VIRTUAL SUGARCANE BIOREFINERY (VSB)
Second Generation Ethanol Production from Sugarcane in BRAZIL

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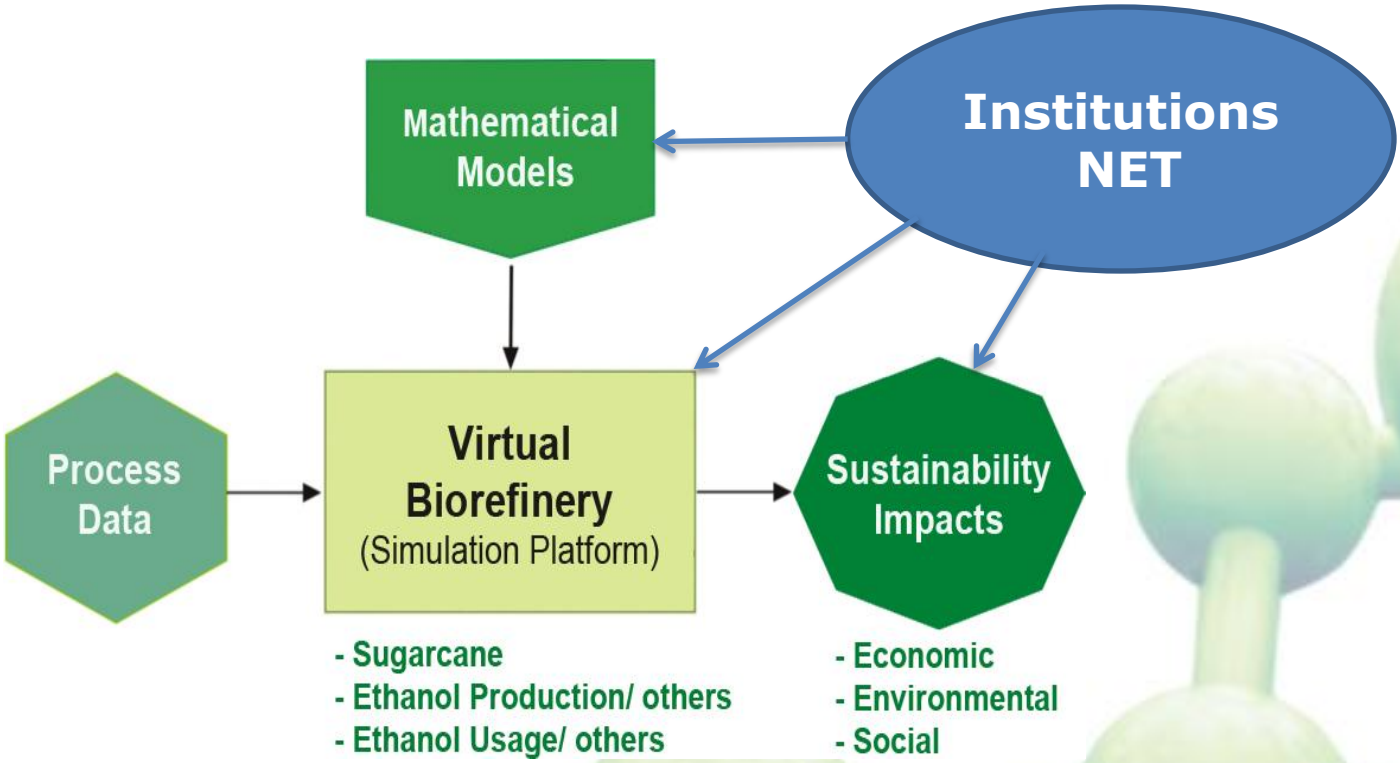
VSB – Concept


Mathematical Models
Institutions NET
Process Data
Virtual Biorefinery
(Simulation Platform)
Sustainability Impacts
- Sugarcane
- Ethanol Production/ others
- Ethanol Usage/ others
- Economic
- Environmental
- Social

VSB – Scope

Basic routes to be designed and technically assessed:

Route 1: ethanol (1st generation), sugar, electricity;

Route 2: ethanol (2nd generation) – hydrolysis;

