*São Paulo Advanced School on the Present and Future of Bioenergy – ESPCA 2014*

# Perspectives for an Integrated 1G+2G Biorefinery

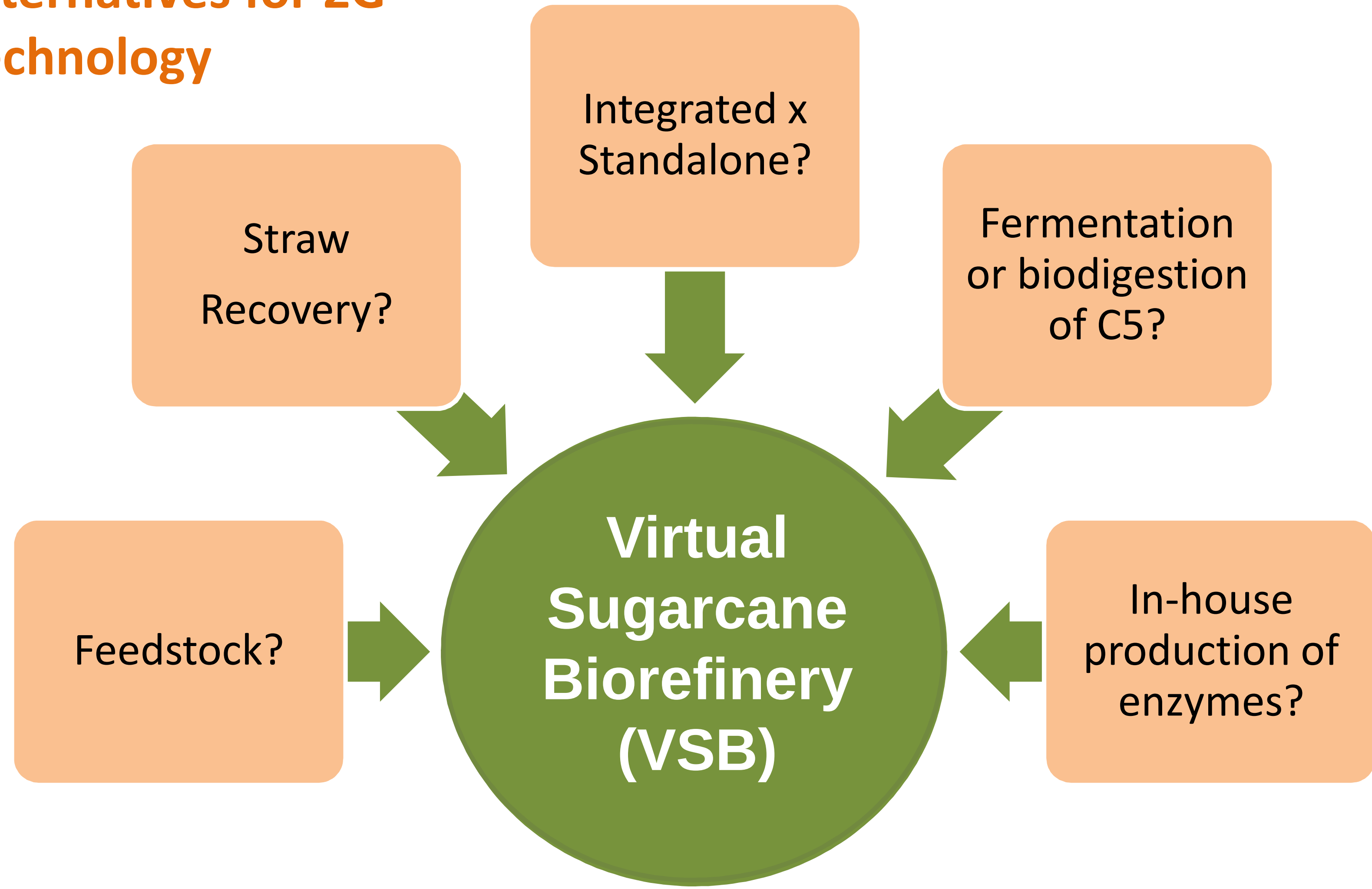
Division of Integrated Assessment of Biorefineries
Brazilian Bioethanol Science and Technology Laboratory - CTBE
Brazilian Center for Research in Energy and Materials - CNPEM

CNPEM CTBE

*October 2014*

# Introduction

## Alternatives for 2G Technology



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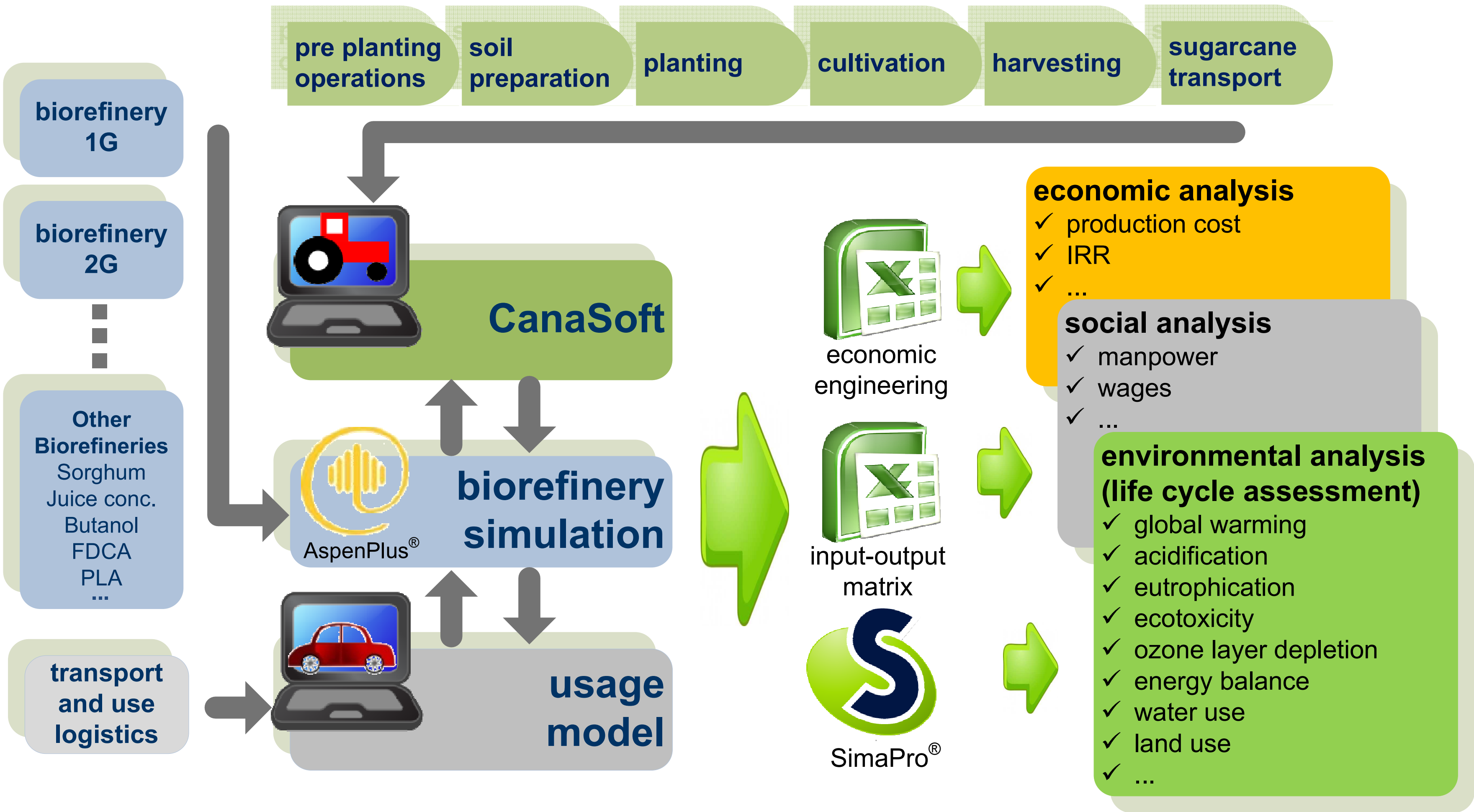
# Virtual Sugarcane Biorefinery



