Laboratório Nacional de Ciência e Tecnologia do Bioetanol

Techno-economic assessment of the competitive potential of E2G in Brazil

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Ministério da Ciência, Tecnologia e Inovação

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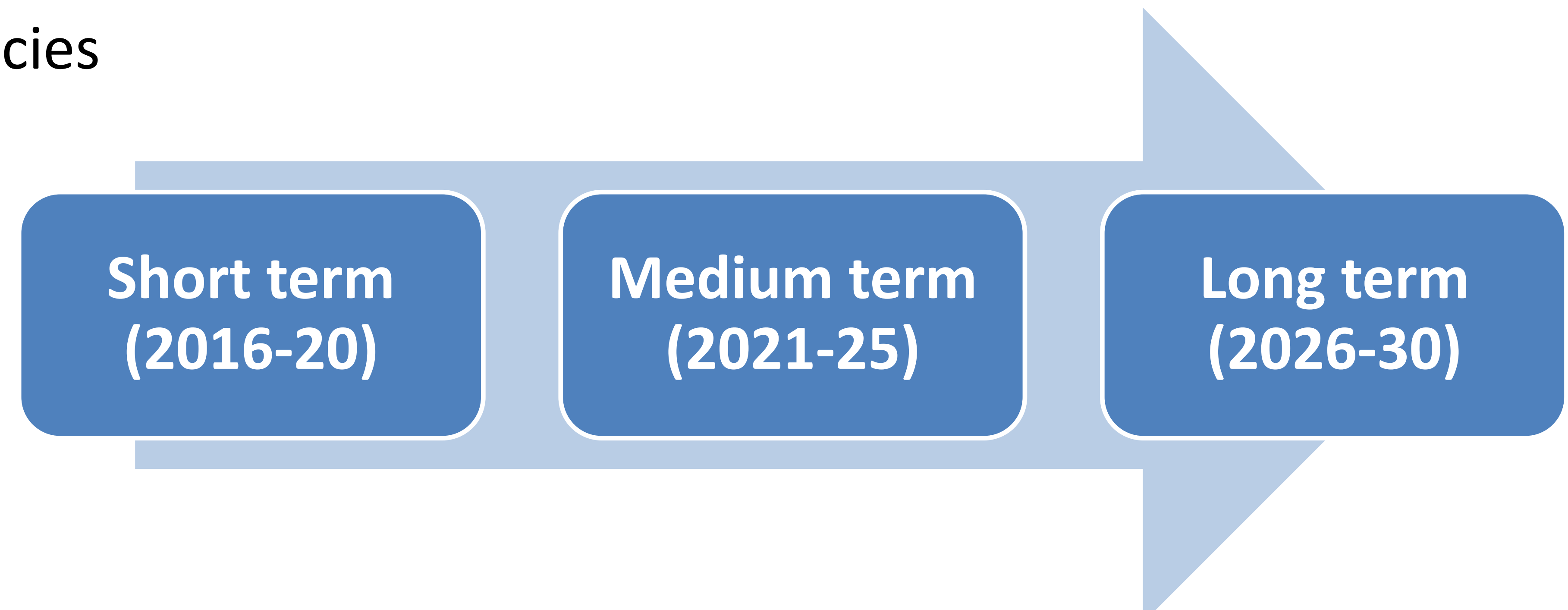
Objectives

- Evaluate 1G and 2G ethanol production costs over time
- Provide information to support formulation of public policies



Scenarios

General and 1G assumptions

Base case	Short term	Medium term	Long term
1G Annexed plant (sugar + ethanol)	Ethanol distillery (ethanol + electricity)	Ethanol distillery (ethanol + electricity)	Ethanol distillery (ethanol + electricity)
Season: sugarcane	Season: sugarcane + straw	Season: sugarcane+straw Off-season: energy cane	Season: sugarcane+straw +energy cane Off-season: energy cane
Vinasse: fertirrigation	Vinasse: fertirrigation	Vinasse: biodigestion (diesel substitution + electricity) and fertirrigation	Vinasse: higher biodigestion yields (diesel substitution + electricity) and fertirrigation
1G steam consumption: ~500 kg/TC	1G steam consumption: ~380 kg/TC	1G steam consumption: ~360 kg/TC	1G steam consumption: ~360 kg/TC

Increase on biomass productivities and straw recovery rates →

2G assumptions

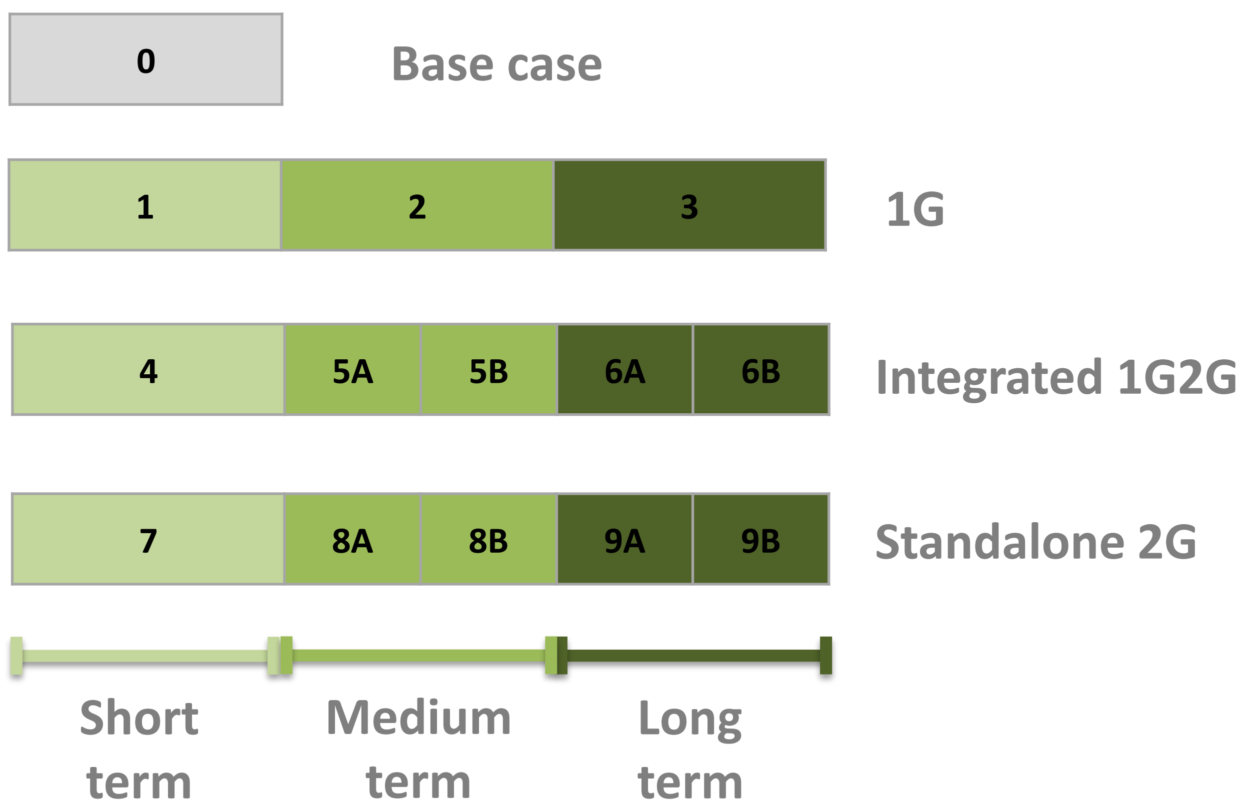
Short term → Medium term → Long term

Increase on 2G yields and recoveries →

	Short term	Medium term	Long term
2G[1]	All year: sugarcane bagasse + straw	All year: energy cane bagasse[2]	All year: energy cane bagasse[2]
1G2G	Season: sugarcane bagasse+ straw	Season: sugarcane bagasse+ straw Off-season: energy cane bagasse[2]	Season: sugarcane bagasse + straw + energy cane bagasse[2] Off-season: energy cane bagasse[2]

[1] Medium and long term scenarios include a small 1G plant processing energy cane juice
[2] Including straw

Scenarios list



- Short term and "A" scenarios – C5 separated fermentation in the 2G process
- "B" Scenarios – C5/C6 co-fermentation scenarios in the 2G process

Biomass

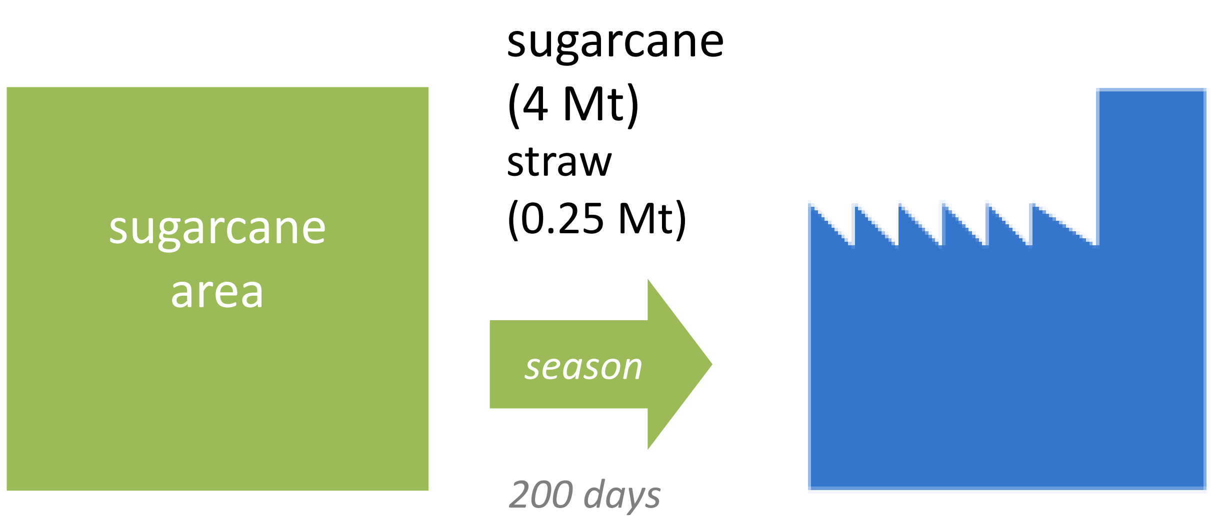
Plant capacities

Short term 1G and 1G2G scenarios

J	F	M	A	M	J	J	A	S	O	N	D

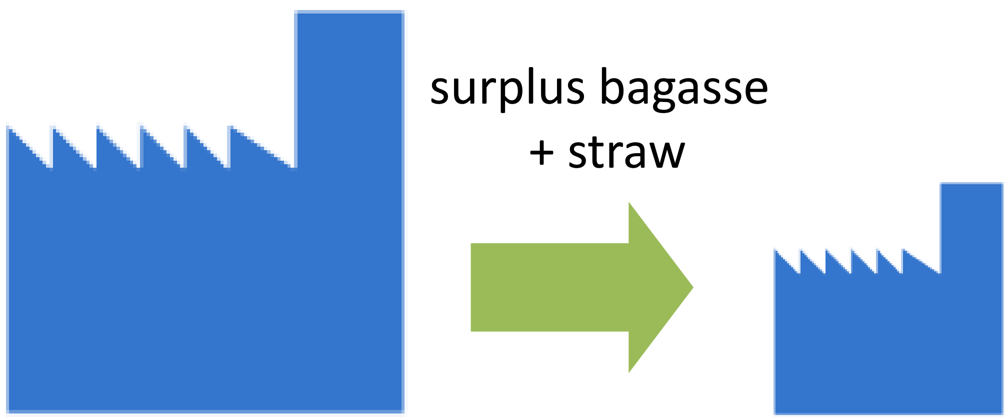
off season

sugarcane season



Plant capacities

Short term 2G standalone scenario



1G plant

(season - 200 days)

2G plant

(all year - 330 days)

