Agro-energy districts: Definition

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Contents of Presentation

- Agro-Energy-District: Definitions
- Understanding Agro-bioresources
  (A) From food to agro-energy systems
  (B) Supply chain management – Biomass potential
- Using Agro-bioresources
  (C) Sustainability assessment - Efficiency vs. Equity
  (D) Supply chain modeling and design
- The Regional Dimension - Examples
Agro-energy districts: definitions

Agro-energy districts

“Agro”: Biological resources of agricultural origin

- Farm residues; i.e. straw, leaves trimmings etc.
- Forest residues; i.e. branches, leaves, tops etc.
- Livestock wastes; i.e. manure etc.
- Dedicated energy crops; i.e. sugar beet, sweet sorghum, rape seed etc.
- Secondary residues from agro-industries; i.e. sugar beet pulp, olive kernel, etc.

- From traditional production function of agro-systems to new residential, recreational and eco-friendly preservation functions

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Agro-energy districts: definitions

Agro - energy districts

“Energy”: Thermochemical, biochemical and other physico-chemical processes applied to “agro” resources for the production of energy end-uses/products:

- Thermal (Bio-Heat)
- Power (Bio-Electricity)
- Biofuels; Solid, i.e. pellets, charcoal; Liquid, i.e. bioethanol, biodiesel; or gaseous, i.e. biogas,
- Combination of the above energy products
- A new integration of agriculture and industry

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### Pathways from bioresource to the end products

<table>
<thead>
<tr>
<th>Technologies</th>
<th>Conversion process</th>
<th>Major biomass feedstock</th>
<th>Energy (or) fuel produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct combustion</td>
<td>Thermochemical</td>
<td>• Wood&lt;br&gt;• Agricultural waste&lt;br&gt;• Municipal solid waste</td>
<td>• Heat&lt;br&gt;• Steam&lt;br&gt;• Electricity</td>
</tr>
<tr>
<td>Gasification</td>
<td></td>
<td></td>
<td>• Producer gas</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td></td>
<td></td>
<td>• Synthetic fuel oil (biocrude)&lt;br&gt;Charcoal&lt;br&gt;Methanol&lt;br&gt;Biogas</td>
</tr>
<tr>
<td>Liquefaction</td>
<td>Bio-chemical</td>
<td>• Animal manure&lt;br&gt;• Agricultural waste&lt;br&gt;Animal manure&lt;br&gt;Agricultural waste&lt;br&gt;Municipal solid waste</td>
<td>• Heat</td>
</tr>
<tr>
<td>Anaerobic (biogas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>production)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerobic decomposition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerobic (ethanol</td>
<td></td>
<td></td>
<td>• Ethanol</td>
</tr>
<tr>
<td>production)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical extraction-esterification</td>
<td>Physicochemical</td>
<td>• Wood waste&lt;br&gt;Pulp sludge&lt;br&gt;Energy crops</td>
<td>• Biodiesel</td>
</tr>
</tbody>
</table>

Agro-energy districts: definition

Agro-energy districts

“Districts”: Regions, Areas, Localities, Territories

- Emphasis on the local/regional dimension of the resources and their exploitation plan
- Activities avoiding the strategies of import/export
- Involvement of local community to the whole process, from the initial decision making process up to the distribution of the added value
- Smart specialization of each region depending on the available resources, infrastructures, culture, previous know-how

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Agro-energy districts: The Pyramid

- End use
- Conversion technology options
- Technical specifications
- Spatial distribution
- Potential
- Type of biomass

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Understanding Agro-Bioresources

PART A: From Food to Agroenergy Systems

- THE CASE OF BIOMASS-TO-BIOETHANOL
Let’s do a few steps back…

Are you familiar (up to a point) with wine?

Wine-making?

Use it as an example
(kind of “model” - metaphor)
Raw materials for wine-making?

Juice from grapes

Which is the actual raw material in wine-making?

Carbohydrates, i.e. simple sugars, i.e. C6 sugars,

Are there upstream / downstream processes in wine-making?

- Upstream (cutting, pressing-juice/water soluble sugars)
- Downstream processes addressing to the commercial product (i.e. wine)
So far food (drink) purposes, let’s consider energy purposes

• What is the necessary condition for using ethanol as fuel?
  Ethanol-water separation!
  You cannot feed the engine with water!

• Only (6-10-)12% ethanol obtainable during fermentation, why?
  Ethanol inhibition (product inhibition!)

• Other potential inhibitions during the fermentation?
  e.g. Is there raw material inhibition?
  Yes!
  example? Glucose! (everyday- life?: sweets!)

So there are constraints!
Boundary conditions!
Difficulties, waiting for engineering solutions, in the transition from food applications to ethanol as fuel (6-10 w/v ethanol because of substrate consistency-concentration)
Potential other raw materials for bioethanol production?

What is their common specification we are looking for?

Carbohydrate sources
So…

Raw materials categories:

a) Simple Sugars
b) Starch
c) Lignocellulosics

170 billion t/a biomass production
75% carbohydrates
20% lignin
5% other

Focus on the efficient access on the carbohydrates is the basis for any biofuel/biorefinery unit.

http://www.biorefinery.nl/public-deliverables/ (July 02, 2012)

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Examples:

Sugar beet, sugar cane and industrial residues, etc.
potato, potato residues etc., i.e. agro-industrial residues
straw (wheat, barley, corn, etc) stems, residues, not the food crop!
A’ concept for bioethanol from lignocellulosic feedstocks:
Raw material --- depolymerisation (acid or enzymic saccharification) --- fermentation

B’ concept for bioethanol from lignocellulosic feedstocks:
Direct bioconversion, i.e. Simultaneous Saccharification Fermentation (SSF) (special microbial system)
Don’t forget physico-chemistry of the raw material:

Structure (order … cellulose crystallinity)

Specific surface area (SSA) - pores

Ligno-cellulose-hemicellulose (LCH) complex (sugars surrounded)
Understanding Bioresources: From Food to Biofuels

Cellulose

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Understanding Bioresources: From Food to Biofuels

Current model for enzymatic degradation of cellulose

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LCH complex

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Lignin

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Upstream needs?:

YES! Any pretreatment enhancing accessibility

- Particle size reduction/SSA increase (milling, grinding)
- Disordering (crystallinity index decrease)
- Get rid of unnecessary or harmful components (e.g. lignin, i.e. delignification)
- Others....
Downstream needs?:

Yes!!! Ethanol-water separation

• distillation? Expensive, energy consuming
• extraction (mainly with a solvent)
Other potential examples?

