Dark fermentation as an environmental-sustainable win-win solution for bioenergy production

Camacho, C.I., Estévez, S., Feijoo, G., Moreira, M.T.
The energy problem in need of a solution

**Volatility** of energy prices

- Energy industries: 24.1%
- Manufacturing industries and construction: 11.6%
- Households, commerce, institutions and others: 14.2%
- Transport (including international aviation): 25.8%
- Industrial processes and product use: 9.1%
- Agriculture: 10.3%
- Waste management: 3.1%
- Other: 22.5%
- Fuel combustion: 76%
- Fuel fugitive emissions: 1.8%

Electricity prices (€/MWh):
- 2011: 180
- 2012: 190
- 2013: 200
- 2014: 210
- 2015: 220
- 2016: 230
- 2017: 240
- 2018: 250
- 2019: 260
- 2020: 270
- 2021: 280
H₂ production as an energy source

Thermal technologies
- Steam reforming
- Thermolysis
- Pyrolysis
- Gasification

Alternative technologies
- Electrochemical
  - Electrolysis
  - Photo-electrochemistry
- Biological
  - Photo-fermentation
  - Fermentation
  - Digestion

Transport and storage
- Transport
- Fuel
- H₂
- Electricity
- Energy carrier

Natural gas
Carbon
Biomass

99% fossil fuels
70-100 Mt CO₂/year
Latest estimates suggest that around 931 million tons of food waste were generated in 2019.

Spain

Waste and subproducts from food industry 23 Mt

<table>
<thead>
<tr>
<th>Category</th>
<th>Waste and subproducts (Mt/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit and vegetables</td>
<td>6.53</td>
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<tr>
<td>Wine production</td>
<td>3.48</td>
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<tr>
<td>Vegetable oils</td>
<td>4.41</td>
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<tr>
<td>Beet processing</td>
<td>1.47</td>
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<tr>
<td>Meat-based products</td>
<td>1.93</td>
</tr>
<tr>
<td>Cheese products</td>
<td>1.9</td>
</tr>
<tr>
<td>Seafood</td>
<td>0.48</td>
</tr>
</tbody>
</table>
Objectives

1. Valorization of food waste
   - Modelling & circular economy

2. Production of energy
   - Dark fermentation and anaerobic digestion

3. Environmental assessment of treatment technologies
   - Environmental profile

4. Interpretation of results
   - LCA inventory

Stage 1.
Definition

Stage 2.
LCA inventory

Stage 3.
Environmental profile

Stage 4.
Interpretation of results

- Valorization of food waste
- Production of energy
- Environmental assessment of treatment technologies
- Interpretation of results
A life cycle approach

System function and functional unit

**OBJECTIVE**

Environmental comparison of 3 food streams

- Wine vinasses and sewage sludge
- Sugar beet molasses
- Cheese whey

**SYSTEM FUNCTION**

Bio-based hydrogen from dark fermentation

**FUNCTIONAL UNIT**

1 m³ of hydrogen (99% purity) in normal conditions
The process

S1. BioH₂ production
- Sugar beet molasses
- Fermenter: 41 m³
- Anaerobic digester: 434 m³
- NaOH
- CH₄
- CO₂
- H₂

S2. Energetic valorization
- Chemical absorption
- SOFC system
- Emissions to air
- Electricity
- Emissions to air
- Heat

S3. Treatment of effluents
- Polyelectrolyte
- MgCl₂
- A/O-MBR
- Liquid fertilizer
- Emissions to air
- Press filter
- Precipitation unit
- Concentrated fertilizer
- Struvite
Stage 1. Definition

Stage 2. LCA inventory

Stage 3. Environmental profile

Stage 4. Interpretation of results

Data gathering

30 m³/d of Waste

- Sugar beet molasses
  - Electricity: 3182.6
  - Heat: 536.4
  - Solid fertilizer & struvite: 1385.7
  - Liquid fertilizer: 20.9
  - Hydrogen: 298.0

- Cheese whey
  - Electricity: 2727.5
  - Heat: 27.9
  - Solid fertilizer & struvite: 526.7
  - Liquid fertilizer: 0.0
  - Hydrogen: 92.9

- Wine vinasses and sewage sludge
  - Electricity: 419.4
  - Heat: 0.0
  - Solid fertilizer & struvite: 2038.6
  - Liquid fertilizer: 27.8
  - Hydrogen: 34.0

Raw materials, utilities and transport

Direct emissions

- Heat: 30 m³/d
- Electricity: 30 m³/d
- Solid fertilizer & struvite: 30 m³/d
- Liquid fertilizer: 30 m³/d
- Hydrogen: 30 m³/d

30 m³/d of Waste

- Heat: 30 m³/d
- Electricity: 30 m³/d
- Solid fertilizer & struvite: 30 m³/d
- Liquid fertilizer: 30 m³/d
- Hydrogen: 30 m³/d
Life Cycle Impact Assessment

After system modelling and data gathering...

Stage 1. Definition

Stage 2. LCA inventory

Stage 3. Environmental profile

Stage 4. Interpretation of results

Software

Method

Indicators

- Midpoint (H)-Impact indicators
- Endpoint (H/H)- Damage indicators

Climate change

Acidification

Freshwater eutrophication

Marine eutrophication

Terrestrial ecotoxicity

Land use

Fossil resource scarcity

Water consumption
Stage 1. Definition

Stage 2. LCA inventory

Stage 3. Environmental profile

Stage 4. Interpretation of results

Analysis of results

- Midpoint analysis
  Benchmark of environmental impacts

- Endpoint analysis
  Single score comparison

- Energy balance
  Process sustainability
Single score benchmark

Environment

-67.1 Pt

-0.76 Pt

5.51

Energy

0.52

2.47

2.96
Conclusions

The relevancy of the feedstock

Stage 1. Definition
Stage 2. LCA inventory
Stage 3. Environmental profile
Stage 4. Interpretation of results

1. Valorization of waste from the food industry
2. Production of energy
3. Environmental assessment of treatment technologies

Sustainable process
- Energy self-efficient
- Environmentally friendly
- Environmentally friendly
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