# 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 and social**

# CanaSoft

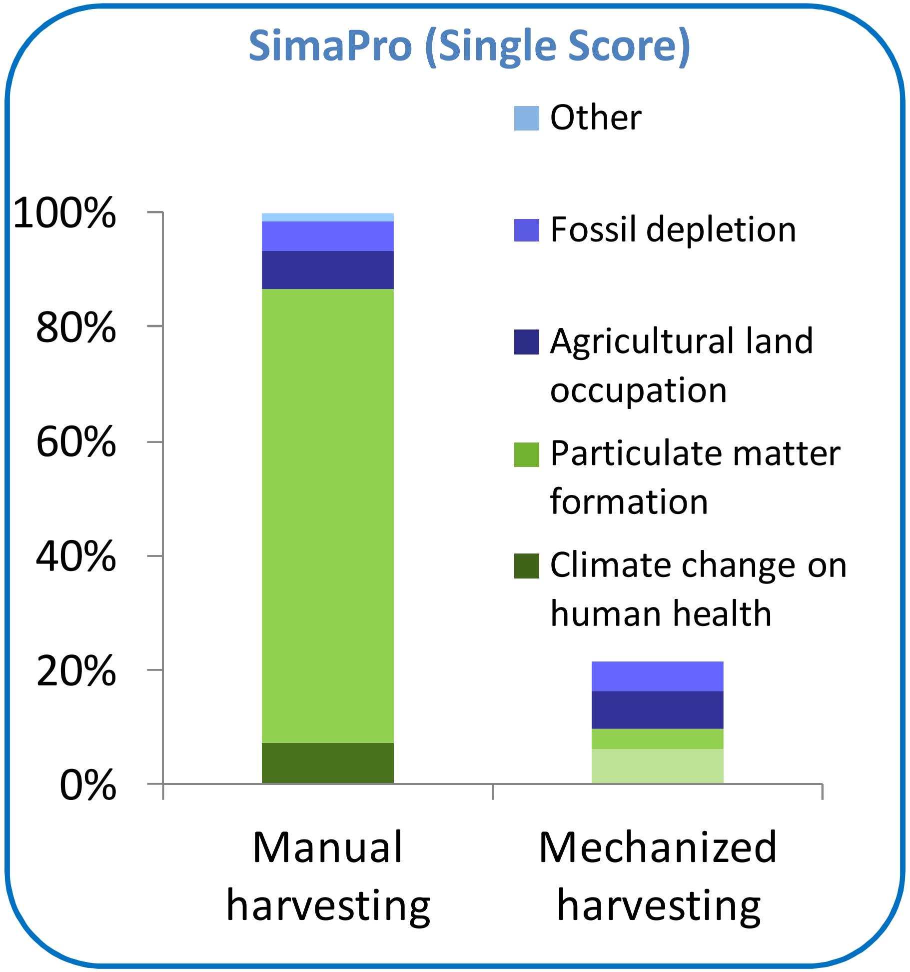
Scenarios Description

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

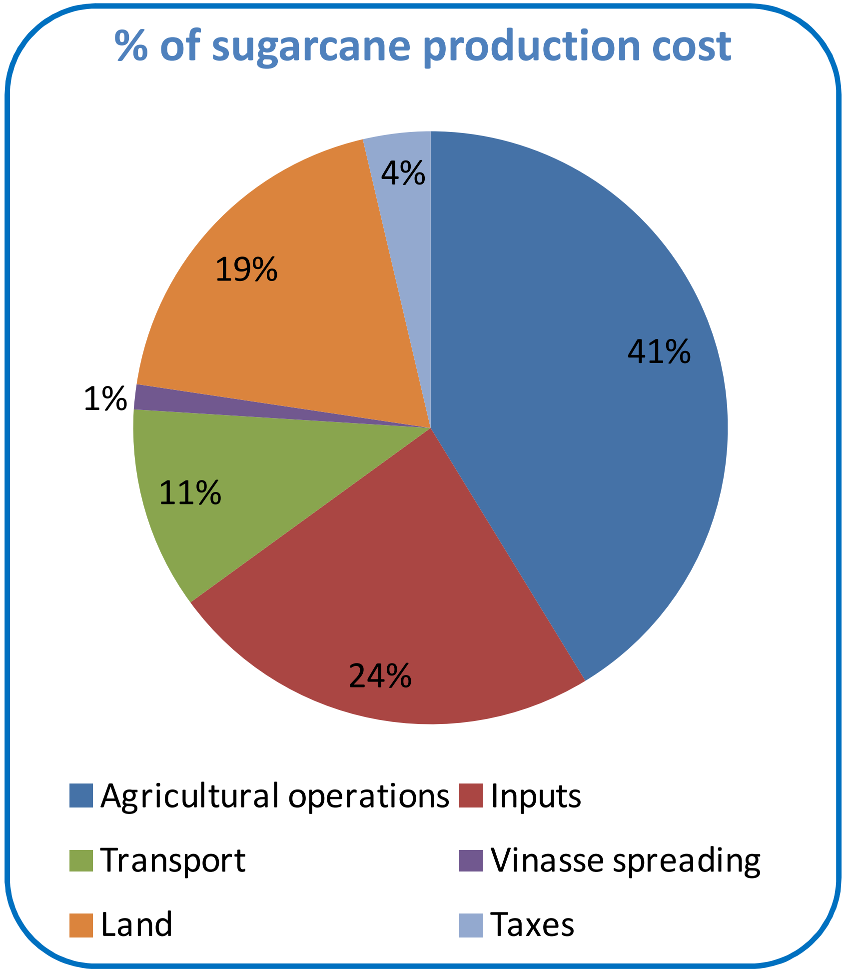
**Economic, Environmental and Social Results**

# CanaSoft Outputs

## Environmental results




## Economic results



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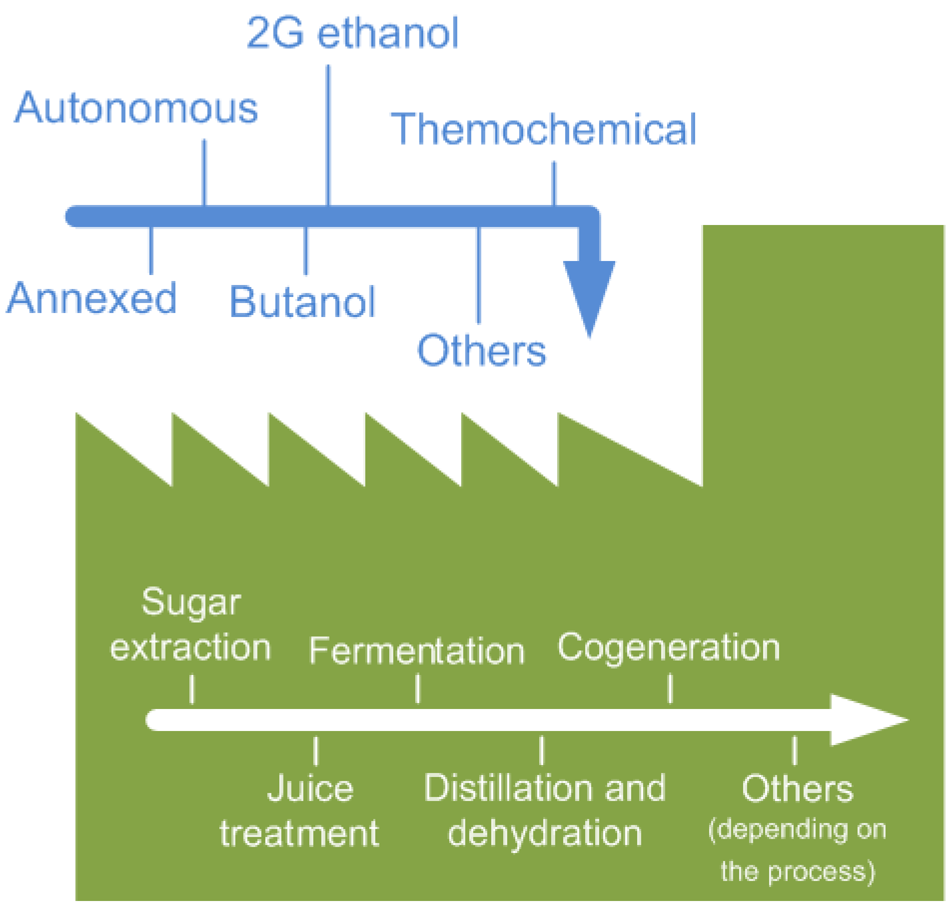
# Biorefinery Simulation




