Sustainability Opportunities and Challenges of the Biofuels Industry

Cesar L. França, Kate Maddigan, Kyle White

School of Engineering
Blekinge Institute of Technology
Karlskrona, Sweden
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Abstract: Liquid biofuels are being produced to displace fossil fuels for transportation, with bioethanol and biodiesel being the primary biofuels produced for this purpose in the world today. While there is consensus on the need for a sustainable biofuels industry, there is little consensus on how to proceed to avoid environmental and social degradation with global biofuel production. A literature review of Life Cycle Analysis (LCA) data, and the generic Strategic Life-Cycle Management (SLCM) and Template for Sustainable Product Development (TSPD) approaches, helped to inform the creation of a specific tool for sustainable industrial biofuels development, called the TSPD for biofuels. Other data collection involved expert and industry dialogue, as well as stakeholder feedback, on the content of the TSPD.

Results showed a variety of sustainability challenges and opportunities, the most significant of which concerns agricultural production. Compelling measures for a sustainable biofuels industry include: cooperation among all stakeholders using a systems approach based on strategic sustainable development, sustainable biofuels certification; and government policies to stimulate research into new technologies and feedstocks, as well as to reduce consumption and increase efficiency.

Keywords: biofuels, bioethanol, biodiesel, life cycle analysis, strategic sustainable development.
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Executive Summary

Liquid biofuels such as biodiesel and bioethanol continue to gain attention as an important renewable energy alternative to fossil fuels in meeting transportation energy needs. However, while they are renewable, the sustainability of biofuels remains questionable, particularly with respect to current production practices.

Many concerns have been raised about the competition between land for food versus energy production, especially in the context of future rising populations, increasingly finite resources, and the perpetuation of ecologically and socially unsustainable agricultural practices. The International Energy Agency predicts that, based on current trends, the increased demand for oil in the coming decades will come largely from the transportation sector, and biofuels are expected to play a large part in displacing fossil fuels for transportation. With the fast growth of the industry comes the urgency for a strategy of sustainable biofuels production, while it is still in relatively nascent stages, in order to maximize ecological and social returns.

This research attempts to answer three main questions, with a scope limited to bioethanol production in Brazil and biodiesel production in Canada. Primarily, what are some major sustainability opportunities and challenges of the biofuels industry? Secondarily, what is the current state of biofuel operations in Brazil and Canada, and thirdly, what first steps toward sustainable biofuel development can be identified?

The response to these questions was researched using tools incorporating a strategic sustainable development approach, as conceived by The Natural Step Framework. Strategic Sustainable Development (SSD) is a planning tool using backcasting from sustainability principles, which assists in dealing with problems strategically rather than one by one as they appear. Backcasting is the approach where a successful outcome is imagined followed by a plan of action of how to get there from today. Sustainability principles are defined by The Natural Step Framework as:

In a sustainable society, nature is not subject to systematically increasing…
1 … concentrations of substances extracted from the Earth’s crust,
2 … concentrations of substances produced by society,
3 … degradation by physical means,
   and, in that society …
4 … people are not subject to conditions that systematically undermine their capacity to meet their needs.

Research methods also explored the combination of scientifically traditional and non-traditional approaches. Traditional Life Cycle Analysis (LCA) is a tool that evaluates impacts of a product throughout its life cycle, from product design to end use, or “cradle to grave.” Strategic Life Cycle Management is based on LCA, however has incorporated SSD by including backcasting from sustainability principles. This allows for an analysis of the industry from a bird’s eye perspective, capturing broadly the industry’s sustainability opportunities and challenges. Establishing this initial broad perspective provided a sustainability direction at the outset, from which a traditional LCA can later proceed.

Sustainable design of products and services has been described as a critical intervention point in moving society toward sustainability. Sustainable Product Development (SPD) methodology, combined with backcasting from sustainability principles was also extensively explored in this research. Templates, or questionnaires, were created for certain stages of biofuel design and development, which provided a venue of engagement for industry, stakeholders (such as regulators and non-government organizations), and sustainability experts. The result was the Template for Sustainable Product Development (TSPD) for biofuels, intended to simplify and strategically guide industry’s efforts toward sustainability. The TSPD can be used by anyone involved or interested in the industry, and can be continually updated as the industry evolves.

Results
Thesis questions were answered by looking at the current state of the industry through the “lens” of the four sustainability principles. The research identified several sustainability gaps, as well as opportunities already in practice.

System Condition 1. Large inputs of fossil fuels throughout the life-cycle of biofuels are employed by the industry, which is the main activity contributing to increasing concentrations of substances extracted from the
earth’s crust, which also contributes to greenhouse gas emissions. While Canada relies heavily on fossil fuels for biofuel production, Brazil has found an alternative to some non-renewable energy through the use of agricultural by-products for electricity co-generation.

**System Condition 2.** Persistent pesticides and other agrochemicals are routinely dispersed into the ecosphere during feedstock production in Canada and Brazil. Genetically modified organisms may also increase concentrations of substances produced by society. While they are still of major concern, some feedstock production practices have already been undertaken to reduce or eliminate these, including the use of biological control of pests and insects.

**System Condition 3.** Global biofuel production has been increasingly associated with deforestation, poor agricultural practices, and other degradation to nature by physical means. These activities, and the resulting concern for decreasing biodiversity and local water quality, characterize the industry, particularly in Brazil. Site selection and alternatives to large scale industrial agricultural production in both countries will largely determine the outcome of compliance with this system condition.

**System Condition 4.** Child labour, and inadequate employment and farm incomes within the industry have undermined people’s ability to meet their basic human needs. In the future this could also include the competition of land for food versus energy production, as human populations increase. While these issues in both countries are just as different as they are complex, solutions continue to be explored, generally involving improved community economic development, as well as improved access to education and health care for Brazilians.

This broad overview, as seen through the four system conditions, provides the main sustainability challenges and opportunities of the industry today. The overwhelming impact of biofuel production for both countries was found in feedstock production, or agricultural activities. Many of these challenges are often intrinsically linked with current large scale industrial agricultural production.

First steps toward sustainable biofuel production involve new technologies and feedstocks, government policies and support, sustainable certification systems, and further research and development
by industry.

Many emerging technologies were researched which offer viable sustainability alternatives. These include cellulosic ethanol production processes, restorative agricultural practices using plants such as jatropha, biotechnology, algae, nano-scale biodiesel production, the Fischer-Tropsch process, and thermodepolymerization. While research in these technologies continues, many will not be commercially viable for some time. Large-scale commercial production of cellulosic ethanol for example is still at least a decade away.

Incentives for sustainable biofuel production are lacking for industry, and there is much work to be done in this area. Governments have not used public policy instruments enough to address sustainability challenges of biofuels. Both Canada and Brazil currently mandate the inclusion of biofuel blends as a percent of total fuel sales. This could be coupled with a requirement that biofuels be sustainably produced, according to an independent certified body’s standards. As well, research and development efforts of emerging biofuel technologies should also be supported by governments to address a product’s sustainability performance.

The TSPD for biofuels developed in this research attempted to provide a tool for industry that would reduce the complexity involved in improving a product’s sustainability performance at various life-cycle stages. The TSPD approach originally was developed to guide and simplify sustainable product development for other sectors of industry. While the TSPD for biofuels did improve stakeholder participants’ understanding of biofuels’ sustainability issues, the approach itself still requires further research to determine its full potential.

Educational institutions and non-government organizations could play an important role in developing sustainable production certification systems for biofuels. Without them, the adoption of sustainable production practices on the part of industry will only occur at an unacceptably slow pace. Research in this area is ongoing and due to the complexity involved in standards and certification systems, along with the lack of attention and support of government and the public, will likely not influence production practices for some time.
**Conclusions**

This research found that an overall, bird’s eye view of the industry assists in determining a strategic direction on how the industry is to develop sustainably. Without an initial broad view, the analysis becomes bogged down in details and actions toward sustainability become ad hoc and unfocussed. Several first steps toward sustainability were identified for both Canada and Brazil, and support a strategic direction.

Sustainability challenges aside, current biofuels production provide an important “flexible platform,” or transitional technology, and an immediate alternative to fossil fuels in meeting our transportation energy needs, until more sustainable options become viable for large-scale use in the future. Emerging technologies with higher sustainability attributes are not expected to replace current biofuel production technologies for some time, and therefore the sustainability challenges of today’s biofuels still need to be addressed.

This research did not examine the more “upstream” sustainability consideration of overall energy consumption patterns. It is acknowledged that switching to liquid biofuels alone will not be adequate in a sustainable society as long as overall consumption rates are not reduced.

**Recommendations**

All stakeholders including industry, government, NGOs, and educational institutions have a role to play in ensuring the biofuels industry develops sustainably. Of greatest importance is that all stakeholders acknowledge and address the need for reducing all transportation energy consumption, in addition to the following recommendations specific to the biofuels industry.

Industry could adopt sustainable agricultural practices that both protect ecological systems, and promote local economies. By adopting a strategic sustainable approach now while the industry is still in nascent stages, sustainability can be more easily realized.

Traditionally, NGOs have spearheaded efforts at fair trade and sustainable certification of products. Currently, no certification systems exist for sustainable biofuels, and this is a gap that NGOs, in partnership with other stakeholders, would ideally be suited to fill. Certification is
extremely urgent, as this is an important incentive for companies to produce sustainable biofuels credibly, at a certified, independent body’s standards.

Further research is required in the following areas:

- Substitution and dematerialization of materials and activities of various life cycle stages
- Sustainable Product Development for biofuels, with greater assistance and broader involvement of stakeholders in new TSPD research
- Sustainable biofuels certification, using a strategic sustainable development approach
- Standardized methods for calculating energy balances
- Sustainability challenges and opportunities of genetically modified organisms
- Research on key leverage points for sustainable biofuels production
- Impacts of biofuel production on biodiversity and food security
# List of Acronyms

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<th>Acronym</th>
<th>Description</th>
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<tr>
<td>BAFF</td>
<td>Bio Alcohol Fuel Foundation</td>
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<tr>
<td>BTH</td>
<td>Blekinge Tekniska Högskola (Blekinge Institute of Technology)</td>
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<tr>
<td>B20</td>
<td>Diesel blend of 20% Biodiesel and 80% petroleum diesel</td>
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<tr>
<td>CFC</td>
<td>Chlorofluorocarbon</td>
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<tr>
<td>EPA</td>
<td>United States Environmental Protection Agency</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
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<tr>
<td>GMO</td>
<td>Genetically Modified Organism</td>
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<td>Ha</td>
<td>Hectare</td>
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<tr>
<td>LCA</td>
<td>Life Cycle Assessment</td>
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<tr>
<td>MSLTS</td>
<td>Masters of Strategic Leadership Towards Sustainability</td>
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<td>MSPD</td>
<td>Method for Sustainable Product Development</td>
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<td>NGO</td>
<td>Non-Government Organization</td>
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1 Introduction

Issues associated with our dependence on fossil fuels, such as energy security, and greenhouse gas (GHG) emissions, has driven global interest in the displacement of fossil fuels by biofuels. Demand for transportation energy is expected to increase the most in the coming decades, over electricity or industrial uses (IEA 2004), and this demand will largely be for liquid fuels.

Biofuels do present an opportunity to displace fossil fuel use in meeting some of the energy demand for current transportation needs, and a solution to the challenge of transitioning to a sustainable society.

Currently biofuels meet a variety of human needs, including:

- Energy for mobility using existing infrastructure
- Energy for electricity, and domestic heating
- Cleaner atmosphere from reduced emissions
- National security by using more local energy production
- Poverty alleviation, as biofuels could provide greater income for the agricultural sector, employment in rural areas, and community development.
- Additional needs met by other products from biofuels and associated co-products include: paint; lubricants; bioplastics; biopolymers; pesticides; glycerine; organic fertilizers; and also biomass for electricity generation.

Transportation energy demands are expected to outpace that of other energy sectors in the coming decades, based on current trends (Figure 1.1), and current ethanol and biodiesel production is not sufficient to displace all fossil fuels at current or projected consumption rates (IEA 2004). To meet future transportation energy needs without the use of fossil fuels, other schemes must be employed, such as reducing consumption through energy conservation, and new technologies for transportation (IEA 2003). Measures introduced by governments could improve the contribution of biofuels in the overall renewable energy mix, making the transition to more sustainable transportation easier.
Many arguments against the production and use of biofuels for transportation include the competition posed by energy crops for food crops (Tillman 1999), competition of small farmers with large agri-energy corporations (Kaltner 2005), and deforestation resulting from land clearing for energy crops (IEA 2004). There is also the debate that they should not be produced for transportation at all, but rather for domestic heating where the opportunity for reduction of GHG emissions is greater (Azar 2000).

The increased use and production of biofuels brings greater pressure on resources and elevated concern for the ability of non-industrialized nations to meet basic human needs. While many people do not have enough to eat in the world, this is due more to unequal distribution of food and wealth than a shortage of food or agricultural land, however this could become a problem in the future with rising global populations and shrinking resources. Greater pressure on resources such as land, can lead to deforestation and the resulting loss of biodiversity (Millenium Ecosystem Assessment 2005).

Another argument against the use of liquid biofuels for transportation energy is that greater GHG reductions can be realized if biomass is used for domestic heating or electricity rather than for production of liquid biofuels; larger energy losses are associated with converting biomass into liquid or gaseous forms, and thus more carbon dioxide (CO2). However, the
demand for transportation energy is much greater than for heating or electricity, is increasing at a much faster rate, and alternatives to fossil fuels for transportation energy, such as hydrogen, are not yet technically available (Azar 2000).