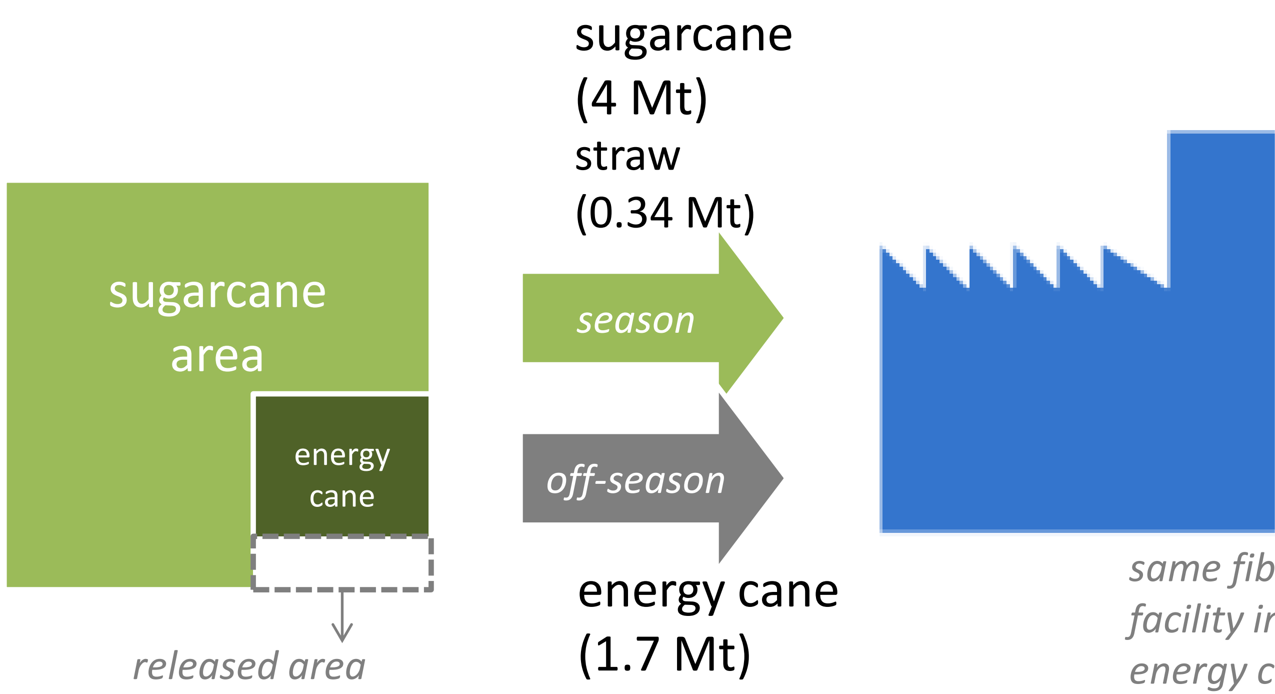
Plant capacities

Medium term 1G and 1G2G scenarios

J	F	M	A	M	J	J	A	S	O	N	D

off season

sugarcane season

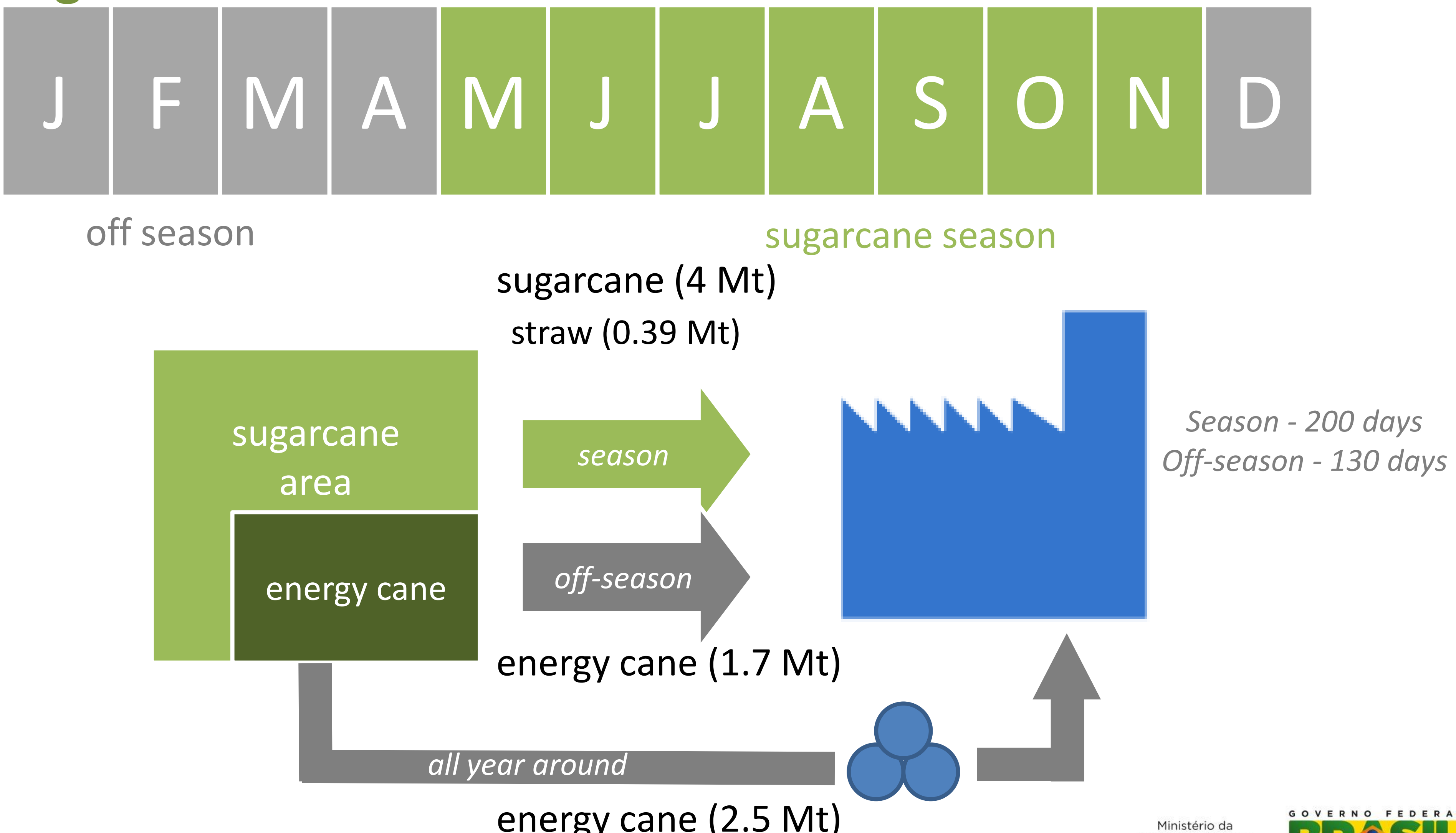


Season - 200 days
Off-season - 130 days

same fiber delivered at industrial facility in the off-season with energy cane

Plant capacities

Long term 1G and 1G2G scenarios

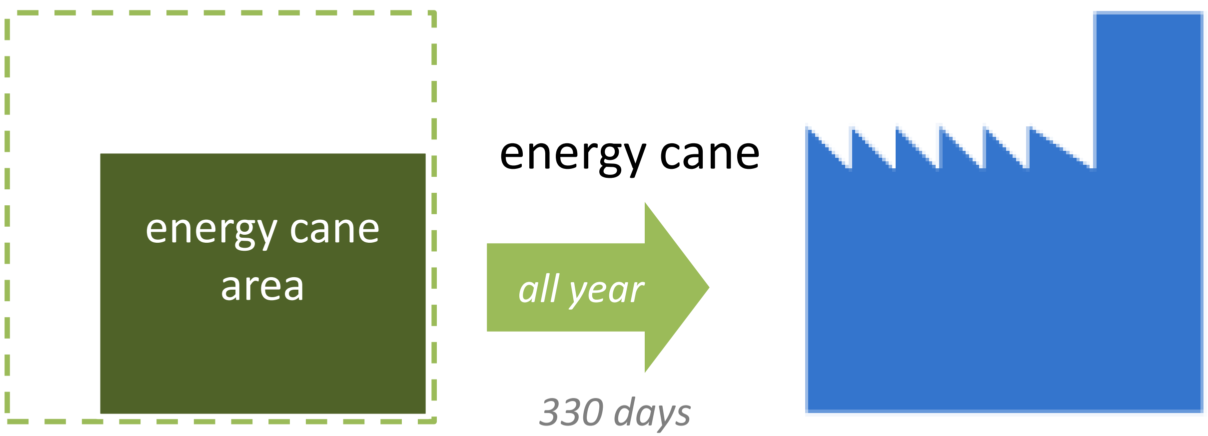


Plant capacities

Medium and long term 2G standalone scenarios

J	F	M	A	M	J	J	A	S	O	N	D

energy cane sugarcane season



2G size defined as the same fiber milling capacities of equivalent integrated plants

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Biomass

	Biomass composition (wt %) [1]		
	Sugarcane stalks	Sugarcane straw [2]	Energy cane[3]
Water	70.3%	15.0%	66.8%
Sucrose	14.0%	4.3%	8.1%
Reducing sugars	0.6%	0.2%	2.5%
Fibers	12.7%	77.9%	21.3%
Cellulose	*6.0%*	*32.4%*	*10.0%*
Hemicellulose	*3.5%*	*24.8%*	*5.9%*
Lignin	*3.2%*	*20.6%*	*5.4%*
Others	2.4%	2.6%	1.3%

[1] Does not consider mineral impurities;

[2] Composition for baled straw. Integral harvested straw moisture varies according to recovery fraction: 33.6 % for 50% recovery; 31.3% for 60% recovery; and 29.6% for 70% recovery;

[3] Energy cane composition includes its straw (100%).

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Main assumptions

Scenarios		0	1/4	2/5A/5B		3/6A/6B		8A/8B	9A/9B
Cane (SC ou EC)[1]	Units	SC	SC	SC	EC	SC	EC	EC	EC
Milling capacity	Mt $year^{-1}$	2	4	4	1.72	4	4.17	4.38	6.78
Agricultural yield	t ha^{-1} ano^{-1}	80	80	100	200	120	250	200	250
Transport distance	km	25	35	35	35	35	35	22.7	25.2
Longevity	harvest/cycle	5	5	5	10	5	10	10	10
Reduced tillage and precision agriculture	% of total area	20	20	80	80	100	100	80	100
Planting system	% Manual	40	20	-	-	-	-	-	-
	% Mechanized	60	80	100	100	-	-	100	-
	% ETC	-	-	-	-	100	100	-	100
Harvesting system	% Manual	30	10	-	-	-	-	-	-
	% Mechanized	70	90	100	100	-	-	100	-
	% ETC	-	-	-	-	100	100	-	100
Straw recovery [2]	% of available straw	-	50	60	100	70	100	100	100
Diesel replacement (biogas) [3]	% of energy used in machinery and trucks	-	-	70	70	70	70	70	70

[1] SC means sugarcane and EC, energy cane;

[2] baling for longer distances (50% of total area) and integral harvesting for short distances (50% of total area);

[3] Limit percentage. Surplus biogas is used as fuel in internal combustion engines for electricity production.

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Biomass – Production cost (using CanaSoft)

	Sugarcane stalks R$/t	Sugarcane straw R$/t dry mass	Energy cane R$/t	Proportion (% dry basis)	Weighted cost R$/t dry mass
0	64.10	-	-	100 : 0 : 0	215.75
1	66.95	62.31	-	83 : 17 : 0	196.84
2	46.71	47.08	32.55	57 : 16 : 27	123.45
3	37.15	47.52	27.82	40 : 13 : 47	95.56
4	67.38	62.31	-	83 : 17 : 0	198.01
5A	47.68	47.08	32.95	57 : 16 : 27	125.63
5B	47.76	47.08	33.08	57 : 16 : 27	125.88
6A	38.37	47.52	29.05	40 : 13 : 47	98.93
6B	38.48	47.52	29.15	40 : 13 : 47	99.21
7	-	-	-	-	103.29[1]
8A	-	-	29.52	0 : 0 : 100	88.87
8B	-	-	29.62	0 : 0 : 100	89.17
9A	-	-	26.36	0 : 0 : 100	79.37
9B	-	-	26.45	0 : 0 : 100	79.62

[1] *Opportunity cost of lignocellulosic material (sugarcane bagasse + straw) based on electricity* (60% of potential revenues).

Industrial Process

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General parameters

Scenarios	0	1/4/7	2/5A/5B/8A/8B	3/6A/6B/9A/9B
Products	ethanol and sugar	ethanol and electricity	ethanol and electricity	ethanol and electricity
Technology	basic	intermediate optimization	optimized	optimized
Boiler pressure	22 bar	65 bar	65 bar	65 bar
Steam consumption (low pressure steam)	no reduction	10 % reduction	20 % reduction	20 % reduction
C6/C12 wine alcoholic content (g/L)	70	70	85	85
Dehydration process	azeotropic distillation	molecular sieves	molecular sieves	molecular sieves
Vinasse biodigestion	-	-	COD[1]: 21 kg/m³ vinasse 72% efficiency 0.29 Nm³/COD removed	COD: 21 kg/m³ vinasse 80% efficiency 0.31 Nm³/COD removed
Extraction efficiency for energy cane [2]	-	-	5 mill-tandem: 90% 2 mill-tandem: 80%	5 mill-tandem: 90% 2 mill-tandem: 80%

[1] COD: chemical oxygen demand.

[2] Sugarcane extraction efficiency in a 5 mill-tandem is 96%.

