Sustainability assessment of second generation bioethanol assessment

Dr Guido Reinhardt

International Conference on 2nd Generation Bioethanol Production
Brussels, 4 December 2013
## Definitions

<table>
<thead>
<tr>
<th>Biofuels</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; generation</td>
<td>E.g. produced from sugar, starch, vegetable oil, or animal fats using <strong>conventional technology</strong></td>
<td>Biodiesel, Vegetable oils, Biogas, Bioethanol</td>
</tr>
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<td>1 ½ generation</td>
<td>E.g. produced from oil using <strong>advanced technology</strong></td>
<td>Hydrotreated vegetable oils or animal fats</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; generation</td>
<td>E.g. produced from non-food biomass, such as lignocellulosity and waste biomass (stalks of wheat and corn, and wood) using <strong>innovative technology</strong></td>
<td>Lignocellulosic ethanol, Biomethanol, BioDME, Biohydrogen, DMF, BtL</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; generation</td>
<td>E.g. produced from extracting oil of algae</td>
<td>Algae fuel</td>
</tr>
</tbody>
</table>

⇒ **Note: no unequivocal definition!**
Examples for ethanol raw materials

For 1\textsuperscript{st} generation Ethanol

- Maize
- Sugar cane
- Wheat
- Sugar beet

For 2\textsuperscript{nd} generation Ethanol

- Miscanthus
- Straw
- Switchgrass
- Arundo
### Definitions

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⇒ **Note:** no unequivocal definition!
BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks

The BIOLYFE System

- **Biomass cultivation + provision**
- **Pre-treatment:** steam explosion
- **Viscosity reduction**
- **Yeast propagation**
- **SSF*:** Simultaneous saccharification and fermentation
- **Solid-liquid-separation**
- **Distillation and dehydration**
- **Biogas plant (cleaning, dehumidification)**

Material use options:
- Use as fuel
- Power to grid
- Sludge
- Natural gas
- Compost
- Boiler
- Heat / Power
- Antifoam
- Urea
- Water
- KOH
- H₂SO₄
- Enzymes (Cellitec 3NZ)
- Medium or additional biomass
- Incineration

* Simultaneous saccharification and fermentation

**proesa™ Technology**

Developed by Biochemtex
Biofuels investigated in the Biolyfe project

Second generation Biolyfe ethanol

- Arundo ethanol
- Fiber sorghum ethanol
- Wheat sorghum ethanol
- Arundo BTL
- Wheat ethanol
- Sugar beet ethanol
- Sugar cane ethanol
- Rapeseed biodiesel
- Corn ethanol
- Maize biomethane

Alternative biofuels
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Sustainable development

Definition

"Meeting the needs of the present generation without compromising the ability of future generations to meet their needs."

Brundtland Commission 1987
BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks

The principle of sustainability

Economy

Social issues

Ecology
Environmental assessment:

Life cycle assessment (LCA & RED*)

Life cycle environmental impact assessment (LC-EIA)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LCA</td>
<td>LC-EIA</td>
</tr>
<tr>
<td>→ Global impacts</td>
<td>→ Site-specific impacts</td>
</tr>
</tbody>
</table>

* RED: Renewable Energy Directive of the European Commission
Life cycle assessment (LCA)

ISO 14040 & 14044

Goal and scope definition

Inventory analysis

Impact assessment

Interpretation
BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks

**Product reference system**
- Resource extraction
- Raw material production
- Transport
- Processing
- Fossil fuel

**BIOLYFE system**
- Agriculture
- Arundo
- BIOLYFE plant
- 2nd generation bioethanol

**Agricultural reference system**
- Idle land

Life cycle comparison

- **Fuel**
- **Fertiliser**
- **Pesticides**

**Resources**
- Agricultural
- Resource extraction
- Fertiliser
- Fuel
- Pesticides

**Utilisation**
LCA: Inventory analysis

**Inputs**
e.g.:
- natural gas
- crude oil
- brown coal
- hard coal
- uranium
- water

**Outputs**
e.g.:
- $\text{CO}_2$
- $\text{SO}_2$
- $\text{CH}_4$
- $\text{NO}_x$
- $\text{NH}_3$
- $\text{N}_2\text{O}$
- HCl
- CO
- C$_6$H$_6$
- VOC

