Perspectives for an Integrated 1G+2G Biorefinery

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Brazilian Center for Research in Energy and Materials - CNPEM

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Introduction

Alternatives for 2G Technology

- Straw Recovery?
- Integrated x Standalone?
- Fermentation or biodigestion of C5?
- Feedstock?
- In-house production of enzymes?

Virtual Sugarcane Biorefinery (VSB)
Virtual Sugarcane Biorefinery

- Pre planting operations
- Soil preparation
- Planting
- Cultivation
- Harvesting
- Sugarcane transport

**Economic analysis**
- Production cost
- IRR

**Social analysis**
- Manpower
- Wages

**Environmental analysis (Life cycle assessment)**
- Global warming
- Acidification
- Eutrophication
- Ecotoxicity
- Ozone layer depletion
- Energy balance
- Water use
- Land use

Other Biorefineries
- Sorghum Juice conc.
- Butanol
- FDCA
- PLA

CanaSoft

Biorefinery simulation

AspenPlus®

Usage model

Input-output matrix

SimaPro®
Virtual Sugarcane Biorefinery

- Assess different routes and technologies
- Assess stage of development of new technologies
- Optimize concepts and operations in the Biorefinery

Model integration

Process simulation
Mathematical models

Sustainability impacts:
- Economic
- Environmental
- Social
CanaSoft

Scenarios Description

- Agricultural operations
- Transport
- Inputs
- Irrigation
- General aspects

Economic, Environmental and Social Results
CanaSoft Outputs

Environmental results

SimaPro (Single Score)

- Manual harvesting
  - Other
  - Fossil depletion
  - Agricultural land occupation
  - Particulate matter formation
  - Climate change on human health

- Mechanized harvesting

Economic results

% of sugarcane production cost

- Agricultural operations: 41%
- Inputs: 19%
- Transport: 11%
- Vinasse spreading: 4%
- Land: 24%
- Taxes: 1%
Biorefinery Simulation

- Mass and energy balances
- Products, coproduct and residues
- Emissions
- Equipment sizes
- Other information

Biorefinery models in AspenPlus®
Ethanol production
Ethanol Distribution System

distances

- biorefinery
- terminal
- transference terminal
- fuel station
- port

transport system

- truck
- rail
- pipeline
- barge
Financial analysis

**Decision-making:**

1. Internal Rate of Return (% per year)
2. Ethanol production cost (R$/L)
3. Minimum ethanol selling price (MESP, R$/L)
Internal Rate of Return (IRR)

IRR is the interest rate at which Net Present Value is zero.

Minimally Acceptable Rate of Return (M.A.R.R)

Business goal: maximizing IRR

IRR < MARR → NPV = -
IRR > MARR → NPV = +
Financial analysis

2. Ethanol production cost (R$/L)

\[ IRR = 0 \quad \implies \quad Price = Production\ cost \]
It doesn’t pay the cost of capital

Public policy goal:
minimizing
Production cost
Financial analysis

3. Minimum ethanol selling price (R$/L)

IRR = MARR → Minimum selling price (MESP)
It pays the cost of capital at the minimum acceptable rate of return

Public policy goal:
minimizing MESP
### Financial analysis

<table>
<thead>
<tr>
<th></th>
<th><strong>Technology 1</strong></th>
<th></th>
<th><strong>Technology 2</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Revenues ($)</strong></td>
<td>260</td>
<td></td>
<td>300</td>
<td></td>
</tr>
<tr>
<td><strong>OPEX ($)</strong></td>
<td>185</td>
<td></td>
<td>210</td>
<td></td>
</tr>
<tr>
<td><strong>CAPEX ($)</strong></td>
<td>490</td>
<td></td>
<td>620</td>
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</table>

**Decision making:**

- **Business side:** not satisfied
- **Policymaker side:** satisfied
- **Business and policy:** not satisfied

<table>
<thead>
<tr>
<th></th>
<th><strong>Technological parameter</strong></th>
<th><strong>Value</strong></th>
<th><strong>Technological parameter</strong></th>
<th><strong>Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IRR$_1$</td>
<td>15%</td>
<td>IRR$_2$</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>Production cost$_1$</td>
<td>0.79</td>
<td>Production cost$_2$</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>MESP$_1$</td>
<td>0.95</td>
<td>MESP$_2$</td>
<td>0.96</td>
</tr>
</tbody>
</table>
Life Cycle Assessment

- Agricultural production
  - Sugarcane
  - Transport
  - Industry
  - Ethanol
  - Distribution
  - Use
  - Residues
  - Straw

- Local emissions
  - (pre harvesting burning, soil emissions...)
  - (diesel use...)
  - (bagasse burning, fermentation...)
  - Ethanol, electricity, co-products,...
  - (diesel use...)
  - (ethanol use...)

- Land use, inputs, machinery, fertilizer, agrochemicals, industrial residues,...
- Machinery, diesel...
- Equipment, buildings, inputs, electricity, diesel,...
- Machinery, diesel, storage...
- Steel, engine efficiency...
Straw Recovery

Existing mechanization

Straw recovery systems

Proposed mechanization

Integral harvesting

Advantages: - reduced losses during harvest
- possibility of separation of sugarcane tops.

Disadvantages: - reduction of truck load density
- investment in dry cleaning station.

Baling

Advantages: - better economics for long distances.