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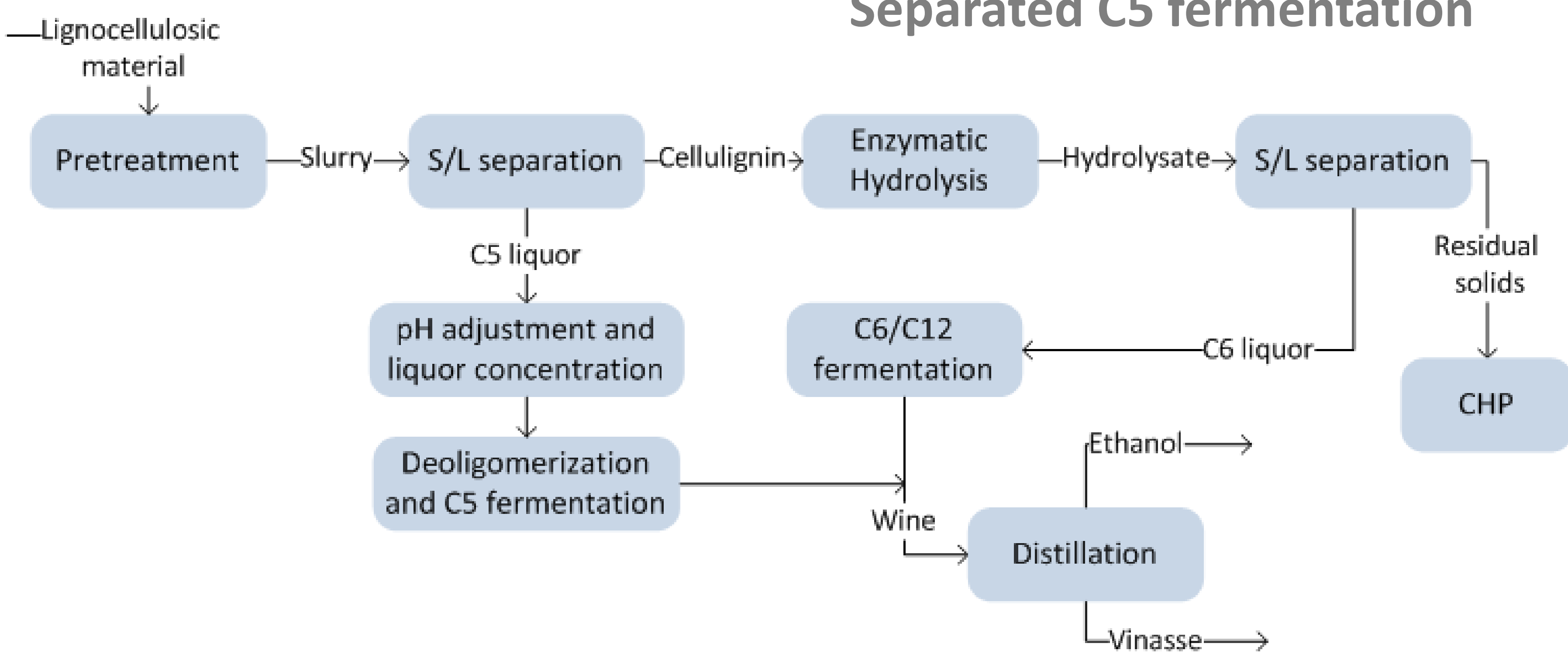
2G Flowsheet

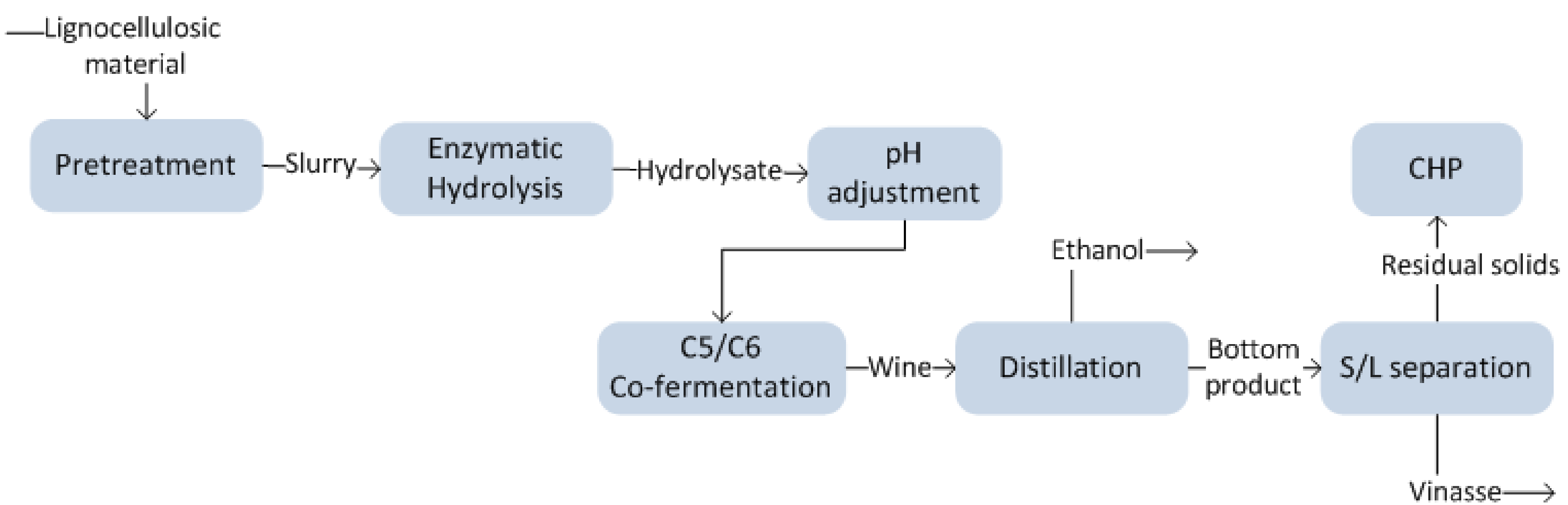
Short term and "A" scenarios– Separated C5 fermentation



C5 fermentation - Partial cell recycling is considered.

2G Flowsheet

"B" scenarios– C5/C6 co-fermentation



C5/C6 co-fermentation - No cell recycling due to solids presence.

Steam explosion pretreatment

	Short term	Medium term	Long term
Temperature (°C)	190	200	210
Residence time (min)	15	10	5
Solids content (%)	*defined by the steam required to achieve reactor temperature*		
Cellulose conversion to glucose (%)	0.5%	1.0%	1.0%
Cellulose conversion to glucose oligomers (%)	3.0%	3.0%	3.0%
Cellulose degradation to HMF (%)	1.5%	1.5%	1.5%
Xylan conversion to xylose (%)	**30%**	**45%**	**60%**
Xylan conversion to xylose oligomers (%)	**30%**	**25%**	**20%**
Xylan degradation to furfural (%)	10%	10%	10%
Lignin solubilization (%)	10%	10%	10%
Acetyl group conversion to acetic acid (%)	70%	80%	90%

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Enzymatic Hydrolysis

	Short term	Medium term	Long term
Temperature (°C)	50	50	65
Pressure (bar)	1.0	1.0	1.0
Residence time (h)	**48**	**36**	**36**
Solids content (%)	**15**	**20**	**25**
Cellulose conversion to glucose (%)	**60%**	**70%**	**80%**
Xylan conversion to xylose (%)	**60%**	**70%**	**80%**
Acetyl group conversion to acetic acid (%)	60%	70%	80%
Xylose oligomers to xylose (%)	60%	70%	80%

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Fermentation

Short term and "A" scenarios – Separated C5 fermentation

Deoligomerization and C5 fermentation	Short term	Medium term	Long term
Temperature (°C)	33	33	33
Residence time (h)	**48**	**36**	**24**
Xylose oligomers conversion to xylose (%)	**80%**	**90%**	**90%**
Glucose oligomers conversion to glucose (%)	80%	90%	90%
C6 conversion to ethanol (%)	**90%**	**90%**	**90%**
C5 conversion to ethanol (%)	**80%**	**80%**	**85%**
Maximum alcoholic content (g/L)	70	70	70
Cell Recycling (%) *	**80%**	**90%**	**95%**

C6/C12 fermentation	Short term	Medium term	Long term
Operational conditions	same as 1G	same as 1G	same as 1G
C6/C12 conversion to ethanol (%)	**88**	**90**	**90**
Maximum alcoholic content (g/L)	70	85	85

Fermentation

"B" scenarios – C5/C6 co-fermentation

C5/C6 co- fermentation	Short term	Medium term	Long term
Temperature (°C)	-	33	33
Residence time (h)	**-**	**36**	**24**
C6 conversion to ethanol (%)	**-**	**90%**	**90%**
C5 conversion to ethanol (%)	**-**	**80%**	**85%**
Maximum alcoholic content (g/L)	-	70	70

Solid-liquid separation

Short term and "A" scenarios – Separated C5 fermentation (After pretreatment)

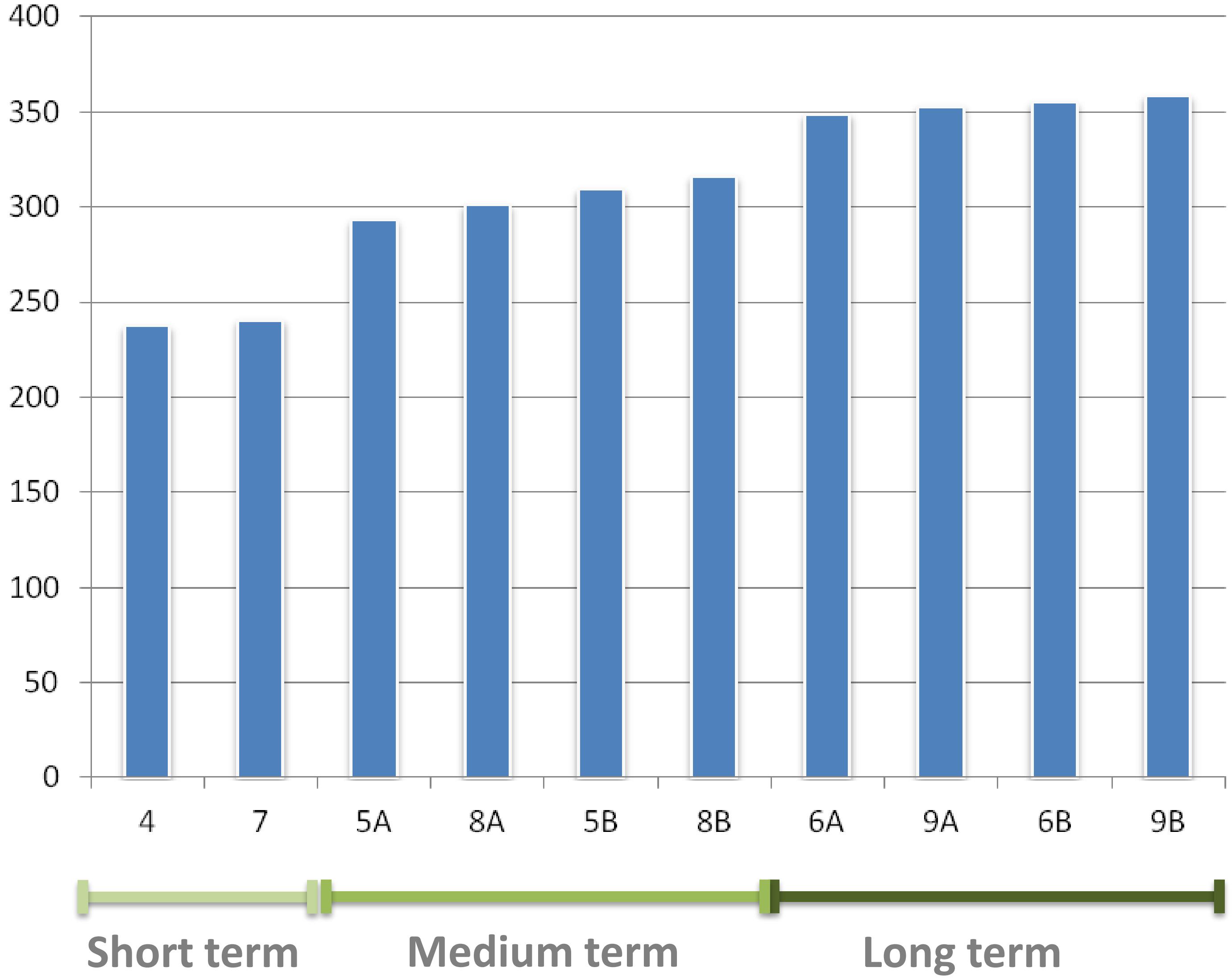
Cellulignin separation	Short term	Medium term	Long term
Proportion of water added (% of cellulignin fibers)	**250%**	**180%**	**180%**
Solids retention (%)	99.5%	99.5%	99.5%
Soluble solids recover in the liquor (%)	**98.0%**	**98.0%**	**98.0%**
Cellulignin moisture (%)	50%	50%	50%

Short term and "A" scenarios – Separated C5 fermentation (After hydrolysis)

"B" scenarios – C5/C6 co-fermentation (After distillation)

Solid residues separation	Short term	Medium term	Long term
Proportion of water added (% of solid residues fibers)	-	-	-
Solids retention (%)	**95%**	**97%**	**99%**
Soluble solids recover in the liquor (%)	**92%**	**95%**	**99%**
Solid residues moisture (%)	55%	50%	50%

2G Ethanol production – L/t dry LCM[1]



[1] *LCM is the amount of lignocellulosic material that is sent to pretreatment.*

Technical Results

Scenario	Ethanol L/t cane[1]	Ethanol L/t dry biomass[2]	Electricity kWh/t cane	Electricity kWh/t dry biomass
0	53.6	180.4	11.5	38.7
1	84.9	235.8	174.3	484.1
2	76.6	209.4	201.5	551.1
3	68.8	190.0	216.7	598.9
4	108.4	301.2	68.6	190.4
5A	116.6	318.8	70.4	192.6
5B	121.9	333.4	66.6	182.0
6A	121.1	334.7	68.0	187.9
6B	124.6	344.3	69.6	192.2
7	22.9[3]	216.9	36.8[3]	348.9
8A	94.0	284.9	69.6	210.9
8B	100.3	304.1	61.1	185.3
9A	99.1	300.2	70.3	213.0
9B	102.5	310.6	65.1	197.2

+ 51.4 kg of sugar/t cane

[1] *Cane includes sugarcane and energy cane.*

[2] *Dry biomass includes sugarcane, energy cane and straw.*

[3]*Based on the sugarcane processed in the plant that sells surplus lignocellulosic material to scenario 7 plant.*