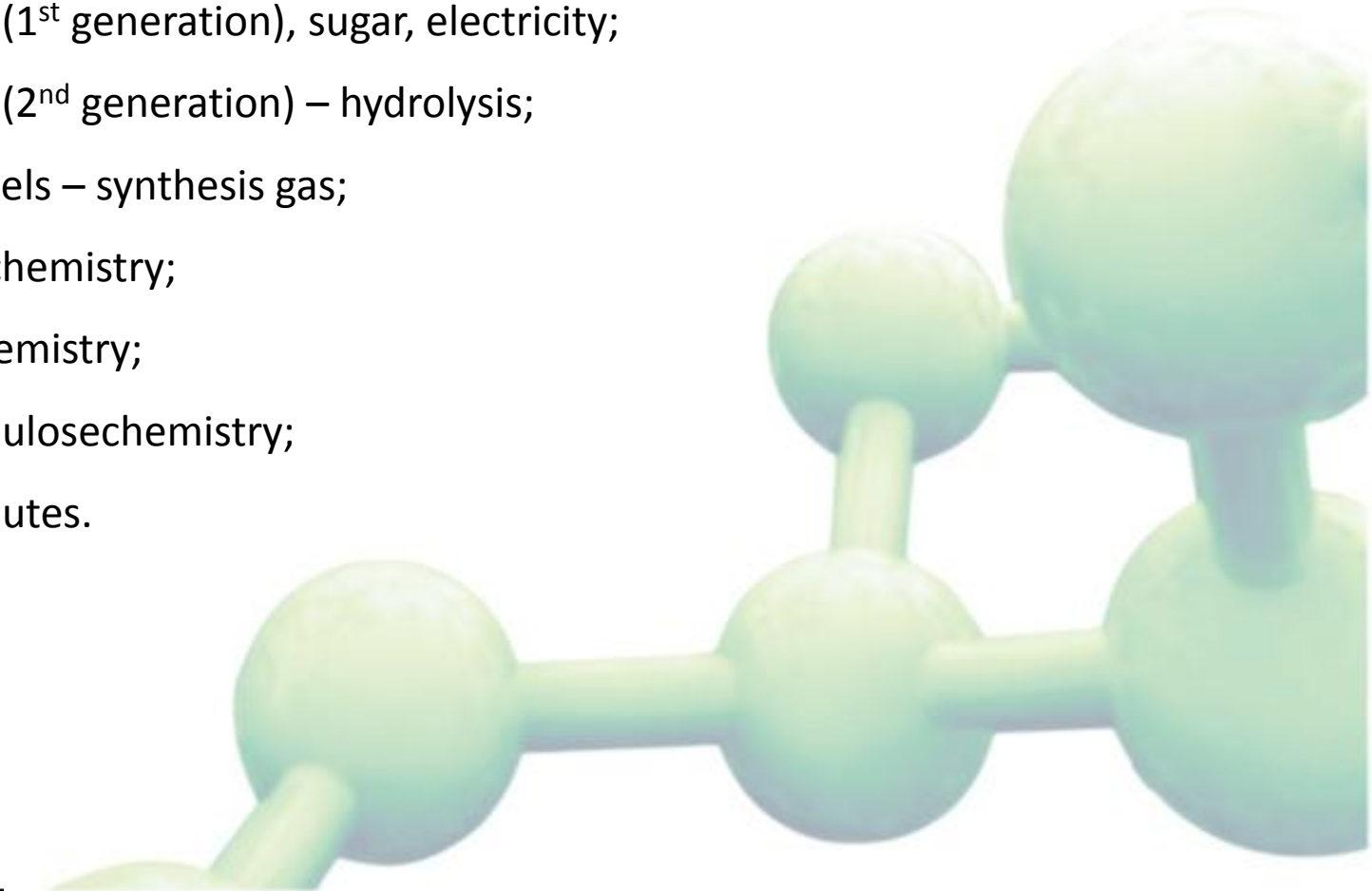
Route 3: liquid fuels – synthesis gas;

Route 4: alcoholchemistry;

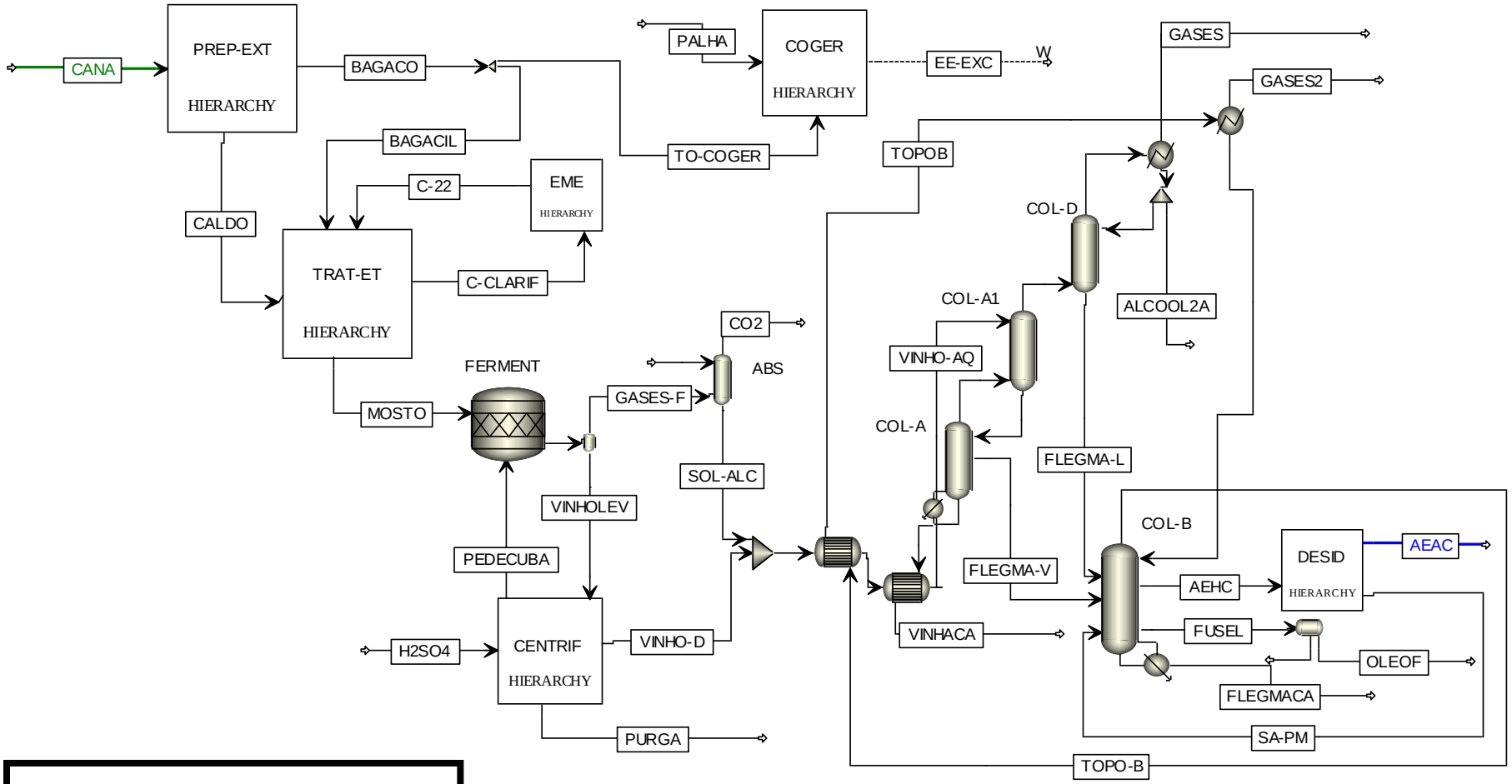
Route 5: sugarchemistry;

Route 6: lignocellulosechemistry;

Route n: other routes.