- Agroindustrial residue, cellulosic mainly: sugar beet pulp to ethanol

- Agricultural residue, lignocellulosic: straw to ethanol (crystallinity, surface area, delignification)

- Energy crop, sugar-cellulosic: sweet sorghum to ethanol (stalks, juice/cake, fed-batch, etc....)
What to take home with you…!

• Know-how for the bioethanol production is available since very old times
• The transition from alcoholic beverages to biofuel ethanol requires optimization in multiple steps of the production and use chain
• Diversity in the resources (crops) which can be used for the bioethanol production
• The future belongs to lignocellulosics, since residual biomass is expected to play the key role in the biofuel/bioenergy generation market
• The development and optimization of the pretreatment of lignocellulosics is a multiple step procedure of high complexity

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PART B: Supply Chain Management - Biomass Potential

- THE CASE OF BIOMASS-TO-FERMENTATIVE BIOHYDROGEN
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Bioresource Supply Chain Management

**Total biofuel chain definition**

- Biomass collection agro-forest residues
- Biomass production for energy applications
- Biomass collection agro-forest industry residues
- Transportation
- Local pretreatment Storage
- Pretreatment Bio-refining

**Co-products**

**Biofuel production**

**Bio-H2**

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Bioresource Supply Chain Management

**Approach**

1. **Security of Supply_ Feedstock:** Estimation of Biomass potential in EU for Fermentative Bio-Hydrogen Production

2. **Security of Supply_ Logistics:** State of the art in the modeling of biomass logistic chains

3. **Security of Supply_ “Biorefining”:** Identification of the crucial parameters of a potential biorefinery approach- handling by-products
Estimation of Biomass potential in EU for Bio-Hydrogen Production

- Assessment of the theoretical potential
- From the theoretical to the sustainable potential
  - Additional technical, economic, environmental and social boundaries
  - Competition by other sectors
- The regional dimension
TECHNOLOGY
Non-Thermal Production of Pure Hydrogen from Biomass

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{H}_2\text{O} \rightarrow 6 \text{CO}_2 + 12 \text{H}_2 \quad \Delta G'_o = +3 \text{ kJ} \]

Water soluble monomeric and oligomeric carbohydrates

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 2\text{H}_2\text{O} \rightarrow 2\text{CO}_2 + 2\text{CH}_3\text{COOH} + 4\text{H}_2 \quad \Delta G'_o = -206 \text{ kJ} \]
(hyper)thermophilic bacteria

\[ \text{CH}_3\text{COOH} + 2\text{H}_2\text{O} \rightarrow 2\text{CO}_2 + 4\text{H}_2 \quad \Delta G'_o = +104 \text{ kJ} \]
photosynthetic bacteria

**Major advantage:** Potential for feasible and sustainable operation of relatively small units, up to 2MW (fed by 8000 dry tons of biomass/a)
Assessment of the theoretical potential
Questions to be asked while assessing the theoretical biomass potential for the specific technology:

Which is the actual raw material in fermentative hydrogen conversion technology?
   Water soluble carbohydrates (monomeric, … oligomeric sugars)

Which are the main crops or industrial by products which can provide, directly or after pretreatment(s), such carbohydrates?
   - Major sugar, starch crops and their industrial by products
   - Easily hydrolysable lignocellulosics from farm or agro-industries
“Mapping the Landscape” of potential for EU biomass
Assumptions

- Identification of relevant crops, based on the current land use data.
- The adoption of “biorefining” approach for these crops in order to identify the relevant biomass sources (main product, crop residues at farm, agro-industrial residues).
- Quantitative statistical data collection for agricultural and agro-industrial production for regions, countries and EU27.
- Assumptions for future land use (1/3 of fallow land to be utilized for energy crop production), agricultural production (10% of the current agricultural production to be utilized for Hydrogen production whenever this is technically feasible), for residue availability (100%) and bm2bh conversion efficiency (100 kg Hydrogen for every ton of Carbohydrate).
- Miscanthus (for Central and North EU27) and sweet sorghum (for South EU27) as potential future energy crops. The relative potential calculations were based on the available yield, carbohydrate and moisture content data for these two crops.
- Carbohydrate content of the potential feedstocks based on either experimental data or literature.
- Development of matrices where all the above are presented in a user friendly way.
### Potential Feedstocks for Hydrogen Production

<table>
<thead>
<tr>
<th>Crop Category</th>
<th>Crop</th>
<th>main product</th>
<th>by-products</th>
<th>sludges-other wet residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar Crops</td>
<td>sugar beet</td>
<td>sugar</td>
<td>leaves</td>
<td>pulp</td>
</tr>
<tr>
<td></td>
<td>potato</td>
<td>tuber</td>
<td>leaves</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>wheat</td>
<td>grain</td>
<td>straw</td>
<td>husks, hulls, bran</td>
</tr>
<tr>
<td></td>
<td>barley</td>
<td>grain</td>
<td>straw</td>
<td>husks, hulls, bran</td>
</tr>
<tr>
<td></td>
<td>maize</td>
<td>grain</td>
<td>straw</td>
<td>corn-oil cake</td>
</tr>
<tr>
<td></td>
<td>other cereals</td>
<td>grain</td>
<td>straw</td>
<td>husks, hulls, bran</td>
</tr>
<tr>
<td></td>
<td>rice</td>
<td>grain</td>
<td>straw</td>
<td>husks, hulls, bran</td>
</tr>
<tr>
<td></td>
<td>grapes</td>
<td>wine, juice</td>
<td>-</td>
<td>wine</td>
</tr>
<tr>
<td></td>
<td>apples</td>
<td>canned prod., juice</td>
<td>-</td>
<td>wood, trimmings</td>
</tr>
<tr>
<td></td>
<td>other fruits</td>
<td>canned prod., juice</td>
<td>-</td>
<td>wood, trimmings</td>
</tr>
<tr>
<td></td>
<td>vegetables</td>
<td>canned prod., juice</td>
<td>leaves</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>oil seeds</td>
<td>veg. oil</td>
<td>-</td>
<td>straw</td>
</tr>
<tr>
<td>Energy crops</td>
<td>sw. sorghum</td>
<td>sugar</td>
<td>leaves</td>
<td>bagasse</td>
</tr>
<tr>
<td>Lignocellulosic crops</td>
<td>Miscanthus</td>
<td>stems/stalks</td>
<td>leaves</td>
<td>-</td>
</tr>
</tbody>
</table>