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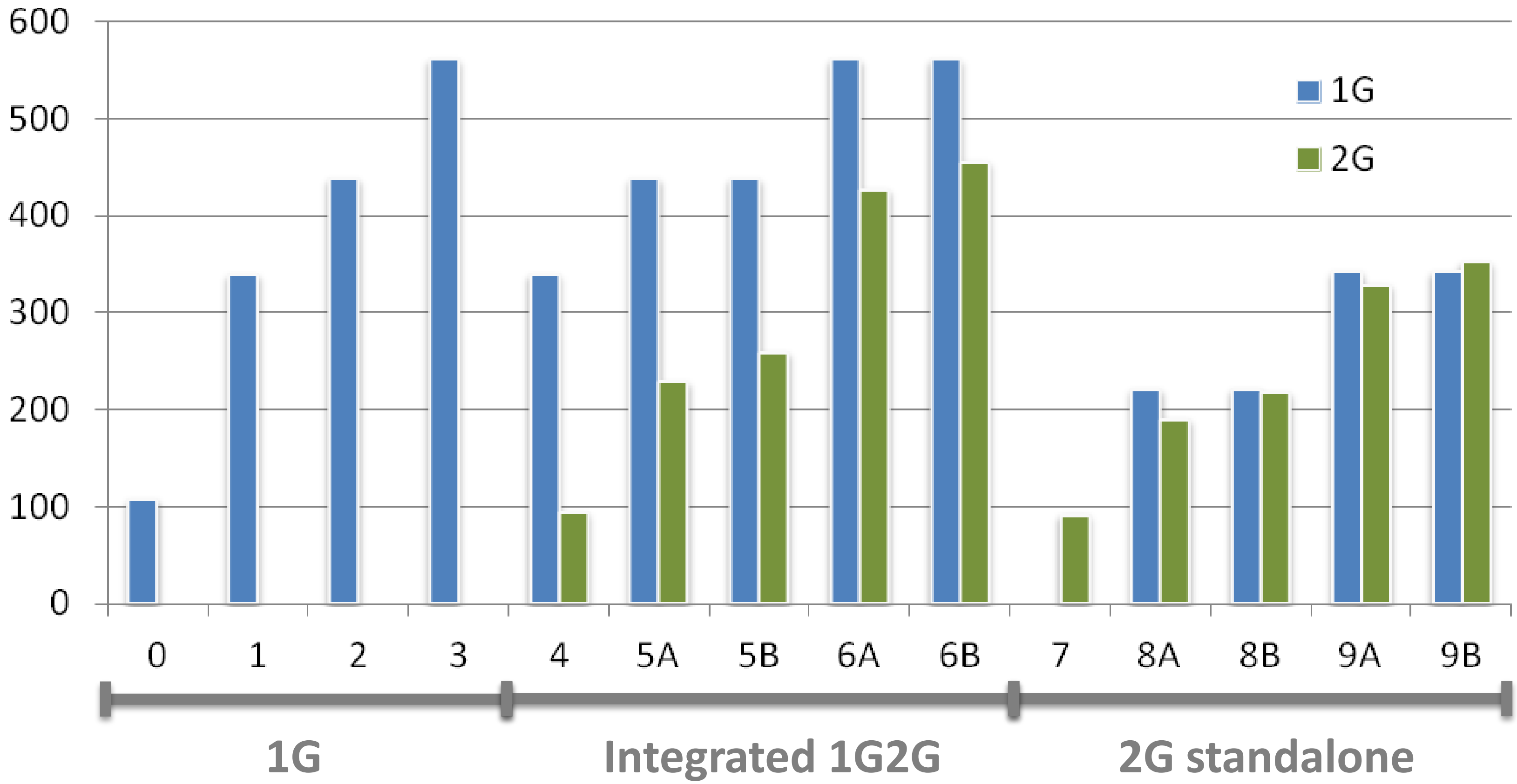
Annual ethanol production – million L/year



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Financial Analysis

Financial parameters

Prices	Value	Reference
Anhydrous ethanol (R$/L)	1.34	CEPEA, moving average (2004-2014)
Electricity (R$/MWh)	132.43	MME, average from auctions (2005-2013)
Sugar (R$/kg)	1.00	CEPEA, moving average (2004-2014)

Main financial parameters	Value
Minimum acceptable rate of return (% per year)	12%
Project life span (years)	25
Depreciation rate (linear, 10 years)	10%
Maintenance (% Capex)	3%
Enzyme cost – short term (US$/L E2G)	0.13
Enzyme cost – medium term (US$/L E2G)	0.08
Enzyme cost – long term (US$/L E2G)	0.06
Income taxes (IRPJ+CSLL)	34%
Month/year base (prices)	July 2014
Exchange rate (R$/US$)	2.30

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Investment (million R$)

Scenario	Investment (million R$)			Ethanol production (million L/year)			Investment (R$/L)
	1G + interface	2G[1]	Total	1G	2G	Total	
0	366	-	366	107	-	107	-[2]
1	1,004	-	1,004	340	-	340	2.96
2	1,088	-	1,088	438	-	438	2.48
3	1,443	-	1,443	562	-	562	2.57
4	944	425	1,369	340	94	434	3.16
5A	1,048	376	1,424	438	229	667	2.13
5B	1,032	436	1,468	438	260	698	2.10
6A	1,349	437	1,786	562	427	989	1.81
6B	1,313	459	1,772	562	456	1,017	1.74
7	169	281	450	-	92	92	4.91
8A	633	289	922	221	190	411	2.24
8B	612	303	915	221	218	439	2.08
9A	899	299	1,198	343	329	672	1.78
9B	886	338	1,224	343	352	695	1.76

[1] 2G refers to the following sections: pretreatment, hydrolysis, solid/liquid separation and C5 concentration, fermentation and propagation.

[2] Annexed plant, it is not comparable due to additional sugar production.

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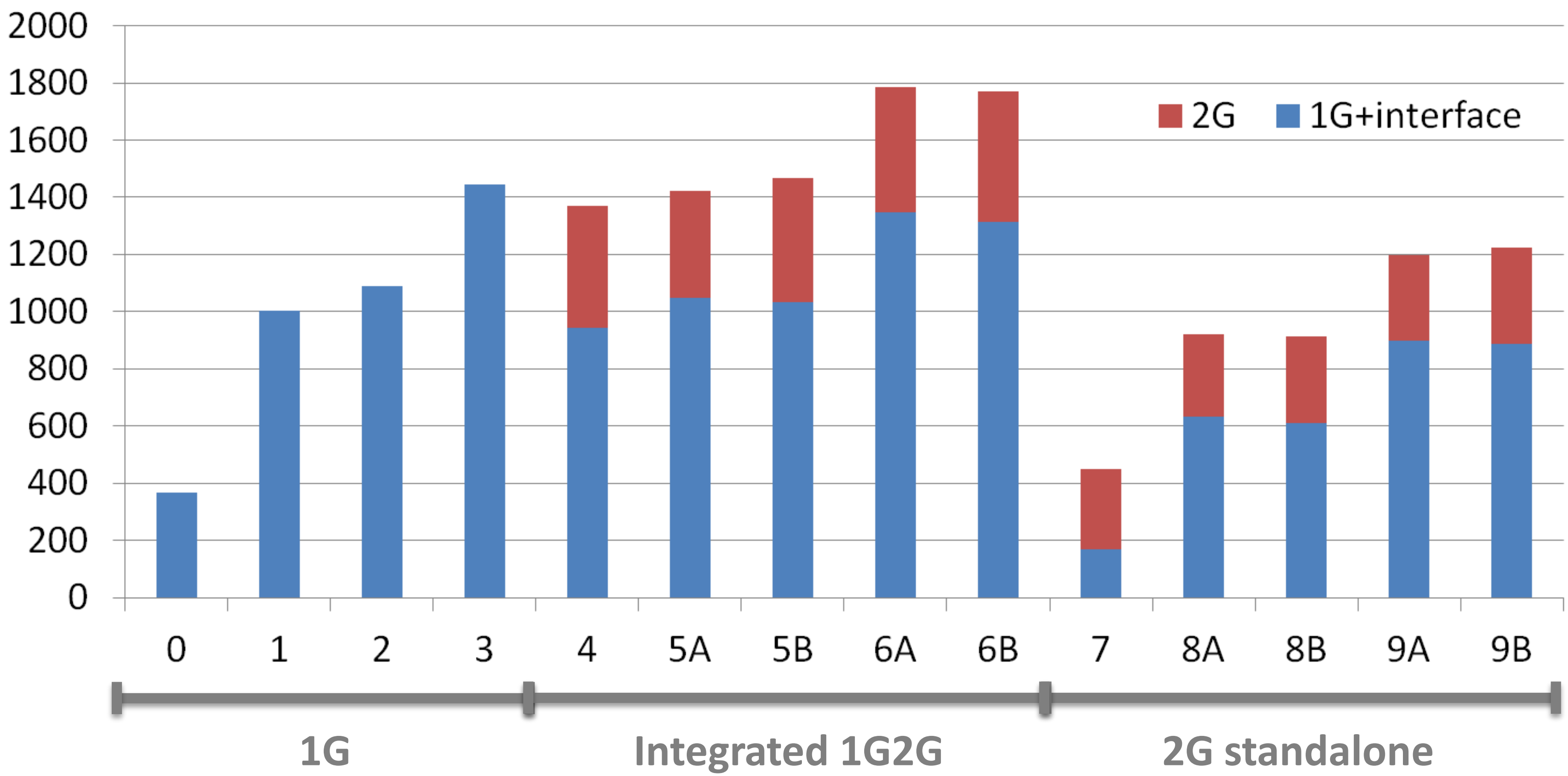
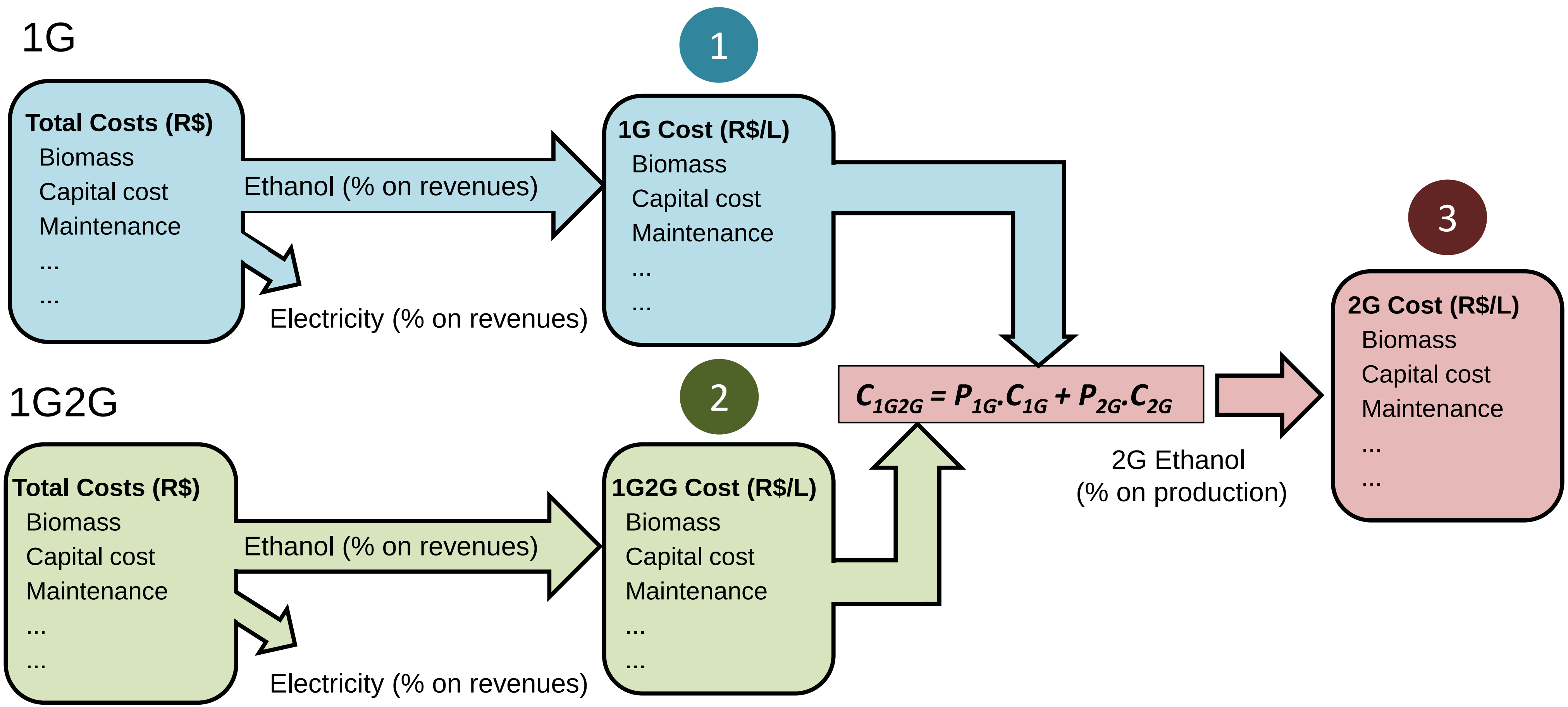
Investment (million R$)



Ethanol production cost



C_{1G2G} – 1G2G ethanol production cost
P_{1G} – 1G ethanol participation on production
C_{1G} – 1G ethanol production cost
P_{2G} – 2G ethanol participation on production
C_{2G} – 2G ethanol production cost

Ethanol production cost

Allocation between ethanol and electricity based on participation on revenues

1G Ethanol production cost

Scenario 1	1G Ethanol
Biomass (total)	0.694
Maintenance	0.074
Enzyme	0.000
Labor	0.025
Other (chemicals)	0.023
Capital cost[1]	0.344
Total (R$/L)	**1.159**

[1] *Considering payment of the total investment at 12% per annum*

Allocation between 1G and 2G ethanol based on participation on production.

$$P1G*C1G + P2G*C2G = C1G2G$$

$$C2G = (C1G2G - P1G*C1G)/P2G$$

Scenario 4	1G2G Ethanol	2G Ethanol
Biomass (total)	0.619	**0.348**
Maintenance	0.089	**0.145**
Enzyme	0.064	**0.295**
Labor	0.028	**0.038**
Other (chemicals)	0.023	**0.025**
Capital cost	0.416	**0.676**
Total (R$/L)	**1.239**	**1.528**

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Ethanol cost (1G and integrated 1G2G)

Integrated scenarios (without co-fermentation)

	Short (2016-2020)	Medium (2021-2025)	Long (2026-2030)	Short (2015-2020)
	Scenarios 1 e 4	Scenarios 2 e 5A	Scenarios 3 e 6A	Scenario 0
1G cost (R$/L)*	1,159	0,845	0,756	1,091
2G cost (R$/L)*	1,528	0,769	0,550	n.a.
Difference Δ (R$/L)	0,369	-0,076	-0,206	n.a.

