Brazilian Bioethanol Science and Technology Laboratory

SBFC Symposium on Biotechnology for Fuels and Chemicals

CNPEM Brazilian Center for Research in Energy and Materials

Comparative technical, economic and environmental assessment of biomass-to-ethanol conversion technologies: Biochemical and thermochemical routes integrated in a sugarcane biorefinery

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April 2015

Ministério da Ciência, Tecnologia e Inovação

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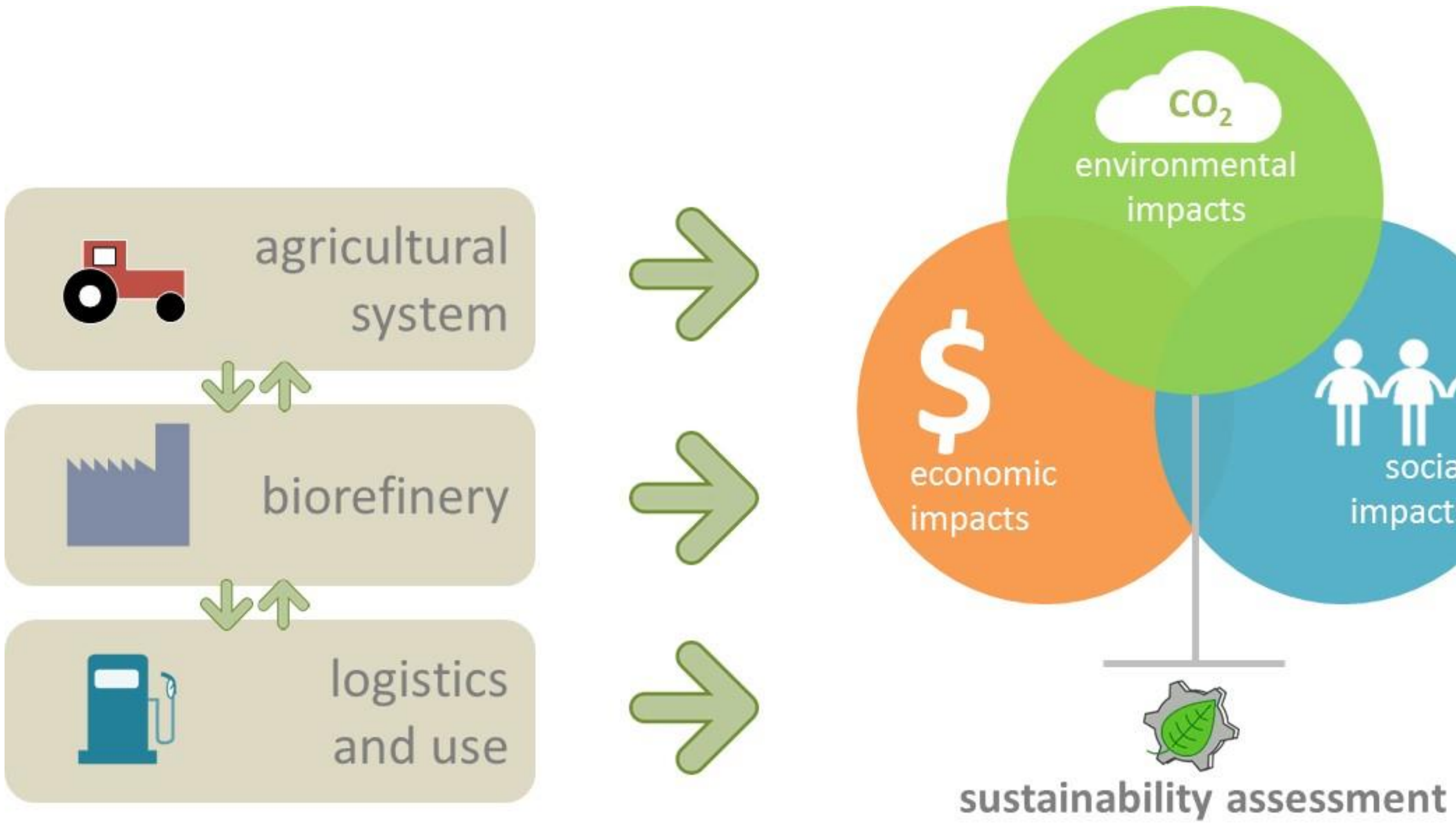
Motivation

- Ethanol production in Brazil: historically performed through biochemical routes.
- Possibility of employing thermochemical routes?