Simulation – Optimized 1G



- **Autonomous distillery**
- **Aspen Plus**

Simulation

Basic parameters – 1G

Parameters	Value
Plant operation - sugarcane processed (TC/h)	500
- operation (days/year)	167
Sugarcane quality - fibers content (%)	13
- TRS content (%)	14.5
- trash produced in the fields (kg/TC)	140
- bagasse moisture (%)	50
- trash moisture (%)	15
Efficiencies - extraction of sugars in the mills(%)	96
- fermentation (%)	90
- 22/90 bar boilers (%)	75/87
- turbines – high/intermediate pressure/condensation (%)	72 / 81 / 70
Sugarcane bagasse/trash LHV (wet basis) (MJ/kg)	7.5/15.1
Energy demand – electricity (mechanical/electric drivers) (kWh/TC)	12/30
Steam – process/molecular sieves – pressure (bar)	2.5 / 6
– demand azeotropic distillation/molecular sieves (kg/L EtOH)	2.0 / 0.6
Anhydrous ethanol purity (wt%)	99.6

Pre planting operations | Soil preparation | Planting - Manual or Mechanical | Cultivation - Cane plant and Ratoon | Harvesting - Manual or Mechanical | Sugarcane transport

Agricultural Spreadsheet

Biorefinery Simulation

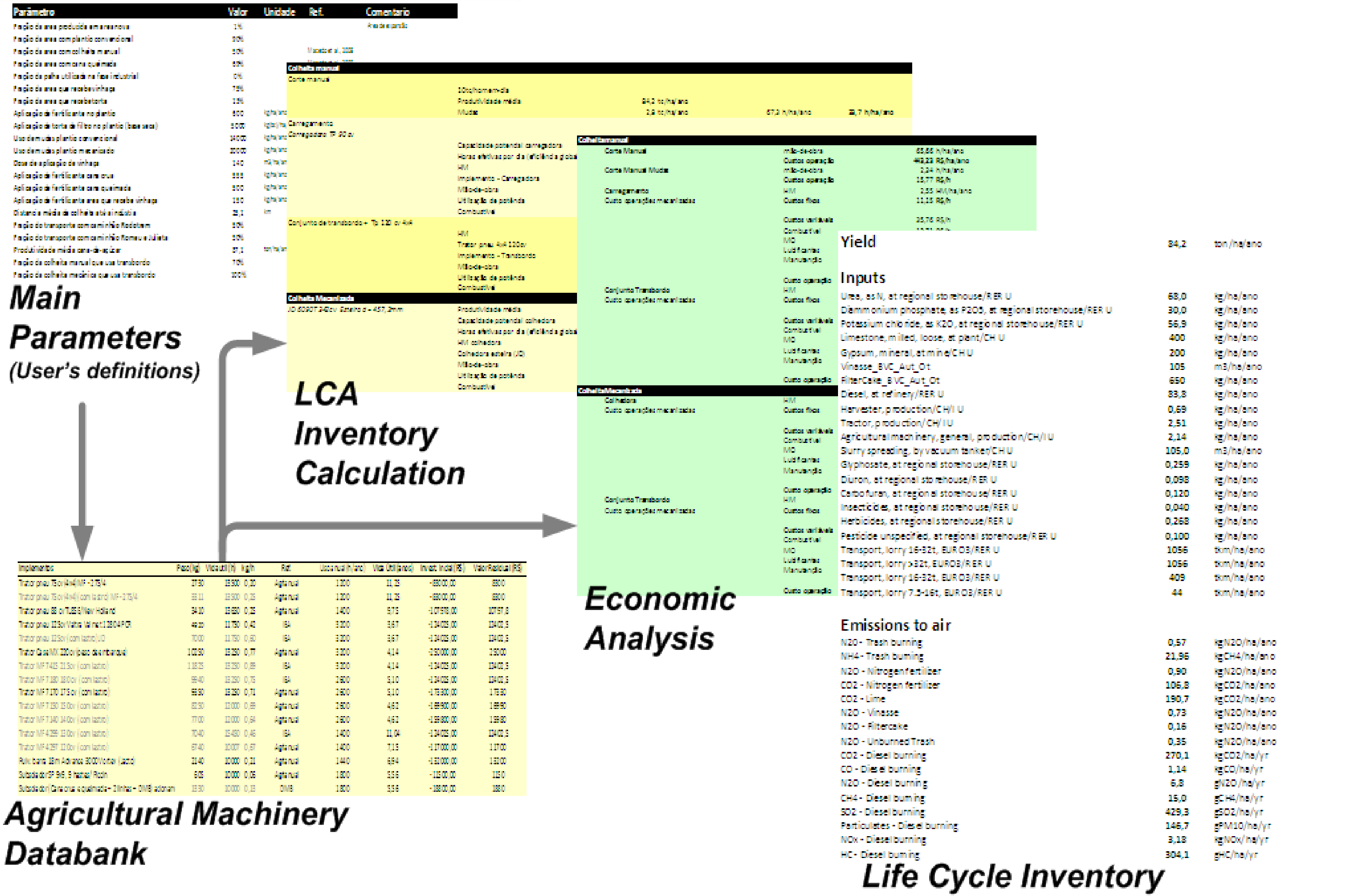
AspenPlus

Usage Spreadsheet

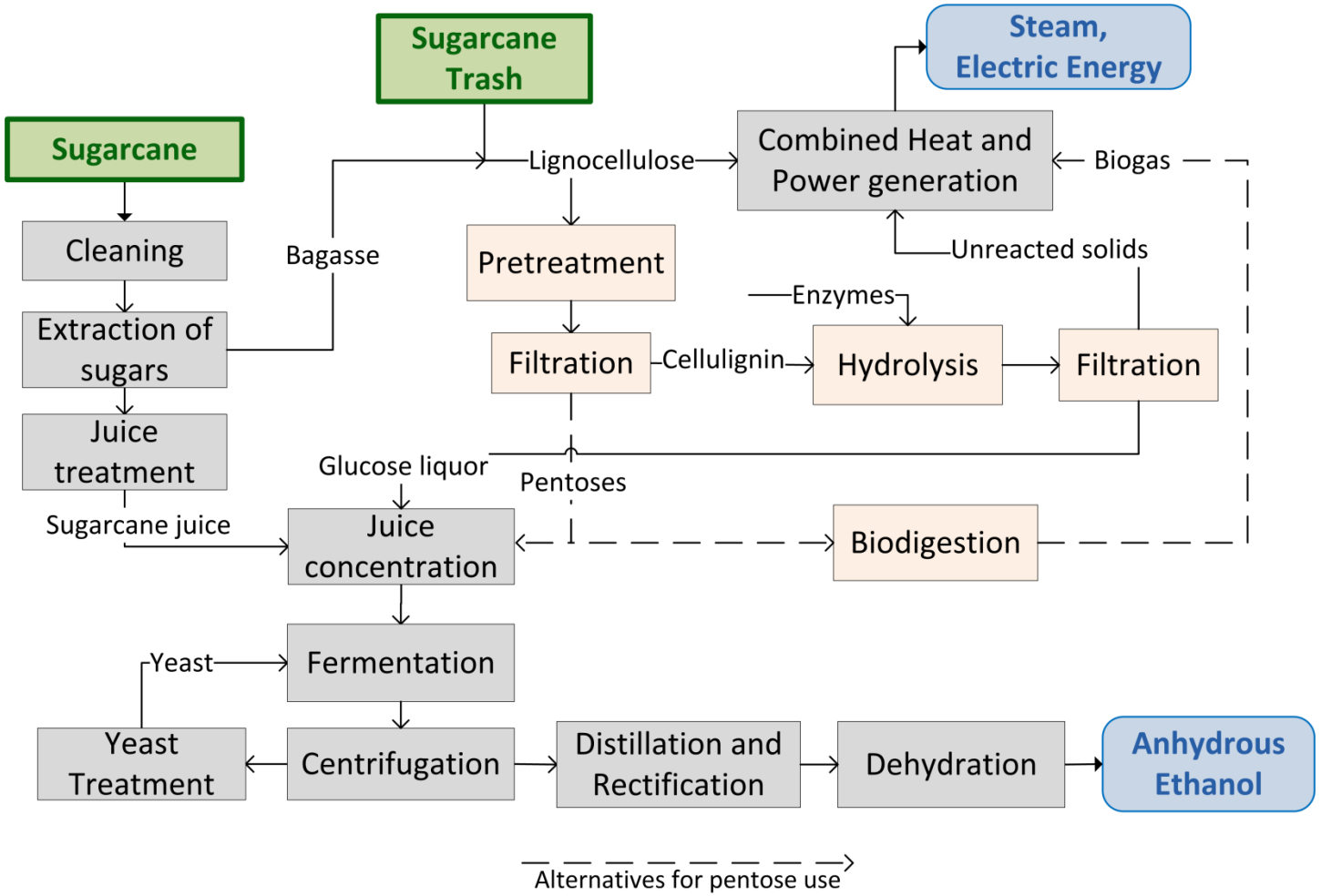
Economic Analysis
- ✓ Production cost
- ✓ IRR

Social Analysis
- ✓ Manpower
- ✓ Income

Environmental Analysis (Life Cycle Inventory)
- ✓ Diesel
- ✓ Fertilizers
- ✓ Machinery
- ✓ Industrial inputs
- ✓ Equipments
- ✓ Local emissions, e.g. N_2O, CO_2
- ✓ Other inputs and outputs...