**Diagram**

**Fossil fuel**
- Resource extraction
- Raw material production
- Transport
- Processing
- Utilisation

**Biofuel**
- Fertiliser
- Fuel
- Pesticides

**Flowchart**

**Caption**

BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks
Biolyfe ethanol from Arundo vs. gasoline

Greenhouse effect

Credits vs. Expenditures

Advantages for bioethanol vs. Disadvantages

Expenditures:
- Agriculture: diesel
- Agriculture: fertiliser
- Agriculture: rest
- Conversion: material input
- Power
- Conversion: emissions from lignin combustion

Biolyfe ethanol vs. Fossil gasoline

Balance

Equals a ride with a compact car of about 41,000 km, which is slightly more than the perimeter of the earth.

Source: IFEU 2013

BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks
<table>
<thead>
<tr>
<th>Impact category</th>
<th>Parameter</th>
<th>Substances (LCI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource demand</td>
<td>Sum of depleteable primary energy carriers</td>
<td>Crude oil, natural gas, coal, Uranium, ...</td>
</tr>
<tr>
<td></td>
<td>Mineral resources</td>
<td>Lime, clay, metal ores, salt, pyrite, ...</td>
</tr>
<tr>
<td>Greenhouse effect</td>
<td>CO$_2$ equivalents</td>
<td>Carbon dioxide, dinitrogen monoxide, methane, different CFCs, methyl bromide, ...</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>F$_{11}$ equivalents, (Nitrous oxide)</td>
<td>CFC, halone, methyl bromide, ...</td>
</tr>
<tr>
<td>Acidification</td>
<td>SO$_2$ equivalents</td>
<td>Sulphur dioxide, hydrogen chloride, nitrogen oxides, ammonia, ...</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>PO$_4$ equivalents</td>
<td>Nitrogen oxides, ammonia, phosphate, nitrate</td>
</tr>
<tr>
<td>Photosmog</td>
<td>Ethylene equivalents</td>
<td>Hydrocarbons, nitrogen oxides, carbon monoxide, chlorinated hydrocarbons, ...</td>
</tr>
<tr>
<td>Human and Ecotoxicity</td>
<td>Nitrogen oxides, carbon monoxide, hydrogen chloride, diesel particles, dust, ammonia, benzene, benzo(a)pyrene, sulphur dioxide, dioxines (TCDD), ...</td>
<td></td>
</tr>
</tbody>
</table>
Biolyfe bioethanol from Arundo vs. gasoline

Advantages for bioethanol  Advantages for gasoline

Energy savings
Greenhouse effect
Acidification
Eutrophication
Summer smog
Ozone depletion
Human toxicity

Arundo

Source: IFEU 2013

Inhabitant equivalents per 100 ha and year

BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks
Bioethanol from sugar beet versus gasoline

Advantages for bioethanol

- Energy savings
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog
- Ozone depletion
- Human toxicity

Advantages for gasoline

Source: IFEU 2013
Biodiesel from rape seed versus diesel

Advantages for biodiesel

- Energy savings
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog
- Ozone depletion
- Human toxicity

Advantages for diesel

Inhabitant equivalents per 100 ha and year

Source: IFEU 2013

BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks
**Life cycle assessment of Biolyfe ethanol:**
Environmental advantages and burdens

- Same pattern for most biofuels for transportation
- Need to identify all environmental implications and optimise the advantages and minimise the disadvantages

![Graph showing environmental advantages and burdens](image)

Source: IFEU 2013
### Greenhouse gas balances for Biolyfe ethanol and other biofuels from different feedstocks

<table>
<thead>
<tr>
<th>Climate change</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bioline</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arundo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fibre sorghum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat ethanol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar beet ethanol</td>
<td></td>
<td></td>
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<tr>
<td>Rapeseed biodiesel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize biomethane</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>t CO₂ eq. / (ha·a)</th>
<th>-12</th>
<th>-10</th>
<th>-8</th>
<th>-6</th>
<th>-4</th>
<th>-2</th>
<th>0</th>
<th>2</th>
</tr>
</thead>
</table>

Source: IFEU 2013

**BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks**
Greenhouse gas balances for Biolyfe ethanol and other biofuels from different feedstocks

- **Biolyfe ethanol from Arundo (and straw) has a remarkable potential to meet and/or even succeed the environmental advantages of conventional biofuels**

- **This is basically not true for Biolyfe ethanol from fibre sorghum under typical conditions**