15 crop main product and 29 farm or industrial level by-products and residues were considered as potential feedstocks.
## Annual Biomass Production for EU-27

<table>
<thead>
<tr>
<th>Crop Category</th>
<th>Crop</th>
<th>main product</th>
<th>by-products</th>
<th>Total Annual Production for EU27</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>leafy biomass</td>
<td>stems-stalks</td>
</tr>
<tr>
<td>Sugar Crops</td>
<td>sugar beet</td>
<td>18.1</td>
<td>7.3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>potato</td>
<td>12.9</td>
<td>8.8</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>wheat</td>
<td>97.5</td>
<td>-</td>
<td>82.6</td>
</tr>
<tr>
<td></td>
<td>barley</td>
<td>48.2</td>
<td>-</td>
<td>40.8</td>
</tr>
<tr>
<td></td>
<td>maize</td>
<td>43.8</td>
<td>-</td>
<td>52.6</td>
</tr>
<tr>
<td></td>
<td>other cereals</td>
<td>25.7</td>
<td>-</td>
<td>18.3</td>
</tr>
<tr>
<td></td>
<td>rice</td>
<td>2.3</td>
<td>-</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>grapes</td>
<td>12.7</td>
<td>-</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td>apples</td>
<td>1.7</td>
<td>-</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>other fruits</td>
<td>3.6</td>
<td>-</td>
<td>15.1</td>
</tr>
<tr>
<td></td>
<td>vegetables</td>
<td>5.0</td>
<td>7.3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>oil seeds</td>
<td>9.4</td>
<td>-</td>
<td>40.3</td>
</tr>
<tr>
<td>Other Food Crops</td>
<td>sw. sorghum</td>
<td>19.5</td>
<td>4.9</td>
<td>7.8</td>
</tr>
<tr>
<td>Energy crops</td>
<td>Sugar Crops</td>
<td>sw. sorghum</td>
<td>19.5</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>miscanthes</td>
<td>21.6</td>
<td>5.6</td>
<td>-</td>
</tr>
</tbody>
</table>

### Total Annual Production
- 322.4
- 33.9
- 294.1
- 56.1
- 28.8
- 738.3
### Total Hydrogen Generation Potential in EU-27

#### HYDROGEN POTENTIAL FOR EU27 (10^6 t H2)

<table>
<thead>
<tr>
<th>Crop Category</th>
<th>Crop</th>
<th>10% of the main product of crops as feedstock for hydrogen except energy crops where 100% goes for Hydrogen</th>
<th>leafy biomass</th>
<th>stems-stalks</th>
<th>pulps-cakes</th>
<th>sludges-other wet residues</th>
<th>Total Hydrogen Generation Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sugar Crops</strong></td>
<td>sugar beet</td>
<td>0.18</td>
<td>0.51</td>
<td>-</td>
<td>0.51</td>
<td>0.05</td>
<td>1.70</td>
</tr>
<tr>
<td></td>
<td>potato</td>
<td>0.10</td>
<td>0.61</td>
<td>-</td>
<td>0.14</td>
<td>0.06</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>wheat</td>
<td>0.68</td>
<td>5.78</td>
<td>0.68</td>
<td>0.24</td>
<td>7.39</td>
<td></td>
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<tr>
<td></td>
<td>barley</td>
<td>0.34</td>
<td>-</td>
<td>2.86</td>
<td>0.34</td>
<td>0.12</td>
<td>4.30</td>
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<tr>
<td></td>
<td>maize</td>
<td>0.31</td>
<td>-</td>
<td>3.68</td>
<td>0.31</td>
<td>0.11</td>
<td>5.94</td>
</tr>
<tr>
<td></td>
<td>other cereals</td>
<td>0.18</td>
<td>-</td>
<td>1.28</td>
<td>0.18</td>
<td>0.06</td>
<td>1.70</td>
</tr>
<tr>
<td></td>
<td>rice</td>
<td>0.02</td>
<td>-</td>
<td>0.12</td>
<td>0.02</td>
<td>0.01</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>grapes</td>
<td>0.02</td>
<td>-</td>
<td>0.77</td>
<td>0.31</td>
<td>0.04</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>apples</td>
<td>0.00</td>
<td>-</td>
<td>0.14</td>
<td>0.06</td>
<td>0.00</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>other fruits</td>
<td>0.01</td>
<td>-</td>
<td>1.96</td>
<td>0.06</td>
<td>0.01</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>vegetables</td>
<td>0.50</td>
<td>0.51</td>
<td>1.53</td>
<td>0.31</td>
<td>0.11</td>
<td>5.94</td>
</tr>
<tr>
<td></td>
<td>oil seeds</td>
<td>-</td>
<td>-</td>
<td>2.82</td>
<td>1.32</td>
<td>0.02</td>
<td>4.16</td>
</tr>
<tr>
<td><strong>Starch Crops</strong></td>
<td>sw. sorghum</td>
<td>1.95</td>
<td>0.34</td>
<td>0.55</td>
<td>-</td>
<td>0.05</td>
<td>2.89</td>
</tr>
<tr>
<td></td>
<td>miscanthus</td>
<td>1.51</td>
<td>0.39</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.90</td>
</tr>
<tr>
<td><strong>Total Hydrogen Generation Potential</strong></td>
<td></td>
<td>5.8</td>
<td>2.4</td>
<td>20.6</td>
<td>3.9</td>
<td>1.9</td>
<td>34.6</td>
</tr>
</tbody>
</table>