Objectives

- To assess ethanol production through a thermochemical route.
- To compare biochemical and thermochemical routes of biomass-to-ethanol conversion integrated to 1G sugarcane mills in a biorefinery concept, evaluating technical, economic and environmental impacts.

Virtual Sugarcane Biorefinery

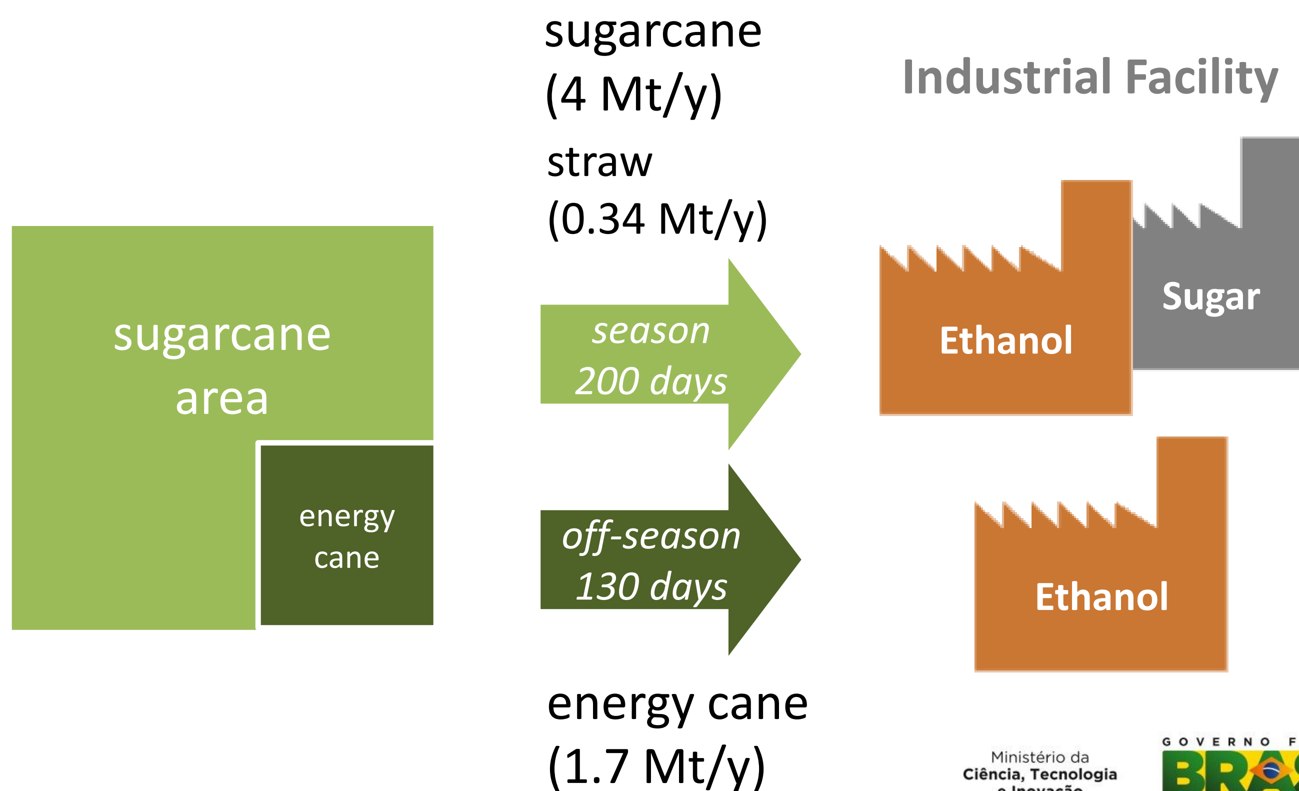


Sugarcane alternatives

Sugarcane production

Conventional cane
- *Widespread use*
- *Higher sugar content*

Energy cane
- *Higher fiber content*
- *Lower sugar content*
- *Higher productivity*



Considered scenarios

- **Scenario 1G**

  Season: 1G ethanol, sugar and electricity production, conventional cane.