<table>
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<th>t CO₂ eq. / (ha·a)</th>
<th>-12</th>
<th>-10</th>
<th>-8</th>
<th>-6</th>
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Source: IFEU 2013
Environmental assessment:

Life cycle assessment (LCA & RED*)

Life cycle environmental impact assessment (LC-EIA)

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* RED: Renewable Energy Directive of the European Commission
RED: Renewable Energy Directive of the European Commission

BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks
Greenhouse gas balances for Biolyfe ethanol according to the renewable energy directive (RED)

Wheat straw

- Less favourable
- Standard
- Favourable
- Std., lignin + s.c. export / NG import
- Std., additional natural gas demand
- Std., surplus power export
- Optimised
- Optimised, lign. + s.c. export / straw import

% GHG savings

Source: IFEU 2013
Biolyfe ethanol from straw can easily meet the long term RED requirements of 60 % GHG reduction.

To meet 60 % GHG reduction with Biolyfe ethanol from Arundo is challenging though comparably easy achievable.

To meet 60 % GHG reduction with Biolyfe ethanol from fibre sorghum needs extraordinary measures.

In general, to meet 60 % GHG reduction with Biolyfe ethanol is achievable, though not a self running story in all cases.
Environmental assessment:

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* RED: Renewable Energy Directive of the European Commission
Description of the environment

- Water
- Climate / Air
- Flora, Fauna, Biodiversity
- Soil
- Humans
- Cultural heritage
- Landscape

Source: IUS 2013

BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks
LC-EIA: Life cycle environmental impact assessment

Fossil fuel
- Resource extraction
- Raw material production
- Transport
- Processing
- Utilisation

Biofuel
- Agriculture
- Fertiliser
- Fuel
- Pesticides

Interactions
- Water
- Soil
- Climate / Air
- Flora, Fauna, Biodiversity
- Humans
- Cultural heritage
- Landscape

Source: IUS 2013

BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks
## Principles of assessment (I)

<table>
<thead>
<tr>
<th>Type of risk</th>
<th>Affected environmental factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>Ground water</td>
</tr>
<tr>
<td>Soil erosion</td>
<td>Soil compaction</td>
</tr>
</tbody>
</table>

Source: IUS 2013

qualitative risk assessment
**LC-EIA results: Wheat straw**  
Reference system: ploughed in

<table>
<thead>
<tr>
<th>Type of risk</th>
<th>Soil</th>
<th>Ground water</th>
<th>Surface water</th>
<th>Plants / Biotopes</th>
<th>Animals</th>
<th>Climate / Air</th>
<th>Landscape</th>
<th>Human health and recreation</th>
<th>Bio-diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil erosion</td>
<td>neutral</td>
<td>neutral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil compaction</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td></td>
<td></td>
<td></td>
<td>neutral</td>
</tr>
<tr>
<td>Loss of soil organic matter</td>
<td>neutral</td>
<td></td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td></td>
<td></td>
<td></td>
<td>neutral</td>
</tr>
<tr>
<td>Soil chemistry / fertiliser</td>
<td>neutral</td>
<td>neutral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eutrophication</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td></td>
<td></td>
<td></td>
<td>neutral</td>
</tr>
<tr>
<td>Nutrient leaching</td>
<td>neutral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water demand</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>neutral</td>
</tr>
<tr>
<td>Weed control / pesticides</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>neutral</td>
</tr>
<tr>
<td>Loss of landscape elements</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td>neutral</td>
<td></td>
<td>neutral</td>
</tr>
</tbody>
</table>

1) Positive in case of long-stalked varieties since less weed control is necessary  

Source: IUS 2013
### Comparison of feedstocks

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Perennial crops</th>
<th>Annual crops</th>
<th>Residues</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Arundo donax</td>
<td>Sugar cane</td>
<td>Rapeseed</td>
</tr>
<tr>
<td>Type of risk</td>
<td>non rsl</td>
<td>cerr.</td>
<td>rsl</td>
</tr>
<tr>
<td>Soil erosion</td>
<td>B</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Soil compaction</td>
<td>A</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Soil organic matter</td>
<td>B</td>
<td>E</td>
<td>D</td>
</tr>
<tr>
<td>Soil chemistry / fertiliser</td>
<td>C</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Nutrient leaching, Eutrophication</td>
<td>B</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Water demand</td>
<td>D</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Weed control / pesticides</td>
<td>B</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Loss of habitat / species diversity</td>
<td>C</td>
<td>E</td>
<td>C</td>
</tr>
<tr>
<td>Loss of landscape elements</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