Main Parameters (User's definitions)
LCA Inventory Calculation
Economic Analysis
Agricultural Machinery Databank
Life Cycle Inventory
Yield 84,2 ton/ha/ano
Inputs
Urea, as N, at regional storehouse/RER U 68,0 kg/ha/ano
Diammonium phosphate, as P2O5, at regional storehouse/RER U 30,0 kg/ha/ano
Potassium chloride, as K2O, at regional storehouse/RER U 56,9 kg/ha/ano
Limestone, milled, loose, at plant/CH U 400 kg/ha/ano
Gypsum, mineral, at mine/CH U 200 kg/ha/ano
Vinasse_BVC_Aut_Ot 105 m3/ha/ano
FilterCake_BVC_Aut_Ot 650 kg/ha/ano
Diesel, at refinery/RER U 83,8 kg/ha/ano
Harvester, production/CH/I U 0,69 kg/ha/ano
Tractor, production/CH/I U 2,51 kg/ha/ano
Agricultural machinery, general, production/CH/I U 2,14 kg/ha/ano
Slurry spreading, by vacuum tanker/CH U 105,0 m3/ha/ano
Glyphosate, at regional storehouse/RER U 0,259 kg/ha/ano
Diuron, at regional storehouse/RER U 0,098 kg/ha/ano
Carbofuran, at regional storehouse/RER U 0,120 kg/ha/ano
Insecticides, at regional storehouse/RER U 0,040 kg/ha/ano
Herbicides, at regional storehouse/RER U 0,268 kg/ha/ano
Pesticide unspecified, at regional storehouse/RER U 0,100 kg/ha/ano
Transport, lorry 16-32t, EURO3/RER U 1056 tkm/ha/ano
Transport, lorry >32t, EURO3/RER U 1056 tkm/ha/ano
Transport, lorry 16-32t, EURO3/RER U 409 tkm/ha/ano
Transport, lorry 7.5-16t, EURO3/RER U 44 tkm/ha/ano
Emissions to air
N2O - Trash burning 0,57 kgN2O/ha/ano
NH4 - Trash burning 21,96 kgCH4/ha/ano
N2O - Nitrogen fertilizer 0,90 kgN2O/ha/ano
CO2 - Nitrogen fertilizer 106,8 kgCO2/ha/ano
CO2 - Lime 190,7 kgCO2/ha/ano
N2O - Vinasse 0,73 kgN2O/ha/ano
N2O - Filtercake 0,16 kgN2O/ha/ano
N2O - Unburned Trash 0,35 kgN2O/ha/ano
CO2 - Diesel burning 270,1 kgCO2/ha/yr
CO - Diesel burning 1,14 kgCO/ha/yr
N2O - Diesel burning 6,8 gN2O/ha/yr
CH4 - Diesel burning 15,0 gCH4/ha/yr
SO2 - Diesel burning 429,3 gSO2/ha/yr
Particulates - Diesel burning 146,7 gPM10/ha/yr
NOx - Diesel burning 3,18 kgNOx/ha/yr
HC - Diesel burning 304,1 gHC/ha/yr

Integrated 1st and 2nd generation bioethanol production from sugarcane



Simulation

Basic parameters – 2G

Parameter	Value
Sugarcane bagasse/trash cellulose content (dry basis) (%)	40.7
Sugarcane bagasse/trash hemicellulose content (dry basis) (%)	26.5
Sugarcane bagasse/trash lignin content (dry basis) (%)	21.9
Steam explosion - temperature (°C)	190
- reaction time (min)	15
- hemicellulose hydrolysis (%)	70
- cellulose hydrolysis (%)	2
LHV (dry basis) – cellulose (MJ/kg)	15.8
– hemicellulose (MJ/kg)	16.25
– lignin (MJ/kg)	25.45
Pentoses Biodigestion – COD removal (%)	70
Pentoses fermentation – conversion to ethanol (%)	80

1G Investment data provided by Dedini:

Autonomous distillery: Total investment R$ 300 million (US$ 150 million; US$75/TC or R$ 150/TC)

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

Investment fraction by sector :

Process step	Fraction (%)
Reception, cleaning, extraction	15
Juice treatment, fermentation, distillation	17
Production of steam and electricity	30
Buildings, laboratories, etc	5
Control system, etc	7
Packing, transportation	3
Set up, etc	20
Engineering, services, etc	3

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)

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

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

Investment - 2G plant:

- Current technology: R$ 124 million – 268,350[(1)] t bagasse/year (R$924/t dry bagasse)
- Future technology: R$ 133 million – 462,451[(1)] t bagasse/year (R$575/t dry bagasse)
- Pentoses biodigestion(2): R$ 22 million for processing 76,000 Nm³ biogas/day

Enzyme costs:

- Current technology : R$ 0,20/L cellulosic ethanol
- Future technology : R$ 0,08/L cellulosic ethanol

(1) Bioetanol combustível: uma oportunidade para o Brasil, CGEE, 2009

(2) Dedini – turn key stillage biodigestion unit

Costs and prices adopted in the simulation

Parameter	Value
Sugarcane cost (R$/TC)[a]	38.81
Sugarcane trash cost (R$/t)	30.00
Electricity price (R$/MWh)	141.00
Anhydrous ethanol price (R$/L) [b]	1.00
Hydrated ethanol price (R$/L) [b]	0.92
Sugar price (R$/kg) [b]	0.69

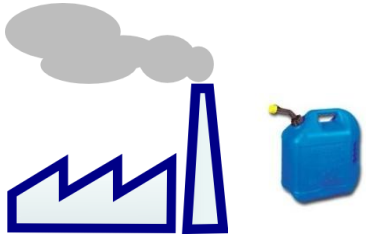
[a] 6 years moving average of sugarcane prices paid to the producer (Dec 2009 values) in São Paulo state (SP), from July 2000 to December 2009 (UDOP, 2009);

[b] 6 years moving average of ethanol and sugar prices paid to the producer (Dec 2009 values) in SP, from July 2000 to December 2009 (CEPEA, 2009).