Biorefinery models in AspenPlus®

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

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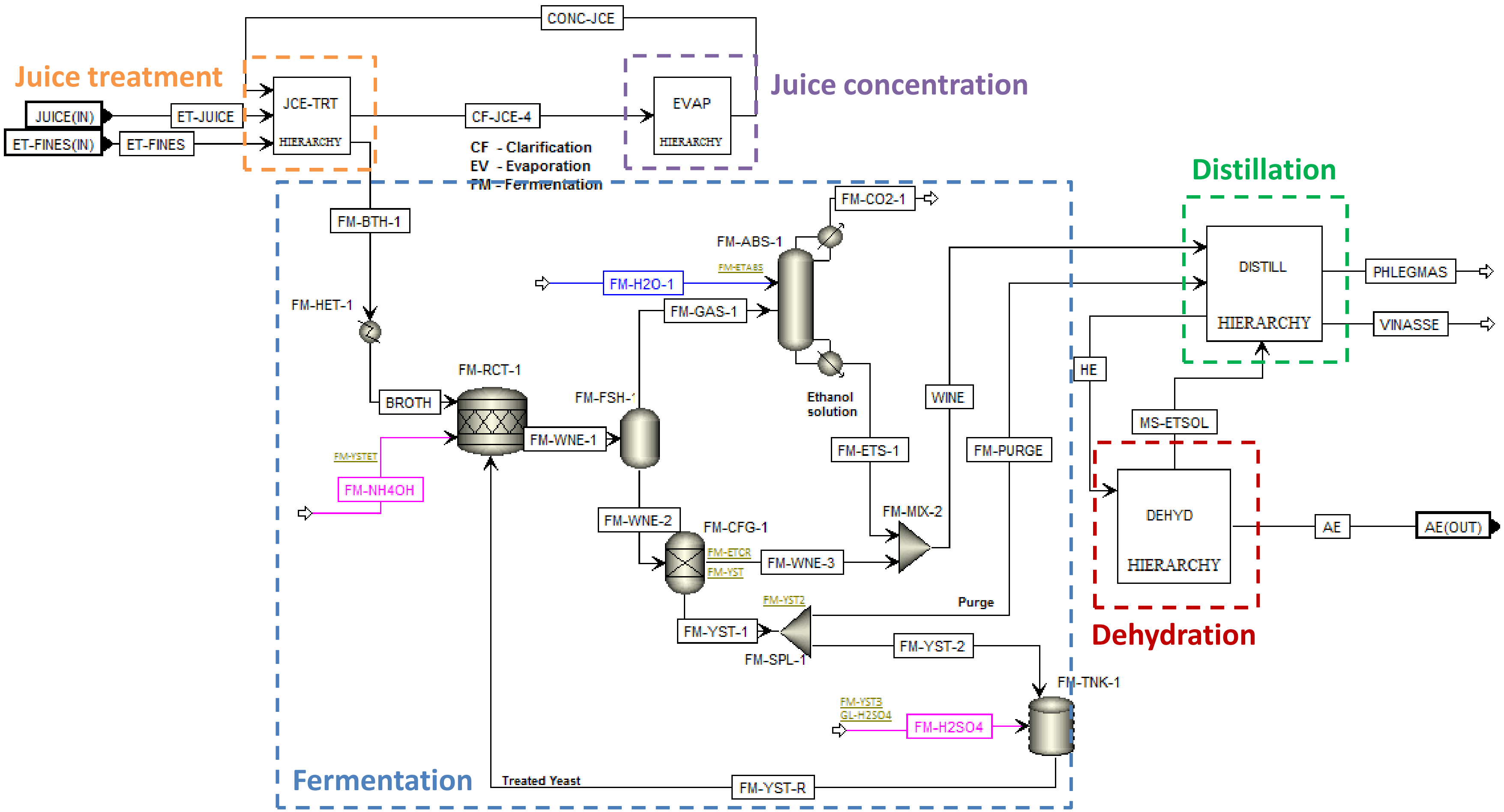
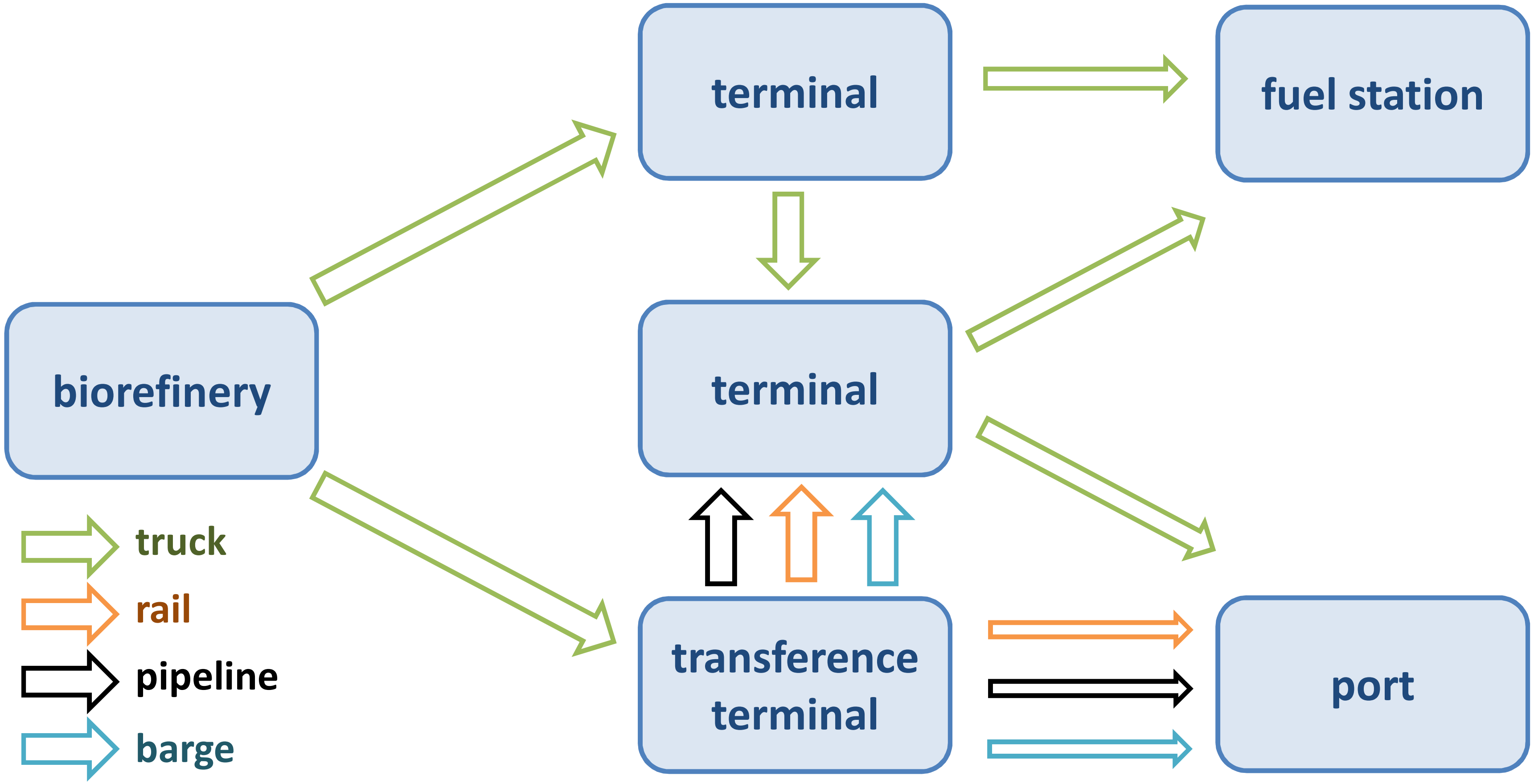
# Ethanol production