**Impact category:** A = minimum impact; E = maximum impact

*non rsl:* non-rotational fallow set-aside land, no cropping; cer.: cerrado (topical savannah); *rsl:* rotational set-aside fallow land, no cropping; *conv. use:* conventional use

Source: IUS 2013
Life cycle environmental impact assessment (LC-EIA) results

<table>
<thead>
<tr>
<th>BIOLYFE scenarios</th>
<th>Alternatives to BIOLYFE</th>
<th>Environment</th>
<th>Source: IUS 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Water</td>
<td>BTL (Arundo)</td>
</tr>
<tr>
<td>Arundo</td>
<td>Fibre sorghum</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>Marginal land (Arundo)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soil</td>
<td>Wheat ethanol</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fauna</td>
<td>Beet ethanol</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flora</td>
<td>Cane ethanol (Brazil)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Landscape</td>
<td>Rape seed biodiesel</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Maize bio-methane</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

Ranking by 5 categories: ++ + 0 − −
Life cycle environmental impact assessment (LC-EIA) results

- The so called LC-EIA “Life cycle environmental impact assessment” enlarges the spectrum of environmental assessment indicators.

- It proves, that it works and it is worth it to include the LC-EIA as a supplementary environmental assessment tool to the standard “life cycle assessment”.

- With respect to LC-EIA, Biolyfe ethanol from straw and Arundo compares to alternative biofuels in general quite positive.
The principle of sustainability

Economy

Social issues

Ecology
Production costs of Biolyfe bioethanol from different feedstocks

Arundo
Wheat straw
Fiber sorghum

Source: Biochemtex 2013
Production costs of Biolyfe bioethanol and several BTL* fuels

* BTL: Biomass-to-liquid fuel

Source: Biochemtex 2013

**BIOLYFE:** Demonstrating large-scale bioethanol production from lignocellulosic feedstocks
Production costs of Biolyfe ethanol and other biofuels from different feedstocks

Source: Biochemtex 2013
Production costs of Biolyfe ethanol and other biofuels from different feedstocks

All biofuels investigated cannot compete with the production costs of fossil fuels as of today.

According to Biochemtex calculations, the production costs of Biolyfe ethanol from Arundo and straw can easily compete with those of conventional biofuels and have even a big potential to be more competitive than most of them.
The principle of sustainability
• SWOT analysis evaluates **Strengths, Weaknesses, Opportunities, and Threats** (involved in a business venture).

• Factors which are **internal** to the system investigated are classified as strengths (S) or weaknesses (W).

• Factors which are **external** to the system investigated are classified as opportunities (O) or threats (T).

<table>
<thead>
<tr>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal</strong></td>
<td><strong>External</strong></td>
</tr>
<tr>
<td>Strength</td>
<td>Weakness</td>
</tr>
<tr>
<td>Opportunity</td>
<td>Threat</td>
</tr>
</tbody>
</table>
## Example for SWOT results for biorefinery