Further problems can arise if large-scale production of biofuels relies on intensive cash-crop monocultures, since this could result in large energy corporations dominating the sector. Many small farmers, particularly in emerging economies, are realizing opportunities for increasing production, and this trend could be reversed if large operations come to dominate this market. New international platforms are being set up to fill the gap in addressing these complex problems (Food Agriculture Organization 2006).

Despite the problems posed by broad-scale use and production of biofuels like ethanol and biodiesel, the advantages they offer in the transition to a sustainable society cannot be ignored. Liquid biofuels are not only a viable alternative to fossil fuels, they may offer the only alternative available in meeting today’s transportation energy needs (providing energy conservation and efficiency also play an equally significant role) and present an excellent transitional technology to more sustainable long-term options. They do not require huge societal and economic transformations in meeting energy needs, for example in requiring large changes in our current infrastructure for producing the energy, or in the technology necessary for using the energy (with some exceptions they can be used with existing vehicles). For this reason they are considered a “flexible platform” and a transitional technology, allowing society the opportunity to immediately begin moving away from the use of fossil fuels, as we explore and develop the commercial and technological viability of longer term sustainability alternatives.

Emerging alternatives to current feedstocks and technologies for the production of liquid biofuels must provide improvements to current sustainability challenges. Currently, cellulose and wood crops are the most promising of these new technologies, potentially producing ethanol more efficiently than current technologies, and using much less fossil fuels in production (IEA 2003). Further research, led by industry, is needed to make this option economically viable, and assistance by governments is crucial to help lower costs and assist in the transition to a more sustainable transportation options (Gielen & Unander 2005).
However, many products initially considered safe are often introduced without a thorough understanding of their social and ecological implications. This has often resulted in costly damage to the biosphere, as discovered with freons (CFCs) and their subsequent damage to the ozone layer (Geiser 2001).

Many of these environmental problems can be eliminated through strategic planning mechanisms early at the product or process design stage, rather than via “end-of-pipe” solutions, as is so often the case. Bhamra et al. (1999) have found that companies believe “…beyond a certain point in the design process it is extremely difficult to alter certain product features that are key to the environmental performance.” Improving a product’s environmental performance can be achieved through the “upstream” approach of sustainable product development (SPD).

SPD provides a powerful leverage point in not only addressing the sustainable design of a product, but also the sustainable development of an entire industry. This research explored an SPD tool referred to as the Template for SPD (TSPD) (Ny et al.). The template is developed through engagement of experts knowledgeable both in sustainability, and in the product under assessment. Through a series of sustainability-based questions and statements about the product, the social, ecological and economic/strategic sustainability “story” for that product evolves, and the resulting “template” can be used as a communication or educational tool, by industry or stakeholders.

To date, application of TSPD has been limited to a single producer, Matsushita Electric Group (Matsushita) in Japan (Ny et al.), and three of its representative products; televisions, refrigerators and recycling plants. The initial success of this project however has led to plans to expand the template to other applications (Grierson and Durgin 2005). The approach developed for the product category of televisions was applied to ethanol and biodiesel categories.

Supporting the SPD approach are a myriad of tools for environmental management and monitoring of sustainable development. Taken together they can be complex, however many can complement each other, and be made more strategic (Ny et al. 2006).

For example, Life Cycle Analysis (LCA) is a traditional tool used to determine environmental impacts throughout the life cycle of a product or
process, from design to end use, or “cradle to grave.” This tool however does not offer a sustainability perspective or assist in strategic planning (Andersson et al. 1998). By applying strategic sustainable development (SSD) to the LCA analysis, the industry’s main sustainability opportunities and challenges are captured, and strategic planning with a sustainability objective is then possible. This approach is called Strategic Life Cycle Management (SLCM) (Ny et al. 2006) and was used in this research, including the development of the TSPD for biofuels.

SSD is based on “backcasting from sustainability principles,” which involves envisioning a sustainable future, and asking the question, what can we do now to get there from here (J.B. Robinson 1990)?

1.1 Aim and Scope

This report outlines research and responses to the following thesis questions, with a scope of ethanol production in Brazil, and biodiesel production in Canada:

Primary

• What are some major sustainability opportunities and challenges of the biofuels industry?

Secondary

• What is the current state of biofuel operations in Brazil and Canada?
• What first steps toward sustainable biofuel development can be identified?

One of the primary contributions to the body of academic research that this thesis aims to provide is to further expand the understanding of the role and limitations of the TSPD generally, and more specifically for biofuels. It is hoped that the results of this study will further contribute to the development of a library of expert-led sustainability templates that can guide product development in a wide range of product groupings.

Through the development of such templates within the relatively new biofuels sector we aim to further refine this methodology to improve its effectiveness.
1.2 Target Audience

The target audience for SPD tools has traditionally been limited to individuals involved in product and process research and design, intended to be of use to individuals involved in producing biofuels, and ethanol and biodiesel in particular. However this thesis is also intended to bring questions of sustainable biofuel production to a larger body of decision makers including

- Regulatory officials
- Stakeholders (including NGOs)
- Industry associations
- Scientific community
- Investors
- SPD practitioners

Of particular interest is the potential for this methodology to be used to improve engagement and dialogue between stakeholder groups and in the process establish a consensus for sustainable biofuel production based on clearly defined sustainability principles. Such a process has previously been successfully implemented between the PVC industry and environmental non-governmental organizations (NGO) (Everard et al. 2000).
2 Methods

Sustainable production of biofuels requires methods to deal with various complex social, ecological and economic activities, serving to guide planning and production processes towards sustainability. The methods used for investigating stated research questions, acquisition of new knowledge, and integrating previous studies were based on: Logic and Inference; Literature Review; backcasting from sustainability principles (Holmberg and Robèrt 2000); MSPD (Byggeth et al. 2006); and SLCM, (Ny et al.).

For this specific study “backcasting from sustainability principles” is the methodology defining system conditions that must be met in a sustainable society. SLCM is a combination of traditional LCA, and backcasting from principles. MSPD is a method intended to complement existing sustainability management tools and quantitative product analysis tools. From this approach the TSPD emerged, as a simplified technique to addresses specific questions that are aligned with the sustainable product development processes.

2.1 Backcasting from Sustainability Principles

SSD is the process of planning ahead with the ultimate objective of sustainability in mind, instead of dealing with the problems one by one as they appear. Backcasting is the approach where a successful outcome is imagined followed by the question “what shall we do today to get there?"

The international non-governmental organization, The Natural Step (TNS), developed and tested this approach to help organizations incorporate SSD into their operations.
The Natural Step Sustainability Principles

Basic Principles for Sustainability

In a sustainable society, nature is not subject to systematically increasing...

1 …concentrations of substances extracted from the Earth’s crust,
2 …concentrations of substances produced by society,
3 …degradation by physical means,
and, in that society...
4 …people are not subject to conditions that systematically undermine their capacity to meet their needs.

These principles were designed to fit a set of strict criteria including that they should:

(i) be based on a scientific world view,
(ii) describe what is necessary to achieve sustainability,
(iii) be general enough to include all activities relevant to sustainability,
(iv) not overlap to allow comprehension and develop indicators for the monitoring of transitions, and
(v) concrete enough to guide problem analysis and decision making (Holmberg and Robèrt 2000).
2.1.2 The ABCD Planning Method

Also called ABCD analysis, this is a specific tool to apply "backcasting from basic principles of success" through four logical steps:

**Figure 2.1** Backcasting from sustainability principles as illustrated by the A-B-C-D planning method. *Source: Ny et al. 2006.*

**Awareness - A**

The first step aims to involve and align organizations and projects around a shared mental model or a common understanding of sustainability, demonstrating how society and organizations are part of the whole system, the biosphere and what the main mechanisms societies are contributing to violate in our living system.
Baseline Mapping - B

What does society or organisation looks like today? This stage consists of an analysis of current reality to identify major flows and impacts of the organization. Sustainability principles are used to scrutinize process and activities and to allow identification of critical sustainability issues, their threats and opportunities. This includes the impacts of the entire supply chain and evaluation of products and services, energy, capital and the social context, providing a basic platform to understand how changes can be introduced further on.

Creating a Vision - C

What does organisation look like in a sustainable society? In this stage a compelling long term vision for a sustainable organization is created and solutions to problems are identified.

From the vision, organizations develop strategies and action plans for moving towards sustainability. Strategies are developed based on a principal vision of success. This approach prevents decision makers setting a direction based on addressing today’s problems, instead they develop a shared vision and goal of sustainability with a series of actions to move the organization towards the eventual sustainability vision. At this stage opportunities and potential actions are identified and priority is given to measures that move the organization toward sustainability fastest. Such priorities are considered as "lower hanging fruits".

Down to Action - D

Suggestions from the C-list are prioritized according to their potential to serve as stepping stones to move the organization towards sustainability.

2.2 Strategic Life Cycle Management (SLCM)

SLCM is a combination of traditional LCA and backcasting that provides a “bird’s eye” approach, or overall view, with a long enough timescale to identify major future sustainability challenges and opportunities.

LCA is a tool for assessing the environmental impact of products, processes or services from raw materials to waste products, which is sometimes used to identify “hot spots”, or parts of the life cycle that are critical to the total
environmental impact. Much of the research in current studies uses a traditional LCA methodology, which has the strength of being an operational tool for quick improvements, but does not in itself offer a function for strategic planning (Andersson et al. 1998). The SLCM addresses the challenges of traditional LCA by integrating a backcasting approach, and was used in this research.

The SLCM approach is not meant to offer an exhaustive list of every potential problem that may be encountered with biofuels now or in the future, rather it is meant to provide a strategic direction for sustainable biofuels development.

The stages 1, 2, 3 and 4 illustrated in figure 2.2, describe the step by step approach of the SLCM planning method that was used to gather the necessary information for development of a TSPD for biofuels.

![Strategic Life Cycle Management](image)

**Figure 2.2** SLCM Framework.
1. Goals and Scope definition
Systems boundaries related to bioethanol and biodiesel production were identified, (Figure 2.3). For the purpose of this research we looked at agriculture for feedstock production (sugarcane for bioethanol in Brazil and canola for biodiesel in Canada), processing of raw feedstock into fuel, and end use (combustion).

![Figure 2.3 Goals and Scope Definition.](image-url)
2. Process and Activity Maps

Within each area, processes and sub-process activities were identified, and life cycle activity maps were created.

![Process and Activity Maps Diagram]

**Figure 2.4** SLCM Process and activity maps created for agriculture, processing, and end use (combustion)
3. Scrutinizing Process Activity

Each process activity was analyzed using the four sustainability principles, and a table with results created.

**Figure 2.5** Scrutinizing Process Activities using Sustainability Principles (SP's).
4. Solution to problems

Solutions were brainstormed and compelling measures identified for further implementation (C-step).

Figure 2.6  Brainstorming Solutions to Problems.

2.3 Template for Sustainable Product Development (TSPD)

The TSPD approach was originally developed from the MSPD (Byggeth 2001). The first TSPD was created for the television industry (Ny et al.), and was adapted in this research to inform the development of the biofuels template. The television template, however, originally consisting of 3 templates, was further reduced to 2 templates for the biofuels industry.
In discussion with the researchers of the original TSPD, and in acknowledgement of the unique product development characteristics of biofuels in general (and bioethanol and biodiesel in particular), it was decided to adapt the TSPD approach and develop a template for biofuels.

The TSPD for biofuels adopted traditional product developments stages aligned with A-B-C-D planning method to address specific questions. The first two stages (figure 2.7) provided a large perspective: an overview of how to create a principle product. Steps three, four and five that are related to more specific activities in industries (production, launching and marketing processes), were not in the scope of this study.

![Figure 2.7 Stages of product development in the MSPD. Items in bold indicate the stages extracted from the MSPD and adopted in the TSPD for biofuels.](image-url)
## 2.3.1 Template for Sustainable Product Development applied to Biofuels

The data and information collected during the SLCM research phase was used to inform the development of the TSPD for biofuels, and was in many cases incorporated into the guidance provided to prospective users.

The templates for biofuels used the A-B-C-D process applied through backcasting. The A step was introduced through specific guidance created for the template and intended to be used without sustainability expert facilitation, and therefore needed to be thorough and effective but still brief, recognizing time constraints of our participants, while balancing the intention of the template approach to be simple and efficient.

The templates follow a pattern of “B” and “C” questions for industry, or “current baseline/gaps” (B), and “visions/solutions” (C). These questions are outlined in Table 2.1: In the D step we offered basic guidelines to support industry to strategically prioritise measures generated during C, and guiding questions to accomplish the process.

### A-Step

Guidance provided assisted in building a common understanding of the context of sustainability, and the assumptions of SSD that this approach was based on. The guidance included direction on the four system conditions, as well as a link to multimedia and educational materials.

### B-Step

The B-Step of the templates refers to current need for the product, and current sustainability opportunities and challenges. Each B-step question was followed by a C-Step answer (see below).

Blekinge Institute of Technology (BTH) biofuels thesis group (authors of this thesis) provided the first response to the templates, which was later reviewed and responded to by participants. The first B-Step question concerned current need in society, and the second B-Step question involved current principal product and product’s life cycle stages (agriculture, processing and end use).
**C-Step**

This step refers to solutions to sustainability challenges, and followed each B-Step question. Following the same pattern outlined above, the BTH biofuels thesis group provided statements to these templates, which were then responded to by participants. For the first C-Step template, in response to future needs that the product might serve, participants added remote power generation. For the solutions to sustainability challenges, many comments focussed on GMO's as a solution to sustainability challenges, as a response to the lack of information in the statements from BTH biofuels thesis group on this topic.

