chain is approximately 35 MJ/kg for consumption of primary non-renewable energy, and approximately 2.5 kg CO_2 eq/kg for the greenhouse effect.

The gain per hectare of cultivated land ranges from 44 to 95 GJ for consumption of primary non-renewable energy, and from 1.7 to 6.8 t CO_2 eq for the greenhouse effect.

In the other impact categories, either few quantitative values are provided in the studies, or results are contradictory and therefore not presented in a quantified manner.

6 Discussion

LCA knowledge of lubricants and hydraulic fluids is poor because no analysis of this type has been conducted of the most recently developed products (mixtures of esters obtained from oleic sunflower oil with additives that improve fluid stability).

Conditions of use, allocation of co-product emissions and quantities needed are important parameters for this supply chain.

LCA analyses of the lubricants and hydraulic fluids supply chain can be based on studies conducted for other plant resource supply chains that also utilize vegetable oils (surfactants, solvents, oil esters, etc.).

7 Bibliographic index

27 references inventoried, 11 studies identified, 4 studies selected

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
VAG C., MARBY A., KOPP M., FURBERG L., NORRBY T., *A comparative life cycle assessment of the manufacture of base fluids for lubricants*	2002	Journal of Synthetic Lubrication, vol. 19, pp. 39-51.	Statoil, Sweden	Statoil Lubricants & Developpement, Nynäshamn, Sweden	No
. MCMANUS M., *Life-cycle assessment of rapeseed and mineral oil based fluid power systems* . BURROWS C.R., HAMMOND G.P., MCMANUS M. C., *Life-Cycle Assessment of Oil Hydraulic Systems for Environmentally Sensitive Applications*	2001 1998	Thesis, University of Bath, 257 p. ASME: Fluid Power Systems and Technology, FPST-vol. 5, pp. 61-68.	University of Bath, United Kingdom	University of Bath, United Kingdom	No
. HERBENER R., REINHARDT G.A., *Ökobilanz von Schmierstoffen aus Rapsöl im Vergleich zu konventionellen Schmierstoffen* (Life-cycle analysis of lubricants from rapeseed oil as compared with conventional lubricants) . REINHARDT G.A., HERBENER R., GÄRTNER S.O., UIHLEIN A., *Life-cycle analysis of lubricants from rape seed oil as compared with conventional lubricants* . ZEMANEK G., REINHARDT G.A., *Notes on life-cycle assessments of vegetable oils*	March 2001 2001 1999	Fachagentur Nachwachsende Rohstoffe e.V. (ed.), Proceedings of the 7th Symposium Biobased materials for chemistry, Gülzow, Dresden. Heidelberg: Institute for Energy and Environmental Research (IFEU) Fet-Lipid, vol. 101, n° 9, pp. 321-327.	Institute for Energy and Environmental Research (IFEU), Germany	Institute for Energy and Environmental Research (IFEU), Germany	No

TITLE	**DATE**	**SOURCE**	**MANDATED BY**	**CONDUCTED BY**	**REFEREED**
. MINISTRY OF AGRICULTURE, FISHERIES AND FOOD OF THE UK (MAFF), *Cost-Benefit Analysis, including Life-Cycle Assessment, of oils produced from UK-grown oilseeds compared with mineral oils*	1998	MAFF project code: NF 0305. Reading: Centre for Agricultural Strategy, 26 p.	. Ministry of Agricultures, Fisheries and Food of UK, United Kingdom . Scottish Office Agriculture Environment and Fisheries Department, United Kingdom	. Scottish Agricultural College (SAC), United Kingdom . Centre for Agricultural Strategy, University of Reading, United Kingdom	No
. WIGHTMANN P., EAVIS R., BATCHELOR S., WALKER K., BENNET R., CARRUTHERS S., TRANTER R., *Life-Cycle Assessment of chainsaw lubricants made from rapeseed oil or mineral oil*	1999	??			
. WIGHTMANN P., EAVIS R., BATCHELOR S., WALKER K., BENNET R., CARRUTHERS S., TRANTER R., *Comparison of rapeseed and mineral oils using Life-Cycle Assessment and Cost-Benefit Analysis*	1999	Oléagineux, Corps gras, Lipides, vol. 6, n°5, pp. 384-388.			