Economic analysis parameters

Parameter	Value
Project lifetime (years)	25
Salvage value of equipment	-
Construction and start-up (years)	2
Linear depreciation (years)	10
Tax rate (%)	34

Comparison of different hydrolysis technologies in the integrated 1G2G process



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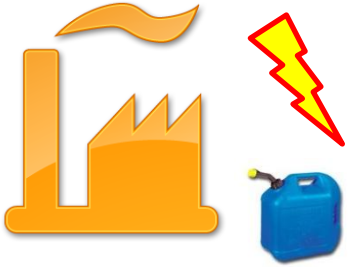
1G - Standard

- ✓ Azeotropic distillation
- ✓ Mechanical drivers
- ✓ 22 bar boilers
- ✓ No surplus electricity



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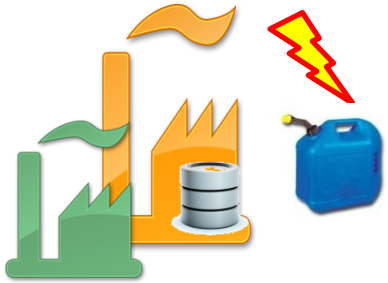
1G - Optimized

- ✓ Molecular sieves
- ✓ Trash use
- ✓ Electrified drivers
- ✓ 90 bar boilers
- ✓ Surplus electricity
- ✓ Reduction on steam consumption



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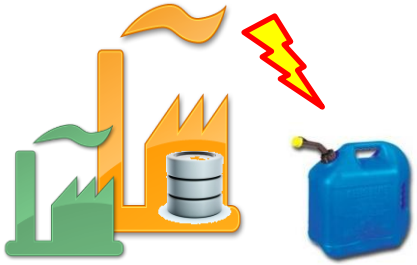
1G2G Current Technology

- ✓ 60% hydrolysis yield
- ✓ 10% solids,
- ✓ Pentose biodigestion
- ✓ High investment and enzyme costs



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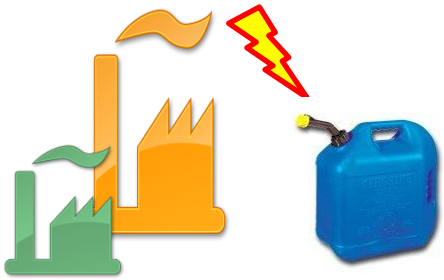
1G2G Future Technology

- ✓ 70% hydrolysis yield
- ✓ 15% solids
- ✓ Pentose biodigestion
- ✓ Lower investment and enzyme costs



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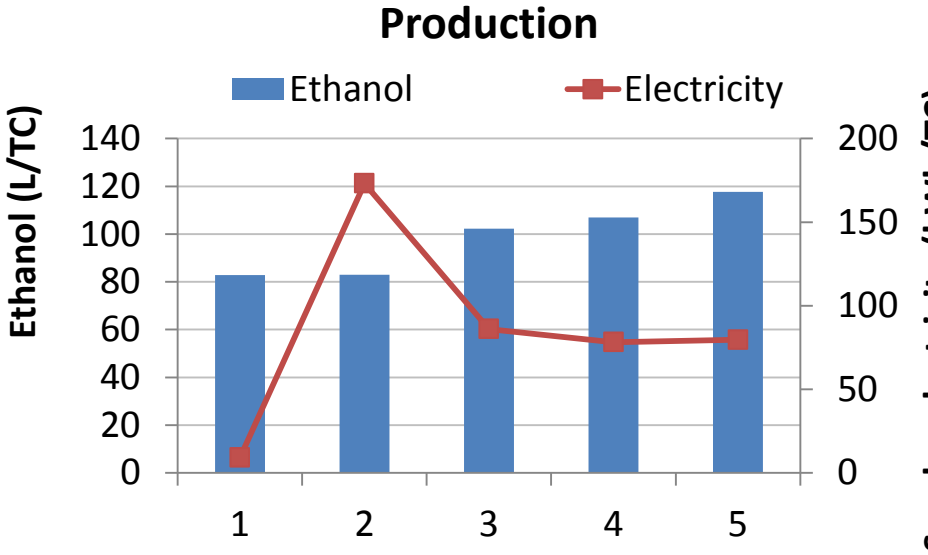
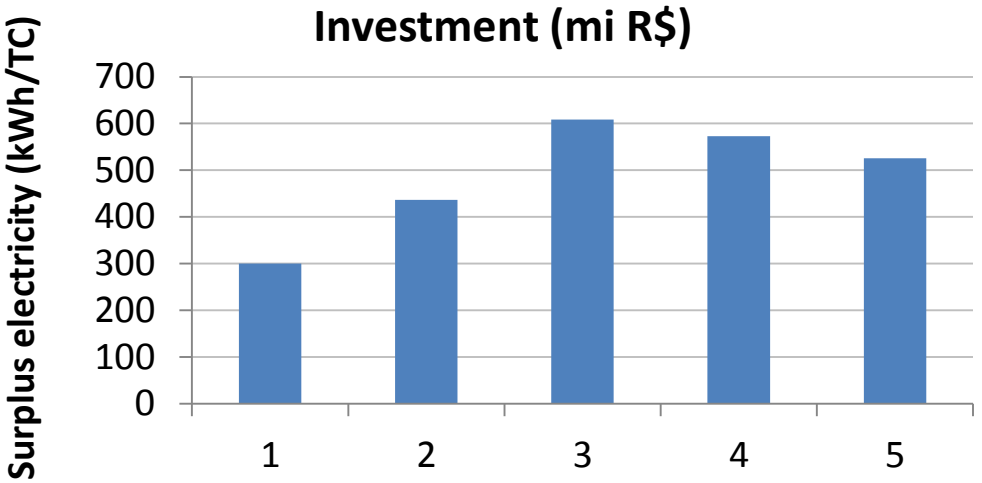
1G2G Future Technology