**D-Step**

The D step offered basic guidance to support industry to strategically prioritise measures generated during C. The process is accomplished by selecting measures where "yes” can be answered to three, key questions: i) will this measure bring us closer to compliance with all the principles of success (i.e. sustainability principles); ii) is the measure possible to develop further (if it needs to come into compliance with the principles of success), so that it doesn’t commit resources to an initiative that is not part of the long term vision (i.e. is it a flexible platform); and iii) is it likely to generate a good return on investment?

Each of the four templates was first responded to by the BTH biofuels thesis group, based on SLCM results. These responses were provided to participants along with the templates for their review and response.

In responding to the templates, we were cognizant of the need to keep the issues framed in the context of global sustainability challenges and opportunities. This was necessary to keep the template at a level of detail for which it was originally intended, at a “bird’s eye” view, avoiding reductionism, or too many details.
Table 2.1 Questions of the TSPD for Biofuels

<table>
<thead>
<tr>
<th>Product Development Stage</th>
<th>B (current baseline/gaps)</th>
<th>C (visions/solutions)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Need for Biofuels – Product Concept</strong></td>
<td><strong>B-1</strong> What services or utility does the product/service currently provide to people in general?</td>
<td><strong>C-1</strong> What current or new applications of the product could be developed to support sustainability and align with the sustainability principles for a future market, given the reality of the impacts on the biosphere and society?</td>
</tr>
<tr>
<td></td>
<td>What are the main sustainability problems linked to this product or service from a full and global life cycle perspective?</td>
<td>Are there any market trends that point in this direction?</td>
</tr>
<tr>
<td><strong>2. Design and Production of Biofuels</strong></td>
<td><strong>B-2</strong> For each system condition, what sustainability benefits and challenges does the biofuels industry currently face, from a full life-cycle perspective (agriculture, processing, transportation of raw materials, and end use)?</td>
<td><strong>C-2</strong> What are solutions to the challenges listed in &quot;B&quot; for ecological and social systems? (This exercise should be completed based on everything that is theoretically feasible – without any constraints.)</td>
</tr>
</tbody>
</table>

Two templates were created: generic biofuels, and biodiesel, based on the questions in Table 2.1. Non-industry stakeholders and sustainability experts provided feedback on the generic template only, while the industry
participant (Canadian Bioenergy Corporation, distributor and future producer of biodiesel), provided input to the biodiesel template.

Feedback and input received on the generic template will provide a foundation for the development of regional and fuel-type specific templates in the future. The completed generic template can be found in appendix III, of this document, and a summary of the comments are in section 3.5.1 (Stakeholders Feedback Summary).

### 2.3.2 Expert Dialogue and Stakeholder Feedback

To strengthen the development of the biofuels template, engagement of sustainability experts and stakeholders was required. The process involved reaching both parties separately; sustainability experts were contacted directly for their feedback via conference call, and stakeholders were sent the TSPD for biofuels individually via email for their written comments.

The sustainability expert dialogue was process chosen to provide a platform for several people with experience and knowledge on the template approach to discuss the template approach generally, and the application of this approach to the biofuels industry.

Since the approach is a relatively new one and is still being developed, consensus on the details of the approach has not yet been reached by these experts. The dialogue was valuable in refining aspects of the generic template process as well as allowing for feedback specifically on the TSPD for biofuels. The expert dialogue covered general aspects on the generic TSPD for biofuels.
Table 2.2  Expert Dialogue Guiding Questions

<table>
<thead>
<tr>
<th>Guiding Questions for Expert Dialogue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What are the strengths and weaknesses of the Template approach?</td>
</tr>
<tr>
<td>2. How effective do you think these templates will be in achieving the goal of improving sustainable product design, development, and biofuel conversion routes selection in particular?</td>
</tr>
<tr>
<td>3. How do we measure the success of the templates, if the goal is to improve sustainable product design and development?</td>
</tr>
<tr>
<td>4. Is the guidance provided appropriate, given the tool is to be used by industry personnel with limited sustainability training?</td>
</tr>
<tr>
<td>5. Comment on TSPD format, suggestions to make it more usable for business</td>
</tr>
</tbody>
</table>

The stakeholder engagement process was chosen as an easy method of engagement, given time constraints. It started with an invitation to a range of selected participants to inform the objectives of the proposal. The stakeholders were invited based on their specific knowledge about the biofuel industry, representing various levels of government, academic institutions, and NGO's. After confirming their participation, an information package containing a letter, the draft TSPD for biofuels created by the BTH biofuels thesis group, and guidelines to introduce the template process, was then sent to participants via email.
**Table 2.3** List of sustainability experts and stakeholders who provided input

<table>
<thead>
<tr>
<th>Organization</th>
<th>Location</th>
<th>View point</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNS Japan</td>
<td>Tokyo Japan</td>
<td>NGO</td>
</tr>
<tr>
<td>BAFF South Africa</td>
<td>Johannesburg South Africa</td>
<td>Business</td>
</tr>
<tr>
<td>BAFF Brazil</td>
<td>Sao Paulo Brazil</td>
<td>Business</td>
</tr>
<tr>
<td>Canadian Bioenergy Corp.</td>
<td>Vancouver Canada</td>
<td>Business</td>
</tr>
<tr>
<td>BAFF Sweden</td>
<td>Umeå Sweden</td>
<td>Business</td>
</tr>
<tr>
<td>TNS and BTH</td>
<td>Stockholm Sweden</td>
<td>NGO and Academic</td>
</tr>
<tr>
<td>BTH</td>
<td>Karlskrona Sweden</td>
<td>Academic</td>
</tr>
<tr>
<td>BTH</td>
<td>Karlskrona Sweden</td>
<td>Academic</td>
</tr>
<tr>
<td>Alberta Government</td>
<td>Edmonton Canada</td>
<td>Government</td>
</tr>
<tr>
<td>University of Alberta</td>
<td>Edmonton Canada</td>
<td>Academic</td>
</tr>
<tr>
<td>Energy Solutions Centre</td>
<td>Whitehorse Canada</td>
<td>NGO</td>
</tr>
<tr>
<td>Agriculture and Agri-Food Canada</td>
<td>Lethbridge Canada</td>
<td>Government</td>
</tr>
<tr>
<td>Northern Climate Exchange</td>
<td>Whitehorse Canada</td>
<td>NGO</td>
</tr>
</tbody>
</table>
3 Results

The review of the current state of the industry has revealed that there are already a number of sustainability opportunities being used by industry, and many challenges remain. In the following sections, the current reality of the biofuels industry, in terms of sustainability opportunities and challenges, is presented in tables, for bioethanol production as researched for Brazil, and biodiesel production as researched for Canada, as according to our predetermined project scope. Solutions to current challenges, emerging technologies and feedstocks, and compelling measures to lead the industry toward sustainability are also outlined in this section. The findings of regarding the TSPD for biofuels are discussed in detail in section 3.5.2.

3.1 Sustainability Analysis of Ethanol Production in Brazil

3.1.1 Sugarcane Agricultural Production

The sugarcane agricultural industry in Brazil was analysed using the SLCM tool, with life cycle processes and activities scrutinized using the four sustainability principles. Results are compiled in the Table 3.1.

Sugarcane is the main feedstock cultivated for ethanol production in Brazil. It is cultivated on about 5.5 million hectares, in 27 states of Brazil. A variety of species are available and production technology has been continuously refined to increase productivity of tonnes per hectare and also to increase sucrose content (Macedo and Nogueira 2005).

The sugarcane agro-industry employs more than 1 million Brazilians, including sixty thousand sugarcane producers and 300 ethanol plants (Macedo and Nogueira 2005). Over 80% of the cane harvest is cut manually, and burning the sugarcane fields before harvesting is a practice used to enhance productivity at the mill by avoiding extra cleaning operations. Burning also reduces the risk of workers encountering poisonous snakes. Legislation has been introduced to phase out burning and mechanized harvest is gradually increasing, consequently resulting in loss of jobs (ibid). This requires realistic government policies to address labour issues, as well as the consequences that follow mechanization practices, such as soil erosion, fossil fuel consumption, and its environmental consequences.
Table 3.1 Results of ethanol agricultural production, as analysed using the four sustainability principles

<table>
<thead>
<tr>
<th>AGRICULTURAL PRODUCTION</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PROCESSES: Land preparation, planting, harvesting and transport operations.</td>
<td></td>
</tr>
</tbody>
</table>

| SUB-PROCESSES: Seed preparation, fertilizer and agrochemical transportation, mechanization processes for lime, vinasse, filter mud cake, and agrochemical applications. Planting and cultivation activities. Burning, mechanical and manual harvesting, loading operations for transport, trash and operational routes for energy generation. Transportation from field to mill. |  |

| INPUTS: oil, mineral coal, gas, agrochemicals, metals, and labour. |  |

<table>
<thead>
<tr>
<th>Sustainability Principle 1</th>
<th>Sustainability Principle 2</th>
<th>Sustainability Principle 3</th>
<th>Sustainability Principle 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net increase of mined materials including oil, metals, alloys, phosphate rocks.</td>
<td>Emissions to: Air: N₂O, SO₂ (causes acid rain), CO₂, NH₃, NOX, CO, particulate ashes, fluorides, organic compounds: HC, CH₄, aldehydes. Water: solids, oil, phenol, organic matter, N, fluorides. Water and soil: Na, K, from excess of vinasse and pesticides, their intermediates, and degradation products, Cd, As, Zn; solid waste.</td>
<td>Degradation and loss of soil nutrients, as a consequence of burning and agrochemicals. Loss of water quality and aquatic habitat, salinization from fertilizers. Loss of biological species through deforestation, open mining, and monoculture.</td>
<td>Chronic and acute health impacts: Exposure to agrochemicals, heat, particulate matter from burning, accidents, toxic spills. Social impacts: Use the work of &quot;boias frias&quot; (child labour). Large scale producers pressing small family production to buy land for expansion, unemployment due to mechanization.</td>
</tr>
</tbody>
</table>

Diseases in sugarcane are avoided by using an appropriate selection of resistant varieties and biological control of pests and insects, but today persistent agrochemicals are also used. Chemical fertilizers are applied and their performance improved when used with biofertilizers from sugarcane processing activities, such as vinasse and filter pie. To avoid soil
degradation and contamination of water resources it is necessary to minimize and control the use of both biological and chemical products. This is a practice that has already been implemented.

There is no need for irrigation in most areas as the Brazilian climate is well suited to the growing requirements for sugarcane cultivation with a rainy period for development, followed by a dry period for maturation and harvest.

Initiatives to expand the industry have resulted in a need to double current levels of ethanol production, to 230 million tons of cane/year, by 2013. This represents an additional agricultural area of 2.2 to 3 million hectares for agriculture. This expansion must be linked with sustainable technologies for electric energy generation, including use of cane residues in agriculture (according to Brazilian Governmental Strategies) (Macedo and Nogueira 2005).

### 3.1.2 Ethanol Processing Industry

The industry in Brazil was analysed according to the four sustainability principles and the results are compiled in Table 3.2.

Ethanol in Brazil is currently produced by more than 320 processing units which own approximately 70% of planted area that supplies its needs for sugarcane. The remaining 30% is supplied by 60 thousand producers, most of them small. The total volume produced during 1995/96 represents around 15.5 Mm$^3$ (million cubic meters) (Macedo and Nogueira 2005).

Almost all equipment used for industrial processes is produced by national companies that are capable of supplying the previously identified expansion needs. Despite dependence on fossil fuels to expand production infrastructure its important to consider that industrial emissions in general have decreased significantly due to current legislation and are currently substantially controlled compared to the beginning of the ethanol program in the 1980’s (Macedo and Nogueira 2005).

The levels of intake and effluent of water for industrial use have been substantially reduced in recent years and treatment efficiency of effluent are above 98%. The sector target is zero effluent emissions, reusing residual water in ferti-irrigation. Also technology for cleaning the raw cane was
substituted for dry cleaning, without liquid effluents, reducing the water demand (UNICA – Sugarcane Producers Association 2004).

The sector currently produces more than 1,500 MW of electrical energy from combustion of bagasse residues, contributing to producer’s self sufficiency and representing a long term potential to produce up to 12,000 MW for the national grid (Pereira 2005).

It is also important to consider that the whole range of products obtained from petroleum oil can also be obtained within the same ethanol production structure. Several biopolymers are produced from ethanol today as polystyrene, acetone, styrene, acetic acid. Products for use in beverage, pharmaceutical and paint industries. Fertilizers as vinasse and filter pie, biodegradable components for fungicides, pesticides and herbicides, animal food and several types of paper can be produced from bagasse. Syrup for cosmetics production and also the mix of sugar and bagasse is used to produce biodegradable plastics.
Table 3.2 Results of the ethanol processing industry as analysed using the four sustainability principles

<table>
<thead>
<tr>
<th>PROCESSING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROCESSES:</strong> Crushing, fermentation, distillation, storage, and distribution.</td>
</tr>
<tr>
<td><strong>SUB-PROCESSES:</strong> Stocking, washing, syrup preparation, co-generation of electric energy from bagasse, filter cake production, centrifugation, rectification, dehydration and transportation to the pump.</td>
</tr>
<tr>
<td><strong>INPUTS:</strong> oil, minerals, metals, chemicals and labour.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sustainability Principle 1</th>
<th>Sustainability Principle 2</th>
<th>Sustainability Principle 3</th>
<th>Sustainability Principle 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net increase of mined materials from oil, metals, and alloys used in processing and infrastructure.</td>
<td>SO₂, CO, CaO, Ca (OH)₂, hydrated lime, CO, H₂SO₄, aldehydes from processing activities.</td>
<td>Degradation of water quality and resources from washing processes.</td>
<td>Chronic and acute health impacts caused by exposure to heat of machinery operations.</td>
</tr>
<tr>
<td>Na, K from vinasse industrial effluents to water systems.</td>
<td>Use of equipment and machinery highly dependent on mining materials and processes that contribute to loss of biodiversity due to open mining activities.</td>
<td>Accidents and toxic spills caused by use of chemicals and poor workplace safety practices.</td>
<td></td>
</tr>
<tr>
<td>Solids, phenol, organic matter N,P,</td>
<td>Cleaning products compounds, NH₃, Cl, Cu, and Zn.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.1.3 Ethanol Combustion

Ethanol combustion was analysed according to the four sustainability principles and results compiled in Table 3.3.