**Colour Scale**
- <0.05
- 0.05-0.50
- 0.51-1.00
- >1.00

*Equi-Agry: efficiency and equity trade off in European agroenergy districts*

_Foggia, June-July 2014_
Country Contribution in Total Hydrogen Production Potential in EU-27

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From the theoretical to the sustainable potential

- Additional technical, economic, environmental and social boundaries considering the local and regional dimension
- Competition by other sectors
Potential Estimation: From Total to Sustainable

\[ B = A \times a \times b \times c \times d \quad \text{with} \quad a, b, c, d \leq 1 \]
Questions to be asked while assessing the sustainable potential for the specific technology:

How to decide which potential feedstock is promising for our application?
- Technical suitability
- Economic feasibility
- Environmental and social sustainability

How to quantify these aspects?
Using Agro-Bioresources

Sustainability Assessment: Efficiency vs. Equity

- EFFICIENCY: Technology, Economy
- EQUITY: Society & Environment
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Foggia, June-July 2014
## Biomass Technical Suitability Index (BTSI)

<table>
<thead>
<tr>
<th>Category</th>
<th>Name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yield Potential</td>
<td>Maximum Hydrogen yield based on two-step stoichiometric hydrogen fermentation, assuming 80% conversion to hydrogen and 20% to microbial biomass production and other byproducts</td>
</tr>
<tr>
<td>2</td>
<td>Mobilisation Efficiency</td>
<td>Percentage of all carbohydrates in the feedstock that can be converted into fermentable sugars</td>
</tr>
<tr>
<td>3</td>
<td>Fermentability</td>
<td>Tendency of pretreated feedstock to inhibit or improve fermentation to hydrogen</td>
</tr>
<tr>
<td>4</td>
<td>Coproduct value &amp; yield</td>
<td>Characterisation of both the value and the volume of the co-product from pretreatment or fermentation</td>
</tr>
</tbody>
</table>
Biomass Technical Suitability Index (BTSI)

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Yield Potential</th>
<th>Mobilisation efficiency</th>
<th>Fermentability</th>
<th>Co-product Application &amp; Yield</th>
<th>Co-product Value &amp; Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar beet (juice)</td>
<td>68.0</td>
<td>90.0</td>
<td>39.0</td>
<td>38.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Wheat grain</td>
<td>80.0</td>
<td>70.0</td>
<td>40.0</td>
<td>40.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>90.0</td>
<td>80.0</td>
<td>50.0</td>
<td>50.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Reed Canary Grass</td>
<td>100.0</td>
<td>90.0</td>
<td>60.0</td>
<td>60.0</td>
<td>40.0</td>
</tr>
</tbody>
</table>

**Equivalent Weighting:**

Sugar beet (juice): 0.685
# Biomass Cost Index (BCI)

<table>
<thead>
<tr>
<th><strong>Cost A (€/wet t)</strong></th>
<th>Primary production or opportunity cost of feedstock (€/wet t)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dry Matter Content (dm)</strong></td>
<td>% water (moisture) content of feedstock</td>
</tr>
<tr>
<td><strong>Carbohydrate Content</strong></td>
<td>% non-carbohydrate content of feedstock</td>
</tr>
<tr>
<td><strong>Transport Distance</strong></td>
<td>Feedstock transportation distance (km)</td>
</tr>
<tr>
<td><strong>BioH2 Plant Capacity</strong></td>
<td>Plant capacity (dry t biomass/h)</td>
</tr>
<tr>
<td><strong>Cost C (index)</strong></td>
<td>Refining Index (refining difficulty due to the type of Carbohydrates – see above)</td>
</tr>
<tr>
<td><strong>Co-product C Credit (Index)</strong></td>
<td>Credit of refining co-products (euro/GJ carb)</td>
</tr>
</tbody>
</table>
| **Co-product A Credit (Index)** | Credit of primary production co-products (euro/GJ carb)  
(on a 0-100 Scale, where 100 for zero credit) |
| **Biomass Cost Index (BCI)** | Index of the Interaction of the 8 Cost Parameters expressed by the surface area of the spider graph (the highest the Index, the less cost efficient the biomass-to-biohydrogen supply chain) |

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Foggia, June-July 2014
Biomass Cost Index (BCI)

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Biomass Sustainability Index (BSI)

BSI = \{ [BSI-A] + [BSI-B] + [BSI-C] \}/3
Biomass Sustainability Index (BSI)

BSI Sugar beet

1. Soil (erosion vs. conservation practices)
2. Nutrients (losses vs. rational management)
3. Fossil fuels ("hidden" links vs. decoupling)
4. Water (wasting/degrading vs. efficient use)
5. Mobilisation of elements (pollution vs. control)
6. Impact on climate (GHG vs. green accounting)
7. Land use ("fuel or food" vs. biorefineries)
8. Biodiversity (monoculture vs. agroecosystem)
9. Social acceptance (concerns vs. consensus)
10. Human Health (ecology vs. economy)
11. Employment (human vs. development and technology)
12. Regional Development

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# Comparative Assessment and Selection of Feedstock

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>BTSI</th>
<th>BCI</th>
<th>BSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>0.715</td>
<td>3224</td>
<td>1.6</td>
</tr>
<tr>
<td>Reed canary grass</td>
<td>0.642</td>
<td>2530</td>
<td>1.3</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>0.931</td>
<td>2405</td>
<td>1.2</td>
</tr>
<tr>
<td>Wheat grain</td>
<td>0.678</td>
<td>2044</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Comparative Assessment and Selection of Feedstock: Performance Maps

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Comparative Assessment and Selection of Feedstock: Performance Maps

Comparing EU Regions

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51-91% H2 Prod Efficiency, Best Practices and Max Profit