Solvents

Solvents are biomolecules with properties that enable them to dissolve, suspend or extract other substances without causing chemical changes in either the substances or themselves. Most solvents are derived from vegetable oils or their esters (VOME from rapeseed, sunflower, soy, etc.), or from esters of fermentation-derived organic acids (acetic, citric, lactic, etc.).

1 *Characteristics of the supply chain*

PLANT SECTOR (FOSSIL SOURCE REPLACED)	**PRODUCT**[2]	**BIOMASS (MOLECULE)**	**PRIMARY USE**[1]
A	. Detergents and degreasing agents . Methyl esters (RME)	. Rapeseed (oil)	Cleaning and degreasing in the metallurgy industry
B	. Detergents and degreasing agents . Ethylhexyl laurate (EHL)	. Coconut (oil)	Cleaning and degreasing in the metallurgy industry
C	Inks (solvents in lacquers)	. Soy (oil) . Wood (tall oil rosin)	Lithographic printing (sheet-fed)
D	Inks (black and colour)	. Rapeseed (oil) . Soy (oil)	Graphics industry
REFERENCE FOSSIL FUEL SUPPLY CHAINS			
A/B	Solvents (mixture of dearomatized C10-C12 hydrocarbons)	-	Cleaning and degreasing in the metallurgy industry
D	Classic inks (black and colour)	-	Graphics industry

2 *Environmental impacts – Plant vs. fossil*

PRODUCTS IMPACT CATEGORY[7]	**RME detergent[1]**	**EHL detergent[1]**	**Rapeseed-based black ink[1]**	**Soy-based black ink[1]**	**Rapeseed-based colour ink[1]**	**Soy-based colour ink[1]**
Primary use	*Cleaning and degreasing in the metallurgy industry*			*Printing in the graphics industry*		
Reference supply chain	**Classic solvents** (**mixture of dearomatized C10-C12 hydrocarbons**)			**Classic inks**		
Consumption of non-renewable energy	++	++	++[3]	++[3]	++[3]	++[3]
Fossil greenhouse effect	0[2]	++[2]	++	++	++	++
Eutrophication	- -	0	- -	- -	- -	- -
Acidification	0	+	++	++	++	++
Destruction of the ozone layer	++	++	++	++	++	++
Photochemical pollution	++	++	n.d.	n.d.	n.d.	n.d.
Terrestrial toxicity	-	n.d.	- -[4]	- -[4]	- -[4]	- -[4]
Aquatic toxicity	- -	- -	- -[4]	- -[4]	- -[4]	- -[4]
Human health	+	++	++	++	++	++

(1) The comparison with the conventional supply chain is based on only two LCA studies (first and second column: Vollebregt et al., 1999; columns three to six: Rafenberg et al., 1998).

(2) In terms of the greenhouse effect, the performance of rapeseed methyl esters (RMEs) is much less favourable than that of ethylhexyl laurate (EHL). This can be partly accounted for by CO_2 from tillage emissions and N_2O emissions from rapeseed.

(3) Impact category results: resource use.

(4) The two impact categories are combined in one: ecotoxicity.

Few studies have examined the production of solvents via the plant resource supply chain, although the rapeseed data set is the most complete in existence.