Integrated scenarios (with co-fermentation)

	Short (2016-2020)	Medium (2021-2025)	Long (2026-2030)	Short (2015-2020)
	Scenarios 1 e 4	Scenarios 2 e 5B	Scenarios 3 e 6B	Scenario 0
1G cost (R$/L)*	1,159	0,845	0,756	1,091
2G cost (R$/L)*	1.528	0,742	0,521	n.a.
Difference Δ (R$/L)	0,369	-0,103	-0,235	n.a.

* Total cost (cash cost + capital cost).

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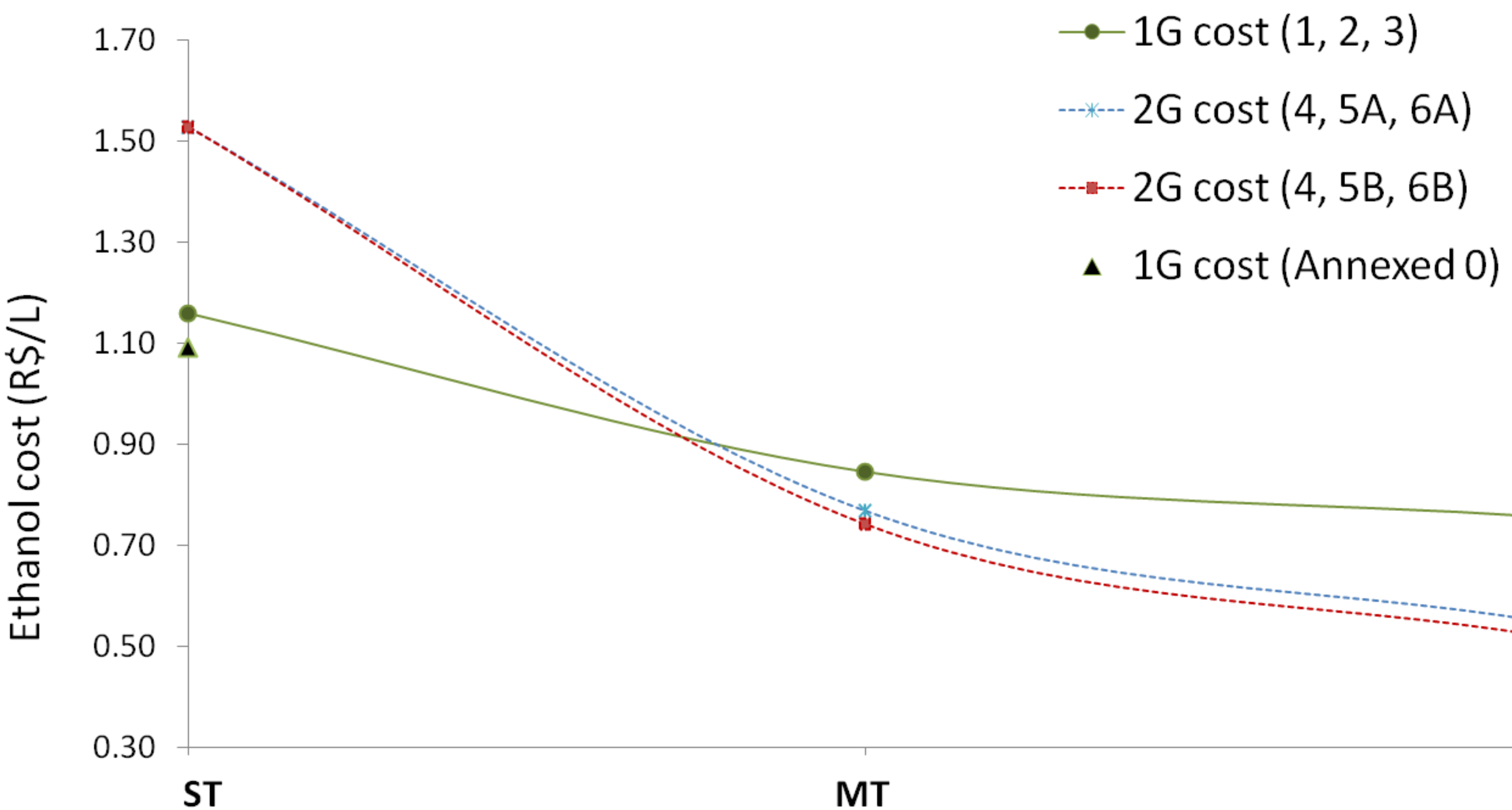
Ethanol cost over time (1G and integrated 1G2G)

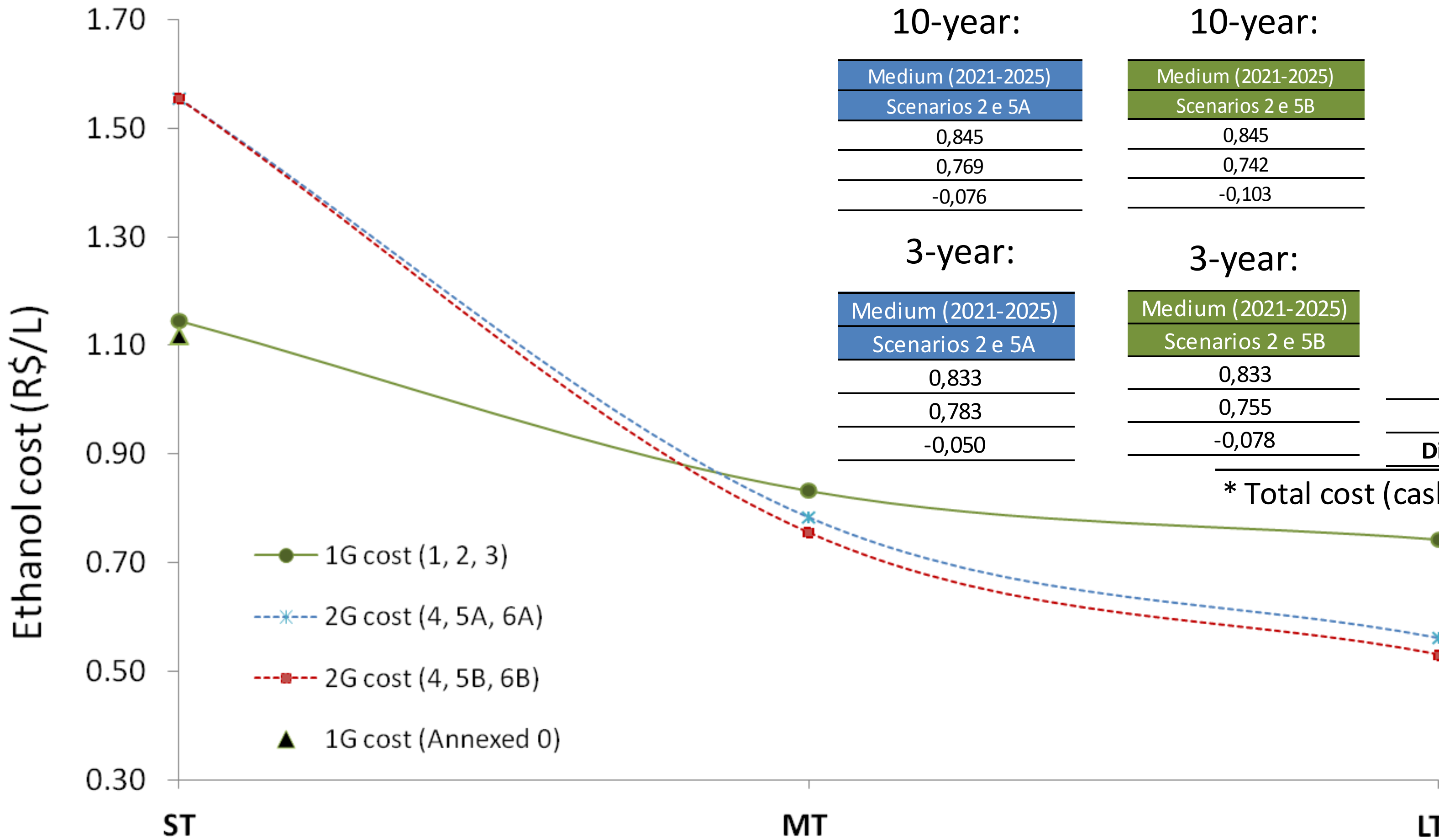
Allocation criteria: 10-year moving average prices



Ethanol cost over time (1G and integrated 1G2G)

Allocation criteria: 3-year moving average prices (2011-2014)

(Ethanol: 1.42 R$/L; Electricity: 151.49 R$/MWh; Sugar: 1.01 R$/kg)



10-year:

	Medium (2021-2025) Scenarios 2 e 5A	Medium (2021-2025) Scenarios 2 e 5B
1G cost (R$/L)*	0,845	0,845
2G cost (R$/L)*	0,769	0,742
Difference Δ (R$/L)	-0,076	-0,103

3-year:

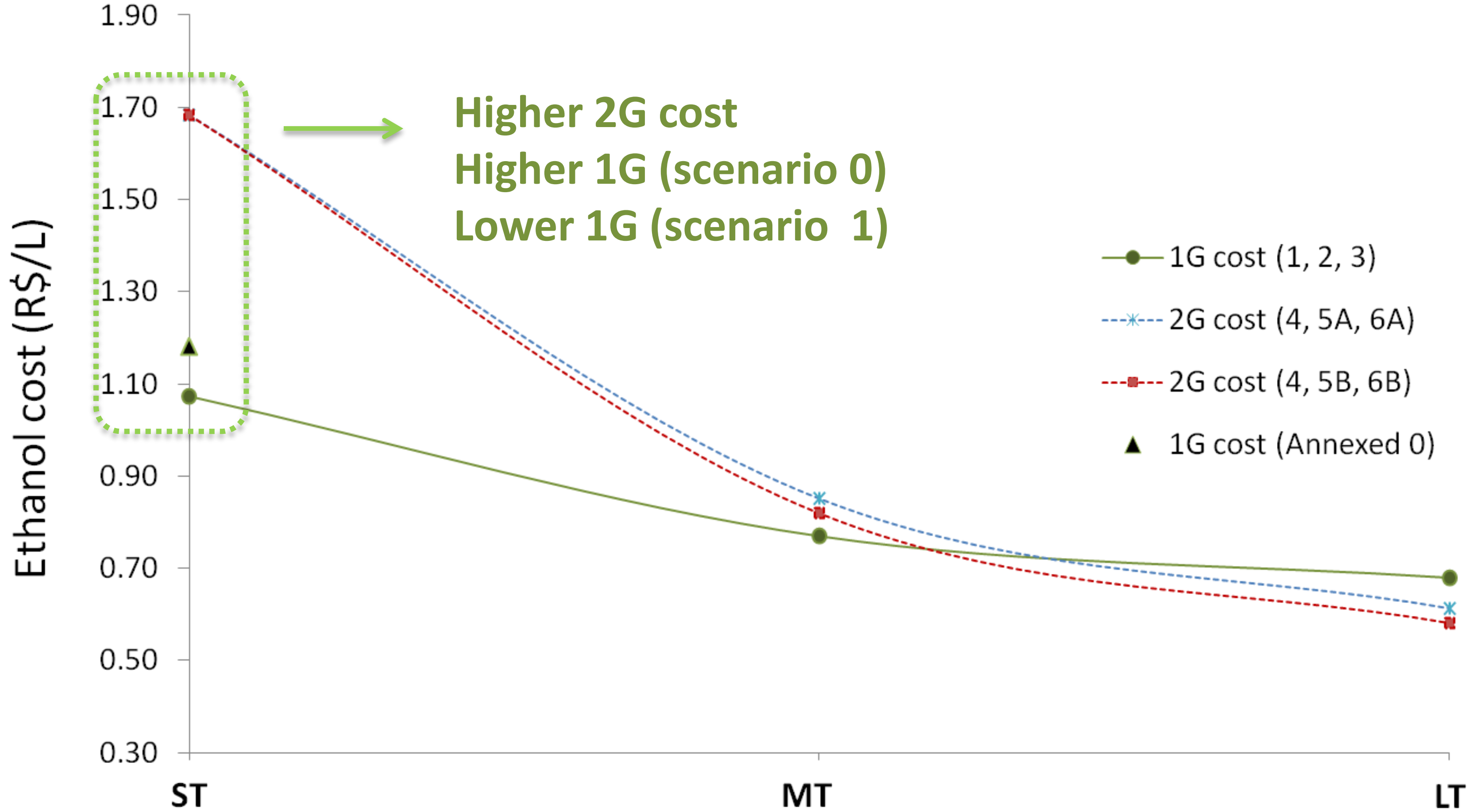
	Medium (2021-2025) Scenarios 2 e 5A	Medium (2021-2025) Scenarios 2 e 5B
1G cost (R$/L)*	0,833	0,833
2G cost (R$/L)*	0,783	0,755
Difference Δ (R$/L)	-0,050	-0,078

* Total cost (cash cost + capital cost)