# Ethanol Distribution System

distances transport system



# Financial analysis

**Decision-making:**

1. Internal Rate of Return (% per year)

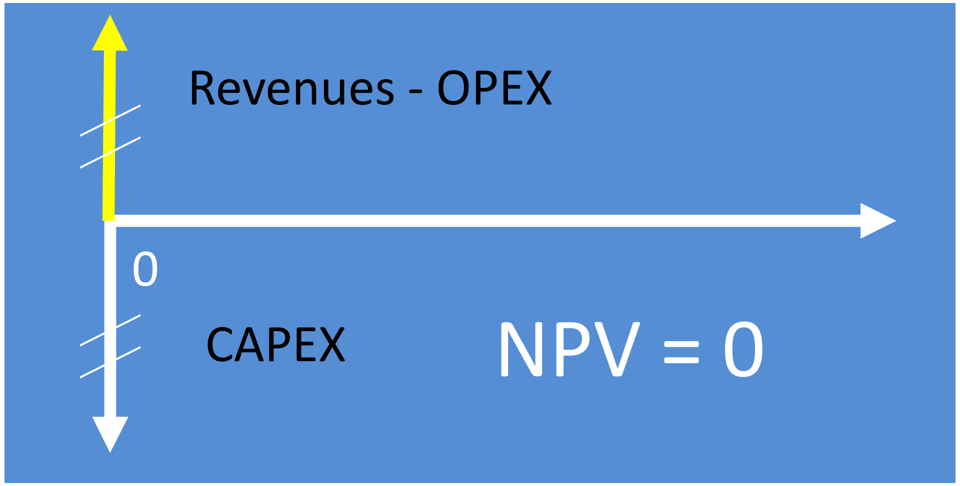
2. Ethanol production cost (R$/L)

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

# Financial analysis

## 1 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 → **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

| | Technology 1 | Technology 2 |
|---|---|---|
| Revenues ($) | 260 | 300 |
| OPEX ($) | 185 | 210 |
| CAPEX ($) | 490 | 620 |

| | Technology 1 | Change | Technology 2 |
|---|---|---|---|
| $IRR_1$ | 15% | decrease | 14% |
| Production $cost_1$ | 0.79 | decrease | 0.78 |
| $MESP_1$ | 0.95 | increase | 0.96 |

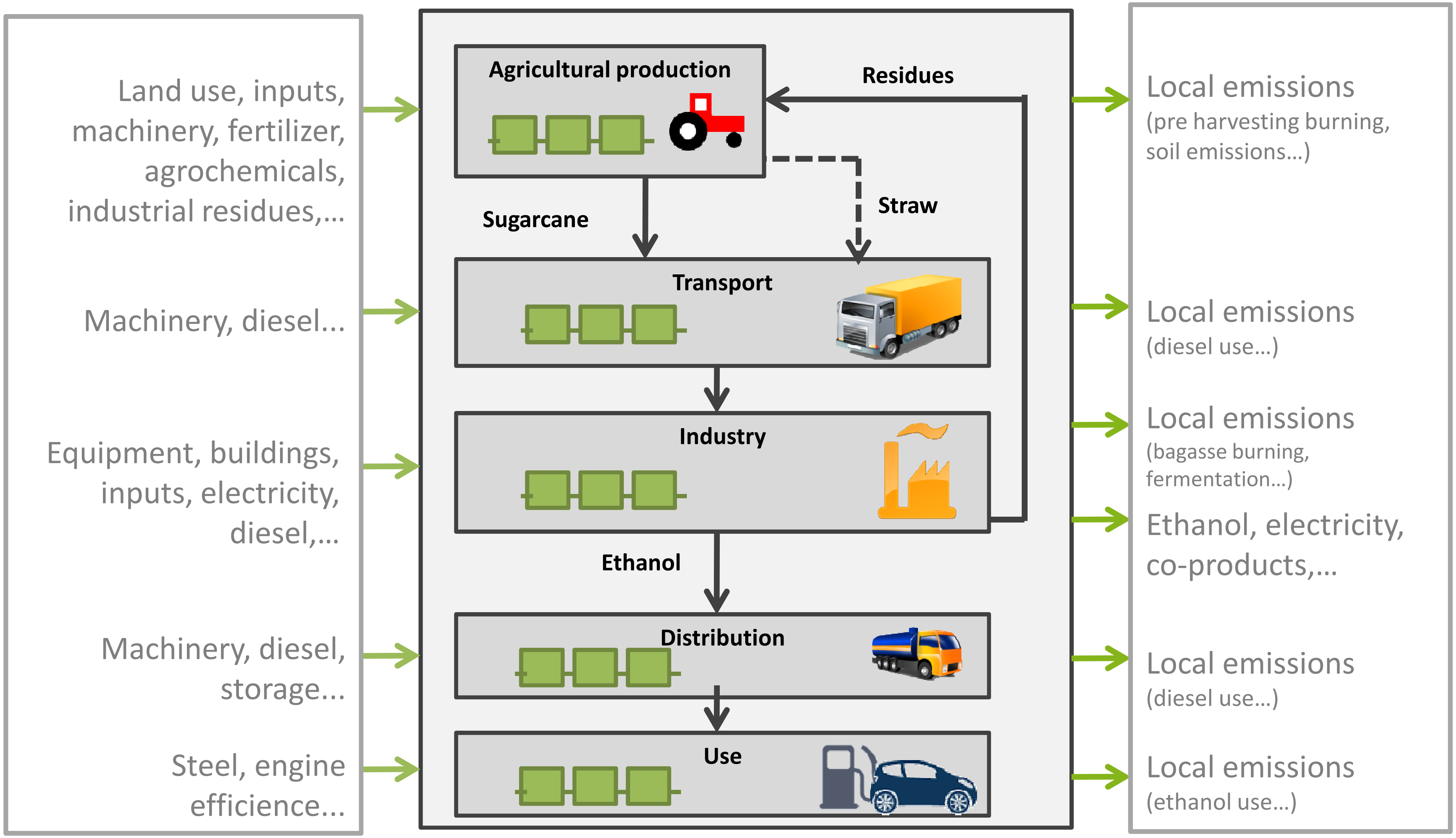
Decision making:

**Business side:** **not satisfied**

**Policymaker side:** **satisfied**

**Business and policy:** **not satisfied**

# Life Cycle Assessment



# Straw Recovery

## Existing mechanization

## Proposed mechanization

(reduction and traffic control)