3 *Influencing parameters and areas for improvement*

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT
STRONG	Choice of functional unit (quantity used per functional unit in comparison with conventional products)	All	All	Improve intrinsic performance of the vegetable solvent
	Raw material used (rapeseed, coconut)	. Resource use . Ecotoxicity . Eutrophication . Acidification	. Detergents and degreasing agents . Black and colour ink	-
	Allocation of emissions associated with co-products	All	Co-products of the production of rapeseed oil	Ensure market opportunities for co-products
	Production-phase technology (e.g. oil extraction)	. Resource consumption . Summer smog . Toxicity	Oil and coconut-based products	Improve the oil-extraction phase
	Agricultural-phase emissions (fertilizer production and use)	. Resource use . Greenhouse effect . Acidification	Methyl esters	Encourage a rational agricultural phase
	Agricultural practices (conventional tillage, reduced tillage, no till)	. Resource use . Ecotoxicity . Eutrophication	Soy for vegetable inks	Improve agricultural practices
WEAK	Transportation	Resource use	All	-
INDETERMINATE	Type of end-of-life recovery (recycling could have a significant impact on the performance of vegetable oils)	. Greenhouse effect . Ecotoxicity . Human toxicity-	All	Ensure that end-of-life recovery is appropriate and effectively implemented
	Production-phase technology: change in product composition (partial replacement of tall oil resin with soy oil)	. Destruction of the ozone layer . Resource use . Ecotoxicity . Eutrophication	Soy-based inks	Replace tall oil resin with soy oil
	Products replaced	. Greenhouse effect . Ecotoxicity . Human health	All products	Replace solvents that have the greatest environmental impact

4 Quality of studies selected

Range of scenarios		**X**			
Reliability of studies		**X**			
Technological sensitivity				**X**	
Geographical sensitivity			**X**		
Consistency of results		**X**			
Need for further data				**X**	
	↑ Very weak	↑ Weak	↑ Moderate	↑ Strong	↑ Very Strong

Very few studies are available on this supply chain. No significant reviews were identified.

Very little quantitative data is available, and the reliability of studies is difficult to assess.

Technological sensitivity is strong in the case of ethylhexyl laurate derived from coconut oil.

The consistency of results cannot be assessed because the number of LCA studies available is insufficient.

Missing or highly uncertain data:

- quantities of vegetable products needed to replace fossil solvents (with the same function),
- emissions from inputs to vegetable solvent production processes,
- solvent emissions during the use phase,
- emissions associated with solvent end of life,
- complete assessment of various solvents derived from the plant resource supply chain, as well as their optimized fossil counterparts (e.g., reduction of quantities used),
- assessment of the environmental impact in terms of photochemical pollution and ecotoxicity.

5 *Quantified assessment of certain indicators*

A single study presents results in absolute terms for two solvents. The environmental gain observed ranges from 34 to 51 MJ/kg for consumption of primary non-renewable energy.

The environmental gain offered by the solvents supply chain per hectare of cultivated land ranges from 20 to 78 GJ for consumption of primary non-renewable energy. The gains achieved are essentially of the same order of magnitude as those associated with the transportation biofuel, lubricant and hydraulic fluid and surfactant supply chains.

In the other impact categories, either few quantitative values are provided in the studies, or results are contradictory and therefore not presented in a quantified manner.

6 *Discussion*

LCA knowledge of the solvent supply chain is poor and applications are very diverse.

A functional-unit-based comparison (conditions of use and quantities required) is essential.

LCA studies of solvents can be based on studies of other plant resource supply chains (surfactants, lubricants, oil esters/transportation biofuels) because these products are derived from the same vegetable oils.

The impact of fossil solvents can be reduced through the use of other solvents not derived from the plant resource supply chain (e.g., water-based paints instead of paints containing organic solvents).

7 Bibliographic index

9 references inventoried, 6 studies identified, 3 studies selected

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
TOLLE D.A., EVERS D.P., VIGON B.W., SHEEHAN J.J., *Streamlined LCA of Soy-Based Ink Printing*	2000	International Journal of LCA, vol. 5, n°6, pp. 374-384.	. Iowa Soybean Promotion Board . Illinois Soybean Checkoff Board (U.S.A.)	Battelle, U.S.A.	No
RAFENBERG C., MAYER E., *Life cycle analysis of the newspaper Le Monde*	1998	International Journal of LCA, vol. 3, n° 31, pp. 131-144.	Le Monde, France	Université de Paris VII U.F. Environnement, France	No
. TERWOERT J., VOLLEBREGT L., FEBER M. ET AL., *LCA of cleaning products in the metal industry - a comparison between solvent products and vegetable oil based fatty acid esters* . VOLLEBREGT L., TERWOERT J., *LCA of cleaning and degreasing agents in the metal industry*	1996 1998	Amsterdam, Chemiewinkel, University of Amsterdam, 132 p. International Journal of LCA, vol. 3, n° 1, pp. 12-17.	European Union	Chemiewinkel, University of Amsterdam, Netherlands	No

Chemical and other intermediates

Sealant, 1,4-butanediol (BD), methyl ethyl hydroxyethyl cellulose (MEHEC)

Chemical intermediates are biomolecules that have no specific final use, but are involved in the production of a number of chemical products that do have a clearly defined final use. “Other” intermediates include biomolecules that are not surfactants, nor are they lubricants, solvents or chemical intermediates. This category includes various products, including binders and additives.