  Off-season: 1G ethanol and electricity production, energy cane.

- **Scenario 1G2G Bio**

  Season: 1G and 2G (biochemical) ethanol, sugar and electricity production, conventional cane.

  Off-season: 1G and 2G (biochemical) ethanol and electricity production, energy cane.

- **Scenario 1G2G Thermo**

  Season: 1G and 2G (thermochemical) ethanol, sugar and propanol production, conventional cane .

  Off-season: 1G and 2G (thermochemical) ethanol and propanol production, energy cane .

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Ethanol production in Brazil

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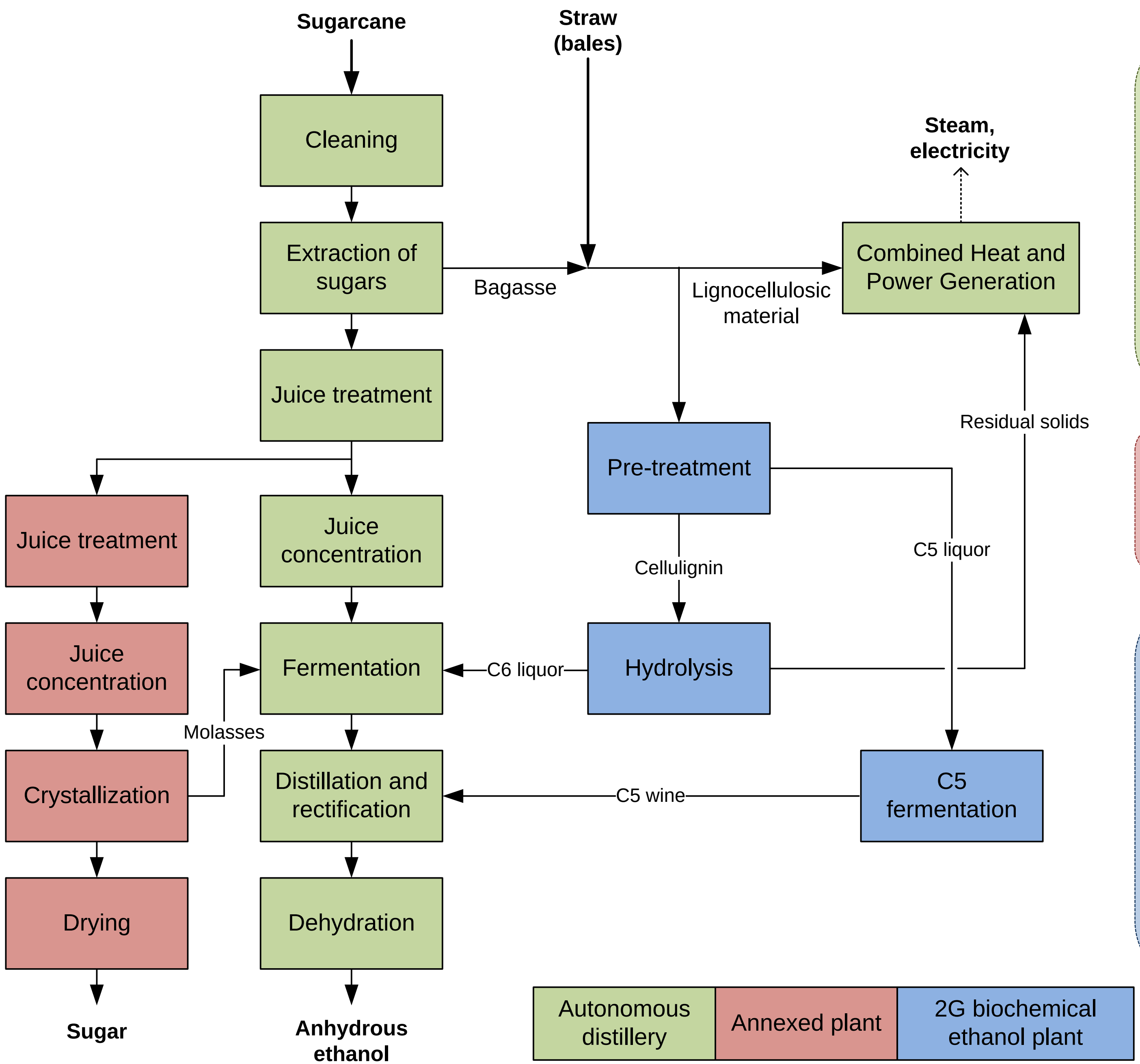