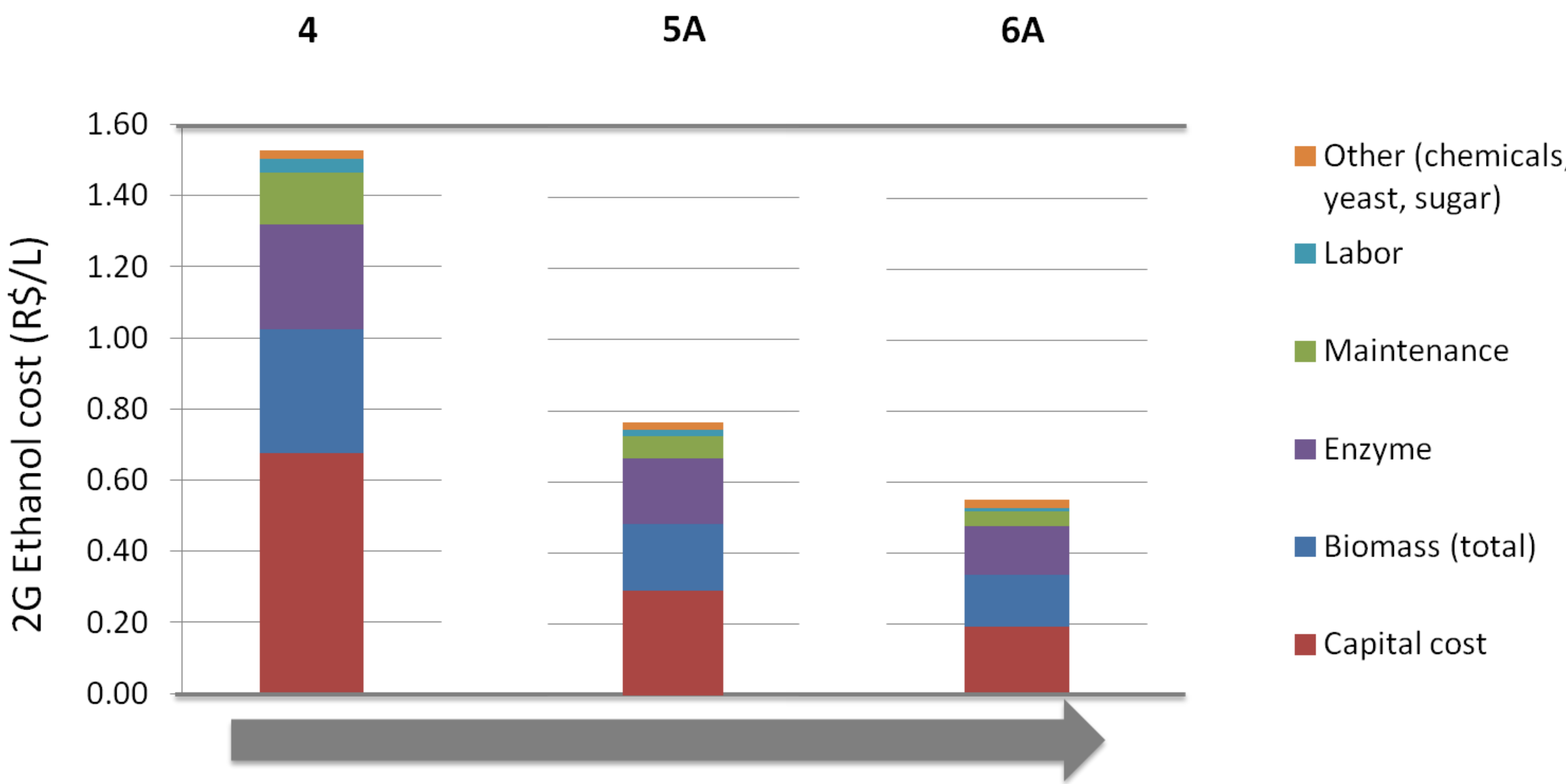
Ethanol cost over time (1G and integrated 1G2G)

Allocation criteria: current prices (July 2014)

(Ethanol: 1.37 R$/L; Electricity: 200 R$/MWh; Sugar: 0.84/kg)



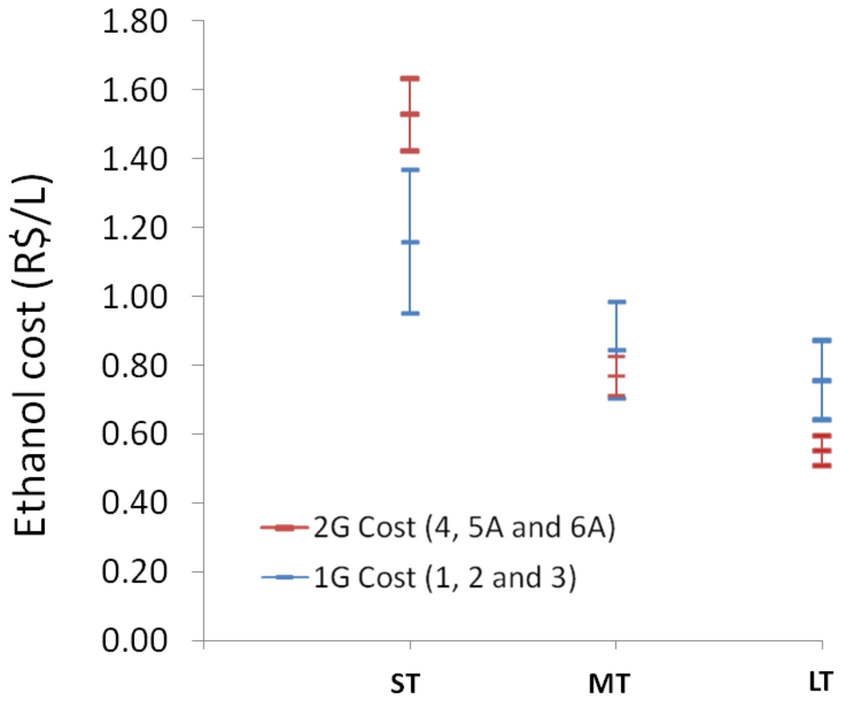
2G cost (integrated 1G2G scenarios)



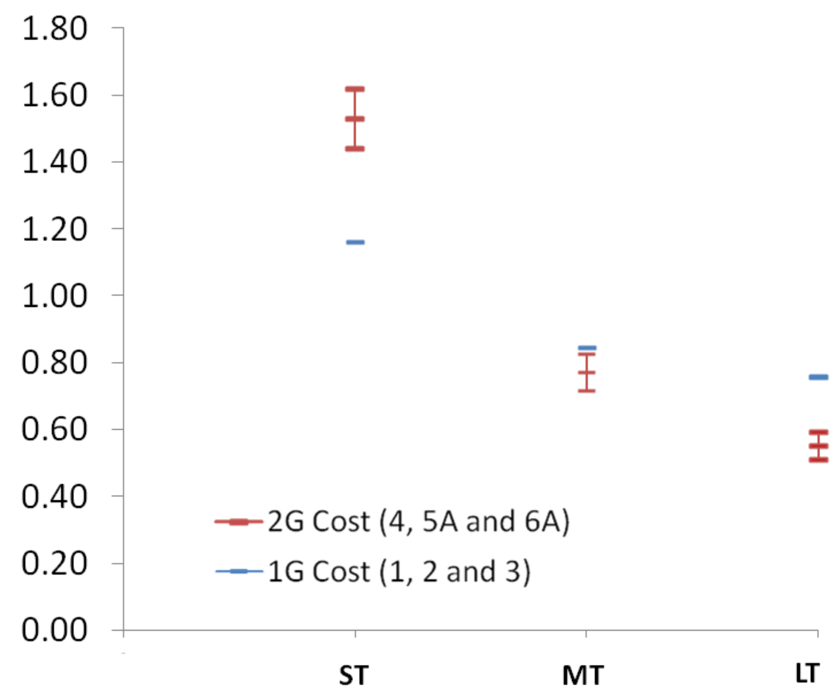
Capital, enzyme and biomass costs reduction and increase on ethanol yield over time

Sensitivity analysis (1G and integrated 1G2G)

Biomass sensitivity



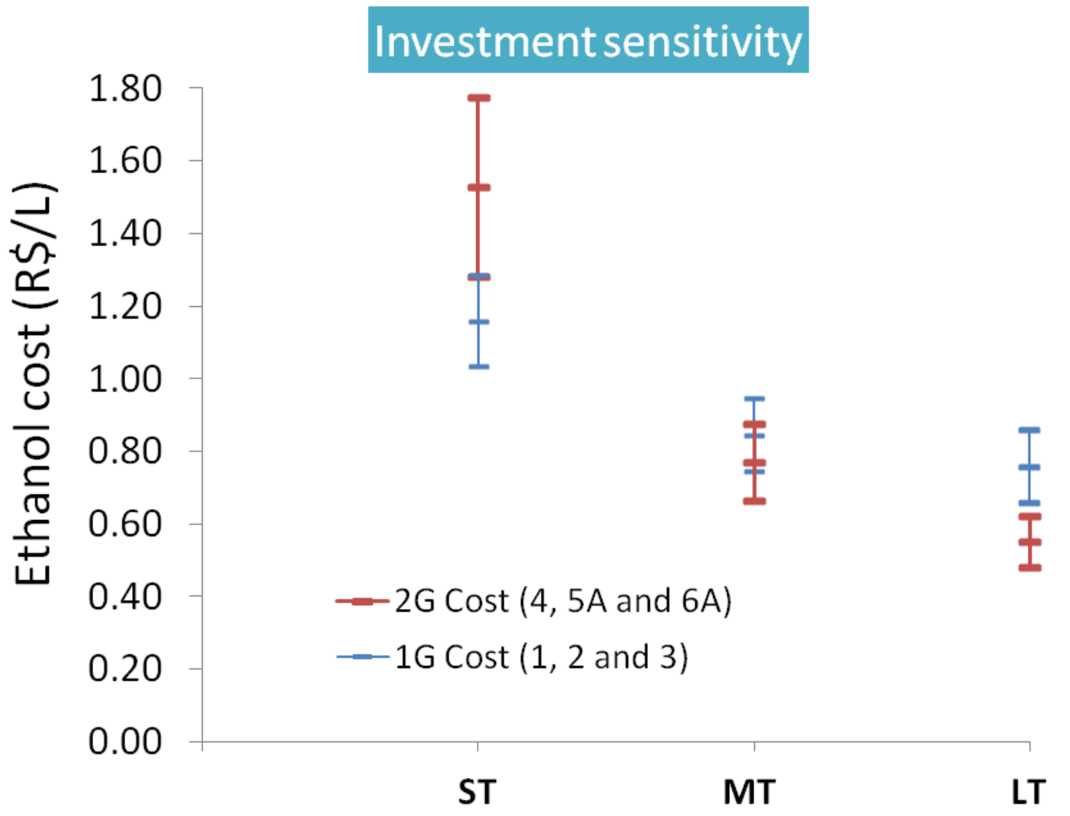
Enzyme sensitivity



Variation +/- 30%
Biomass cost

Variation +/- 30%
Enzyme cost

Sensitivity analysis (1G and integrated 1G2G)



Variation +/- 30% Investment

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Ethanol cost (1G and 2G stand alone)

Stand alone scenarios (without co-fermentation)

	Short (2016-2020)	Medium (2021-2025)	Long (2026-2030)
	Scenario 7 (and 1)	Scenario 8A	Scenario 9A
1G cost (R$/L)*	1,159	0,836	0,755
2G cost (R$/L)*	1,475	0,727	0,524
Difference Δ (R$/L)	**0,316**	**-0,109**	**-0,231**

Stand alone scenarios (with co-fermentation)

	Short (2016-2020)	Medium (2021-2025)	Long (2026-2030)
	Scenario 7 (and 1)	Scenario 8B	Scenario 9B
1G cost (R$/L)*	1,159	0,836	0,755
2G cost (R$/L)*	1,475	0,675	0,521
Difference Δ (R$/L)	**0,316**	**-0,161**	**-0,235**

* Total cost (cash cost + capital cost).