1 Characteristics of the supply chain

PLANT SECTOR **(FOSSIL SOURCE REPLACED)**	**PRODUCT**	**BIOMASS** **(MOLECULE)**	**PRIMARY USE**
A	Binder	Flax (seed)	UV-hardening binder (additive-free lacquer) for flat surfaces
B	Lacquer	Flax (seed)	Protective layer for outside surfaces
C	1,4-butanediol (BD)	Corn (seed)	Synthesis of various chemical products
D	MEHEC (methyl ethyl hydroxyethyl cellulose)	Wood (cellulose)	Additive for cementing materials
REFERENCE FOSSIL FUEL SUPPLY CHAINS			
A/B	Sealant (50% tripropyleneglycoldiacrylate - TPGA - and 50% bisphenol-A-diglycidetheracrylate - DGEABA)	-	Binder
C	1,4-butanetiol (BD)	-	Synthesis of various chemical products

PRODUCTS IMPACT CATEGORY[7]	**Linseed oil-based binder**[1]	**1,4-butanediol containing glucose derived from corn (BD)**[1]
Primary use	*Lacquer*	*Synthesis of various chemical products*
Reference supply chain	**Petrochemical products**	
Consumption of non-renewable energy	++	n.d. [2]
Fossil greenhouse effect	++	++
Eutrophication	n.d.	0
Acidification	n.d.	- -
Destruction of the ozone layer	n.d.	n.d.
Photochemical pollution	n.d.	- -
Terrestrial toxicity	n.d.	++
Aquatic toxicity	n.d.	- -
Human health:		
. by inhalation	n.d.	- -
. carcinogenic	n.d.	++

(1) Only one study is available that compares products of the plant resource supply chain with conventional products for these sub-supply chains.

(2) Consumption of non-renewable energy is not detailed in the study (Vignon et al., 1996). According to the authors, the plant-based supply chain offers no advantage from the point of view of total energy consumption. More electricity is required to product glucose-based BD than fossil-based BD. However, this does not explain why the ratio of carbon dioxide emissions to energy is exceptionally high for the petrochemical scenario, but of the same order of magnitude as in other similar LCA studies for the plant scenario. It is very possible that the inventory overestimates the carbon dioxide emissions or underestimates energy consumption.

Because of the few studies available and the wide range of chemical and other intermediates, it is not possible to compare the plant sub-supply chains and identify the best one in terms of environmental impact.

3 Influencing parameters and areas for improvement

INFLUENCE OF PARAMETER	PARAMETER	CORRESPONDING IMPACT CATEGORIES	PRODUCT CONCERNED	AREAS FOR IMPROVEMENT
STRONG	Production-phase technology (consumption of electricity and preparation of the oil for synthesis of 1,4-butanediol)	. Resource use . Greenhouse effect	Preparation of the oil accounts for approximately one quarter of the energy consumed in the synthesis of 1,4-butanediol	-
	Agricultural practices (making fertilizer available)	. Resource use . Greenhouse effect	1,4-butanediol (40% of the consumption required for the production of corn)	Encourage a rational agricultural phase
	Raw material (corn)	. Resource use . Greenhouse effect	1,4-butanediol	-
	Type of production (local or centralized pressing of the oil)	. Resource use . Greenhouse effect	Binders Lacquers	-
INDETERMINATE	Choice of functional unit (quantity of product used per functional unit)	All	-	-
	Raw material used	All	Rapeseed oil and VOME	-
	Products replaced	. Resource use . Greenhouse effect . Photochemical pollution . Human health	Lacquers	-
	Type of end-of-life recovery	All	-	-

4 *Quality of studies selected*

Range of scenarios					**X**
Reliability of studies	**X**				
Technological sensitivity					
Geographical sensitivity					
Consistency of results					
Need for further data					**X**
	↑ Very weak	↑ Weak	↑ Moderate	↑ Strong	↑ Very Strong

The very wide diversity of studies reflects the diversity of the supply chain. No significant review was identified of the chemical and other intermediates supply chain.