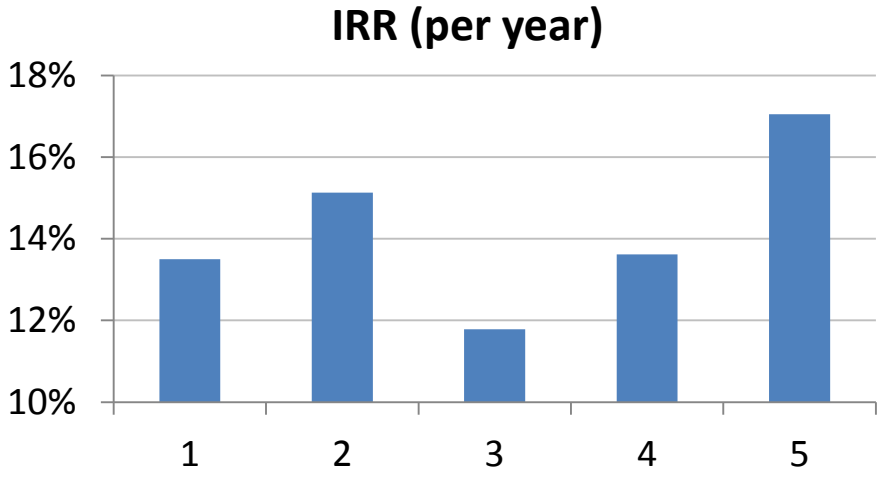
- ✓ Idem 3
- ✓ Pentose fermentation to ethanol

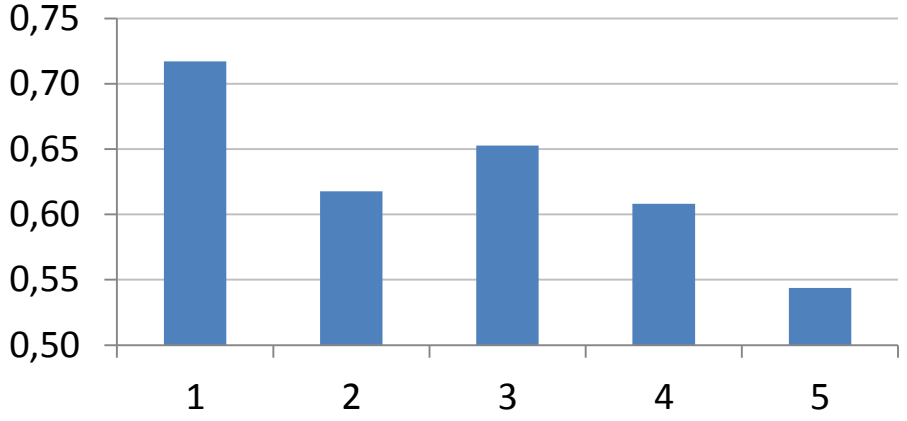
Results -1G 2G

1. 1G - standard
2. 1G - optimized
3. 1G + current hydrolysis, pentose biodigestion
4. 1G + future hydrolysis, pentose biodigestion
5. 1G + future hydrolysis, pentose fermentation





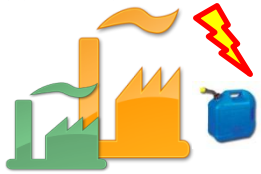




Comparison between 1G, integrated 1G 2G and stand-alone 2G

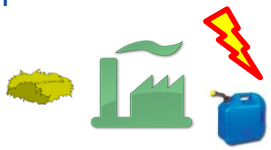
1G: optimized with electricity maximization

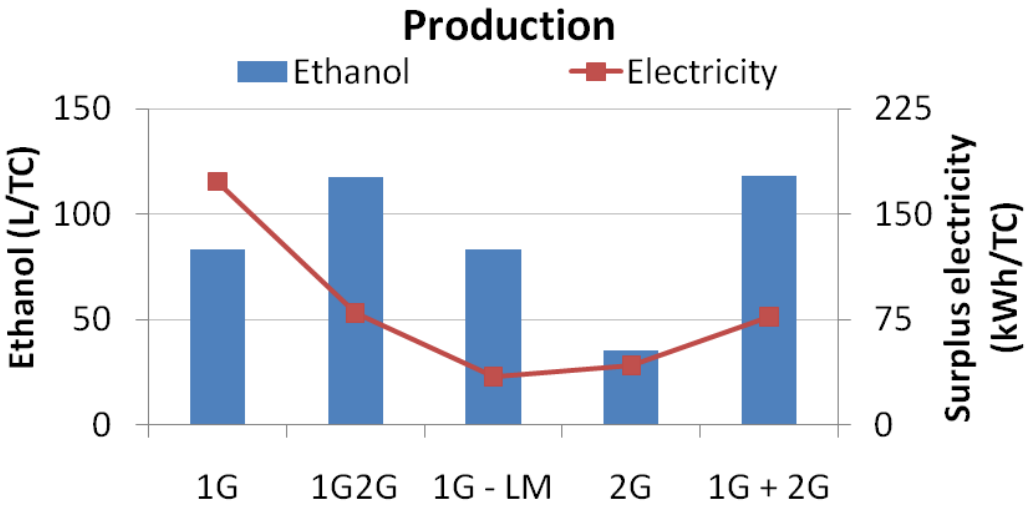
1G2G: integrated process with future hydrolysis technology and pentose fermentation