## Straw recovery systems

### Integral harvesting

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

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

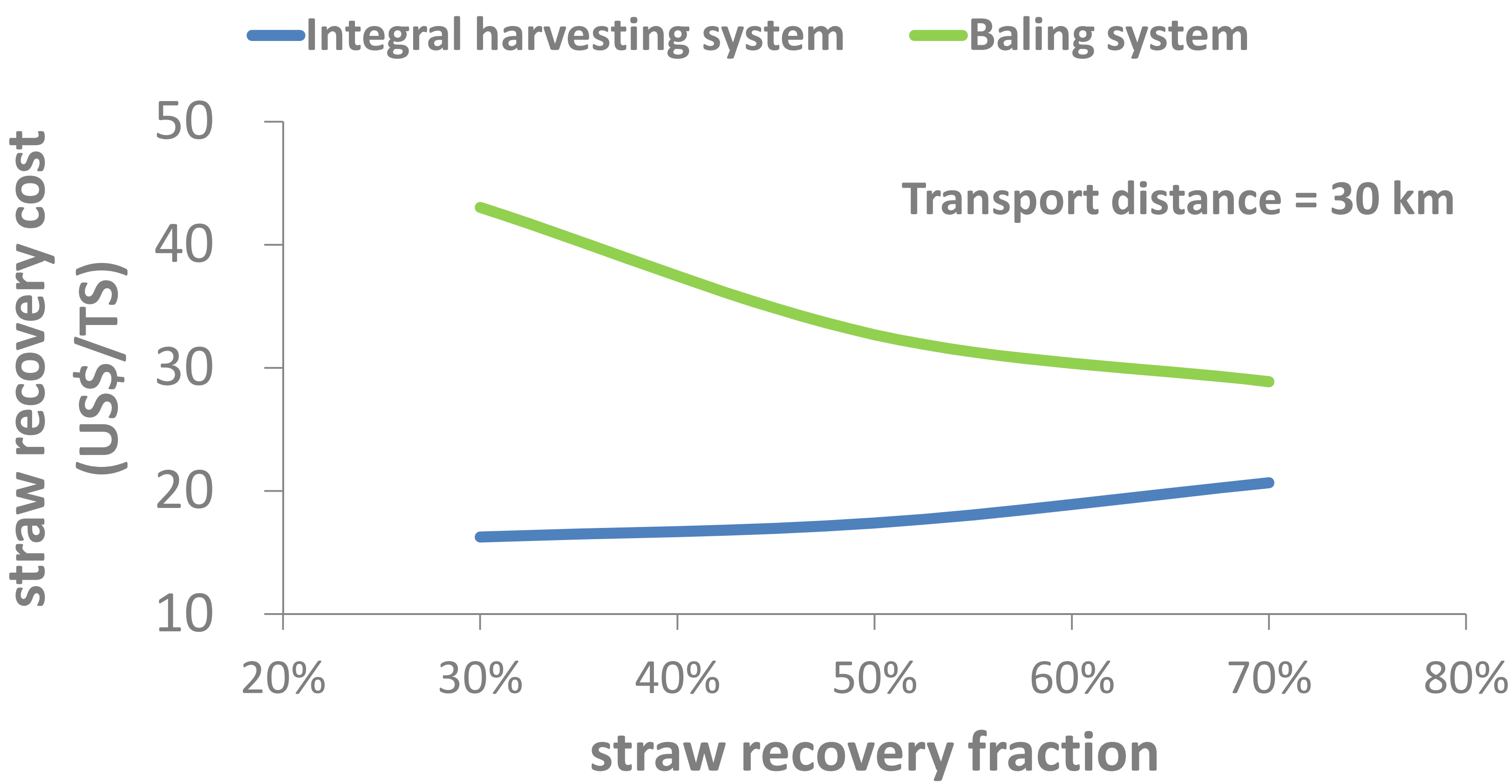
### Baling

**Advantages:** - better economics for long distances.

**Disadvantages:** - additional mechanized operations
- higher mineral impurities
- cost and destination of wires.

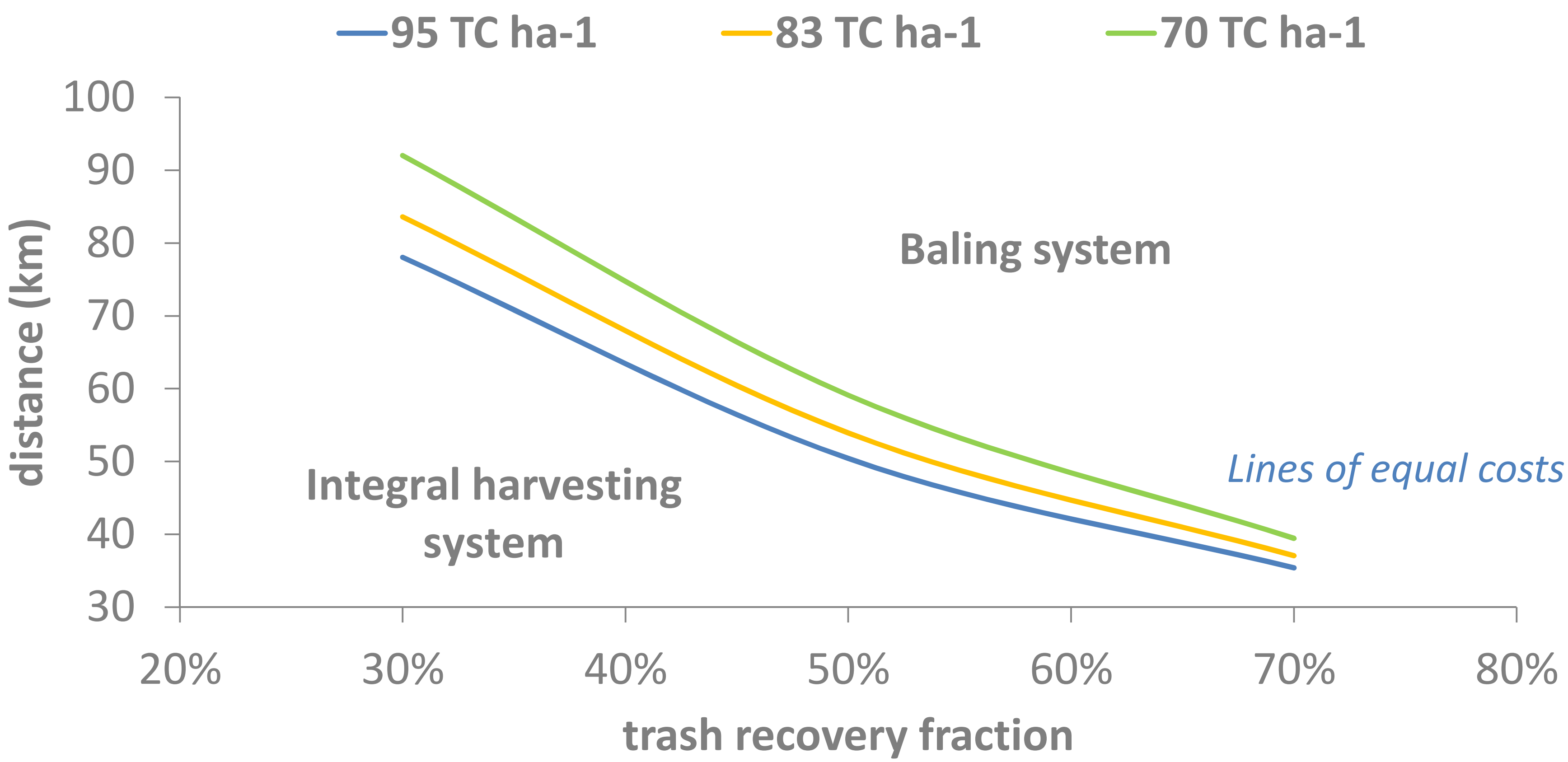
# Straw Recovery Systems

## economic assessment

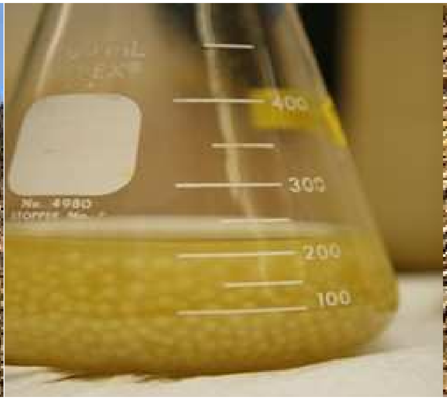


# Straw Recovery Systems

## economic assessment



# Integrated 1G2G ethanol production

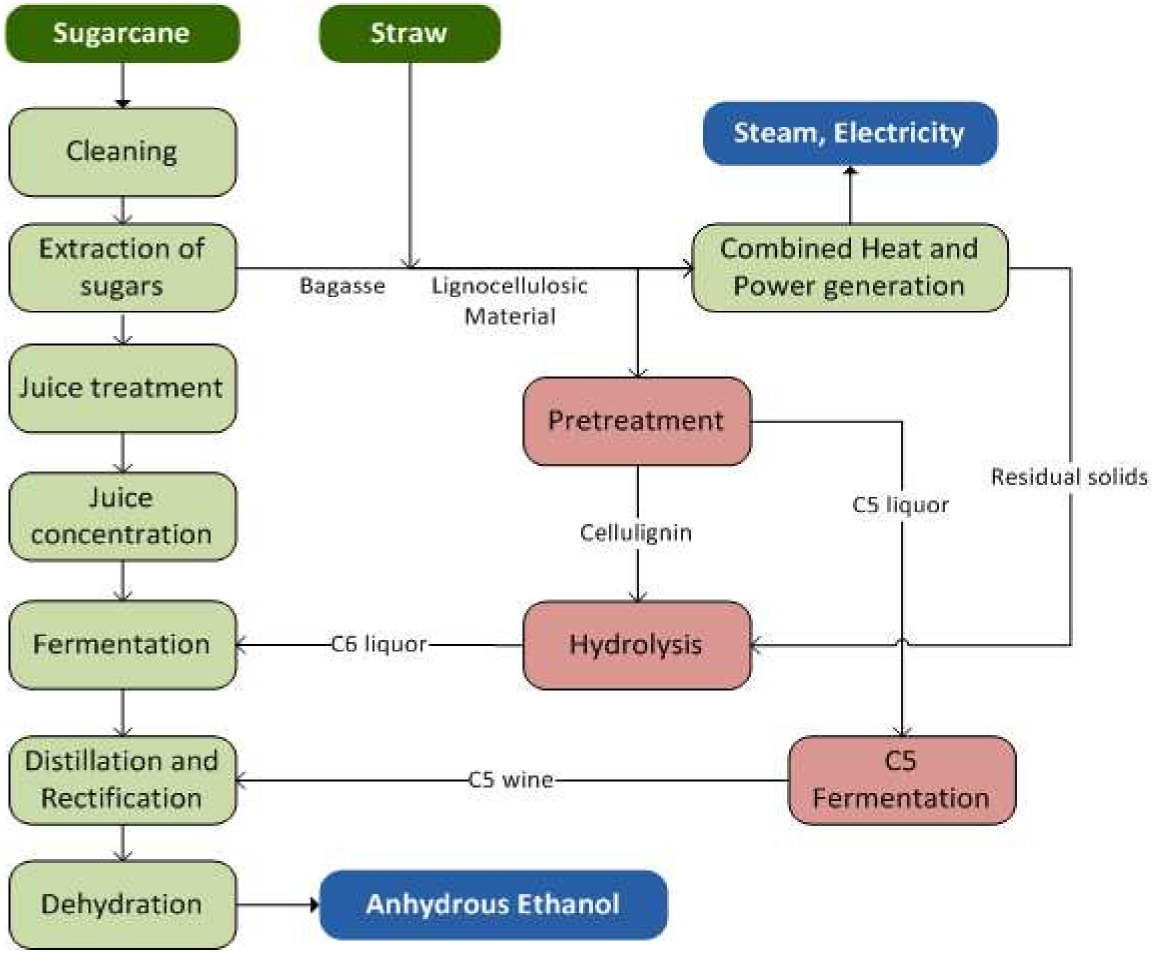