Disadvantages: - additional mechanized operations
- higher mineral impurities
- cost and destination of wires.
Straw Recovery Systems

economic assessment

- Integral harvesting system
- Baling system

Transport distance = 30 km

Straw recovery cost (US$/TS) vs straw recovery fraction

Transport distance = 30 km
Straw Recovery Systems

economic assessment

- 95 TC ha-1
- 83 TC ha-1
- 70 TC ha-1

Integral harvesting system

Baling system

Lines of equal costs
Integrated 1G2G ethanol production
Why integrate 2G to 1G plant?

- Feedstock available in the plant (bagasse) or close to it (straw)
- Share part of the infrastructure of 1G plant
  - concentration, fermentation, distillation, storage and cogeneration
- Dilution of potential fermentation inhibitors present in hydrolyzed liquor when mixed to 1G juice
- Increase of thermal integration possibilities when considering overall 1G2G process
- Improvement of C5 and C6 fermentations adding C12
- Increase of flexibility for CHP operation
Ethanol production

1G optimized configuration
- Straw use (50%)
- Molecular sieves for dehydration
- 90 bar boilers
- 20% reduction on steam demand

2G configuration
- Steam explosion pretreatment
- Hydrolysis: 48h, 15% solids
- C5 use: fermentation to ethanol
- Use of solid residues as fuel in the boilers
### 1G parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant capacity – sugarcane processed (million tonnes/year)</td>
<td>2.0</td>
</tr>
<tr>
<td>Efficiency – sugar extraction in the mills (%)</td>
<td>96</td>
</tr>
<tr>
<td>– fermentation (%) – annexed/autonomous plant</td>
<td>90</td>
</tr>
<tr>
<td>– boiler 90 bar (LHV basis) (%)</td>
<td>87</td>
</tr>
<tr>
<td>LHV – bagasse (50% moisture)/straw (15% moisture) (MJ/kg)</td>
<td>7.5/14.9</td>
</tr>
<tr>
<td>Energy demand of the process – electricity (kWh/TC)</td>
<td>30</td>
</tr>
<tr>
<td>Steam – process/molecular sieves – pressure (bar)</td>
<td>2.5 / 6</td>
</tr>
<tr>
<td>– molecular sieves (kg/L EtOH)</td>
<td>0.6</td>
</tr>
<tr>
<td>Anhydrous ethanol purity (wt%)</td>
<td>99.6</td>
</tr>
</tbody>
</table>
## 2G parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam explosion – hemicellulose conversion (%)</td>
<td>70</td>
</tr>
<tr>
<td>– cellulose conversion (%)</td>
<td>2</td>
</tr>
<tr>
<td>Enzymatic hydrolysis – cellulose conversion (%)</td>
<td>70</td>
</tr>
<tr>
<td>– solids loading</td>
<td>15</td>
</tr>
<tr>
<td>– reaction time</td>
<td>48h</td>
</tr>
<tr>
<td>Fermentation – C6 conversion (%)</td>
<td>90</td>
</tr>
<tr>
<td>– C5 conversion (%)</td>
<td>80</td>
</tr>
</tbody>
</table>
Integrated 1G2G - convergence

Steam demand of the process → Calculation of the available LM → Calculation of the generated steam

Iterative calculation until generated energy = process demand
1G Investment

Base case plant:
- 2,000,000 TC/year
- 22 bar boiler
- Azeotropic distillation

Autonomous distillery:

Transmission lines – electricity credit
- Costs (R$/km): R$ 480,000/km
- Length: 40 km
- R$ 19.2 million for transmission lines

Technological improvements (optimized 1G):
- + 40% on distillation sector (molecular sieves)
- + 40% on cogeneration sector (90 bar boilers)
- + 10% on distillation sector (heat exchanger network)
2G Investment

2G plant

- Additional investment: US$ 76 million – 462,451\textsuperscript{(1)} t bagasse/year

  (US$ 327/t dry bagasse)

Investment calculation as a function of equipment capacity (steam flow, bagasse processed on hydrolysis, biogas produced, etc):

\[
Cost_2 = Cost_1 \left( \frac{Capacity_2}{Capacity_1} \right)^{0.6}
\]

Enzyme Costs

- US$ 0.05/L cellulosic ethanol

\textsuperscript{(1)} Bioetanol combustível: uma oportunidade para o Brasil, CGEE, 2009
Technical Results

Dias et al., 2012. Integrated versus stand-alone second generation ethanol production from sugarcane bagasse and trash. Bioresource Technology
Economic Assessment

Dias et al., 2012. Integrated versus stand-alone second generation ethanol production from sugarcane bagasse and trash. Bioresource Technology
Environmental Impacts

1G ethanol  1G2G ethanol

Energy Balance  Global Warming Potential  Eutrophication

Renew out/fossil in  $KgCO_{2eq}/kg_{ethanol}$  $KgPO_4^{3-}_{eq}/kg_{ethanol}$

10.6  11.8  0.39  0.35  0.47  0.42
Flexibility ethanol 2G vs electricity

IRR (per year)

16.0%
16.5%
17.0%
17.5%
18.0%
18.5%

1G2G (+electricity) 1G2G (+ethanol) 1G2G (flex)

(no condensing turbine)

(50% of LM used in 1G2G +ethanol is sent to CHP)

Source: Dias et al., 2013. Biorefineries for the production of first and second generation ethanol and electricity from sugarcane. Applied Energy
Thank you!

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