Ethanol use contributes to the reduction of GHG and the sector promotes the reduction of approximately 18% of fossil fuel emissions in Brazil (Nastari et al. 2005). Ethanol is responsible for significant reductions of
atmospheric pollution in urban areas, enabling the elimination of lead in gasoline, sulfur, sulfates compounds, reduction of Volatile Organic Compounds (VOC’s) emissions, and consequently toxicity.

It is estimated that the social costs avoided due to these environmental benefits in order of 167 million euros per year (Nastari et al 2005).

Table 3.3 Results of ethanol end use (combustion), as analysed using the four sustainability principles

<table>
<thead>
<tr>
<th>END USE</th>
<th>PROCESSES: Combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUB-PROCESSES:</td>
<td></td>
</tr>
<tr>
<td>INPUTS: Anhydrous and hydrated ethanol.</td>
<td></td>
</tr>
<tr>
<td><strong>Sustainability Principle 1</strong></td>
<td><strong>Sustainability Principle 2</strong></td>
</tr>
<tr>
<td>Exhaust gas emissions: CO, HC, NOX, and aldehydes.</td>
<td>Degradation of air quality dependence on open mining or metals and alloys used in automobiles.</td>
</tr>
<tr>
<td>Use of automobile and engine components highly dependent on mining materials that comes from open mining processes that contributes to loss of biodiversity.</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Sustainability Analysis of Biodiesel Production in Canada

Current biodiesel production in Canada has both sustainability opportunities and challenges in all life cycle stages. These are outlined in the following sections.

3.2.1 Biodiesel Agricultural Feedstock Production

Sustainability impacts are linked to the manipulation of natural systems and processes through physical and mechanical processes and chemical alterations of soil and water resources. Within the agricultural production process the following sub-processes with significant issues associated with them were identified.

- Seed Application
- Fertilizer Application
- Land Preparation
- Fertilizer, herbicide and pesticide application
- Irrigation
- Harvesting

Canola, also known as *Brassica rapa*, and as “rape seed” in Europe, is the dominant oilseed produced in Canada accounting for 2/3 of Canadian oilseed acreage or 5.6 million Ha in the year 2000 (Natural Resources Canada 2005) and is currently primarily produced from transgenic seeds (Canola Council of Canada 2001).

While this study focused primarily on biodiesel from canola, many of the sustainability aspects with respect to soybean production, which is Canada’s second largest oilseed crop, are similar. As of 2004-2005, Canada’s soy production reached an all time high of over 3 million tonnes produced on 1.17 million hectares. Between 50 and 55% of the Ontario crop was Monsanto’s GM Round-up Ready™ variety (OSG 2004).

While GMO’s do offer the potential to maximize crop yields through the selection of traits such as increased oil production, increased hardiness, and pest and chemical resistance, some current variants also pose significant social and economic risks (Pilson and Prendeville 2004, Dunfield and Germida 2004). Ecological risks include increased pesticide use, increased
weed and insect resistance, invasion of wild habitats, and the disruption of natural biological communities (Ibid).

Fertilizer production has become virtually synonymous with modern industrial agricultural processes as evidenced by table 3.4, which compares the fertilization rates for transgenic and conventional varieties with the soil nutrient removal rates for canola.

**Table 3.4** Canola Nutrient Removal Rates and Fertilizer Application Rates*1lb=0.45Kg; 1 bushel of canola=22.6Kg; 1 acre=0.404Ha.

<table>
<thead>
<tr>
<th>Canola Nutrient Removal Rates</th>
<th>Fertilizer Application</th>
<th>Transgenic Varieties</th>
<th>Conventional Varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb/acre</td>
<td>lb/bushel*</td>
<td>lbs/acre</td>
</tr>
<tr>
<td>N</td>
<td>61-74</td>
<td>1.74-2.1</td>
<td>67</td>
</tr>
<tr>
<td>P</td>
<td>33-40</td>
<td>0.94-1.14</td>
<td>24</td>
</tr>
<tr>
<td>K</td>
<td>16-20</td>
<td>0.45-0.57</td>
<td>6</td>
</tr>
<tr>
<td>S</td>
<td>10-12</td>
<td>0.28-0.34</td>
<td>12</td>
</tr>
<tr>
<td>Ave. Yield Bushel/Acre</td>
<td>35</td>
<td>Ave. Yield Bushel/acre</td>
<td>29</td>
</tr>
</tbody>
</table>


There are 11 nitrogen fertilizer production facilities in Canada, which collectively produced 8.1 million tonnes of nitrogen based fertilizer in 2004 (Canadian Fertilizer Institute 2004). There are 8 major forms of nitrogen fertilizer but urea, the most commonly used form globally, and ammonia, which is produced from natural gas through a process called steam reforming, are the dominant sources in Canada. On an industry wide basis
nitrogen fertilizer in Canada requires 10,000 BTU of energy per lb of fertilizer produced (NRCAN 2005).

In Canada, phosphate fertilizer is produced at a single site in Ontario, through open pit mining techniques. This site produces over 1 million tonnes of phosphate concentrate annually for use both domestically and for export.

Potassium fertilizer, which is commonly referred to with the generic term potash, is comprised of potassium chloride which is extracted both through underground solution mining and traditional underground ore mining techniques.

In addition to the energy consumption and associated GHG emissions associated with fertilizer production, mineral based fertilizer as previously identified disturbs natural landscapes and disrupts ecological process through mining operations. The changes in soil structure and chemistry as a result of agricultural processes, and excessive fertilizer application rates in particular, are responsible for 60% of the net GHG emissions associated with canola production (NRCAN 2005).

Eutrophication, degradation of biodiversity, and impairment of natural processes in both surface and groundwater resources, has been observed to be a significant concern due to sediment- and nutrient-laden water of many modern agricultural effluents entering watercourses. These effluents can damage fish and invertebrate habitat through siltation, or in the case of nutrient rich water, cause excessive nutrient level fluctuations, further endangering aquatic habitats (Myers, Marion, O'Meara 1993, Narayanaswamy et al. 2002, Tillman 1999).

In addition to fertilizer inputs, modern agriculture has also introduced numerous chemical inputs to control nuisance weed and insect species. Canola production in Canada currently uses in the order of 0.033lbs of pesticide active ingredients per bushel of production (NRCAN 2005). The impacts of these chemical inputs on human health and ecosystem biodiversity are increasingly being felt (Narayanaswamy et al. 2002, Benyus 1998).

While it is necessary to keep the issue of systemic poverty in the Canadian agricultural sector in perspective, compared to the extreme poverty associated with landless laborers and small scale subsistence farmers in the
world, Canadian farm income levels are a serious concern. Years of depressed commodity prices coupled with rapidly increasing input costs for fuel, equipment, seed and fertilizer have made many family farm operations un-economic. A survey conducted by the Canadian Wheat Board in March 2006, illustrates how dire the situation is with 70% of farmers polled anticipating their input costs to exceed their revenue during this upcoming season with 50% stating they will leave farming in the next couple of years if profitability does not increase (Canadian Broadcasting Corporation 2006).

Table 3.5 Results of biodiesel agricultural production, as analysed using the four sustainability principles.

<table>
<thead>
<tr>
<th>Sustainability Principle 1</th>
<th>Sustainability Principle 2</th>
<th>Sustainability Principle 3</th>
<th>Sustainability Principle 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net increase of mined materials (petroleum products metals, alloys, phosphate rocks) for fertilizer and agrochemical production, equipment production and petroleum fuel inputs</td>
<td>Dispersal of persistent agrochemicals, biofertilizers, fossil fuels, release of engine exhaust gases: SO₂, NOₓ, N₂O, CO, CO₂, VOC, BOD, As, Zn, fluorides, organic compounds</td>
<td>Degradation of soil including soil exhaustion, compaction, salinization, open pit mining and erosion</td>
<td>Chronic Health Risks: Exposure of workers and nearby residents to agrochemicals, extreme heat; systemic poverty, changes to aesthetic quality of landscape, restrictive covenants and legal covenants, reduction in aesthetic and recreational opportunities due to allocation of water resources for agricultural purposes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-consumption and contamination of surface and groundwater resources</td>
<td>Acute Health Risks: Agricultural accidents, chemical spills and poisoning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ecosystem manipulation leading to degradation</td>
<td></td>
</tr>
</tbody>
</table>
3.2.2 Biodiesel Processing Industry

Impacts, or sustainability “hot spots” from processing of feedstocks in the production of biodiesel, are focused around energy use, GHG emissions, and release of by-products.

For biodiesel production, the data available on energy consumption during the processing stages vary between operations, and particular stages are very energy intensive, such as seed crushing. There is general consensus that some of the processes have become increasingly energy efficient in recent years (Natural Resources Canada 2005). However the energy for such processes often is supplied from non-renewable sources. For soybean crushing for example, natural gas or coal generates the steam required for this process stage. Table 3.6 illustrates the inputs required for the crushing and transesterification stages in biodiesel production. Canadian production capacity was anticipated to reach 91 million litres in 2006, with the majority coming from two facilities in eastern Canada (Canadian Renewable Fuels Association 2006).

Table 3.6: Energy and chemical inputs used in biodiesel processing (USG=3.89L; MCF=1000cubic feet or 28m³).

<table>
<thead>
<tr>
<th>Canola Crushing</th>
<th>Electricity</th>
<th>Natural Gas</th>
<th>Hexane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.302kwh/USG</td>
<td>6,710 BTU/USG</td>
<td>0.004 USG/USG</td>
</tr>
<tr>
<td>Esterification</td>
<td>Power</td>
<td>Fuel</td>
<td>Methanol</td>
</tr>
<tr>
<td></td>
<td>0.666kwh/USG</td>
<td>4.7MCF/USG</td>
<td>0.11USG/USG</td>
</tr>
</tbody>
</table>

Source: Natural Resources Canada 2005.
Hexane, a product of petroleum, is widely used around the world as a solvent in the production of vegetable oils. It is more economical and efficient at extracting oil from seeds than expeller-pressed methods. It can only be produced from fossil fuels however, and is considered a hazardous air pollutant by the US EPA (Environmental Protection Agency 1995). Fugitive emissions are commonplace at oil extraction plants (Ibid). The status of hexane as a GHG is not fully understood; however its degradation results in a rapid release of carbon dioxide into the atmosphere, and may in the future be more officially considered a GHG in Canada (Environment Canada 2000).

The use of hexane could be substituted with expeller processes already in use elsewhere in the industry. While yields using the expeller process are lower than those from the hexane process, research and development could be supported with a focus on improving this technology for higher yields.

Table 3.7 Results of biodiesel processing as analysed using the four sustainability principles

<table>
<thead>
<tr>
<th>PROCESSING</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROCESS: Oil extraction, trans-esterification</td>
</tr>
<tr>
<td>SUB-PROCESS: seed washing, crushing, catalyst, reaction, by-products (glycerin) production, and transportation to the pump.</td>
</tr>
<tr>
<td>INPUTS: oil, minerals, metals, chemicals, and labor.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sustainability Principle 1</th>
<th>Sustainability Principle 2</th>
<th>Sustainability Principle 3</th>
<th>Sustainability Principle 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil fuel energy-intensive (coal, natural gas, electricity)</td>
<td>GHG Emissions</td>
<td>Degradation of water quality and resources due to consumption of water in processing activities</td>
<td>Potential Occupational Health &amp; Safety issues</td>
</tr>
<tr>
<td>Other emissions include hexane, VOCs</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2.3 Biodiesel Combustion

A number of studies on biodiesel exhaust have shown reductions in tailpipe emissions of particulate matter, hydrocarbons, and carbon dioxide for biodiesel and biodiesel blended with petroleum diesel relative to petroleum diesel. However, most studies also show an increase in nitrogen oxides (NOₓ) emissions for both biodiesel and ethanol (Environmental Protection Agency 2002). For example, one study showed 2% more NOₓ emissions in a B20 biodiesel blend compared to conventional diesel (Ibid). While many emissions are reduced with biofuels generally, they are still often of concern at any level. Further, CO₂ emissions are not an issue if they result in neutral emissions.

Table 3.8 Results of biodiesel combustion as analyzed using the four sustainability principles.

<table>
<thead>
<tr>
<th>END USE</th>
<th>PROCESS: Combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUB-PROCESS</td>
<td></td>
</tr>
<tr>
<td>INPUTS</td>
<td>biodiesel</td>
</tr>
<tr>
<td>Sustainability Principle 1</td>
<td>Sustainability Principle 2</td>
</tr>
<tr>
<td>Increasing concentrations of emissions including CO, HC NOₓ, VOC’s</td>
<td>Degradation of air quality, acid rain generation leading to degradation of ecosystems.</td>
</tr>
</tbody>
</table>
3.3 Opportunities Resulting from Emerging Technologies and Feedstocks

Through the course of researching the opportunities and challenges of both ethanol and Biodiesel several promising technologies and processes were identified. While these results are similar to what would be expected in the “C” step in the template process these results are presented as part of the background research into biofuel sustainability opportunities and challenges as they were obtained as a result of the literature review conducted prior to the template creation.