Reliability of LCA data is very poor (partial studies, few critical reviews, studies containing inconsistencies in energy and greenhouse-gas performances, etc.).

Missing or highly uncertain data:

- ♦ assessment of the environmental impact of plant product-based chemical intermediates in terms of all impact categories.

5 Quantified assessment of certain indicators

The few studies identified for this supply chain do not reflect its diversity. However, as observed in the studies, the environmental gain offered is 50% greater per kilogram of product for consumption of non-renewable energy and for the greenhouse effect.

It is difficult to compare the various products of the chemical and other intermediates supply chain because the available LCA studies are not based on functional units that reflect the function of the products in question.

In the other impact categories, either few quantitative values are provided in the studies, or results are contradictory and therefore not presented in a quantified manner.

6 Discussion

The chemical and other intermediates supply chain is very heterogeneous and LCA knowledge of it is poor.

Not enough information is available to permit identification of general trends or trends associated with individual sub-supply chains.

Where the few products studied are concerned, the environmental impact in the various impact categories seems to follow trends similar to those of the other plant-based supply chains. The chemical and other intermediates supply chain does offer benefits in terms of the consumption of non-renewable energy and greenhouse gas emissions. As far as the other impact categories are concerned, results are not sufficiently reliable or well documented to permit identification of trends.

7 Bibliographic index

11 references inventoried, 7 studies identified, 2 studies selected

TITLE	DATE	SOURCE	MANDATED BY	CONDUCTED BY	REFEREED
DIEHLMANN A., KREISEL G., *Oekologische Bilanzierung ausgewählter Lackrohstoffe: Vergleich von Bindemitteln auf nativer und petrochemischer Basis* (environmental balance sheet for certain lacquers: comparison of natural and petrochemical binders)	2000	Deutschland, Jena University, ITUC (Institute for Technical Chemistry and Environmental Chemistry), 90 p. (www.chemie.uni-oldenburg.de/oc/metzger/download/lacke/abschlussbericht.htm)	Deutsche Bundesstiftung Umwelt, Germany	Institute for Technical Chemistry and Environmental Chemistry, Jena University, ITUC, Germany	No
VIGON B.W., FREEMAN S.L., LANDUCCI R. ET AL., *Use of Streamlined Life-cycle Assessment for Technology R&D Investment Analysis*	1996	Richland, Columbus, Golden: Pacific Northwest National Laboratory, Battelle Columbus Laboratories, National Renewable Energy Laboratory, 17 p.	Strategic Environmental Research and Development Program (SERDP), U.S.A.	. Pacific Northwest National Laboratory . Battelle Columbus Laboratories . National Renewable Energy Laboratory, U.S.A.	?
ESTERMANN R., SCHWARZWAEDLER B., GYSIN B., Life Cycle Assessment of Mater-Bi bags for the collection of compostable waste	1998	Study prepared by Composto, Olten, Switzerland, 53 p.	Novamont SpA, Italy	Composto, Switzerland	Yes
HAKALA S., VIRTANEN Y ET AL., Life-cycle assessment, comparison of biopolymer and traditional diaper systems	1997	Finland: Technical Research Centre of Finland (VTT), 92 p.	Neste Group et Tekes Biopolymers Programme, Finland	Technical Research Centre of Finland (VTT), Finland	No
DINKEL F., POHL C., ROS M., WALDECK B., Ökobilanz stärkehaltiger Kunststoffe (environmental balance sheet for starch-based plastics)	1996	Bern, Schweiz, Bundesamt für Umwelt und Landschaft (BUWAL) n°271: vol. 1, pp.1- 188 - vol 2, pp. 189- 536	Office Fédéral de l'environnement, de la forêt et du paysage (OFEFP) (federal environment, forest and landscape office), Switzerland	Carbotech SA, Switzerland)	Yes