1G autonomous distillery

- Straw use (50%)
- Molecular sieves for dehydration
- 65 bar boilers
- 20% reduction on steam demand

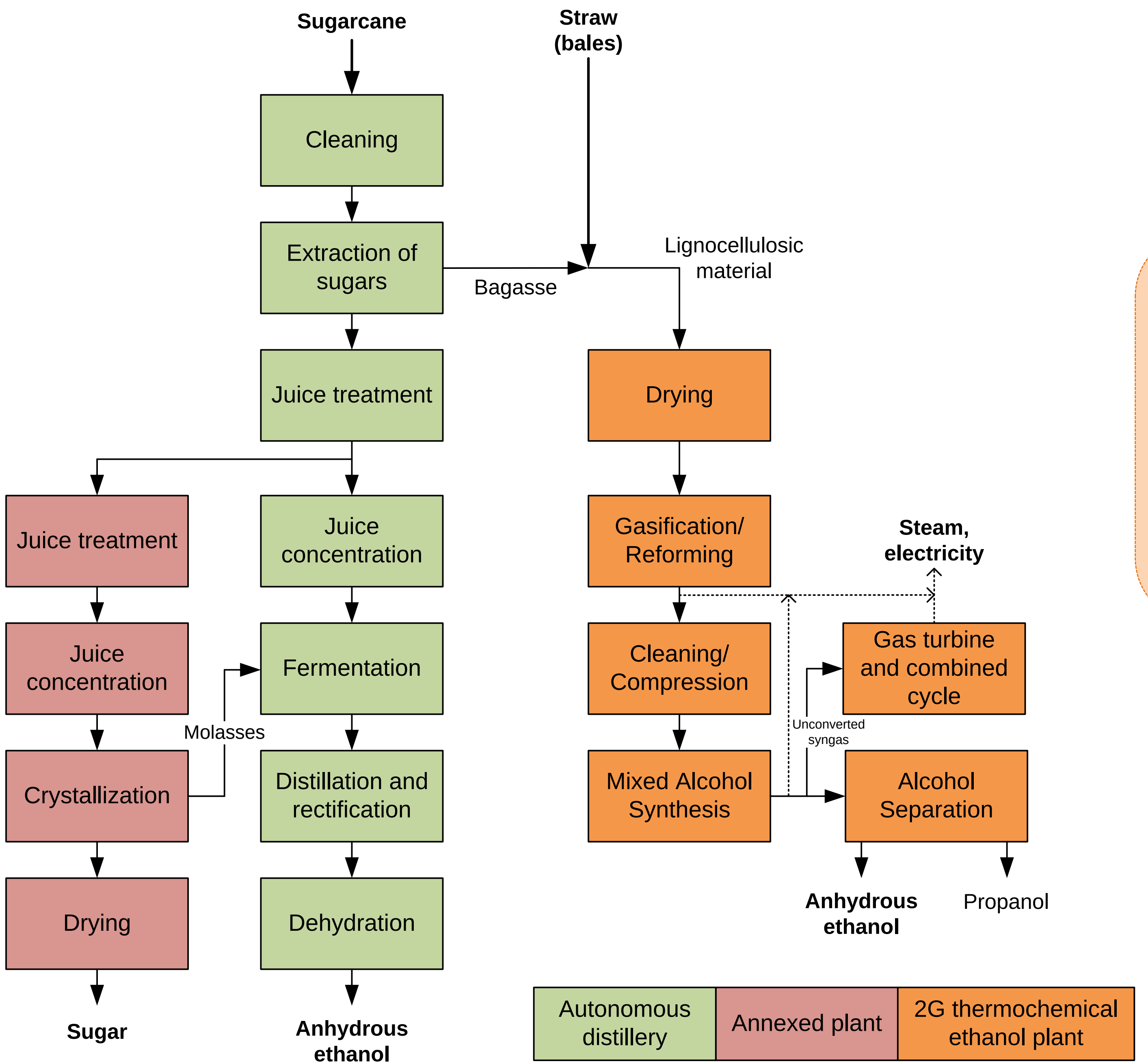
1G annexed plant

- Flex ethanol:sugar production

2G biochemical ethanol plant

- Steam explosion pretreatment
- C6 Hydrolysis: 36h, 20% solids
- Separate C5 fermentation to ethanol
- Use of solid residues as fuel in the boilers