# Why integrate 2G to 1G plant?

- 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

# Process flow diagram

## 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

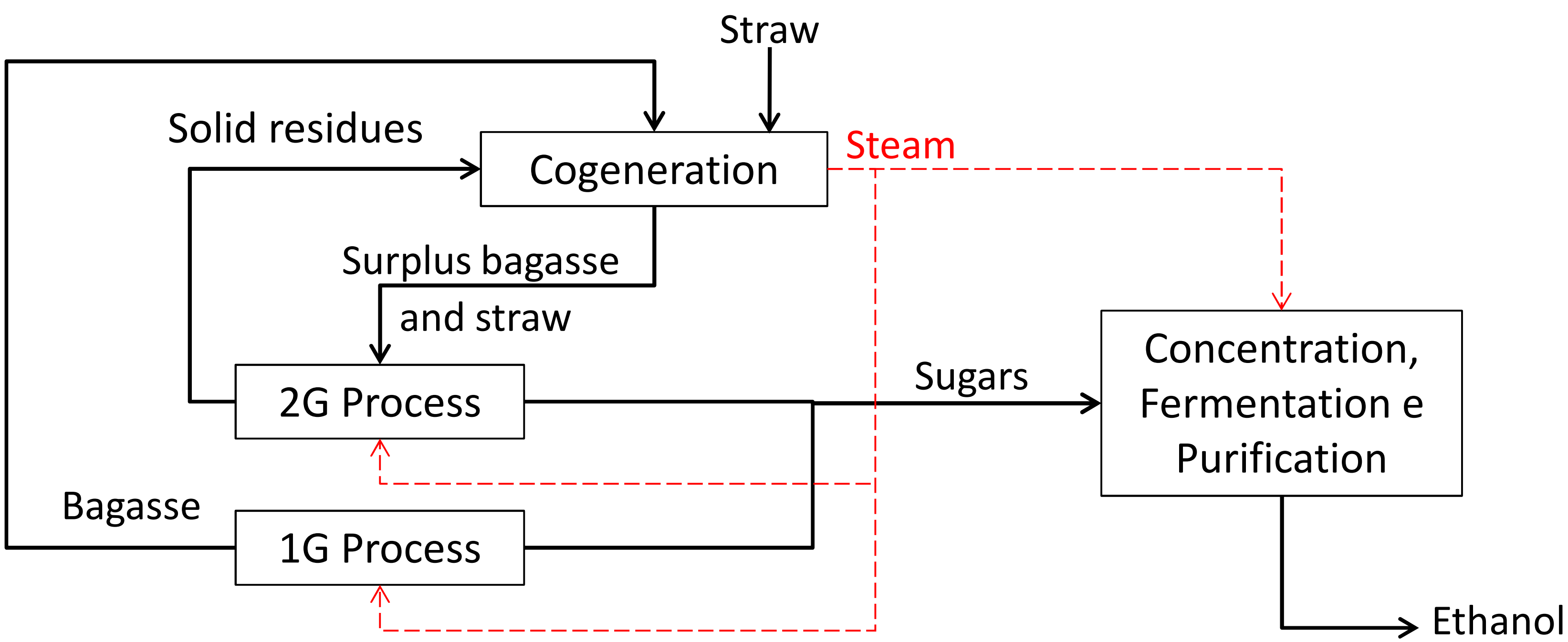
# 1G parameters

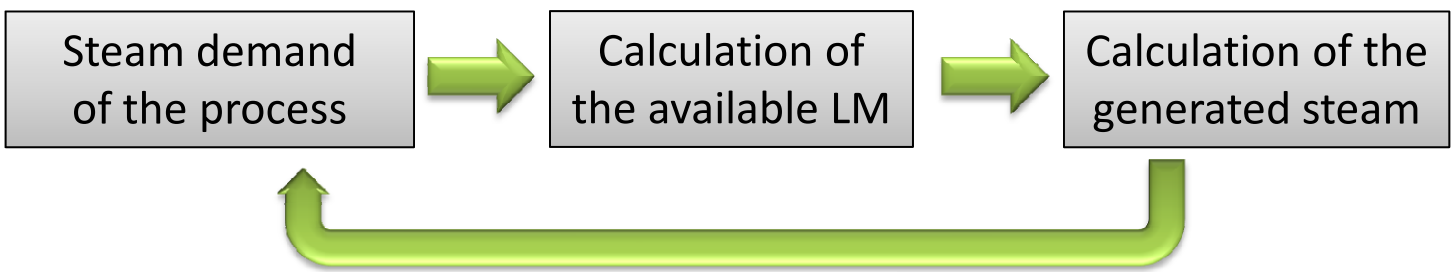
| Parameters | Value |
|---|---|
| Plant capacity – sugarcane processed (million tonnes/year) | 2.0 |
| Efficiency – sugar extraction in the mills (%) | 96 |
| – fermentation (%) – annexed/autonomous plant | 90 |
| – boiler 90 bar (LHV basis) (%) | 87 |
| LHV – bagasse (50% moisture)/straw (15% moisture)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