Biomass Cost (euro/GJ H2)

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## Alternative Biomass-to-Hydrogen Pathways

<table>
<thead>
<tr>
<th>High Carb – Low DM:</th>
<th>High Carb – High DM:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass -&gt; BioH2 (HYVOLUTION)</td>
<td>Biomass -&gt; Bioethanol -&gt; Reforming -&gt; H2</td>
</tr>
<tr>
<td>Low Carb – Low DM:</td>
<td>Low Carb – High DM:</td>
</tr>
<tr>
<td>Biomass -&gt; Biogas -&gt; Reforming -&gt; H2</td>
<td>Biomass -&gt; Thermo-chemical Gasification -&gt; H2</td>
</tr>
</tbody>
</table>

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Using Agro-Bioresources

Security of Supply & Logistics:

State of the art in the modeling of biomass logistic chains
Agricultural biomass supply logistics are characterized by:

- Wide areal distribution of biomass sources
- Variable biomass yield
- Time and weather-sensitive crop maturity
- Variable moisture content
- Time-sensitive, variable biomass quality (carbohydrate content)
- Low bulk density of biomass material
- Short time window for collection with competition with concurrent harvest operations
Security of Supply-Feedstock Transport & Handling

Crucial parameters affecting the feedstock Transport & Handling

- Plant scale
- Biomass productivity
- Collection/harvesting area
- Geographical and Geometrical specifications of the feedstock collection area
- Average haul distance
- Maximum extent of feedstock collection
- Feedstock Characteristics (DM, C/H Content, bulk density)

An optimized collection, storage and transport network can ensure timely supply of optimum biomass quality with minimum cost

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State of the Art

Example of transport cost calculation model from the literature

\[ R_j = \left( \frac{n_j S_j}{100 \pi \bar{Y}_s \phi_j} \right)^{1/2} \]  

where \( R_j \) is the radius of the circle around store \( j \) in km, \( 1/n_j \) the sectorial fraction of the circular area with straw fields, \( S_j \) the supply of straw into the storage barn in t, \( \bar{Y}_s \) the average straw yield in t/ha and \( \phi_j \) the fraction of \( A_j \) occupied by straw fields. The transport distance \( d_{ij} \) between a field \((x_i, y_i)\) and either a storage area or another field \((x_j, y_j)\) is described by

\[ d_{ij} = \tau ((x_i - x_j)^2 + (y_i - y_j)^2)^{1/2} \]

where \( \tau \) denotes the tortuosity factor, or the real transport distance in relation to the straight line distance.

---

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Security of Supply_ Feedstock Transport&Handling (B)

State of the Art

Example of an “Agri-Fuel” Chain

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Security of Supply: Feedstock Transport & Handling (B)

State of the Art

From Agri-Food Chain to “Agri-Fuel” Chain

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Security of Supply _ Biomass Conversion - “Biorefining”:

Identification of the crucial parameters of a potential biorefinery approach- handling by-products
The crucial parameters affecting the sustainability of the “bio”-refining and fractionation stage of the whole chain:

- Range of the feedstock type which can be processed (one or multiple feedstock types)

- Seasonality of the plant operation (optimization of the feedstock selection for the full year operation)

- Capacity optimization

- Optimization of the process location (on-site or centralized)

- Exploitation of Co-Products

- Plant location
Security of Supply_ Refining (C)

---

**Sugar Beet**
- Washing Slicing
- Extraction
- Sugar Juice
- Sugar Crystallization
- Molasse

**Wheat Bran**
- Potato steam peels
- Liquefaction
- Hydrolysis
- Solid residue

**Barley Straw**
- Cutting
- Milling
- Alkaline Pretreatment
- Enzymatic Hydrolysis
- Solid residue
- Hydrolysate

---

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Building Supply Chains (ABC)

Mapping the complexity of biomass supply chains

- List of materials
  - Feedstock(s)
  - Intermediate products
  - Possible End products

- List of possible processes
  - Transport treated as process step
  - The steps also have an indication for the respective logistical handling

Example from the literature (single feedstock case)

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Building Supply Chain (ABC)

Strategic Decisions

- Selection of Energy Production Technologies
- Supply and Demand Contracts
- Network Configuration
  - Sourcing
  - Location of Energy Production Facilities
  - Capacity of Energy Production Facilities
  - Location of Storage Facilities
  - Network Design
- Ensuring Sustainability

Tactical & Operational Decisions

- Aggregate Production Planning
  - Inventory Management & Control
  - Fleet Management
  - Vehicle Planning & Scheduling
  - Outsourcing
- Selection of Collection, Storage, Pre-treatment & Transportation Methods
  - Selection of Harvesting Methods and Equipment
  - Selection of Storage Methods
  - Selection of Pre-treatment Technology
  - Timing & Place of Pre-treatment

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I: Processing the feedstock as close as possible to the production site having the Hydrogen plant either at local or central level

II: Only the initial transport and storage at local level, all feedstock processing steps at the central Hydrogen plant

III: Central transport, storage and processing without any “local involvement”

The present “sugar beet for sugar” chain concept is either II or III depending on the local conditions

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Building Supply Chain (ABC)

Spatial dimension

Hydrogen plant

Fermentable sugar syrup
Fermentable sugars (FS)
Dry Matter (DM)
Total Cost (∑C)

Setting Quality Standards According to the End-use

Co-products

Initial quality parameters:
Fermentable sugar content (FS₀)
Dry Matter (DM₀)
Bulk density (BD₀) - if solid-
Particle size (PS₀) - if solid-
Initial cost-cost A- (C₀)

A: Farm-Feedstock source
B: Transport-Handling
C: Biomass Refining Plant

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Total “complex” chain definition

“Players”/stakeholders

- **Farmer (Agro-residue)**
- **Farmer (energy plant)**
- **Agro-industry (Residues)**
- **Transporter**
- **Storage**
- **Refiner**
- **Hydrogen plant**
- **Consumer**

Present user

Potential user

Co-products

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• **Types of EU regions for BioH2 plants**
  – Rural (field residues, energy crops, wastes)
  – Agro-Industrial (wet residues, energy crops)
  – Integrated (linked to a source or energy crop)
  – Mixed (combinations of the above)