Many emerging feedstocks and processes have been identified at various stages of research and development, and while this list is in no way intended to be a comprehensive listing it does illustrate the range of opportunities currently being explored. Some of the technologies and approaches that currently look promising in terms of addressing sustainability challenges presently faced by biofuel production include ethanol from cellulose, restorative agriculture from high yield plants, the Fischer-Tropsch processes, and hydrothermal upgrading (HTU). GMOs may also offer some sustainability benefits, as well as challenges.

3.3.1 Cellulosic Ethanol

Cellulosic ethanol could help address the sustainability challenges that current mass production of energy crops pose, such as land use, biodiversity, and very low, or even zero, GHG emissions, with much less fossil-fuel intensity of many of today’s energy crops (IEA 2003). In the process of cellulose-to-ethanol conversion, the unused cellulosic and lignin parts of the plant being processed can provide for nearly all process energy (Fulton 2004). There seems to be consensus in the scientific community that hydrogen and ethanol from cellulose and wood crops are the only two future alternatives that provide significant enough CO₂ reductions (Gielen & Unander 2005). Hydrogen is outside the scope of this paper and will not be addressed here.

Much of the feedstocks for cellulosic ethanol are currently from agricultural wastes, forest residues, municipal solid wastes, wastes from the pulp and paper industry, and residues from crops grown for biofuel production. The
cellulosic part of these waste feedstocks can range from 30 to 70%. Other feedstocks include dedicated energy crops from switchgrass, hybrid willow, and hybrid poplar (Fulton 2004). Large-scale cellulose-to-ethanol conversion facilities will begin operating in 2006, with the first plant likely opening in Canada (IEA 2004). Cellulosic ethanol production is currently not economical, but with research by industry continuing, costs of production are expected to be addressed in the near future, making fuel production economically attractive.

3.3.2 Restorative Agricultural Practices

Many plants such as the jatropha plant (*Jatropha curcas*) are being researched for their energy-yielding properties, and properties for growing in poor soil. This plant is currently being cultivated for the dual purpose of restoring land in bioremediation projects, and for the production of biofuels. One such project has been researched at a demonstration project in the Phillipines, where land degraded through a mining project was used to grow jatropha for local off-grid energy use (Green Car Congress 2005). Other restorative, high energy-yielding species include palm which also allows for other crops to be grown (Kaltner 2005).

3.3.3 Fischer-Tropsch process

There is continued research on the Fischer-Tropsch and hydrothermal upgrading (HTU) processes for biodiesel production. Higher quantities of diesel fuel can be produced per hectare of land using these than present approaches, though currently the process has not been found economical for large-scale production of fuels (IEA 2004).

3.3.4 Biotechnology

Biotechnology involving genetically modified organisms (GMOs) also offers some possible benefits around increasing yield, among others, such as increased pest resistance. Opponents of GMO’s have raised concerns about this technology, which has influenced the debate on biofuels. Current thinking would suggest that due to rising global population, coupled with increased global affluence, GMO’s will be required to meet increased food and bio-energy demands. However society must also address increasing population and reduce global energy demand regardless of the biofuel question. The GMO debate also highlights the need to ensure we are not effectively limiting future options through these activities. The scope of
ecological, social and economic opportunities potentially eliminated by GMO’s is sobering, and if GMO’s can be developed in such as manner that they do not permanently limit future opportunities, they may offer assistance in helping the biofuel industry transition to a sustainable future. In particular, if GMOs can be found to meet all four system conditions, they would contribute greatly to a sustainable society. The GMO industry needs to address social concerns around their safety in the food chain, and in the biosphere, as this currently is the largest barrier to the use of GMOs (IEA 2004).

### 3.3.5 Algae

Field tests on algae conducted by the US Department of Energy achieved yields in excess of 60,000L/ Ha (Sheehan et al. 1998) of oil. While this program was suspended in 1998, work is ongoing at the University of New Hampshire to commercialize this technology. A particular focus of the current research is to co-site the facility with coal powered electricity generation plants to utilize the CO₂ from the plant to enhance algae production while also capturing CO₂ coming from the plant.

### 3.3.6 Nano-Scale Bilodeisel Production

Oregon State University Researchers in association with the Oregon Nanoscience and Microtechnologies Institute (ONAMI), have developed a processor consisting of a series of parallel channels, each smaller than a human hair through which vegetable oil and alcohol are pumped simultaneously, resulting in an almost instantaneous process. While each micro processor produces a small stream of biodiesel many processors can be connected to increase production with a device the size of a small suitcase capable of producing enough biodiesel to power several farms, or produce hundreds of thousands of gallons per year (Jovanovic 2006).

### 3.3.7 Thermodepolymerization

Changing World Technologies (CWT) has commercialized a process based on moderate heat and pressure to turn organic waste into bio-diesel. According to their corporate website, the process utilizes a self-contained system in which wastes are mixed with water, under pressure and then heated to around 300°C. They have recently opened a 200 ton per day facility to produce fuel from turkey carcasses and turkey manure, but have
previously developed facilities to produce fuel from municipal Solid Waste as well (Changing World Technology 2000).

### 3.4 Template for Sustainable Product Development for Biofuels

Both the dialogue between sustainability experts, and feedback from stakeholders, provided very constructive criticism and comments on the TSPD for biofuels approach. Assumptions were made about biofuels industry in general, and ones based on their specific experience with either ethanol or biodiesel fuel. Feedback and comments also reflected a growing global awareness of the SSD approach, from a wide range of backgrounds and viewpoints (see Table 2.3 List of Sustainability Experts and Stakeholders Who Provided Input). Participants provided comments that challenged, validated, and expanded on the response by the BTH biofuels thesis group. Their comments challenged us to evaluate our perspective on biofuels, the general approach of the TSPD, and ultimately allowed for greater understanding on this topic.

#### 3.4.1 Expert Dialogue Comments Summary

While the Guiding Questions for Dialogue assisted in providing structure to the Expert Dialogue session, the dialogue did not rigidly conform to the structure as we have presented them below. Comments have been edited for length, and clarity.

1. **What are the strengths and weaknesses of the Template approach?**

   There is a real danger with the template being developed with either excessive detail or in such a manner as to be too vague and general to provide value. To prevent this, the sustainability objectives and big-picture must remain front and centre. The template must look at the whole global picture, then form guidelines into specifics and into biofuels.

   The advantage of a template approach is that it is fast, and you have the big picture in front of you with no huge details (assists in avoiding reductionist dialogue). The downside is that you need a new template for each product category.

   Details could get unmanageable – need more of a bird’s eye on all sorts of aspects, and the template provides this.
A strength is that it is a shortcut for producers.

The template covers 3 phases, but should be used early in the product design process, prior to commencement of production in order to maximize its effectiveness.

With respect to the template audience, it would be better for the template to address “to whom it may concern” which makes it something for everyone to use. It could be an integrated tool for politicians, industrialist, the public, etc. With respect to the biofuels template, currently it is unclear who the audience is? The farmer, the producer? Who? Make it explicit who the audience is.

2. How effective do you think these templates will be in achieving the goal of improving sustainable product design and development and biofuel conversion route selection in particular?

There is some danger of blurring the look at sustainable biofuel production and transport systems. The templates would be more effective if they did not overlay sustainable transport system and production; do not include sustainable transport systems within this template - make it part of another template topic.

Introduction and the Global Picture

To improve template effectiveness, the client needs an introduction or preamble that brings out the global context, explaining the rationale as to why biofuels are important.

If you have a good introduction, two unfortunate outcomes can be avoided. The first is that you try to consider everything in the world and go nowhere, and the second is that you are so focussed on biofuels that all we want to do is support biofuel production. A good introduction can avoid both of these outcomes if the reader does not understand sustainability. A good introduction also links the template with human needs.

Services should be taken into account because they are in competition with each other – address this in the introduction. Human needs aspects are in competition with biofuels production – make this linkage.
Flexible platforms

Biofuels can provide energy in a way that complies with the system conditions, but this is only one aspect. The other aspect is that they do not prevent our ability to proceed with other energy systems. Agriculture is used in order to produce biofuels and this is very resource consuming. In exploiting biofuels, it is important to proceed so that it doesn’t tie our hands; it should also serve as a flexible platform for future scenarios. This means that we are not ruining land, not creating huge infrastructure that we are unsure what they will be used for in the future, once the technology is no longer relevant.

Even if we believe that there is no place for biofuels in a sustainable society, biofuels and the template are still important to arrive at that future. Biofuels are a transitional energy option and we need them as long as they are produced in sustainable way. In other words, they are a “flexible platform” that can easily be substituted in the event that other technologies that are more sustainable come along.

There is no other solution to move away from oil, so this option is our “lowest hanging fruit.”

3. How do we measure the success of the templates, if the goal is to improve sustainable product design and development?

Success could be measured in terms of how it has explicitly resulted in change. In scope of this thesis it is not realistic, but you could try to measure “a-ha’s,” or moments when people’s awareness has been broadened.

A questionnaire could be used.

The templates are useful as a manual and a guide for people in the world, and can be useful for those who want to develop the industry, but also useful for those concerned it is being developed in the wrong way.

The templates could be used in enviro-labelling efforts.

Take some real life examples, and test the template with best case, and worst case examples to show how the template could work in real life stories. The template could also be used to disprove why using biofuels for cars is wrong.
4. Is the guidance provided appropriate, given the tool is to be used by industry personnel with limited sustainability training?

The template is not to be used alone, it needs sustainability experts, or a facilitator, as a guide.

Points on human needs should be framed so that industry’s operations should not be expected to meet all people’s human needs, rather that they do not violate them.

5. Comments on TSPD format, and suggestions to make it more usable for business

Stages of the life cycle of biofuels (agriculture, processing, and end use) used in the templates, should exclude transportation infrastructure. There is a danger that the templates could become unmanageable and important details lost if the scope is too broad.

The format tends to follow a pattern of problem-solution-problem-solution; are you driving solutions from current reality or standing in the space of the C-step?

3.4.2 Stakeholder Feedback Summary

General comments regarding the format of the TSPD for biofuels survey instrument were provided, as well as detailed comments on each of the template questions.

Experience with the TNS framework varied among participants, however almost without exception, all general comments included the view that there was too much material and that it was too complex. In spite of this, many other relevant comments on the template were made, and these are included below.

General comments

- Guidance not adequate – need for further guidance or facilitator, particularly on backcasting and the 4 system conditions
- Stakeholder input was intended to follow BTH biofuels thesis group responses to questions in template, in order to provide assistance;
instead these responses were distracting and created difficulty in putting in own ideas, creating confusion

- Extremely thorough, and in many cases, too much information
- Some “a ha” moments
- Heating, electricity, and remote power generation should also be included as services
- Positives of biofuels should be highlighted more
- Need to explore bigger picture questions, such as competition between food and fuel production
- How do we reduce consumption and improve efficiency?

Tables 3.9 - 3.12. Responses provided by the biofuels stakeholders through the TSPD evaluation processes. Comments have been edited for length and clarity.

**Table 3.9** B1 Questions and Responses.

<table>
<thead>
<tr>
<th>Question B1.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What services or utility does the product/service currently provide to people in general?</strong></td>
</tr>
<tr>
<td><strong>What are the main sustainability problems linked to this product or service from a full and global life cycle perspective?</strong></td>
</tr>
</tbody>
</table>

**Response to B1**

Linking production with ecosystem services will address critical sustainability problems

As demand for mobility increases “due to an increasing population and affluence” the demand for food such as grains, vegetables and meat increases. Developing an integrated system utilizing waste products from food would address partly the critical sustainability problems
Table 3.10 C1 Questions and Responses

<table>
<thead>
<tr>
<th>Question C1.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>What current or new applications of the product could be developed to support sustainability and align with the sustainability principles for a future market, given the reality of the impacts on the biosphere and society?</em></td>
<td></td>
</tr>
<tr>
<td><em>Are there any market trends that point in this direction?</em></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Response to C1.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Applications in addition to mobility could be described as shelter, manufacturing and recreation (i.e. heating oil, bio-gas filled high efficiency window panes.)</td>
<td></td>
</tr>
</tbody>
</table>
**Table 3.11 B2 Questions and Responses**

**Question B2.**
For each system condition, what sustainability benefits and challenges does the biofuels industry currently face, from a full life-cycle perspective (agriculture, processing, transportation of raw materials, and end use)?

**Response to B2.**

**SC1:**
Need to also consider raw materials and energy associated with transport infrastructure

**SC2:**
Need for GMOs in order to meet need for increased food and fuel crops to be addressed. Consider opportunity for GMOs if impacts to society and environment including prevention of accumulation in biosphere can be addressed

**SC3:**
Agree in principle with statements, but significance on regional, continental, and global basis of actions needs to be addressed. Documenting real impacts on spatial scale will allow most important issues to be done first

End use applications have more significant footprint than transportation network. Footprint of processing plants could be exacerbated through use of many decentralized plants.