# 2G parameters

| Parameter | Value |
| --- | --- |
| Steam explosion – hemicellulose conversion (%) | 70 |
| – cellulose conversion (%) | 2 |
| Enzymatic hydrolysis – cellulose conversion (%) | 70 |
| – solids loading | 15 |
| – reaction time | 48h |
| Fermentation – C6 conversion (%) | 90 |
| – C5 conversion (%) | 80 |

# Integrated 1G2G - convergence




*Iterative calculation until **generated energy = process demand***

# 1G Investment

**Base case plant:**

- 2,000,000 TC/year
- 22 bar boiler
- Azeotropic distillation

**Autonomous distillery**:

Total investment R$ 300 million (~US$150 million) – Dedini (2010)/Sousa and Macedo (2010)

**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[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):

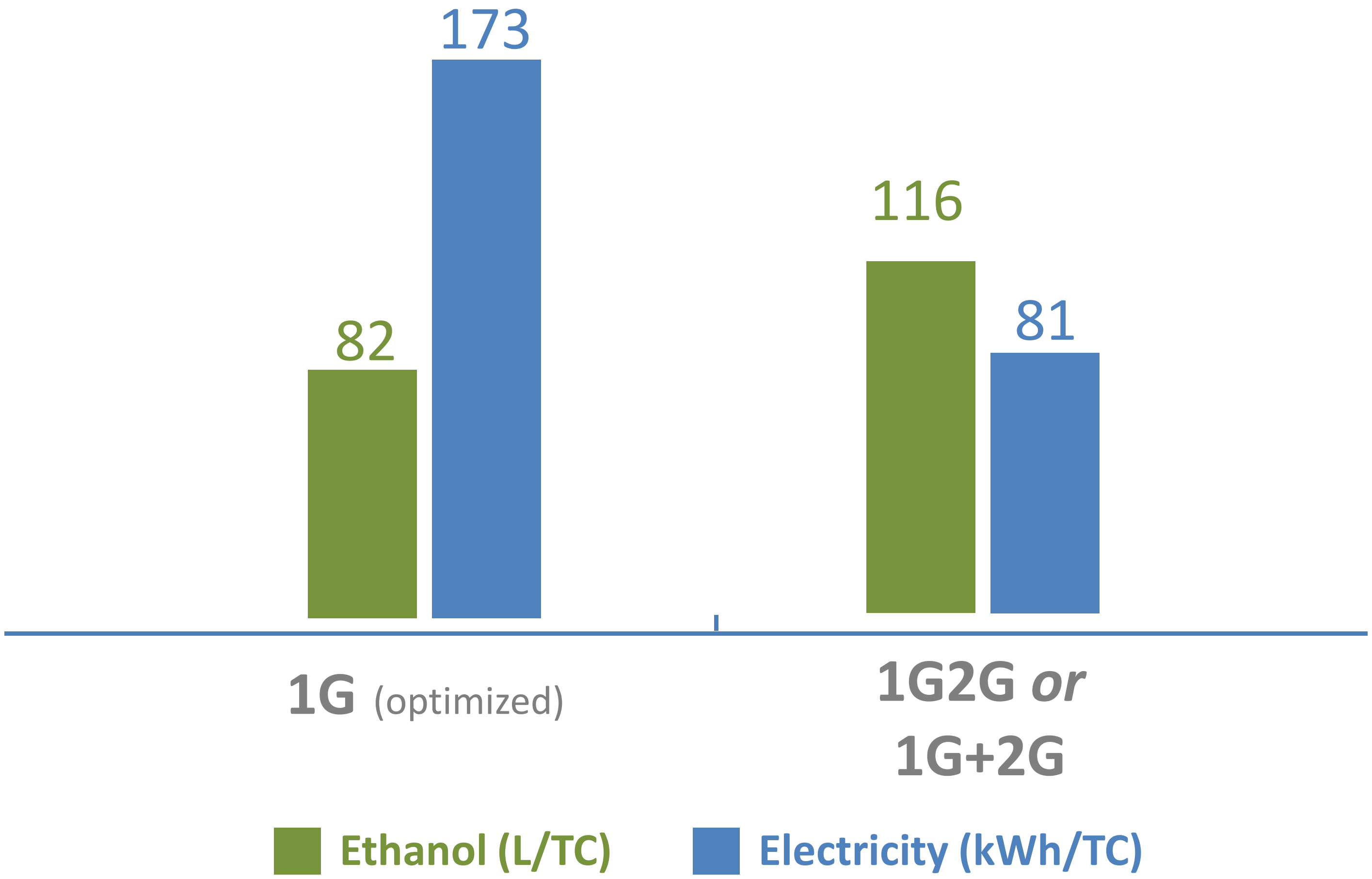
$$Cost_2 = Cost_1 \left( \frac{Capacity_2}{Capacity_1} \right)^{0.6}$$

# Enzyme Costs

- US$ 0.05/L cellulosic ethanol

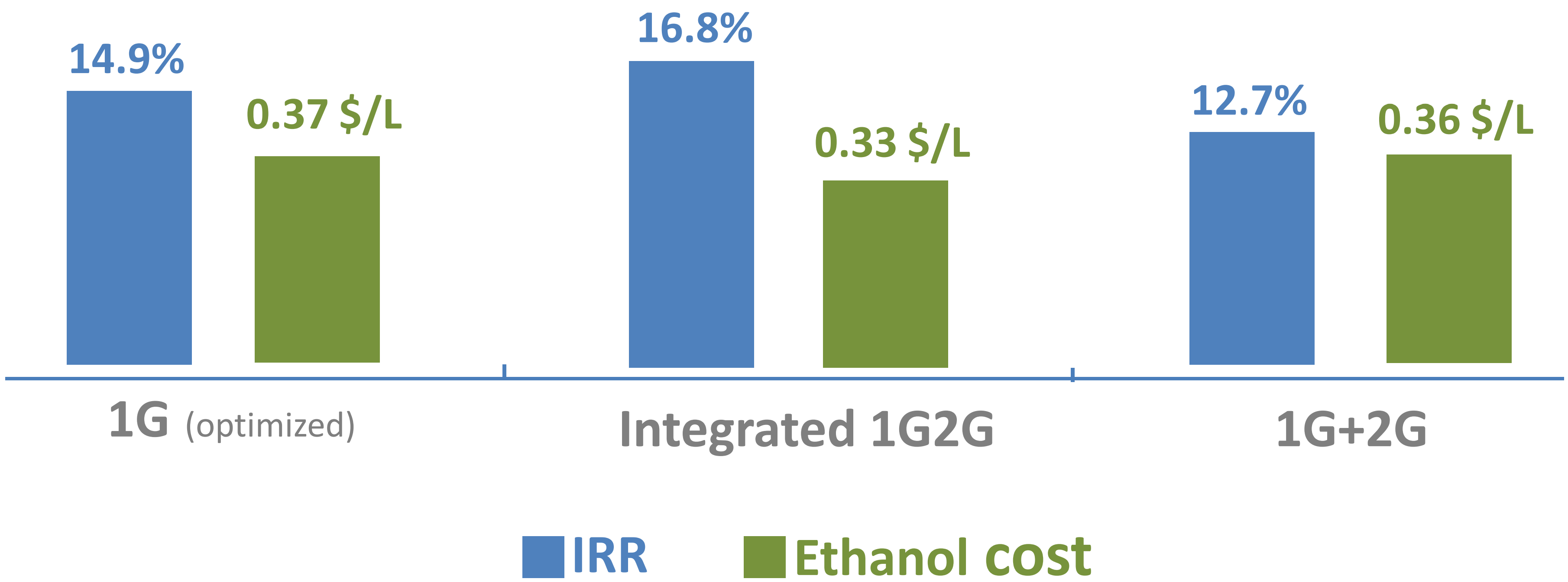
[1] *Bioetanol combustível: uma oportunidade para o Brasil, CGEE, 2009*