• **Types of biomass-to BioH2 systems**
  – One feedstock, e.g., potato wastes
  – More feedstocks of the same type, e.g., starchy
  – Multi-feedstock, of various types

Equi-Agry: efficiency and equity trade off in European agroenergy districts
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• Utilising less than 10% of the EU27 potential will be enough to satisfy the targets
• In the short term, the use of food crops for non-food purposes does not seem necessary
• On the other hand, utilising wet residues and agro-food industrial wastes is an immediate option
• Sugar-rich energy crops - e.g., sweet sorghum or “energy” beet - will play a major role in the medium-to-long run
• More than 50% of the potential is linked to cereal crops, esp. straws, i.e., another strategic option for the EU
• A key finding is that the potential can support the operation of small BioH2 plants (1 dry t/h) with ALL types of biomass feedstocks assessed (local/regional/… applications)
What to take home with you...!

- Enough biomass production in EU27 without the need for major land use change
- System complexity should be considered and dealt when designing biomass-to-biofuel supply chains
- Decision making which will be based on technical, economic, environmental and social aspects
- Regional dimension is crucial for the success of any emerging biofuel technology
The Regional Dimension
Potential regional implementation of Hyvolution technology

EU Policy

National Policy

Regional dimension

Regional Conditions

- Societal attitudes towards innovation
- Energy demand/supply
- Energy market structure
- Renewables Potential vs exploitation
- Supply/ demand of animal feeds
- Land use & Agricultural production
- Natural conditions (Water, soil, climate)
- Supply chain experience from agro-food
- Strategic regional policies
- Agro-industrial activities
- Transport infrastructure
- Socio-economic conditions (GDP/capita, employment,...)
- Biomass-based renewables
Regional dimension

2 basic selection criteria:
GDP/capita and Innovation index, both have a direct impact on the economic and social structure of the regions
Target: to derive useful insight through two “extreme” EU cases

«Industrial North»

<table>
<thead>
<tr>
<th>Innovation Score</th>
<th>Thessaly</th>
<th>0.1 (200/203 Regions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zuid Holland</td>
<td>0.58</td>
<td>(38/203 Regions)</td>
</tr>
<tr>
<td>Range of Scores</td>
<td>0.01-0.90</td>
<td></td>
</tr>
<tr>
<td>GDP/Capita</td>
<td>Thessaly</td>
<td>73.8</td>
</tr>
<tr>
<td>Zuid Holland</td>
<td>134.5</td>
<td></td>
</tr>
<tr>
<td>EU Average</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Range of GDP/capita within EU</td>
<td>24-303</td>
<td></td>
</tr>
</tbody>
</table>

«Rural South»

Equi-Agry: efficiency and equity trade off in European agroenergy districts
Foggia, June-July 2014
### Regional dimension

<table>
<thead>
<tr>
<th>Land use / Main Agricultural Products</th>
<th>“Rural South”: THESSALY</th>
<th>“Industrial North”: ROTTERDAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Total Agricultural Land: 490000 ha</td>
<td>- Total Agricultural Land: 150000 ha</td>
<td></td>
</tr>
<tr>
<td>- Cotton: 150000 ha</td>
<td>- Cereals: 12500</td>
<td></td>
</tr>
<tr>
<td>- Wheat: 110000 ha</td>
<td>- Potatoes: 9000 ha</td>
<td></td>
</tr>
<tr>
<td>- Barley: 14000 ha</td>
<td>- Sugar beet: 4000 ha</td>
<td></td>
</tr>
<tr>
<td>- Sugar beet: 7000 ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Fallow/puture land/other not utilised agricultural land: 38000 ha</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Estimated Agricultural Income        | 850-2500 €/ha (40-50% coming from national or EU subsidies) | 900-2500 €/ha (much higher for greenhouse agriculture) |

<table>
<thead>
<tr>
<th>Agro-industrial Units</th>
<th>2 large wheat mill units</th>
<th>- grain processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 1 large juice production unit</td>
<td>Several small canned product units</td>
<td>- large beer breweries</td>
</tr>
<tr>
<td>- Several oil production/processing units</td>
<td></td>
<td>- potato processing facilities</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spatial Distribution of Agro-industrial Units</th>
<th>- 2 wheat mills are placed in Larissa and Magnesia prefectures</th>
<th>Main agro-industrial units are placed around the port of Rotterdam, within a 30 km radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The juice production unit is placed in Magnesia prefecture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- The rest units are distributed throughout the 4 prefectures</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potentially Available Agricultural and Agro-industrial By-products</th>
<th>- wheat bran</th>
<th>- wheat bran</th>
</tr>
</thead>
<tbody>
<tr>
<td>- wheat and barley straw</td>
<td>- potato steam peels</td>
<td></td>
</tr>
<tr>
<td>- pulp from juice industry</td>
<td>- cake from oil industry</td>
<td></td>
</tr>
<tr>
<td>- cake from oil industry</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transport Infrastructure</th>
<th>- a major port in Magnesia prefecture</th>
<th>- Rotterdam port (Europe’s cheapest bunker port): the third largest port in the world</th>
</tr>
</thead>
<tbody>
<tr>
<td>- good road network</td>
<td>- railway and road network supplying the port</td>
<td></td>
</tr>
</tbody>
</table>

| Available Supply Chain Infrastructures | Already existing import (oil/oil seeds, cereals) and export (flour and other processed cereal and juice products) activities in the region | The agro-industrial units of the region are largely based on imported feedstock. The Agri-bulk handled in Rotterdam is about 9.5 million tones |