**SC 4:**
Difficult to understand the relationship between “displaced subsistence agricultural activities” and “insufficient farm income levels” - subsistence agriculture has subsistence income.
### Table 3.12 C2 Questions and Responses

<table>
<thead>
<tr>
<th>Question C2.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>What are solutions to the challenges listed in &quot;B&quot; for ecological and social systems? (This exercise should be completed based on everything that is theoretically feasible – without any constraints.)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Response to C2.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate goal of society should be a sustainable existence. Competitive biodiesel market a means of working towards that goal; may still be unrealistic for industry to meet strict criteria for sustainability</td>
<td></td>
</tr>
</tbody>
</table>

**SC1:**
Reduce demand

**SC2:**
Biofuels will still contribute to increased GHGs, need for reduced consumption of all fuels, including biofuels

**SC3:** None

**SC4:**
What are heritage seeds? Are they the original plants produced by nature or is it plants developed through breeding and defined by a point in time? Currently there are a number of excellent seedbanks around the world that are preserving germplasm. Are these inadequate to serve the purpose of sustainable development?
3.4.3 Prioritizing Steps Toward a Sustainable Biofuels Industry

Several proposed measures toward making the industry more sustainable have been identified in previous sections. The following is an attempt to prioritize these.

Public policy can be used to integrate a biofuels economy with socio-ecological issues, as a way to strategically arrive at goals defined by the sustainability principles. (Holmberg and Robèrt 2000). This could be used as a means to complement economic frameworks in Canada or Brazil, using economic incentives and disincentives, in order to reflect society’s goals and values.

Government policies are already used extensively for energy and transportation, and have contributed to the development of the biofuel industry in Canada and Brazil. For example, one of the most promising policy options currently being pursued in Canada involves the establishment of government mandates for biofuel blends as a percent of total fuel sales, and this is being used in many other countries including Brazil. Coupling this with a requirement for the fuel to be sustainably produced and certified through a credible and impartial process, would make this policy a good starting point for establishing the biofuel industry while it is still in nascent stages. This is a leverage point that is more effective if introduced early in the development of the industry.

As many challenges and opportunities in the agricultural life cycle stage of the biofuels were identified in the previous sections, governments have a role to play in stimulating the sustainable production of feedstocks. For example, the increased availability of expertise for sustainable production to farmers was identified by industry stakeholders as an important starting point for moving agricultural practices toward sustainability. This access to expertise could be facilitated by government.

Industry can assist in the sustainable development of biofuels, but they must act strategically now. Dematerializations and substitutions of material flows in the life cycle of biofuels have been identified, and the agricultural stage is where actions will be most effective. Examples of reduction of material flows in Brazil can be achieved by substituting practices such as replacing chemical fertilizers with bio fertilizers based on leguminosaes plants with high capacity to fix atmospheric nitrogen. The controlled use of vinasse and filter pie can also improve
sustainable agriculture performance if soil and water contamination is avoided.

Another example of a positive first step in addressing agricultural challenges is the use of permaculture approaches to production, which offer significant opportunities for reducing agricultural chemical and fertilizer inputs, while also virtually eliminating soil erosion and chemical runoff (Benyus 1998). Polyculture is a form of permaculture which, in the case of canola or soy in North America, could include the establishment of a community of herbaceous perennial legumes that would mimic a biological community structure with properties similar to a native grassland ecosystem.

The TSPD research provided in this paper is a first step to strategic sustainability, but the continued participation of industry in research and development of the templates will be essential for their ongoing improvement and relevancy.

Non-government organizations (NGOs) also have a role to play in creating a sustainable biofuels industry. Efforts around sustainable product certification have traditionally been most effectively administered by independent certification bodies, often NGOs. Sustainable biofuels certification and ecolabelling is one of the most urgent first steps we have identified. While there is a market for sustainable products, as evidenced by the success of organic and fair trade products, consumers cannot easily differentiate between sustainable and unsustainable biofuels without the assistance of independent ecolabelling and certification bodies. Currently no such bodies exist for biofuels, however the International Energy Agency and others have taken the lead on research around standards and criteria (Lewandowski & Faaij 2004). Certification provides companies with an incentive to produce according to a certifiable body’s standards, and can charge a premium for a sustainable product, based on the market’s willingness to pay. An international certification system could ensure a sustainable biofuels industry, provided prices of non-certified products do not undercut certified ones. Government incentives such as higher taxes on non-sustainable products would assist in supporting certified products in the market.

The most recent efforts toward the certification of biofuels on the part of NGOs are in part by the World Wildlife Fund (WWF), which has called on the European Union to “endorse the mandatory eco-certification of
all biofuels used in Europe.” The WWF, along with many other NGOs through the Roundtable on Sustainable Palm Oil, have spearheaded the development of practical criteria for the sustainable production of palm oil (World Wildlife Fund 2006).
4 Discussion

We developed a broad picture of the social, ecological and economic challenges facing the expansion of the global biofuels market through our work using SLCM approach and LCA data. From this basic understanding of the industry we used backcasting to assemble a series of statements regarding current baseline and gaps (“B-step”) and visions and solutions (“C-step”) and integrated them to create the content of the TSPD for biofuels. Based on feedback to the TSPD content, it is clear that site-specific current challenges and opportunities with regard to feedstock production are the most critical to address in order to move strategically toward sustainability.

We acknowledge that we have based our approach primarily on the SSD approach utilizing backcasting, and that there are other approaches to sustainable development.

4.1 Thesis Questions

What are some of the major sustainability opportunities and challenges of the biofuels industry?

Research from SLCM indicates that main sustainability challenges to the current biofuels industry (ethanol production in Brazil and biodiesel in Canada), are found in land use activities, including: site selection; industrial agricultural practices; energy balance; energy use derived from fossil fuels; GHG emissions; farm income; and production activities which have a negative effect on community development. Current sustainability opportunities include: rural diversification; energy security; economic benefits from by-products (e.g. glycerin); some air quality benefits; biodegradability of the product; and improved engine longevity. Further solutions for sustainability were generated in a backcasting exercise to produce content for the TSPD for biofuels, and these were later prioritized.

One of the main challenges is how the concept of sustainability is interpreted and practiced today with respect to the biofuels industry. There is no theoretical or practical consensus, which may bring a grave risk to this great opportunity presented by the biofuel industry today.
The major contribution of this study is how it is differentiated from others by incorporating SSD. When comparing more deeply our outcomes with the results of other studies, specifically with those aiming to provide guidance for certification schemes, there are similarities regarding identified problems, but also discrepancies with a lack of a concrete definition of sustainability in these studies.

No research was found that used the TSPD, TNS expert feedback, or backcasting from sustainability principles with respect to the development of the biofuels industry. Therefore, this research addresses a gap in existing data dealing with major sustainability challenges and opportunities of the industry. Previous studies provided many details that assisted in building a larger picture of the sustainability of the industry.

Many studies commented on the great necessity for the bioenergy industry in general to develop sustainably, but did not have definitions for sustainability, or strategic sustainable development. For example, Faaij and Lewandowski generated a certification system for sustainable biomass trade using a set of criteria and indicators. They commented, “There is no clear definition of what is to be considered sustainable. Therefore the definition of a sustainable product stays subject to individual perceptions of sustainability (Faaij and Lewandowski 2004).” This does not offer a base from which consensus can easily occur using agreed-on sustainability principles.

Other studies also did not offer a direction for sustainability before conducting their analysis. These studies include the NREL LCA analysis on biodiesel and the public transit system (Sheehan et al. 1998), and Blottnitz and Curran’s review of assessments on bioethanol concerning net energy, greenhouse gas, and environmental life cycle (2006). They lacked an overall view of sustainability and did not utilize backcasting from a future state of sustainability.

What is the current state of biofuel operations in Canada and Brazil?

Biofuel operations today, including ethanol in Brazil and biodiesel in Canada, can be described as offering a sustainability improvement over fossil fuel use in meeting transportation energy demand. However, research shows that with biofuel production now increasing in both Brazil and Canada, the current lack of SSD is expected to slow efforts
towards future sustainability.

The Canadian industry is currently in its infancy with only a couple of medium scale producers on the east coast and a single pilot scale plant in the province of Saskatchewan. GMOs are a major issue that will need to be addressed as the long-term ecological and socio-economic implications of this technology is not well understood, despite virtually all canola in Canada being GMO derived. The potential for feedstock to provide biofuels from animal or other waste is also limited.

There are several concerns with the proposed expansion of sugarcane agriculture in Brazil by up to 50% by the year 2010. The government argues that environmental impact should not be proportional to the area that will be planted because the expansion occurs over pasture areas and not native forests. This current biofuel sector in Brazil has evolved without a strategic approach towards a concrete sustainability vision and poignantly illustrates the purpose of this study and the need for a systems level approach to the myriad of issues surrounding biofuel production.

In contrasting our study with others, SSD facilitates an understanding of today’s problems so that reasonable solutions can be addressed without undermining future improvements. In other words, this study addresses today’s challenges from the perspective of a platform that can be flexible enough to promote gradual improvement, and planning with a concrete definition of sustainability in mind.

**What first steps toward sustainable biofuel development can be identified?**

Several compelling actions were identified as first steps toward a sustainable biofuels industry.

The use of backcasting from sustainability principles is one of the most important first steps in any sustainable development effort in the biofuels industry. This would assist enormously in providing a definition for sustainability, which is currently stunting many sustainability efforts in the industry, including certification.

Sustainable biofuel certification has been advocated as an important first step toward a sustainable biofuel industry. Efforts toward setting up effective verification and certification systems by NGOs must be
developed with a sound definition of sustainability, using backcasting from sustainability principles, if the exercise is indeed to be effective. The use of byproducts, such as bagasse and others, for power generation should be further researched and employed in order to improve the economics of the biofuels industry, providing incentives for its further development, as well as its sustainability.

A cost benefit analysis of the sustainable biofuels industry which includes “externalities” to the current economic model should be undertaken to build the business case for the global biofuels industry. Currently the benefits of the production and use of biofuels do not materialize in these analyses because they are non-monetary, and difficult to measure. Some of these benefits include:

- increased air quality,
- reduced GHG emissions, and
- preservation of biodiversity.

This analysis could help make the development of a sustainable biofuels industry a much more attractive option for many countries.

### 4.2 Research Validity

In establishing a solid foundation for the sustainable development of industry and biofuel-specific guidance, we are confident that some opportunities and threats, as they exist today, have been identified. One of the challenges we faced was the rapidly evolving nature of the data and technologies in this field. However we feel that the birds-eye approach, shifting the focus away from the rapidly changing details in favour of the big picture trends, provides the industry with a perspective from which a strategic plan can be initiated to provide a sustainable direction. Once this direction is identified, further study and more detailed steps can evolve from that point, avoiding ad hoc solutions without strategy.

The TSPD for biofuels, if used by industry, is a living document and an iterative process that will change with the evolution of the industry, and so will adapt with new technologies.

The TSPD does require further research, however we feel that it provides a good starting point for improvement. With further input from industry, experts, and other stakeholders, we are confident that we have
provided a foundation of results that can be built upon and provide a much more useful tool for industry.

### 4.2.1 Strengths and Weaknesses

#### Strengths

Current information was readily available in peer-reviewed scientific journals. As we were completing more of an overview of the industry in this thesis, we found this data adequate for the needs of this study.

While there is a great deal of study already completed on the biofuels industry, we could find no study using a backcasting or SLCM approach in evaluating sustainability challenges and opportunities of the industry. We have successfully used a SSD approach to give a complete overview of the industry.

Particularly strong were the B- and C-step analysis of the industry, prompted by template development in our research. The feedback and input on both of these steps validated our own findings, and offered additional ideas from key people, particularly from sustainability experts.

#### Weaknesses

More time was required to synthesize the data and draw conclusions. Given the evolving nature of the data and the global scope of impacts, there will always be the need for further data review, and the synthesis undertaken was suitable and appropriate.

Another factor in the difficulty encountered in drawing conclusions was the need for much more conclusive data in biofuels research. With rapid research and development in this broad field continuously occurring, much of the data can become obsolete very quickly.

While there is a great deal of information available, there is a confusing array of results, metrics, and yields of various feedstocks from different geographical areas. Because of this, it was difficult to draw conclusions from the analysis of energy balances of the different feedstocks and processes.

While some biofuel development is currently at a design stage, solutions
for dematerialization and substitution are at a minimum. This partly has to do with the nature of the product; at end use, the product almost ceases to exist in a tangible form, as it is combusted and dispersed to the atmosphere. The product already offers some dematerialization and substitution, in the sense that it has been largely “decarbonised,” offering better GHG balances compared to fossil fuels, and is in fact a direct substitution for many fossil fuel applications. Further dematerialization could be realized through reduction in NOx and particulate emissions, using various evolving technologies.

The stakeholder engagement process needs improvements. This could be done by using a more refined process for communicating information to stakeholders, and providing more guidance. The original template is actually designed with the expectation that a sustainability expert would guide participants through the template development process. Our research took a departure from this, offering stakeholders some written guidance on SSD, and little sustainability expert assistance. Our work with the stakeholders did confirm that guidance was inadequate for those with little SSD background, however some participants without SSD background actually responded very well, while others understandably had difficulty with the material.

Many stakeholders made comments concerning the complexity of the TSPD, i.e. that the templates contained too much material. This problem was predicted by one participant in the sustainability expert dialogue (see section 3.5.1) who suggested that the templates might get bogged down in details by trying to consider too much, and nothing would be concluded. This highlights the original intention of the templates to be used with a facilitator’s assistance.

In order to improve the TSPD and address the global scope of biofuels development, a broader stakeholder group is needed.
5 Conclusion

SSD and the SLCM and TSPD approaches used throughout this research, offer an opportunity to avoid reductionism, and strengthen the role of biofuels as a stepping stone or a platform to be gradually explored, toward a future generation of sustainability.

The key relationship between SSD, SLCM, and TSPD, is backcasting from sustainability principles. Other approaches to LCA and SPD have not incorporated backcasting, and therefore lack strategy to achieve sustainability, and an overall view from which a sustainable direction can be attained.