Thermochemical ethanol



2G thermochemical ethanol plant

- Indirect steam gasifier: 869 ºC, 2.3 bar
- Compression and alcohol synthesis: 200 bar
- Molecular sieves for dehydration
- Methanol recycle

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Technical assumptions

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- All scenarios: energy self-sufficiency.
- Year-round operation: conventional cane (season) and energy cane (off-season).

  All scenarios consume equal amounts of conventional cane (4 Mt) and energy cane (1.7 Mt).

  2G operational level: off-season = 70% season.

  Same fiber delivered at milling (sugar extraction) in the off-season with energy cane.
- 2G biochemical ethanol production operates with surplus LCM from 1G CHP unit.
- Total lignocellulosic material is consumed by the thermochemical plant.

  Thermochemical plant supplies steam and electricity to itself and to 1G annexed plant (CHP unit in 1G plant no longer required).

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Technical assumptions

- 2G biochemical plant based on 2015 CTBE/BNDES study.
- 2G thermochemical plant based on 2011 NREL Report

Process Design and Economics for Conversion of Lignocellulosic Biomass to Ethanol - Thermochemical Pathway by Indirect Gasification and Mixed Alcohol Synthesis.

Composition of producer gas from sugarcane LCM: based on experimental study from Hofbauer, 2009 (UT Vienna).

- Different biomass LCM composition (% dry basis)

Component	NREL, 2011 Southern pine tree	CTBE Conventional cane	CTBE Energy cane
Carbon	50.94	46.69	47.81
Hydrogen	6.04	5.72	5.84
Nitrogen	0.17	0.32	0.27
Sulfur	0.03	0.05	0.04
Oxygen	41.90	44.03	44.85
Ash	0.92	3.15	1.17
Moisture	35%	45%	50%

Higher energy consumption in drying step for sugarcane

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Thermochemical ethanol

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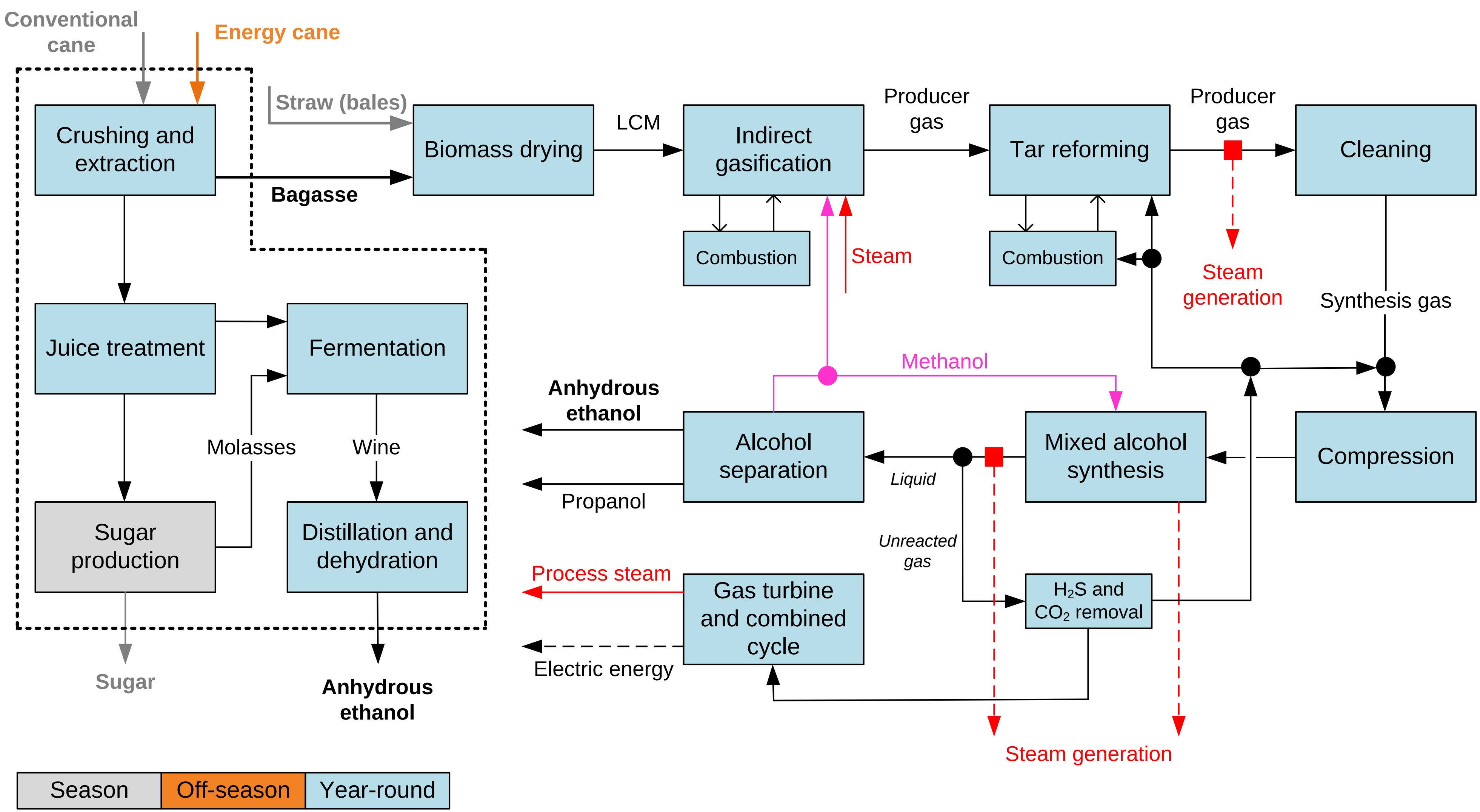
- 1G and 2G thermochemical ethanol integrated plant