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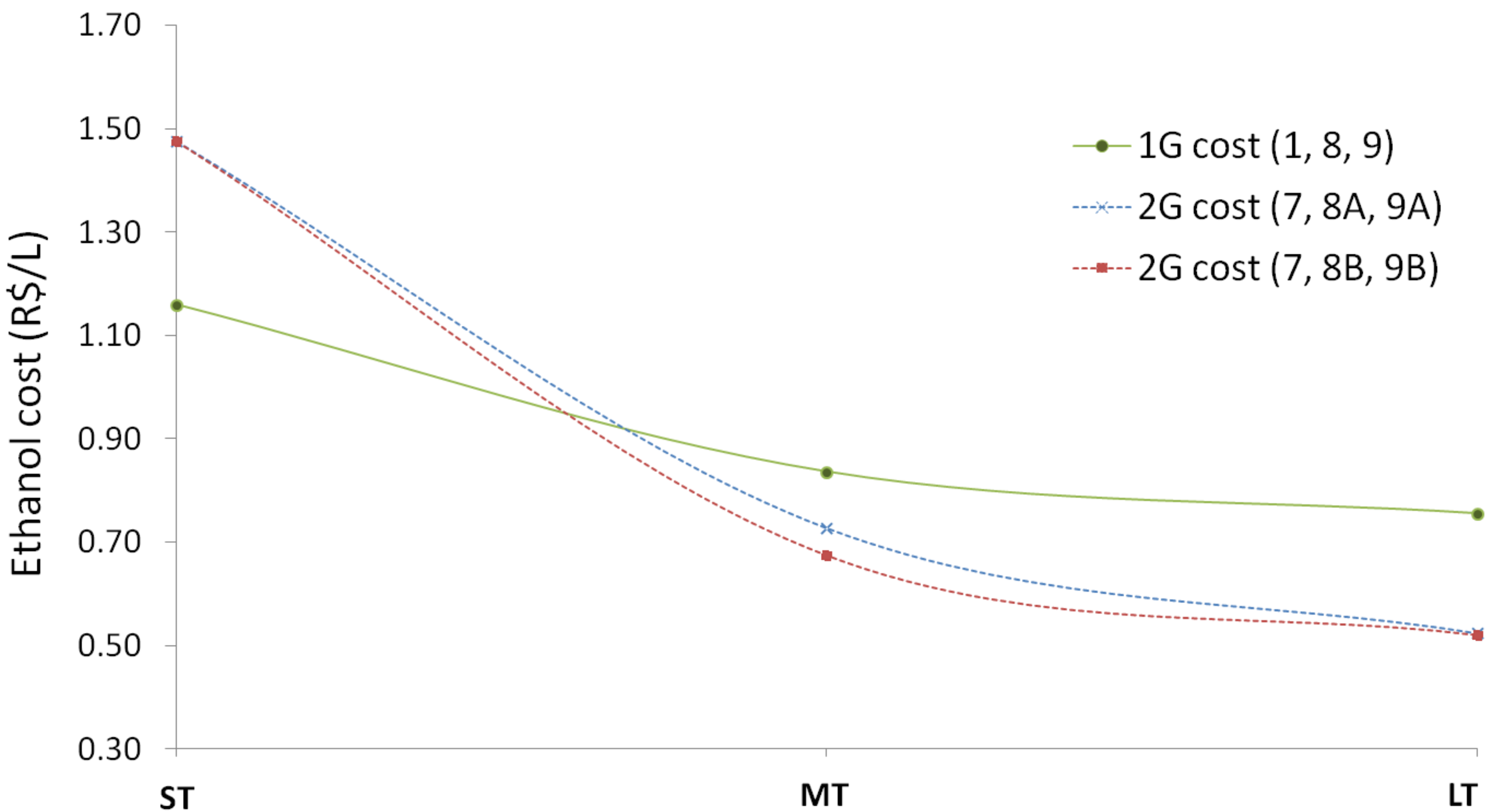
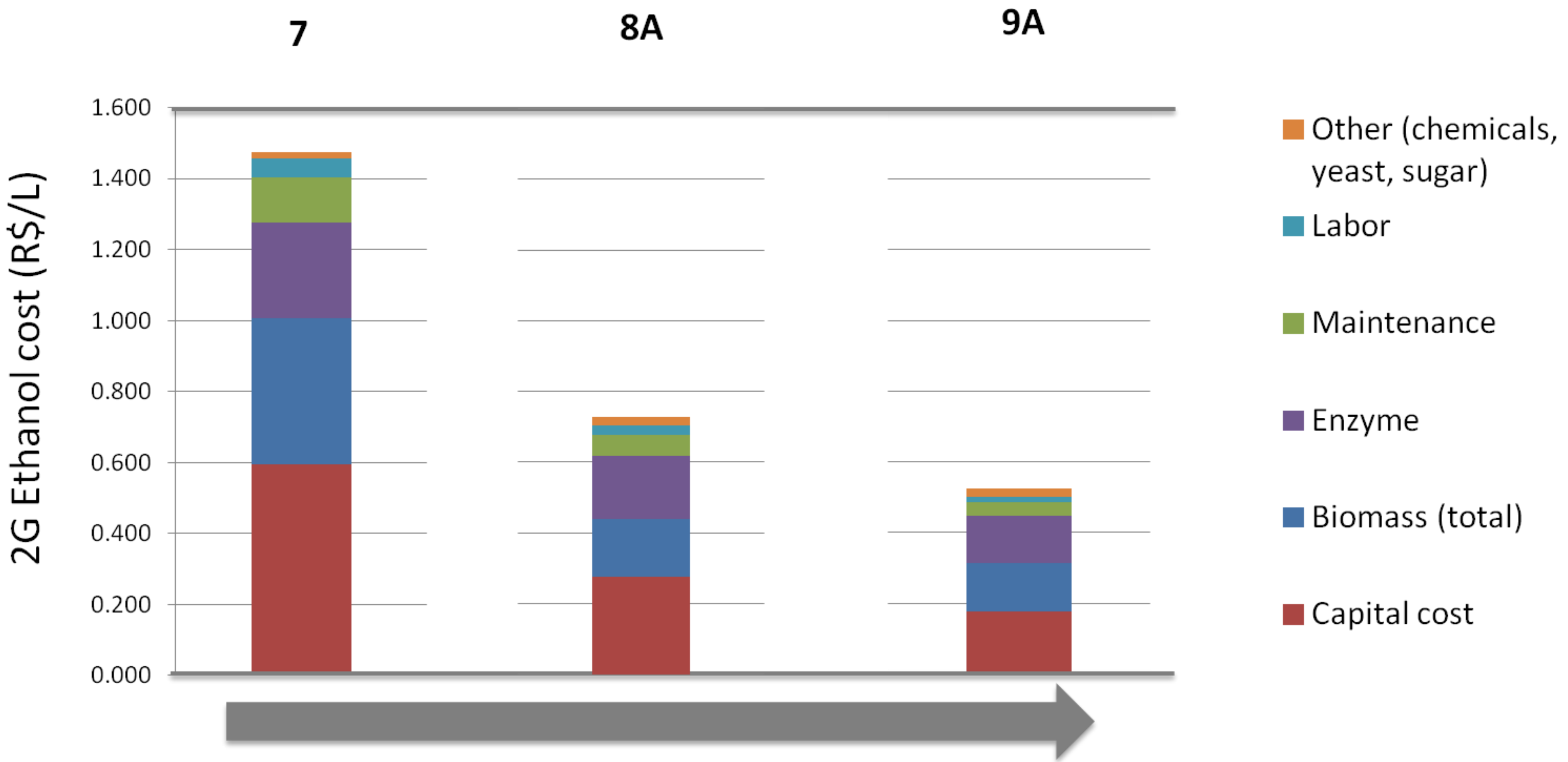
Ethanol cost (1G and 2G stand alone)



2G cost (standalone scenarios)



Capital, enzyme and biomass costs reduction and increase on ethanol yield over time

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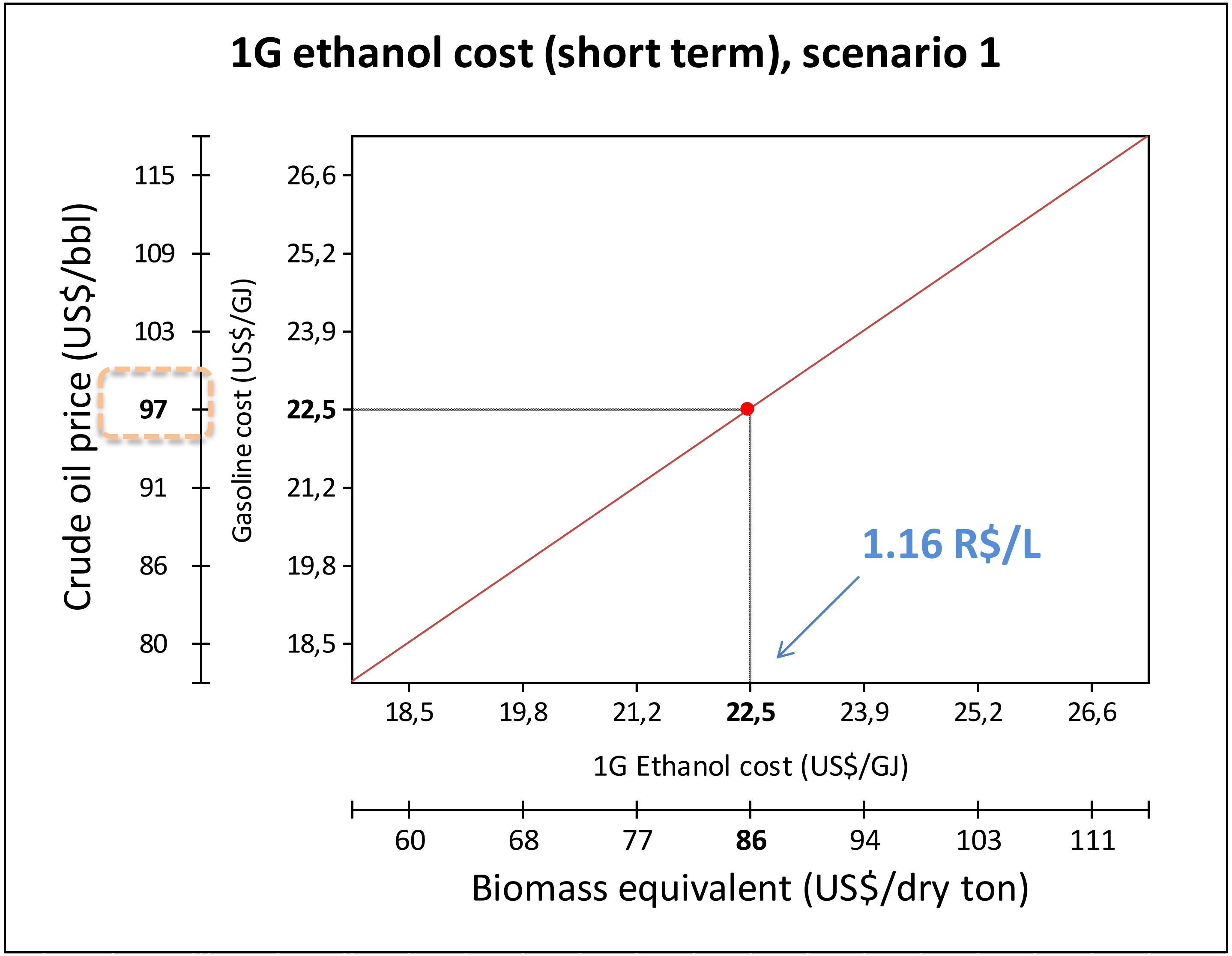
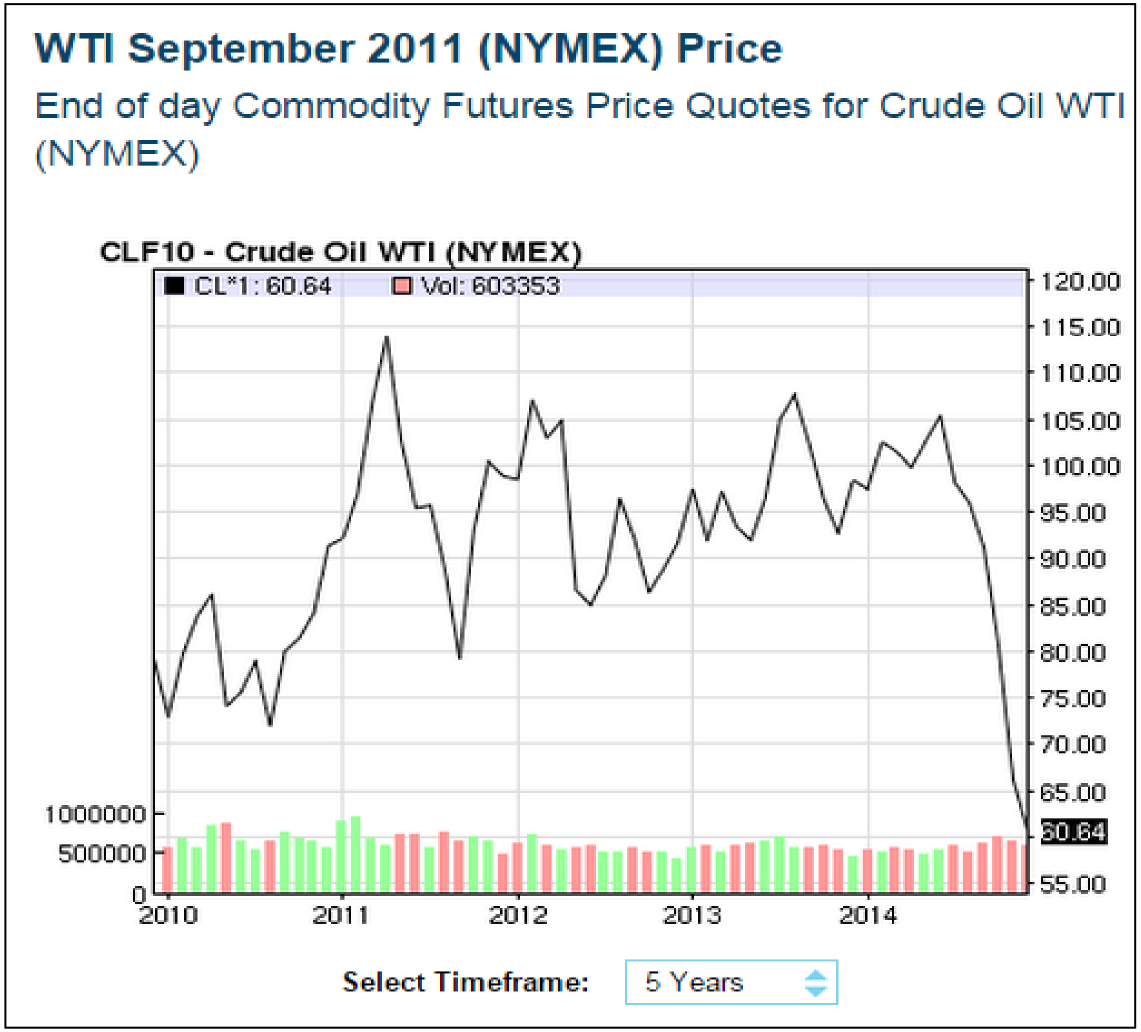
Biomass x Oil Prices

1G Ethanol cost (oil price equivalent)



Crude oil prices (last 5 years)