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Adding value to the use of biomass</td>
<td>• Broad undefined and unclassified area</td>
</tr>
<tr>
<td>• Maximising biomass conversion efficiency minimising raw material requirements</td>
<td>• Involvement of stakeholders for different market sectors (agriculture, forestry, energy, chemical) over full biomass value chain necessary</td>
</tr>
<tr>
<td>• Production of a spectrum of bio-based products (food, feed, materials, chemicals) and bioenergy (fuels, power and/or heat) feeding entire bioeconomy</td>
<td>• Most promising biorefinery processes/concepts not clear</td>
</tr>
<tr>
<td>• Strong knowledge Infrastructure available to tackle technical and non-technical issues</td>
<td>• Most promising biomass value chains, including current/future market volumes/prices, not clear</td>
</tr>
<tr>
<td>• Biorefinery is not new, it builds on agriculture, food and forestry industries</td>
<td>• Studying and concept development instead of real market implementation</td>
</tr>
<tr>
<td>• Stronger focus on drop-in chemicals facilitating market penetration</td>
<td>• Variability of quality and energy density of biomass</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Biorefineries can make a significant contribution to sustainable development</td>
<td>• Economic change and volatility in fossil fuel prices</td>
</tr>
<tr>
<td>• Challenging national and global policy goals, international focus on sustainable use of biomass for the production of bioenergy</td>
<td>• Fast implementation of other renewable energy technologies feeding the market requests</td>
</tr>
<tr>
<td>• International consensus on the fact that biomass availability is limited meaning that raw materials should be used as efficiently as possible — i.e. development of multi-purpose biorefineries in a framework of scarce raw materials and energy</td>
<td>• Bio-based products and bioenergy are assessed to a higher standard than traditional products (no level playing field)</td>
</tr>
<tr>
<td>• International development of a portfolio of biorefinery concepts, including technical processes</td>
<td>• Availability and contractibility of raw materials (e.g. climate change, policies, logistics)</td>
</tr>
<tr>
<td>• Strengthening of the economic position of various market sectors (e.g. agriculture, forestry, chemical and energy)</td>
<td>• (High) Investment capital for pilot and demo initiatives difficult to find, and underappreciated existing industrial infrastructure</td>
</tr>
<tr>
<td>• Strong demand from brand owners for biobased chemicals</td>
<td>• Changing governmental policies</td>
</tr>
<tr>
<td></td>
<td>• Questioning of food/feed/fuels (Indirect land use competition) and sustainability of biomass production</td>
</tr>
<tr>
<td></td>
<td>• Goals of end users often focused on single product</td>
</tr>
</tbody>
</table>

Source: IEA Bioenergy, Task 42 Biorefinery
Challenges and opportunities for lignocellulosic ethanol biorefineries

A SWOT analysis based on the BIOLYFE concept

Workshop preparation document

3rd ICLE, 3rd April 2013, 17:15-19:00,
Casino de Madrid, Madrid, Spain

→ > 200 international delegates and experts

→ Finalization of SWOT Biolyfe analysis
Many SWOT indicators have been identified and assessed

Need for prioritization and/or ranking of the results

Dedicated extraction of results with respect of social assessment
# Social assessment

## BIOLYFE scenarios

<table>
<thead>
<tr>
<th></th>
<th>Arundo</th>
<th>Fibre sorghum</th>
<th>Wheat straw</th>
<th>Marginal land (Arundo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to land (local comm. &amp; farmers)</td>
<td>——</td>
<td>——</td>
<td>——</td>
<td>0</td>
</tr>
<tr>
<td>Access to jobs &amp; income (local comm. &amp; farmers)</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Acceptance (local comm. &amp; farmers)</td>
<td>——</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Acceptance (general society)</td>
<td>——</td>
<td>——</td>
<td>——</td>
<td>——</td>
</tr>
<tr>
<td>Contribution to innovation (general society)</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
</tbody>
</table>

## Alternatives to BIOLYFE

<table>
<thead>
<tr>
<th></th>
<th>BTL (Arundo)</th>
<th>Wheat ethanol</th>
<th>Beet ethanol</th>
<th>Cane ethanol (Brazil)</th>
<th>Rape seed biodiesel</th>
<th>Maize bio-methane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to land (local comm. &amp; farmers)</td>
<td>——</td>
<td>——</td>
<td>——</td>
<td>——</td>
<td>——</td>
<td>——</td>
</tr>
<tr>
<td>Access to jobs &amp; income (local comm. &amp; farmers)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Acceptance (local comm. &amp; farmers)</td>
<td>——</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Acceptance (general society)</td>
<td>——</td>
<td>——</td>
<td>——</td>
<td>——</td>
<td>——</td>
<td>——</td>
</tr>
<tr>
<td>Contribution to innovation (general society)</td>
<td>++</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Ranking by 5 categories:**

- ++
- +
- 0
- —
- ——

Source: IUS / IFEU 2013

**BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks**
Flow chart of “Integrated assessment of sustainability”

Technological assessment

- Environmental assessment
- Economic assessment
- SWOT analysis

Integrated assessment of sustainability

BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks
## BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks

### Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Maturity</th>
<th>Availability of infrastructure</th>
<th>Use of GMOs</th>
<th>Toxicity risks</th>
<th>Risk of explosions and fires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arundo</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Fibre sorghum</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Marginal land (Arundo)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BTL (Arundo)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wheat ethanol</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Beet ethanol</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cane ethanol (Brazil)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rape seed biodiesel</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maize bio-methane</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Environment

| Resource depletion: energy | DL / t ethanol (eq.) | Climate change | t CO₂ eq. / t ethanol (eq.) | Acidification | kg SO₂ eq. / t ethanol (eq.) | Terrestrial eutrophication | kg PO₄ eq. / t ethanol (eq.) | Aquatic eutrophication | kg PO₄ eq. / t ethanol (eq.) | Photochem. ozone formation | kg ethene eq. / t ethanol (eq.) | Ozone depletion | g Cp/Ct eq. / t ethanol (eq.) | Respiratory inorganics | kg PM10 eq. / t ethanol (eq.) | Lecithin | kg lecithin eq. / t ethanol (eq.) | Direct agricultural land use | ha/a / t ethanol (eq.) | Water | - |
|---------------------------|----------------------|-----------------|----------------------------|---------------|-----------------------------|---------------------------|----------------------------|---------------------------|-----------------------------|-----------------------------|----------------------------|------------------------|--------------------------|----------------------------|------------------------|-------------------------|-----------------|-----------------|
| Arundo                    | -20                  | -5              | -21                        | -19           | 9                           | 1.0                       | 2.1                       | 7.6                       | 0.00                        | 0.15                        | 0.20                       | 0.20                   | 27                       | 13                       | 6                         | 0.5                     | 0.00                     | 0.0             |
| Wheat straw               | -21                  | -19             | -34                        | -19           | 7                           | 0.9                       | 0.3                       | 0.9                       | 0.00                        | 0.15                        | 0.20                       | 0.20                   | 52                       | 32                       | 5                         | 0.5                     | 0.00                     | 0.0             |
| Marginal land (Arundo)    | -21                  | -19             | -34                        | -19           | 9                           | 1.0                       | 2.1                       | 7.6                       | 0.00                        | 0.15                        | 0.20                       | 0.20                   | 52                       | 32                       | 5                         | 0.5                     | 0.00                     | 0.0             |
| BTL (Arundo)              | -21                  | -19             | -34                        | -19           | 9                           | 1.0                       | 2.1                       | 7.6                       | 0.00                        | 0.15                        | 0.20                       | 0.20                   | 52                       | 32                       | 5                         | 0.5                     | 0.00                     | 0.0             |
| Wheat ethanol             | -21                  | -19             | -34                        | -19           | 9                           | 1.0                       | 2.1                       | 7.6                       | 0.00                        | 0.15                        | 0.20                       | 0.20                   | 52                       | 32                       | 5                         | 0.5                     | 0.00                     | 0.0             |
| Beet ethanol              | -21                  | -19             | -34                        | -19           | 9                           | 1.0                       | 2.1                       | 7.6                       | 0.00                        | 0.15                        | 0.20                       | 0.20                   | 52                       | 32                       | 5                         | 0.5                     | 0.00                     | 0.0             |
| Cane ethanol (Brazil)     | -21                  | -19             | -34                        | -19           | 9                           | 1.0                       | 2.1                       | 7.6                       | 0.00                        | 0.15                        | 0.20                       | 0.20                   | 52                       | 32                       | 5                         | 0.5                     | 0.00                     | 0.0             |
| Rape seed biodiesel       | -21                  | -19             | -34                        | -19           | 9                           | 1.0                       | 2.1                       | 7.6                       | 0.00                        | 0.15                        | 0.20                       | 0.20                   | 52                       | 32                       | 5                         | 0.5                     | 0.00                     | 0.0             |
| Maize bio-methane         | -21                  | -19             | -34                        | -19           | 9                           | 1.0                       | 2.1                       | 7.6                       | 0.00                        | 0.15                        | 0.20                       | 0.20                   | 52                       | 32                       | 5                         | 0.5                     | 0.00                     | 0.0             |