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Technical results

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Production	1G	1G2G Bio	1G2G Thermo
Ethanol (million L/year)	310	517	596
Sugar (million kg/year)	206	206	206
Propanol (million L/year)	-	-	30
Electricity (GWh/year) *	1056	357	-

* Equivalent to an average power output to the grid of 134 MW (1G) and 45 MW (1G2G Bio).

Specific production	1G	1G2G Bio	1G2G Thermo
ton C in biofuels/ton C_{input} ** (%)	13.6	22.7	27.6
Total energy (MJ)/ton C_{input} **	11.5	13.8	15.2

** ton C_{input} = ton C_{CC} + ton C_{EC} + ton C_{straw} - ton C_{sugar}

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Economic assumptions

- Product prices (average of Brazilian historic series updated to July/2014).
  - Propanol: - sold to the fuel market.
    - selling price determined by lower heating value (LHV).

$$Price_{Propanol} = Price_{Ethanol} * \frac{LHV_{Propanol}}{LHV_{Ethanol}}$$

  - Electricity: - average price from 2005-2013 Regulated Contract Environment (RCE) in Brazil.

- CAPEX and OPEX estimated for each scenario.

  Based on CTBE database (1G and 1G2G Bio) and 2011 NREL report (1G2G Thermo).

- Economic parameters: - **Internal Rate of Return (IRR)**
  - **Ethanol production cost**