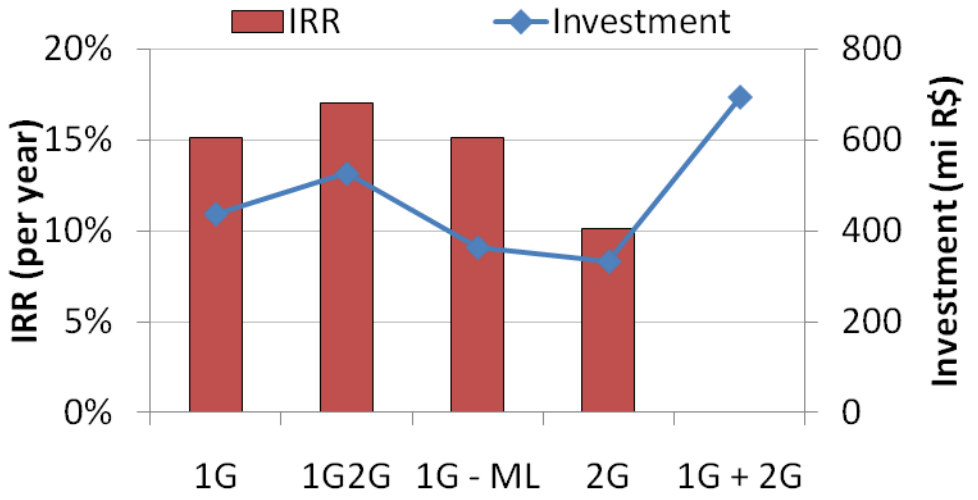


1G-LM: 1G unit producing surplus Lignocellulosic material

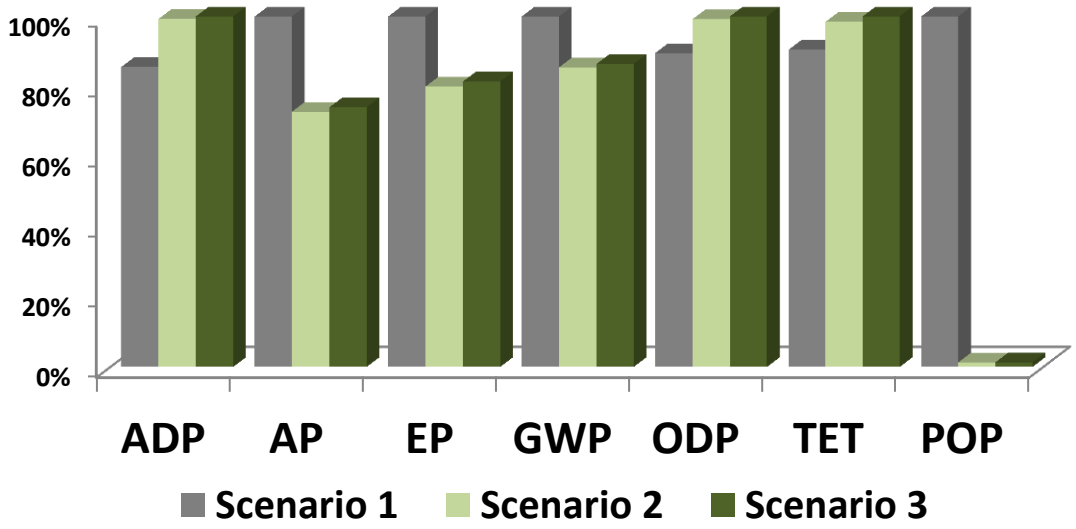
2G: stand-alone 2G with future hydrolysis technology and pentose fermentation







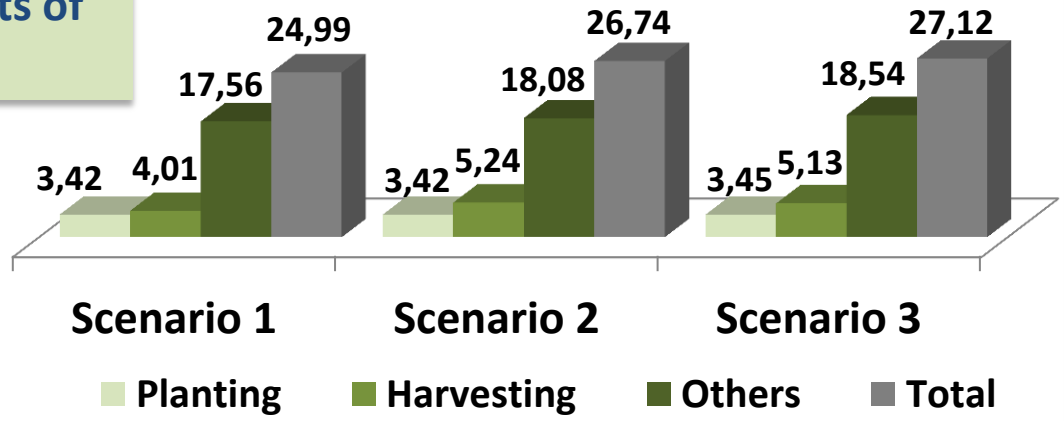
Economic and Environmental Assessment



Relative environmental impacts of sugarcane production

Note: ADP: Abiotic Depletion; **AP:** Acidification; **EP:** Eutrophication; **GWP:**Global Warming; **ODP:** Ozone Layer Depletion; **TET:** Terrestrial Ecotoxicity **POP**: Photochemical Oxidation.

1. **Semi Mechanical Planting**
   Manual Harvesting
2. **Semi Mechanical Planting**
   Mechanical Harvesting
3. **Mechanical Planting**
   Mechanical Harvesting



Sugarcane Production Costs (US$/tc)

VSB Preliminary Conclusions

- importance of integration of 2G ethanol production to 1G sugarcane mills;
- identification and quantification main technological bottlenecks on 2G;
- in the integrated process, ethanol production cost is reduced using current 2G technology, although profitability is decreased;
- today maximizing electricity production in the biorefinery is more attractive than 2G;
- in the mid term (5 to 10 years) 2G will be more attractive than electricity;
- production of high aggregate value products may encourage the adoption of 2G;
- biogas from vinasse and 2G residues may allow all bagasse and trash as feedstock;
- 3 levels for the increase of ethanol production: 25% not converting pentoses; 50% converting pentoses; 75% all vinasse is biodigested;
- improvements in the agricultural sector – significant environmental and economic gains;
- environmental gains on the integrated 1G and 2G may exist (still working);

THANK YOU!

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