As we do not know what social, economic or ecological resources will be needed in the future, we must cautiously develop the industry such that future decision makers are not constrained by choices made today. The biofuels industry must evolve in such a manner that future options are not limited through such practices today that, for example, degrade ecosystem diversity and productivity, destroy rural communities, or commit large amounts of capital.

Biofuels will likely not be able to achieve their full potential in contributing to a sustainable society if global consumption patterns are not significantly changed. More upstream considerations outside the scope of renewable transportation energy options must be addressed, including reducing present consumption patterns of transportation goods and services, as well as increasing the energy efficiency of transportation, now and in the future.

Further Research

Our research identified the necessity of incorporating SSD within development of the biofuels sector. This can be assisted through further research into SPD, further research and refinement of the TSPD for biofuels, and into substitution and dematerialization of various life cycle stages of the product.

Further research into feedstock and location sustainability attributes is recommended, particularly in order to address biodiversity and food security concerns.
Sustainability certification for biofuels, or eco-labelling, requires much more research effort to speed its implementation, and this research needs to ensure that SSD is incorporated.

Key leverage points for industry, government, and other sectors of society, such as energy efficiency and reducing energy consumption, could also be researched, within a strategic sustainable development framework.

More exploration of stakeholder engagement is needed in further research of the TSPD for biofuels. Further research with stakeholders could include a) greater numbers and a broader representation of stakeholders, geographically and in viewpoints represented, since its limited use in this research did provide much valuable feedback, and b) research on how to engage stakeholders and prepare them for the templates, including guidance on backcasting, the sustainability principles, and how these are used within the template context. The latter could include further study on tools that reduce the need for direct expert guidance, such as the tool Touchpoint, developed by Durgin and Grierson (2005).

Given the potential of GMOs in offering significant sustainability challenges or opportunities, they require examination through the lens of SSD, and the precautionary principle applied, before any further application of GMOs in the sector.

Any efforts around standardized methods for calculating energy balances need to be presented clearly so as to allow a comparison between different feedstock options, and to address potential competing approaches internationally.

In order to speed adoption of more sustainable emerging technologies for biofuel production, greater research is required in this area. This research would best be led by industry, with government support.
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Narayanaswamy et. al. 2002. A Primer on Environmental Life Cycle Assessment (LCA) for Australian Grains, Centre of Excellence in Cleaner Production, Curtin University of Technology, Perth Australia.


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**Additional References**


Robèrt, K.-H. , B. Schmidt-Bleek, J. Aloisi de Larderel, G. Basile, L.


Appendices

Appendix I

The Natural Step Sustainability Principles

<table>
<thead>
<tr>
<th>Basic Principles for Sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>In a sustainable society, nature is <em>not</em> subject to systematically increasing …</td>
</tr>
<tr>
<td>1 … concentrations of substances extracted from the Earth’s crust,</td>
</tr>
<tr>
<td>2 … concentrations of substances produced by society,</td>
</tr>
<tr>
<td>3 … degradation by physical means,</td>
</tr>
<tr>
<td>and, in that society …</td>
</tr>
<tr>
<td>4 … fundamental human needs are met worldwide.</td>
</tr>
</tbody>
</table>

These principles were designed to fit a set of strict criteria including that they should
(vi) be based on a scientific world view,
(vii) describe what is necessary to achieve sustainability,
(viii) be general enough to include all activities relevant to sustainability,
(ix) not overlap to allow comprehension and develop indicators for the monitoring of transitions and
(x) concrete enough to guide problem analysis and decision making.

The ‘backcasting from principles’ planning process starts by discussing and sharing the framework as such for it to serve as a shared mental model for the work to come (A) and then it includes an iterative process of brainstorming, describing current activities in relation to those principles (B) and alternative future product concepts that comply with the principles (C). The gap analysis results are then translated into a prioritized set of early actions and products that can serve as economically and strategically feasible stepping stones towards complete compliance with the principles (D). The questions in this template follow this A-B-C-D approach, beginning from the “B” stage.

*Link to Natural Step e-Learning Tutorial (paid subscription required)*
http://www.naturalstep.ca/SBNS_FINAL_Jan302006/SBNS_Introduction.htm
Appendix II

Instructions Provided to Template Users

Directions for filling out the template questions

This template is organized according to the following format:

<table>
<thead>
<tr>
<th>Question</th>
<th>Guidance for each question</th>
<th>Response to each question from BTH Biofuels Thesis Group</th>
<th>Feedback from Sustainability Experts and Stakeholders</th>
</tr>
</thead>
</table>

- Read through the entire text and all questions before answering.
- Use the following assumptions in reviewing this template:

  The Sustainability Principles as conditions for sustainability on appendix I.

  Biofuels here refer to Liquid Fuels produced from biomass (non-fossil fuels), specifically ethanol and biofuels

  Correct or modify any general statement in the templates that you find flawed, incomplete or sub-optimal.

  For industry representatives: Reflect on your typical organizational perspective, on the templates: “how is your organization currently dealing with this issue in comparison to the respective templates, and how are you planning to deal with it either in the long term, or near future?”

  Critical to the sustainability analysis are areas where no data are available, or where the answer lies outside your domain. Unknown relevant aspects of sustainability are as important to identify as aspects that have concrete, detailed or quantitative answers.
Therefore, such unknown and relevant aspects should be specifically noted.

In a strategic sustainability analysis (based on SLCM), it is critical to present the overall picture so that important aspects are not overlooked in a sea of details of information that may be less important. Please note that a more in-depth Life-Cycle Analysis may be completed later.

**Context & Guiding Principles**

Based on the ongoing SPD research being conducted at Blekinge Institute of Technology (BTH), we have developed a decision making tool to support sustainable production design of liquid biofuels for transportation.

The tool, the Template for Sustainable Product Development (TSPD) for Biofuels, is meant to provide a simple and manageable tool to industry for social, ecological, and strategic sustainability throughout the life cycle production of biofuels.

The foundation of the methodology for these templates is “backcasting from basic principles for sustainability,” as developed by The Natural Step (TNS) in its approach to SSD.

<table>
<thead>
<tr>
<th>Basic Principles for Sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>In a sustainable society, nature is <em>not</em> subject to systematically increasing…</td>
</tr>
<tr>
<td>1 …concentrations of substances extracted from the Earth’s crust,</td>
</tr>
<tr>
<td>2 …concentrations of substances produced by society,</td>
</tr>
<tr>
<td>3 …degradation by physical means,</td>
</tr>
<tr>
<td>and, in that society. . .</td>
</tr>
<tr>
<td>4 …fundamental human needs are met worldwide.²</td>
</tr>
</tbody>
</table>

**Backcasting**

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¹ TNS is an international non-profit NGO, advising enterprises and other organizations on strategic sustainable development.
² For a definition of fundamental human needs, see the Human Needs Matrix in Appendix IV.
How can these system conditions be applied to an organization's everyday operations? TNS has developed and tested an approach to help organizations incorporate sustainability into their business strategies. The A-B-C-D Analytical Approach includes four elements:

**Awareness**
Align your organization around a common understanding of the situation. Discuss the broad system in which society operates and the current economic, social and ecological trends. Examine the ways in which these conditions limit the range of opportunities for all humans and organizations.

**Baseline Mapping**
What does your organization look like today? Analyze current operations in terms of the four system conditions. Map out and list flows of raw materials and energy and assess your organization in terms of addressing human needs.

**Clear Vision**
What does your organization look like in a sustainable society? Imagine what your operations will look like in a sustainable society based upon the four system conditions. Create a vision statement and list measures that may take you from where your organization is now to where you imagine your organization can be in the future, whether or not they are realistic in the short-term.

**Down to action**
Prioritize and manage your opportunities. Prioritize measures from your future vision that move the organization toward sustainability fastest, while optimizing flexibility as well as maximizing social, ecological and economic returns equally. Utilize backcasting as a method for continually assessing decisions in terms of

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3 For an animated version of the approach, go to http://www.naturalstep.ca/implementation.html
whether or not they move the organization towards a future desired outcome identified in Step C$^4$ (The Natural Step Canada 2006).

You will note in reviewing this template that they include only questions on the “B” and “C” elements of the backcasting approach. Elements “A” and “D” are not included and can be completed by the biofuels producer, with assistance from a sustainability expert if needed.

Appendix III

Template for Sustainable Product Development for Biofuels Questionnaire

B-1. CURRENT NEED FOR BIOFUELS

**Question B1.** What services or utility do biofuels currently provide to people *in general* and what are the overall critical sustainability problems linked to these services from a full and global life cycle perspective?

**Guidance:**

When thinking about the service or utility delivered, focus on the abstract function or value that customers receive, not the physical materials themselves. This stage is meant to focus thinking and creativity at the product concept level before rigid physical boundaries exist, so that the next stage (II – Principle Product Development) begins without preconceptions and creativity is fostered. For example – vehicles are more than wheels and steel, they deliver mobility; homes are more than bricks and mortar, they deliver shelter; etc.

**BTH Biofuels Thesis Group Response to B-1:**

**Needs currently addressed by product**

Liquid fuels are currently primarily used in powering modes of transportation including trucks, buses, and personal vehicles using existing infrastructure. The consumption of liquid motor fuels is currently increasing exponentially due to a combination of increasing population and affluence. Driving the rapid expansion of the biofuel industry are government programs and incentives, growing awareness of alternatives that reduce the release of greenhouse gases, energy security, recent price increases in fossil fuel prices, and the growing availability of both biofuels and biofuel-powered vehicles. The market for mobility is poised for continued growth, however as the impacts on the biosphere and society through resource depletion, pollution and wasteful use continue, it is imperative that mobility needs are met sustainably.
Please give comments and feedback here, or use a separate document.

**C-1. VISION & SOLUTIONS FOR BIOFUELS**

**Question C-1.** What current or new applications of the product could be developed to support sustainability and align with the sustainability principles for a future market, given the reality of the impacts on the biosphere and society? Are there any market trends that point in this direction?

**Guidance:**

When thinking about current or new uses for biofuels, think specifically about how the problems you identified above in “B-1” could be ultimately eliminated while delivering equal or greater value to the customer. Keep your thinking at the highest level and try to eliminate preconceptions about what the physical product might look like. For example, you might consider different contractual arrangement with the customer such as selling mobility instead of simply selling biofuels.

When thinking about future market trends, consider the potential of reaching out to different target markets that could use the product, different product adaptations that might change the scope of its application, etc.

**BTH Biofuels Thesis Group Response to C-1:**

There are a number of short, medium, and long-term applications of the product conducive to a more sustainable society.

Current and future applications for biofuels:

- Public transit buses
- Alternative transportation devices, scooters, mopeds etc.
- Locomotives
- Diesel hybrid cars
• Fuel cell applications
• Air travel
• Car sharing programs
• Marine travel
• Small engine applications
• Bioplastics, biopolymers, biolubricants
• Domestic Heating oil

Sustainability Experts’ and Stakeholders’ Feedback to C-1:

Please give comments and feedback here, or use a separate document.

B-2. CURRENT DESIGN & PRODUCTION OF BIOFUELS

Question B2. For each system condition, what sustainability benefits and challenges does the biofuels industry currently possess, from a full life-cycle perspective (agriculture, processing, transportation in product life-cycle, and end use)?

Guidance:

When considering the main flows of materials and processes, consider the aspects under each sustainability principle as they relate to the different stages of the product’s life cycle (i.e., agriculture (or feedstock production), processing, transportation of materials for production, and end use).

The analysis, however, should remain at the highest level, identifying flows and processes qualitatively, or identifying areas where more information is necessary to identify potential “hot-spots” or critical areas. Do not allow the analysis to get bogged down in details – this is meant to brainstorm ideas. The intent of the exercise is simply to identify existing and/or potential “hot-spots” using the sustainability principles so that no critical sustainability aspects are left out at the various points in the product’s life cycle.

When considering flows and impacts associated with all stages of biofuels production, consider whether they are a result of a) excessive
material flows and could potentially be addressed through quantity/dematerialization efforts, or b) whether the impacts are as a result of material choice or processing activity and if a quality/substitution approach would be an appropriate method to address sustainability problems identified.

**Basic Sustainability Principles**

**Sustainability Principle #1:**
- Are metals or other minerals involved in a consumptive or dissipative manner anywhere in the life cycle of biofuels production?
- Are fossil fuels consumed in any part of the fuel production life cycle?
- Are recycled or otherwise recovered metals or minerals used to substitute virgin material inputs

**Sustainability Principle #2:**
- Are persistent compounds foreign to nature involved anywhere in the life cycle of biofuels production?
- Are the compounds recycled in a closed-loop or used in a dissipative way?

**Sustainability Principle #3:**
- Are the natural systems required for agriculture degraded?
- Are transportation systems involved in the purchase of materials considered with regard to their area-consuming qualities (e.g., long distance road traffic)?
- Are organisms foreign to nature released to the environment?
- Are natural systems required for fertilizer mining restored after mining?

**Sustainability Principle #4:**
- Is your company socially responsible not only with regard to society and your employees, but also toward all suppliers?
- Do your activities affect people directly, including those in other countries, or future generations?

Do activities of you or your suppliers systematically undermine people’s abilities today and in the future to meet the following human needs (as per the Human Needs?

As you consider each sustainability principle, examine potential sustainability “hot-spots” where main material flows and processes:

- Are particularly large or inefficient (e.g., recycling rates are low; purity, and therefore value, of recycled materials is low; unnecessarily high product weight).
- Pose a particular threat due to leakage into the biosphere (e.g., CO2 from fossil fuels; scarce metals that have the likelihood of accumulating in the biosphere more readily; compounds that are toxic, bio-accumulative, or persistent).
- Result in direct physical manipulation of the biosphere as a result of poor planning or poorly managed ecosystems.
- Affect people directly, including impacts in other countries and on future generations

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BTH Biofuels Thesis Group Response to B-2:

System Condition 1
(Not systematically increasing concentrations of substances extracted from the Earth’s crust)

Fossil fuels are often used throughout the entire biofuels life-cycle and give rise to increasing concentrations of waste in the biosphere, as a result of activities in the following broad life cycle stages: agriculture, processing, transportation between life-cycle stages, and end use (combustion).