Economic results

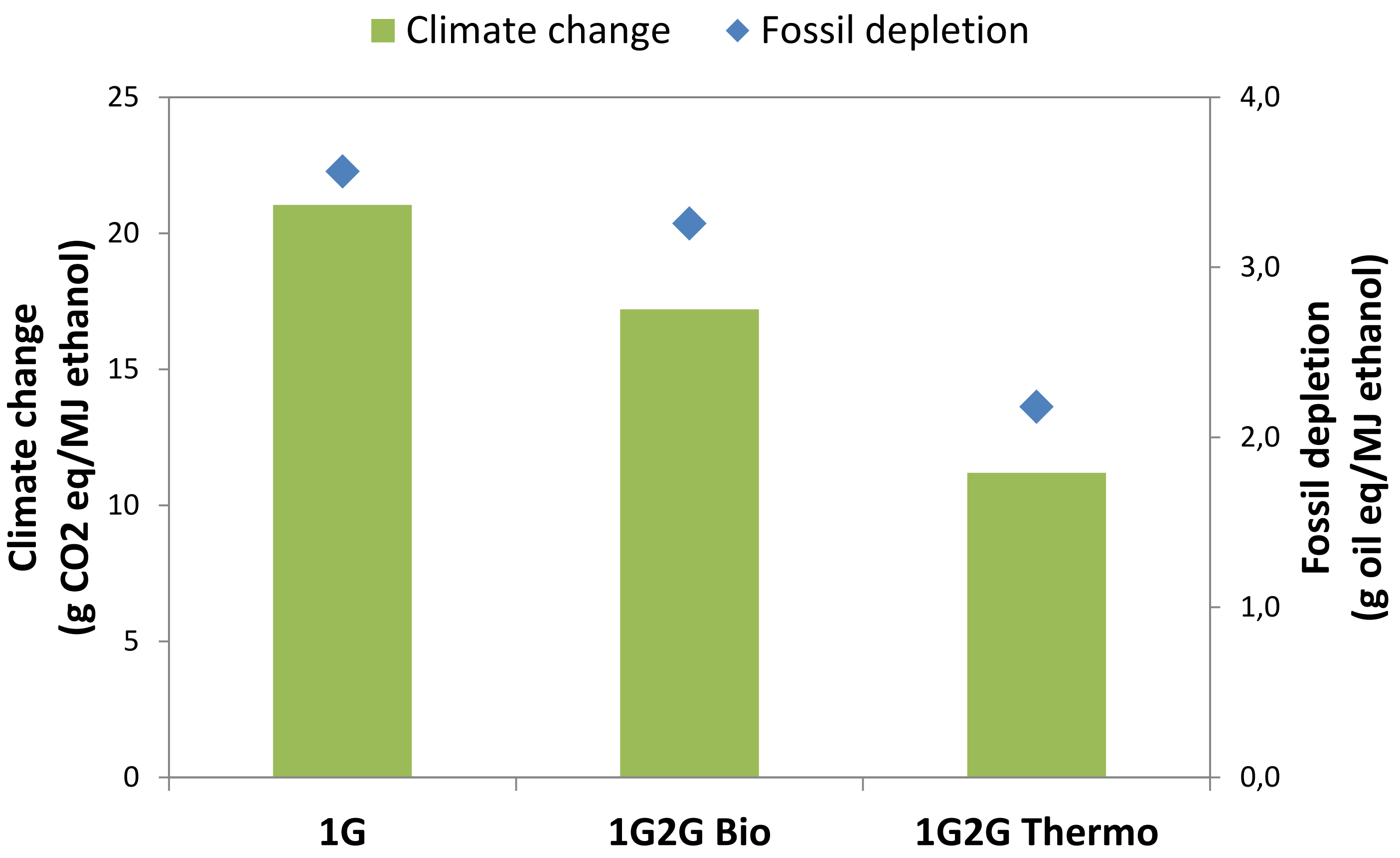
Parameters	1G	1G2G Bio	1G2G Thermo
Total CAPEX - MUS$	425.7	660.8	887.8
1G plant	425.7	463.6	229.6
2G plant	-	197.2	658.1

IRR - %	23.8	20.4	19.0

Ethanol production cost - US$/L **(US$/gal)**			
Combined 1G2G cost	0.35 **(1.31)**	0.36 **(1.38)**	0.35 **(1.34)**
1G ethanol cost	0.35 **(1.31)**	0.35 **(1.31)**	0.35 **(1.31)**
2G ethanol cost	-	0.39 **(1.48)**	0.36 **(1.37)**

1 US$ = R$ 2.30 (July/2014)

Environmental results



- 2G biorefineries have potential to substantially decrease environmental impacts of ethanol.
- Main factor for environmental performance of 1G2G Thermo: high ethanol yield.

Conclusions

- 1G2G thermochemical biorefinery greatly increases output of liquid biofuels.
- Ratio $C_{biofuels}/C_{input}$ is higher for 1G2G Thermo.
- Ethanol production cost remains practically unchanged in all scenarios.
- CAPEX of thermochemical unit is higher, impacting IRR results.
- Considering greenhouse gases emission and fossil depletion, thermochemical route presents better performance.

Thank you

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VSB Team