# Technical Results



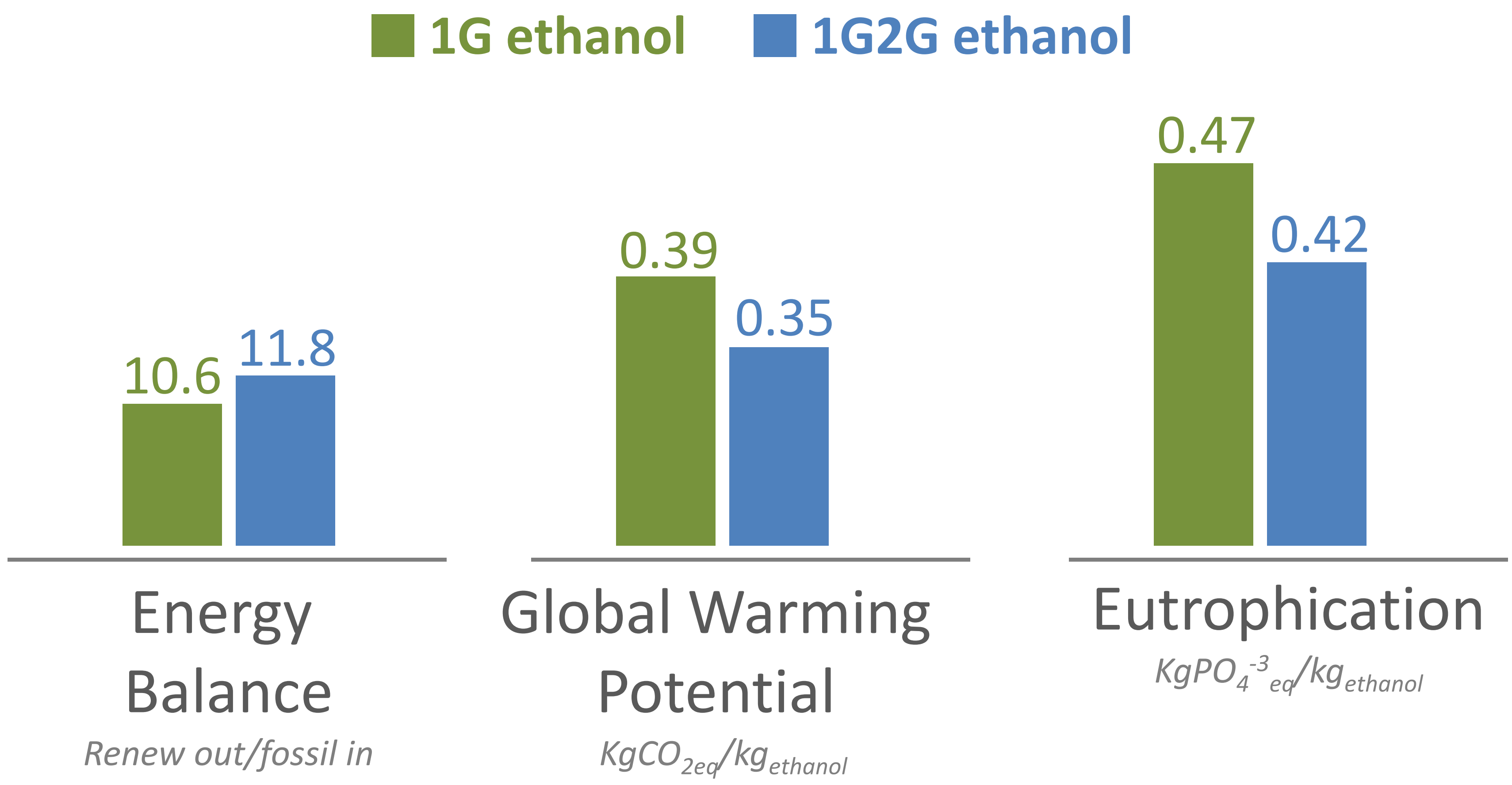

*Dias et al., 2012. Integrated versus stand-alone second generation ethanol production from sugarcane bagasse and trash. Bioresource Technology*

# Economic Assessment

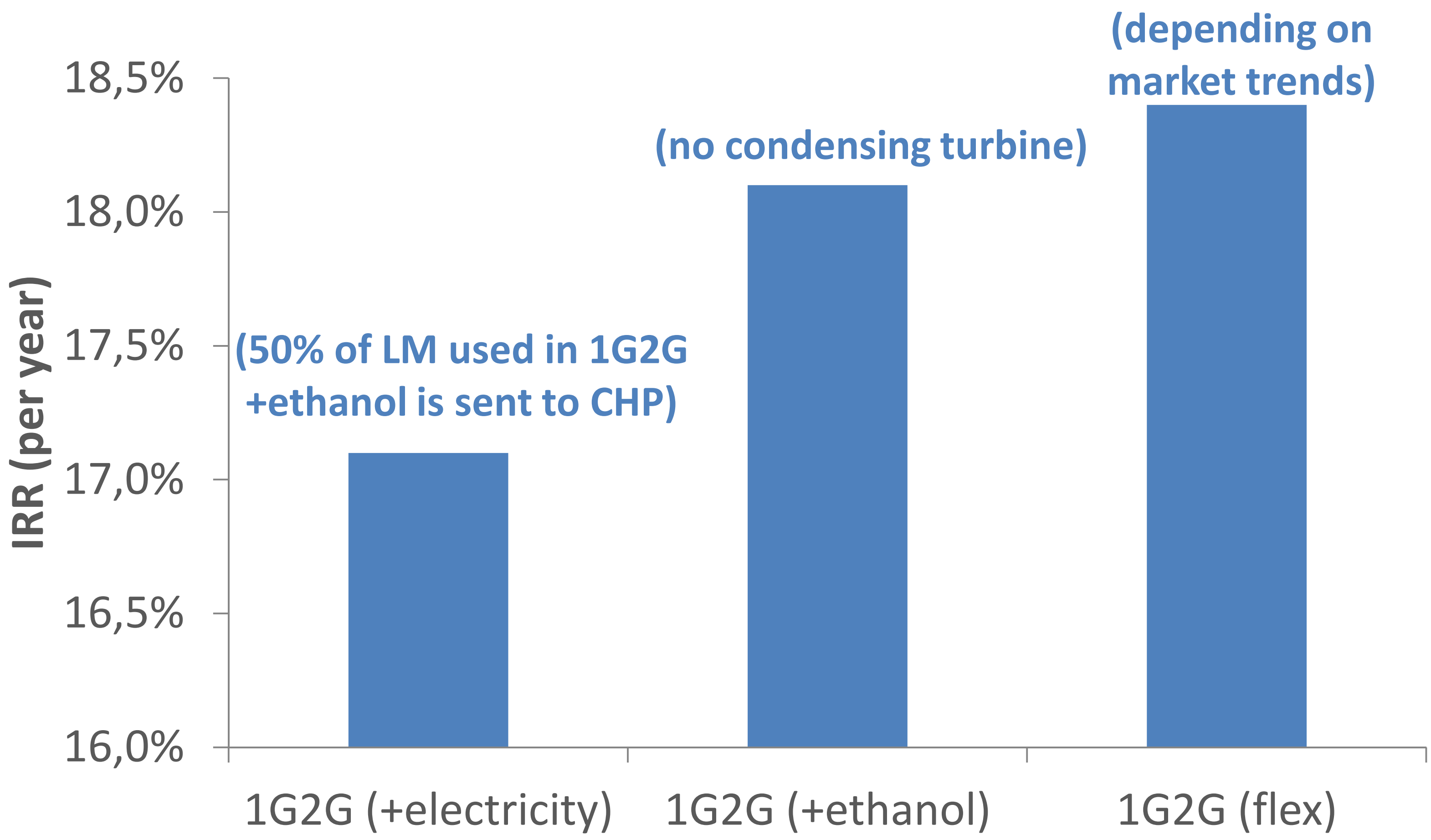



*Dias et al., 2012. Integrated versus stand-alone second generation ethanol production from sugarcane bagasse and trash. Bioresource Technology*

# Environmental Impacts



# Flexibility ethanol 2G *vs* electricity




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

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# Thank you!

*antonio.bonomi@bioetanol.org.br*