<table>
<thead>
<tr>
<th>Renewable Energy in the Region</th>
<th>135 MW power produced in H/E plants, and 2 biodiesel production units</th>
<th>- electricity production using imported wood residues(1 Mton dry wood residues)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 2 biodiesel production units (using imported feedstock) of 55000 tonnes total capacity</td>
<td>- wind energy</td>
<td>- co-firing of wood for electricity</td>
</tr>
<tr>
<td>- 1 bioethanol unit (from sugar beet and cereals) to be operational within 2010 *</td>
<td></td>
<td>- surplus of heat from oil refinery</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- farm scale biogas digesters</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- several bioethanol facilities around the port area</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Population</th>
<th>About 750000 persons</th>
<th>About 1600000 persons</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>GDP/Capita - Employment</th>
<th>73.2 (considering 100 the GDP of EU25)</th>
<th>- 204 billion Euro regional product</th>
</tr>
</thead>
<tbody>
<tr>
<td>13% employed in primary sector</td>
<td>- 21% of the total employment of NL, 1.5% in primary sectors</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Special Regional Conditions - Policies</th>
<th>Governmental initiatives encouraging the land use change (especially from cotton to alternative crops)</th>
<th>Sustainable production program for all the economic sectors</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Social Acceptance of Bioenergy Projects</th>
<th>“Thessaly Biofuel Technology Platform” along with the Thessaly University play a positive role in the social acceptance of biofuels</th>
<th>- Positive public response to “green electricity”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Negative public response to large biofuel plant projects</td>
<td></td>
</tr>
</tbody>
</table>

---

*Foggia, June-July 2014*
**Potential Feedstocks for Hydrogen Production**

<table>
<thead>
<tr>
<th>Crop Category</th>
<th>Crop</th>
<th>main product</th>
<th>leafy biomass</th>
<th>stems-stalks</th>
<th>pulps-cakes</th>
<th>sludges-other wet residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar Crops</td>
<td>sugar beet</td>
<td>sugar</td>
<td>leaves</td>
<td>-</td>
<td>pulp</td>
<td>molasses</td>
</tr>
<tr>
<td>Starch Crops</td>
<td>potato</td>
<td>tuber</td>
<td>leaves</td>
<td>-</td>
<td>peels</td>
<td>starch</td>
</tr>
<tr>
<td></td>
<td>wheat</td>
<td>grain</td>
<td>-</td>
<td>straw</td>
<td>husks,hulls,bran</td>
<td>wet milling wastes</td>
</tr>
<tr>
<td></td>
<td>barley</td>
<td>grain</td>
<td>-</td>
<td>straw</td>
<td>husks,hulls,bran</td>
<td>wet milling wastes</td>
</tr>
<tr>
<td></td>
<td>maize</td>
<td>grain</td>
<td>-</td>
<td>straw</td>
<td>corn-oil cake</td>
<td>brewery waste</td>
</tr>
<tr>
<td>Other cereals</td>
<td>rice</td>
<td>grain</td>
<td>-</td>
<td>straw</td>
<td>husks,hulls,bran</td>
<td>wet milling wastes</td>
</tr>
<tr>
<td></td>
<td>grapes</td>
<td>wine, juice</td>
<td>-</td>
<td>vine</td>
<td>pulp</td>
<td>wet residue</td>
</tr>
<tr>
<td>Other Food Crops</td>
<td>apples</td>
<td>canned prod., juice</td>
<td>-</td>
<td>wood, trimmings</td>
<td>pulp</td>
<td>wet residue</td>
</tr>
<tr>
<td></td>
<td>other fruits</td>
<td>canned prod., juice</td>
<td>-</td>
<td>wood, trimmings</td>
<td>pulp</td>
<td>wet residue</td>
</tr>
<tr>
<td></td>
<td>vegetables</td>
<td>canned prod., juice</td>
<td>leaves</td>
<td>-</td>
<td>pulp</td>
<td>wet residue</td>
</tr>
<tr>
<td></td>
<td>oil seeds</td>
<td>veg. oil</td>
<td>-</td>
<td>straw</td>
<td>oil cake</td>
<td>wet residue</td>
</tr>
<tr>
<td>Lignocellulosic crops</td>
<td>sw. sorghum</td>
<td>sugar</td>
<td>leaves</td>
<td>bagasse</td>
<td>-</td>
<td>sludge</td>
</tr>
<tr>
<td></td>
<td>Miscanthus</td>
<td>stems/stalks</td>
<td>leaves</td>
<td>-</td>
<td>pulp</td>
<td>-</td>
</tr>
</tbody>
</table>

15 crop main product and 29 farm or industrial level by-products and residues were considered as potential feedstocks.
### HYDROGEN POTENTIAL (10^3 t) FOR THESSALY

<table>
<thead>
<tr>
<th>Crop Category</th>
<th>Crop</th>
<th>10% of the main product production as feedstock for hydrogen&lt;sup&gt;×&lt;/sup&gt;</th>
<th>leafy biomass</th>
<th>stems-stalks</th>
<th>pulps-cakes</th>
<th>sludges-other wet residues</th>
<th>Total Hydrogen Production Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sugar Crops</strong></td>
<td>sugar beet</td>
<td>0.356</td>
<td>1,433</td>
<td>-</td>
<td>0.996</td>
<td>0.089</td>
<td>0.897</td>
</tr>
<tr>
<td></td>
<td>potato</td>
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</table>

* 100% of main product for H₂ production in the case of energy crops

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Equi-Agry: efficiency and equity trade off in European agroenergy districts
Foggia, June-July 2014
Selection of promising feedstocks and chains

Indices

Technical
- TSI

Economic
- CI

Social
- Environmental
- SI

Feedstock selection
Supply chain configuration

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Foggia, June-July 2014
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Performance Maps

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Foggia, June-July 2014
Promising feedstocks

Selected Feedstocks: Techno-Economic Criteria

Feedstocks selected by applying, in a top down approach, the Methodology developed in Hyvolution for the Assessment of Technical and Economic Feasibility of Biomass sources:

- **Sugar beet**
- **Potato steam peels (PSP)**
- **Wheat bran**
- **Barley straw**

Biohydrogen generation potential from 4 selected feedstocks in Thessaly: 3.2 kt

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Foggia, June-July 2014
Assessing the current perspectives in the two regions