Feedstock Production:
- High fossil fuel inputs to fertilizer and agrochemical production, and raw materials for equipment and infrastructure (such as for agricultural implements)
- Net gain of GHG emissions in atmosphere as a result of burning of fossil fuels, and mining and production of fertilizers and other soil additives (such as limestone).
- Industrial agriculture relies heavily on mining of raw materials for fertilizers
Consumption of farm equipment with short life spans increases need for raw mined materials.

Processing:
- Co-products are often used for electricity production (such as bagasse from sugarcane processing), reducing the need for non-renewable energies
- Petroleum-based chemicals are used for processing
- Reliance on fossil fuel sources for energy
- Mined materials for infrastructure
- GHG emissions from fossil-based energy consumed for esterification processes

Transportation:
- Fossil fuel inputs for vehicles

End Use
- Wasteful product uses (i.e. inefficient vehicle choices and operational practices such as idling)
- Poorly maintained, worn out engines in end use applications result in incomplete combustion and excessive release of emissions resulting in increased fuel consumption

**System Condition 2**
(Not systematically increasing concentrations of substances produced by society)

Feedstock Growth
- Emissions like SOx and NOx and nitric oxide from agricultural soils contribute to climate change and disrupt global BioGeoChemical cycle (acidification of aquatic and terrestrial ecosystems)

- Agrochemicals (pesticides, fungicides, herbicides) in general are persistent in soil and aquatic environments and often bio-accumulate in high trophic level organisms in these environments
- Genetically modified organisms accumulating in the biosphere

Processing
- Emissions of SOx and NOx

Transportation
- SOx and NOx and other emissions
End Use
- SOx, NOx and other emissions
- Some biofuels, like biodiesel, offer significantly reduced tail-pipe emissions of many pollutants typically associated with petroleum derived diesel fuels

System Condition 3
(Not systematically increasing degradation by physical means)

Feedstock Production
- Some feedstocks such as jatropha are grown on poor soil where no vegetation exists, increasing the value of the land
- Land is often cleared for large-scale industrial agriculture
- Agriculture practices including crop selection, intensity of production and crop rotation lead to decreased biological diversity in natural systems
- Siltation of freshwater and marine habitats occurs due to soil erosion from unsustainable agricultural practices
- Soil nutrient exhaustion, soil structure degradation, and soil erosion
- Eutrophication of water resources due to release of excess nutrient loads from fertilizer run-off and effluent from processing facilities
- Mines that are not restored ecologically after mining
- Poorly managed mining processes
- Phosphate mining and sulphuric acid production for fertilizers and agrochemicals used for feedstock production
- Crop by-products are composted, reducing the need for chemical fertilizers.

Processing
- co-products (biomass waste) are not always used for energy and other purposes which create waste disposal issues and consumption of resources

Transportation
- Large spatial footprint of transportation infrastructure
- Transportation between life-cycle stages is often reduced when biofuels processing is located closer to source of feedstock
- High consumption of natural resources used in infrastructure construction and maintenance
End Use
- footprint of global transportation network on natural systems

System Condition 4
(people are not subject to conditions that systematically undermine their capacity to meet their needs)

Feedstock Growth
- Feedstock production provides employment in economically depressed areas
- Poor labour conditions due to seasonality related to harvesting, leading to lack of social security for the unemployment period, and reduced income opportunities with fair minimum wages
- Due to technological advances such as mechanical harvesting, unemployment is occurring in the agricultural sector of many countries, and there is a need for educational opportunities and capacity building
- Farmers and workers are frequently exposed to hazardous substances, and are not provided with adequate training on use of equipment and agrochemicals
- In some regions there are violations of indigenous rights, children work without receiving basic schooling, and women are frequently discriminated against
- Farmers often do not have access to potable water, sanitary facilities, adequate housing, education and training, transportation, and health services
- Small farmers and producers are often excluded from the market and communications systems
- Degradation of land and water prevents people from meeting human needs, such as subsistence food acquisition and recreational opportunities
- Some agricultural practices undermine individual self determination, and/or displace subsistence agricultural activities
- Many farm income levels are insufficient to allow people to meet their basic human needs
Processing
- Provides employment however does not always provide adequate wages, training, or job security
- Occupational health and safety concerns

Transportation
- Public health issues with end-use combustion (VOCs and particulate matter)

End Use
- Biofuels can be used affordably in existing public transit systems
- High fuel prices makes mobility inaccessible to lower-income individuals
- Lack of access to public transit
- Public health issues with end-use combustion (VOCs and particulate matter)

**Sustainability Experts’ and Stakeholders’ Feedback to B-2:**

Please give comments and feedback here, or use a separate document.

**C-2. VISION & SOLUTIONS TO DESIGN & PRODUCTION OF BIOFUELS**

**Question C-2.** What are solutions to the challenges listed in "B-2" for ecological and social systems? (This exercise should be completed based on everything that is theoretically feasible – *without any* .)

The ultimate production goal of biofuels in the future should be to ensure that it does not contribute to…

(i) Systematically increasing concentrations of elements from the earth’s crust;
(ii) Systematically increasing concentrations of compounds such as chemicals;
(iii) Systematically increasing physical degradation; and
(iv) Disempowerment of people and social structures to the extent that people are unable to meet their needs.
For each “hot-spot” you identified in the “B” analysis above, consider the possibility of addressing it through one or more of the dematerialization/substitution options at each life cycle stage of the product.

When considering flows and impacts associated with all stages of biofuels production, consider whether they are a result of a) excessive material flows and could potentially be addressed through quantity/dematerialization efforts, or b) whether the impacts are as a result of material choice or processing activity and if a quality/substitution approach would be an appropriate method to address sustainability problems identified.

### BTH Biofuels Thesis Group Response to C-2:

#### System Condition 1

**Feedstock Growth**
- Replace petroleum based agricultural inputs for energy and virgin materials with biofuels, bioplastics, biopolymers, biolubricants, and other abundant organic materials
- To meet energy demands, alternative sources of energy could be pursued including solar and wind
- Organic fertilizers could replace unsustainably mined fertilizers
- Increase life spans of farm equipment and close the material input loop by recycling equipment components back into high grade material fractions suitable for use in new farm equipment.
- Adopt agricultural practices that mimic natural systems while conserving soil balance, reducing need for soil additives such as limestone, and reducing energy intensive aspects of production such as tillage and amendment application.

**Processing**
- Use biofuels co-products including residual seed cake, husks, and glycerin for energy inputs
- Investigate oil extraction materials and processes that do not rely on petroleum-based inputs such as hexane, or methanol
- Begin, or continue, to ensure the purchase of processing equipment with high life spans, practice maintenance of processing equipment, and recycle materials from equipment that is obsolete.

**Transportation**
- Minimise routes between feedstock sources to processing facilities, and from processing facilities to distribution networks for end use.
- More efficient transportation systems such as rail, pipeline, ship.
- Use biofuels for transport vehicles.
- Promote use of recycled construction materials in maintaining, upgrading and expanding transportation infrastructure.

**End Use**
- Industry can encourage governments to impose taxes and subsidies favouring biofuels over fossil fuels and on vehicles that do not meet certain fuel efficiency standards, both for new and used vehicles.

**System Condition 2**

**Feedstock Growth**
- Co-products from biofuels production can be used to replace synthetic fertilizers (i.e. controlled use of Filter cake as fertilizers).
- Use of biological, physical, mechanical control techniques to eliminate use of persistent agrochemicals.

**Processing**
- Promote regulatory standards for vehicle emissions of NOx and SOx.

**Transportation**
- Promote regulatory standards for vehicle emissions of NOx and SOx.

**End Use**
- Promote regulatory standards for vehicle emissions of NOx and SOx.

**System Condition 3**

**Feedstock Growth**
- Use of degraded land for agriculture, rather than clearing remaining natural ecosystems such as primary forests for agriculture.
- Use of crops that can grow on land that is not contributing to a productive ecosystem (such as jatropha)
- Production of high energy yielding feedstocks requiring less area such as algae can be considered and actively explored
- Preserve biological diversity by adopting more sustainable agricultural methods to preserve health of soil and freshwater resources, such as conservation tillage and through planting of crop species with high genetic diversity
- Engage in ecosystem restoration for old mines, including erasing mining transportation systems
- Materials that depend on mining, especially phosphates fertilizers, are purchased from businesses that restore natural systems during and after mining processes
- Feedstock suppliers for biofuels of unsustainably managed ecosystems can be exchanged for others or supported through improvement programs
- Management of transportation logistics to minimize actual transportation distances
- Diversification of agricultural productive systems
- Elimination of residue burning except in regions where fire is an identified part of vegetation ecology
- Adopting watershed basin as unit for management towards sustainability
- Less area-consuming transportation can be consciously pursued (e.g. ships and trains)

Processing
- Using co-products from other parts of the life-cycle to generate electricity or heat for other processes

Transportation
- Agricultural production areas, processing plants, and end use distribution networks should be located close to each other to reduce transportation needs
**System Condition 4**

**Feedstock Growth**

- Sustainable agricultural activities can alleviate many challenges, including sedimentation problems affecting subsistence food acquisition, and degradation of recreational areas.
- Minimise occupational health and safety concerns through elimination of agrochemicals.
- Diversification of rural economies through agri-toursim.
- Heritage seed cooperatives and seed banks are supported and uncompromised.
- Company adoption of national health and safety standards.
- Company encouragement of government legislation around particulate traps on all compression ignition engines.
- Company to provide job security, wages that allow for human needs to be met, and opportunities for year-round employment (or insist this certification from suppliers).
- Purchase of materials and feedstocks from developing countries can take social responsibilities and costs for purchased materials into account. This could be done by systematically inquiring about the working and living conditions, and basic human rights of the people from the country of feedstock or biofuels origin.
Processing
- Company to provide job security, wages that allow for human needs to be met, and opportunities for year-round employment (or insist this certification from suppliers)
- Purchase of materials and feedstocks from developing countries can take social responsibilities and costs for purchased materials into account. This could be done by systematically asking about the working and living conditions, and basic human rights of the people from the country of feedstock or biofuels origin

Transportation
- Company encouragement of government legislation around particulate traps on all compression ignition engines

End Use
- Company support of improved community public transit systems
- Company encouragement of government legislation around particulate traps on all compression ignition engines

Sustainability Experts’ and Stakeholders’ Feedback to C-2:

Please give comments and feedback here, or use a separate document.
# Appendix IV

## Fundamental Human Needs Matrix

Table 2. Fundamental Human Needs Matrix

<table>
<thead>
<tr>
<th>NEEDS</th>
<th>Being (qualities)</th>
<th>Having (things)</th>
<th>Doing (actions)</th>
<th>Interacting (settings)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsistence</td>
<td>physical, emotional and mental health</td>
<td>food, shelter, work</td>
<td>Work, feed, procreate, clothe, rest/sleep</td>
<td>living environment, social setting</td>
</tr>
<tr>
<td>Protection</td>
<td>care, adaptability, autonomy</td>
<td>social security, health systems, rights, family, work</td>
<td>cooperate, plan, prevent, help, cure, take care of</td>
<td>Living space, social environment, dwelling</td>
</tr>
<tr>
<td>Affection</td>
<td>respect, tolerance, sense of humour, generosity, sensuality</td>
<td>friendships, family, relationships with nature</td>
<td>share, take care of, make love, express emotions</td>
<td>privacy, intimate spaces of togetherness</td>
</tr>
<tr>
<td>Understanding</td>
<td>critical capacity, receptivity, curiosity, intuition</td>
<td>literature, teachers, educational and communication policies</td>
<td>analyse, study, meditate, investigate</td>
<td>schools, families, universities, communities</td>
</tr>
<tr>
<td>Participation</td>
<td>adaptability, receptivity, dedication, sense of humour</td>
<td>responsibilities, duties, work, rights, privileges</td>
<td>cooperate, propose, dissent, express opinions</td>
<td>associations, parties, churches, neighbourhoods</td>
</tr>
<tr>
<td>Idleness</td>
<td>Creation</td>
<td>Identity</td>
<td>Freedom</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
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<tr>
<td>imagination, curiosity, tranquillity, spontaneity</td>
<td>games, parties, spectacles, clubs, peace of mind</td>
<td>day-dream, play, remember, relax, have fun</td>
<td>landscapes, intimate spaces, places to be alone, free time</td>
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<td></td>
<td>imagination, boldness, curiosity, inventiveness, autonomy, determination</td>
<td>skills, work, abilities, method, techniques</td>
<td>invent, build, design, work, compose, interpret</td>
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<td>spaces for expression, workshops, audiences, cultural groups</td>
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<td>symbols, language, religion, values, work, customs, norms, habits, historical memory</td>
<td>get to know oneself, grow, commit oneself, recognize oneself</td>
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<td>places one belongs to, everyday settings, maturation stages</td>
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<td></td>
<td></td>
<td>sense of belonging, self-esteem, consistency</td>
<td>autonomy, passion, self-esteem, open-mindedness, tolerance</td>
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<td>equal rights</td>
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<td>dissent, choose, run risks, develop awareness, be different from, disobey</td>
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<td>temporal / spatial plasticity (anywhere)</td>
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