### Economy

<table>
<thead>
<tr>
<th>Production costs</th>
<th>€ / t ethanol (eq.)</th>
<th>485</th>
<th>602</th>
<th>474</th>
<th>485</th>
<th>900</th>
<th>850</th>
<th>670</th>
<th>470</th>
<th>860</th>
<th>940</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost difference to gasoline</td>
<td>€ / t ethanol (eq.)</td>
<td>-115</td>
<td>-232</td>
<td>-104</td>
<td>-115</td>
<td>-530</td>
<td>-480</td>
<td>-300</td>
<td>-100</td>
<td>-490</td>
<td>-570</td>
</tr>
<tr>
<td>Fixed capital investment</td>
<td>Million €</td>
<td>89</td>
<td>103</td>
<td>88</td>
<td>100</td>
<td>N/D</td>
<td>N/D</td>
<td>N/D</td>
<td>N/D</td>
<td>N/D</td>
<td>N/D</td>
</tr>
<tr>
<td>Energy resource savings costs</td>
<td>€ / GJ</td>
<td>101</td>
<td>N/A</td>
<td>82</td>
<td>103</td>
<td>323</td>
<td>224</td>
<td>250</td>
<td>36</td>
<td>263</td>
<td>456</td>
</tr>
</tbody>
</table>

### Society

<table>
<thead>
<tr>
<th>Access to land (local comm. &amp; farmers)</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to jobs &amp; income (local comm. &amp; farmers)</td>
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<td>0</td>
</tr>
</tbody>
</table>

### Ranking by 5 categories:

- ++
- +
- 0
- –
- ---

Source: IUS / IFEU 2013
Conclusions I (selection)

- Biolyfe ethanol compares to gasoline with the same result pattern as most other biofuels sharing benefits with drawbacks.

- Compared to other biofuels, Biolyfe ethanol shows a remarkable set of benefits especially if produced from Arundo on marginal land and straw.

- Biolyfe ethanol is not a self running story: not all pathways are genuinely sustainable, though most of them have the potential to being directed into being best possible sustainable. For its further market introduction, there is still need for incentives for a certain transition period by e.g. political measures.
Conclusions II (selection)

- It was proved that the methodology of the “integrated assessment of sustainability” works well and is very powerful.

- With this, it is worth it to expand the standards of environmental LCA and upcoming economic LCC and social sLCA supplementary with the environmental LC-EIA and SWOT. This should become a standard in future sustainability assessments.

- With respect to Biolyfe ethanol, it was shown, that there are some action fields for either improvement or optimisation such as:
  - to assure always a sustainable biomass production
  - optimise energy integration and most efficient energy use
  - improve enzyme efficiency and minimise enzyme production impacts
  - use BAT (best available technologies) in all process units
  - et cetera
Recommenations I (selection)

Many recommendations have been identified for several stakeholders such as for politicians, researchers, companies, and farmers. Some important include:

- **Politicians**: If it is a political goal to introduce second generation fuels make sure to guarantee sufficient incentives for a certain transition period.
- **Politicians**: Develop and agree on both, a biomass allocation and land use allocation plan.
- **Politicians**: Implement compulsory regional planning tools.
Recommendations II (selection)

- **Companies:**
  - Use only sustainable produced biomass
  - Use BAT in all processes
  - Optimise energy provision, integration and use et cetera

- **Farmers:**
  - Guarantee long term soil fertility when straw extraction
  - Guarantee sustainable biomass production et cetera

- **Researchers:**
  - For sustainability assessment use integrated tool
  - Optimise enzyme efficiency and production impacts
  - Optimise process integration for ethanol purification
  - Optimise the use of fermentation residues et cetera
Integrated sustainability assessment of BIOLYFE second generation bioethanol

(Deliverable 12.3: Final report)

Supported by the European Commission’s Seventh Framework Programme (FP7) under grant agreement no. 239204

Heidelberg, Germany, 31 December 2013
Acknowledgements

• Thanks to all BIOLYFE partners for data, information, discussions and all kind of support which was extremely valuable for the integrated assessment of sustainability.

• Many thanks especially to the Biochemtex team for their valuable contributions for the economic assessment and the WIP team for their contribution to the SWOT analysis.

• Thanks also to Julie Tondeur and Kyriakos Maniatis from the European Commission for all their efforts to support the Biolyfe project.

• Special thanks to Arianna and David for being available all times throughout the project and their excellent co-ordination.
Concluding remark

Biolyfe ethanol has a remarkable potential to become a sustainable biofuel in the future. Still, it is not a self running story and quite some homeworks are still due for all stakeholders: politicians, researchers, industry and farmers.
BIOLYFE: Demonstrating large-scale bioethanol production from lignocellulosic feedstocks

For the sake of the environment

Biofuel plantation establishment
Thank you very much for your attention

Questions?
...... don‘t hesitate to ask!

Contact:
...... guido.reinhardt@ifeu.de

Downloads:
...... www.ifeu.de