<table>
<thead>
<tr>
<th>Potential Feedstock</th>
<th>Location</th>
<th>Co-operation with existing or potential industrial units</th>
<th>Hydrogen Unit Type</th>
<th>Potential Capacity</th>
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</thead>
<tbody>
<tr>
<td>Sugar beet</td>
<td>Larissa</td>
<td>Bio-ethanol Production Unit (under construction)</td>
<td>Add-on</td>
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<td>Wheat Bran</td>
<td>Volos</td>
<td>Wheat Mill (locally produced and imported wheat)</td>
<td>Add-on</td>
<td>&gt; 8000 dry t/year</td>
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<td>Potato Steam Peels</td>
<td>Lamia (city close to Thessaly region)</td>
<td>Potato Chips Production Plant</td>
<td>Add-on</td>
<td>~ 8000 dry t/year</td>
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<td>Barley Straw</td>
<td>Karditsa-Trikala</td>
<td>Regionally produced straw</td>
<td>Local stand alone</td>
<td>~ 8000 dry t/year</td>
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<table>
<thead>
<tr>
<th>Potential Feedstock</th>
<th>Location</th>
<th>Co-operation with existing or potential industrial units</th>
<th>Hydrogen Unit Type</th>
<th>Potential Capacity</th>
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<td>Rotterdam port area</td>
<td>Sugar Production Unit</td>
<td>Add-on</td>
<td>&gt;&gt; 8000 dry t/year</td>
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<td>Potato Steam Peels</td>
<td>Rotterdam port area</td>
<td>Potato Chips Production Plant</td>
<td>Add-on</td>
<td>&gt;&gt; 8000 dry t/year</td>
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<td>Wheat Bran</td>
<td>Moerdijk industrial area</td>
<td>Wheat Mill (mainly imported wheat)</td>
<td>Add-on</td>
<td>&gt;&gt; 8000 dry t/year</td>
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<td>Barley Straw</td>
<td>Rotterdam agricultural land area</td>
<td>Regionally produced straw</td>
<td>Local stand alone</td>
<td>~ 8000 dry t/year</td>
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</table>
Stakeholders and policy aspects

TODAY 2010

EU BIOFUEL ROADMAP

THESSALY BIOFUEL ROADMAP

EU CAP

THESSALY BIOFUEL PLANTS

EU HYDROGEN ROADMAP

1ST GENERATION TO H2
SUSTAINABILITY
(WATER, SOIL etc.)
COMPETITION / OTHER TECHS

DEVELOPMENT OF HYVOLUTION TECHNOLOGY

HYDROGEN SUPPLY & END USE TECHNOLOGIES
BIOLOGICAL H2 IN H2 BALANCE

BIOFUEL TARGETS FROM 1ST GENERATION TO H2

CONVERSION EFFICIENCY
FEEDSTOCK SUITABILITY
SUSTAINABILITY

LAND USE CHANGE (COTTON, SUGAR BEET)
FALLOW LAND
SUBSIDIES

ETOH PLANT
(UNDER CONSTRUCTION)
Biodiesel
COMPETITION FOR LAND AND RESIDUES

FUTURE 2030

THESSALY

SUSTAINABLE BIO-H2 GENERATION

INDUSTRIAL INFRASTRUCTURE,
BIOREFINERY, BIO-H2 INTEGRATION

ENERGY NEEDS, BIOENERGY IN
ENERGY BALANCE

COMPETITION BETWEEN
BIOENERGY APPLICATIONS

OTHER H2 TECHNOLOGIES

H2 SUPPLY AND END-USE TECHNOLOGY

Equi-Agry: efficiency and equity trade off in European agroenergy districts
Foggia, June-July 2014
Stakeholders and policy aspects

Best Case Scenario

2010

2015

2020

2025

2030

Worst Case Scenario

2010

2015

2020

2025

2030

Thessaly

Rotterdam

Equi-Agry: efficiency and equity trade off in European agroenergy districts

Foggia, June-July 2014
Concluding Remarks

**General**

- Simultaneous research on the improvement of the hydrogen production efficiency and on the enrichment of the techno-economically suitable and sustainable feedstock portfolio should be carried out.
- It is assessed that the transition from first generation to second generation biofuels and biohydrogen will play a crucial role for the land and infrastructure availability in both examined regions.
- Diverse effects of existing biofuel production plants on the development of Hyvolution technology:
  - Positive, in the “start-up” phase, providing the necessary infrastructure for pilot or small scale production
  - Possible negative effect in further development phase due to land use competition
  - “Success stories” of first generation biofuels will improve the social acceptance of biofuels and will create a “bio-society” culture which will facilitate the integration of Biohydrogen generation into the existing energy system
Concluding Remarks

**Thessaly**

- The social impact assessment of cotton culture replacement, in Thessaly, by energy crops should also consider the impact of this situation on the secondary sector, the cotton gin plants of the region, which employ a large number of labourers (about 200 permanent and 600 seasonal).

- The energy crop cultivation scenarios, even the most conservative ones, increase the potential significantly, increasing the importance of Thessaly in the future hydrogen economy, as well. According to the assumed “maximum energy crops” scenario in the region, 2.5 to 4.7% of the expected transport sector energy needs [EC - DG for Energy and Transport, 2007] (or 1.0 to 1.9% of the expected overall energy needs) of Greece in 2020 can be covered by the “Hyvolution” Hydrogen which will be produced in the region.

*Equi-Agry: efficiency and equity trade off in European agroenergy districts*  
Foggia, June-July 2014
Concluding remarks

Rotterdam

- The supply and demand site scenarios showed that the hydrogen demand of the region can be easily covered by the feedstock availability from the regional agro-industrial units, under the conditions that the continuous future development of these units is secured and that the techno-economic feedstock suitability issues for a larger number of potential Hyvolution feedstocks are solved.

- The land need for the reactor of the photochemical fermentation (currently 60ha for an 8000 dry tonne/year biomass plant capacity, estimation for 10 ha after process optimisation) is a further concern especially for Rotterdam case where the land availability is already limited.
Acknowledgements

Part of the presented work was carried out within the framework of EU FP6 IP Project “Hyvolution”.

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