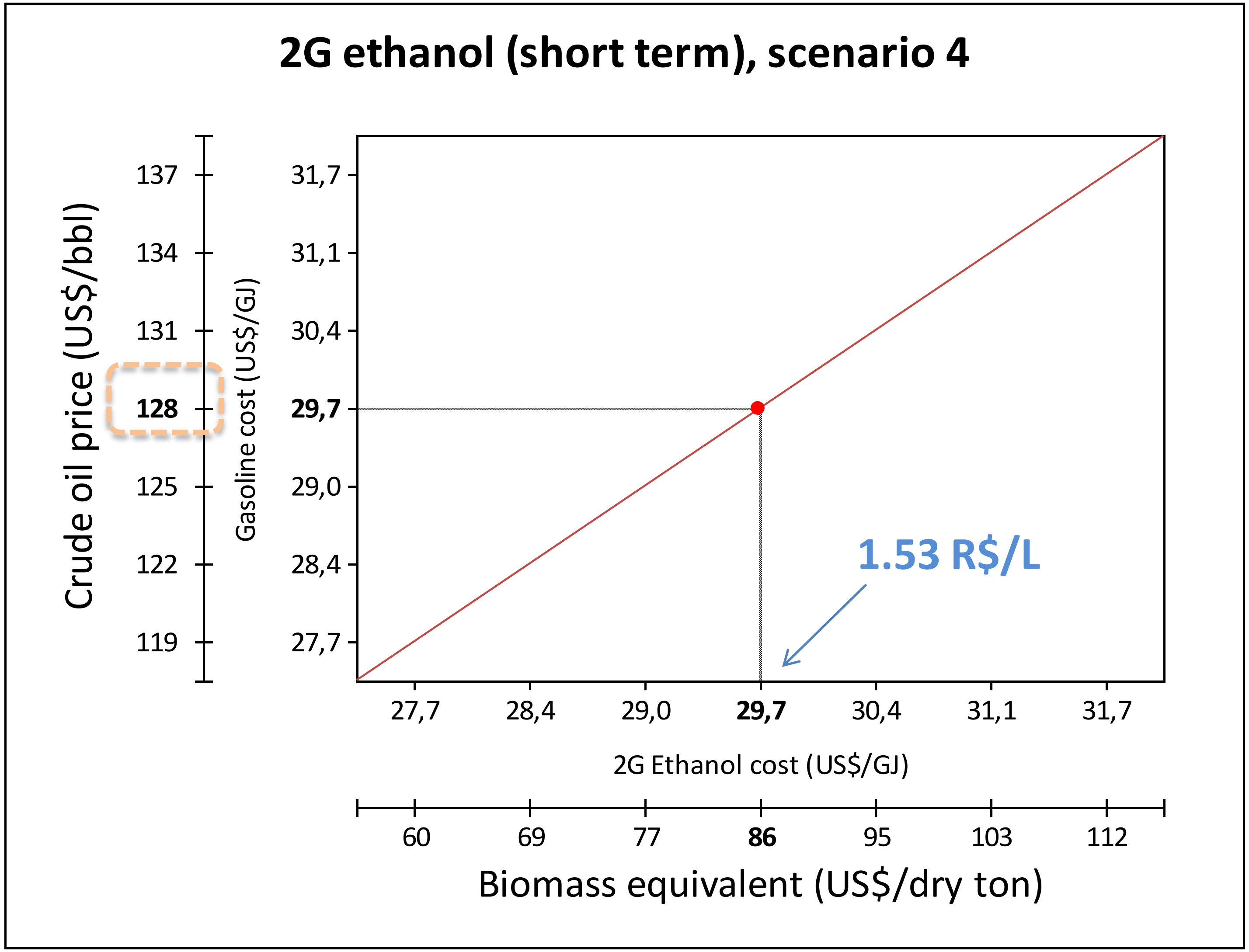


Beginning of 2014:
US$ 100/bbl

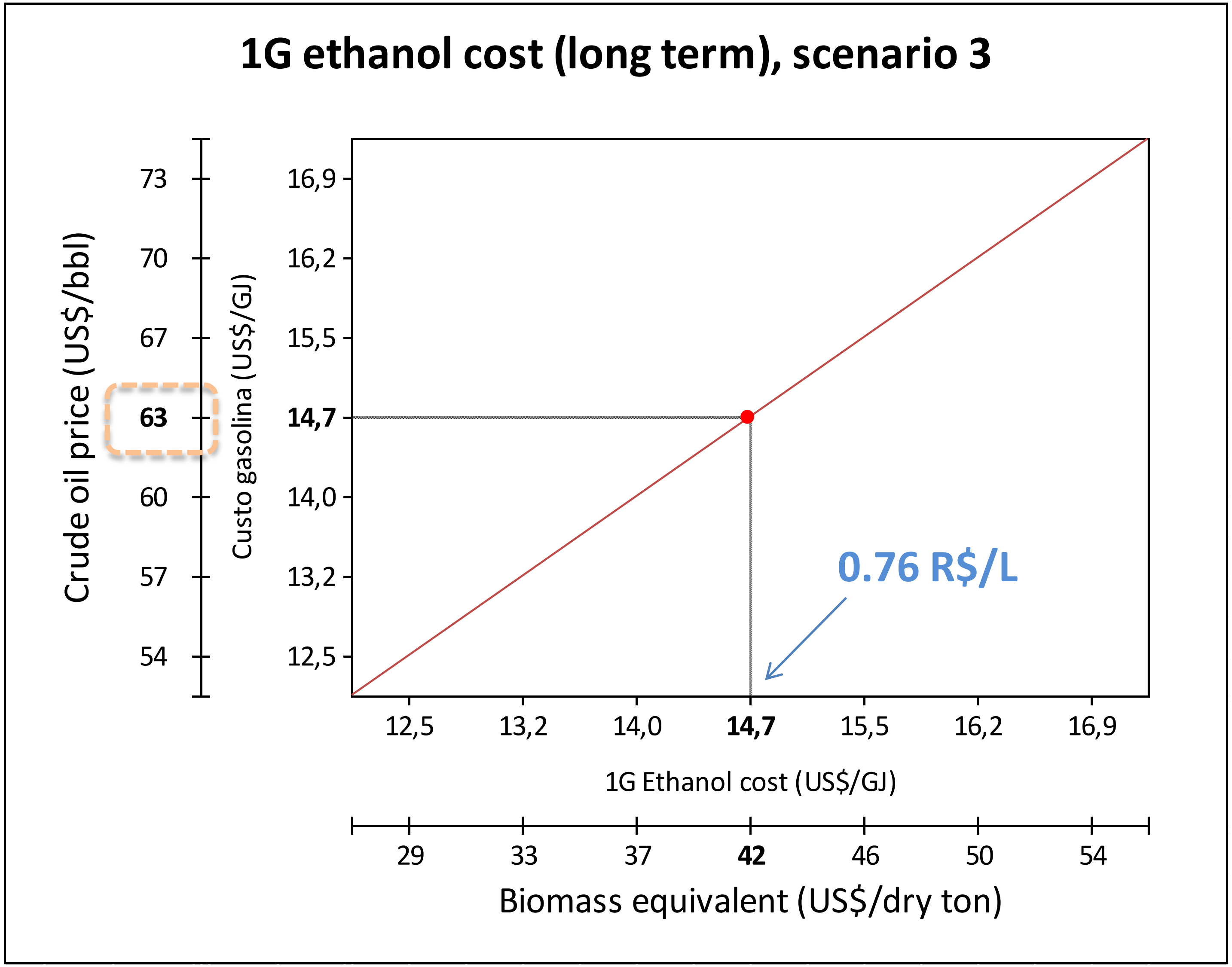
End of 2014:
US$ 65/bbl

http://www.nasdaq.com/markets/crude-oil.aspx?timeframe=5y

2G Ethanol cost (oil price equivalent)



1G Ethanol cost (oil price equivalent)



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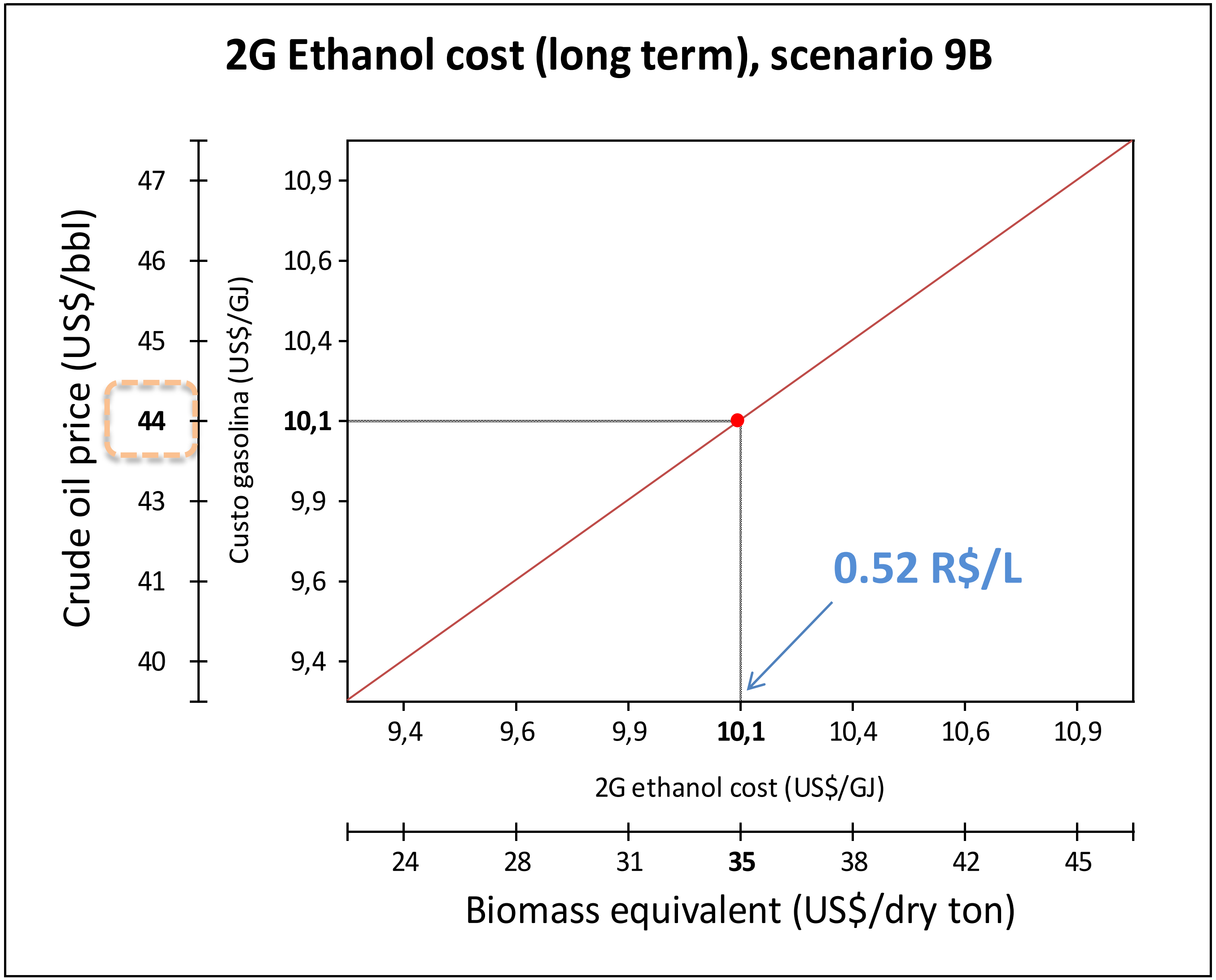
2G Ethanol cost (oil price equivalent)



Integrated scenarios (without co-fermentation)

	Short (2016-2020)	Medium (2021-2025)	Long (2026-2030)	Short (2015-2020)
	Scenarios 1 e 4	Scenarios 2 e 5A	Scenarios 3 e 6A	Scenario 0
1G cost (US$/bbl)	97,173	70,855	63,380	91,425
2G cost (US$/bbl)	**128,083**	64,463	46,733	n.a.
Difference Δ (US$/bbl)	30,910	-6,391	-16,647	n.a.

Integrated scenarios (with co-fermentation)

	Short (2016-2020)	Medium (2021-2025)	Long (2026-2030)	Short (2015-2020)
	Scenarios 1 e 4	Scenarios 2 e 5B	Scenarios 3 e 6B	Scenario 0
1G cost (US$/bbl)	97,173	70,855	63,380	91,425
2G cost (US$/bbl)	128,083	62,214	43,647	n.a.
Difference Δ (US$/bbl)	30,910	-8,641	-19,733	n.a.

Stand alone scenarios (without co-fermentation)

	Short (2016-2020)	Medium (2021-2025)	Long (2026-2030)
	Scenario 7 (and 1)	Scenario 8A	Scenario 9A
1G cost (US$/bbl)	n.a.	70,095	63,312
2G cost (US$/bbl)	123,662	60,956	43,907
Difference Δ (US$/bbl)	n.a.	-9,140	-19,405

Stand alone scenarios (with co-fermentation)

	Short (2016-2020)	Medium (2021-2025)	Long (2026-2030)
	Scenario 7 (and 1)	Scenario 8B	Scenario 9B
1G cost (US$/bbl)	n.a.	70,095	63,312
2G cost (US$/bbl)	123,662	56,559	**43,645**
Difference Δ (US$/bbl)	n.a.	-13,536	-19,668

Comments on the assumptions

- Introduction of energy cane in the medium and long terms can be considered optimistic. At the same time, the limited processing capacity would be conservative;
- There is scarce information available on 2G vinasse and its biodigestability;
- Ethanol production (in L/t of LCM) in the short term was considered conservative, however there is no public information about 2G yields and residence times for a precise comparison.

Final remarks

- Biomass, capital and enzyme costs are the main drivers for 2G ethanol cost reduction. Sensitivity analysis showed that a variation on these parameters can affect timing, but not the trend on 1G/2G projections;
- No significant differences were observed comparing co-fermentation vs. C6/C12 fermentation and integrated vs. stand alone 2G production;
- A significant reduction on capital cost was observed as a consequence of reduction of equipment sizes (higher solids content and lower residence times) and increase on 2G yields;
- Current low oil prices make ethanol (1G and 2G) cost hardly competitive;
- Long term 2G ethanol will be clearly competitive even in a low oil price scenario.

Thank you!

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