Biorefinarias associadas ao setor sucro energético e etanol de milho

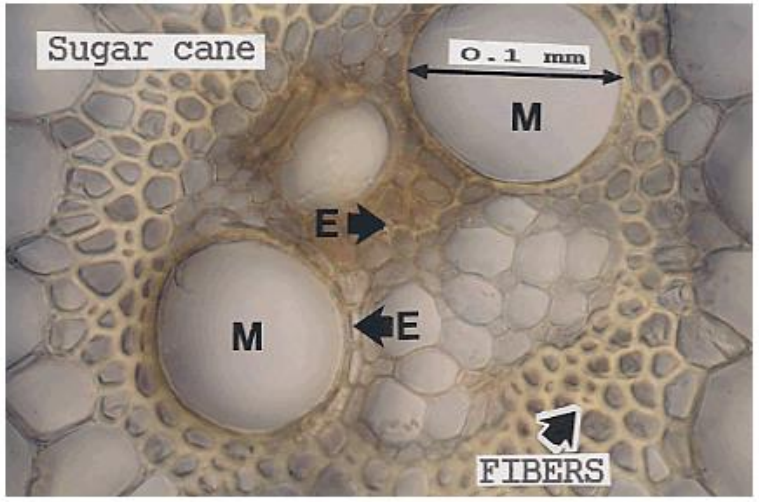
Soluções usadas em escala industrial ou escala ampliada

<u>Produção de açúcar e álcool</u> (e eletricidade)

(produz açúcar estocado nas células de parênquima da planta, além de etanol por fermentação de sacarose. Eletricidade é produzida numa termoelétrica abastecida por bagaço da cana)

Diversidade celular em cana de açúcar

(material mais complexo para o processamento)



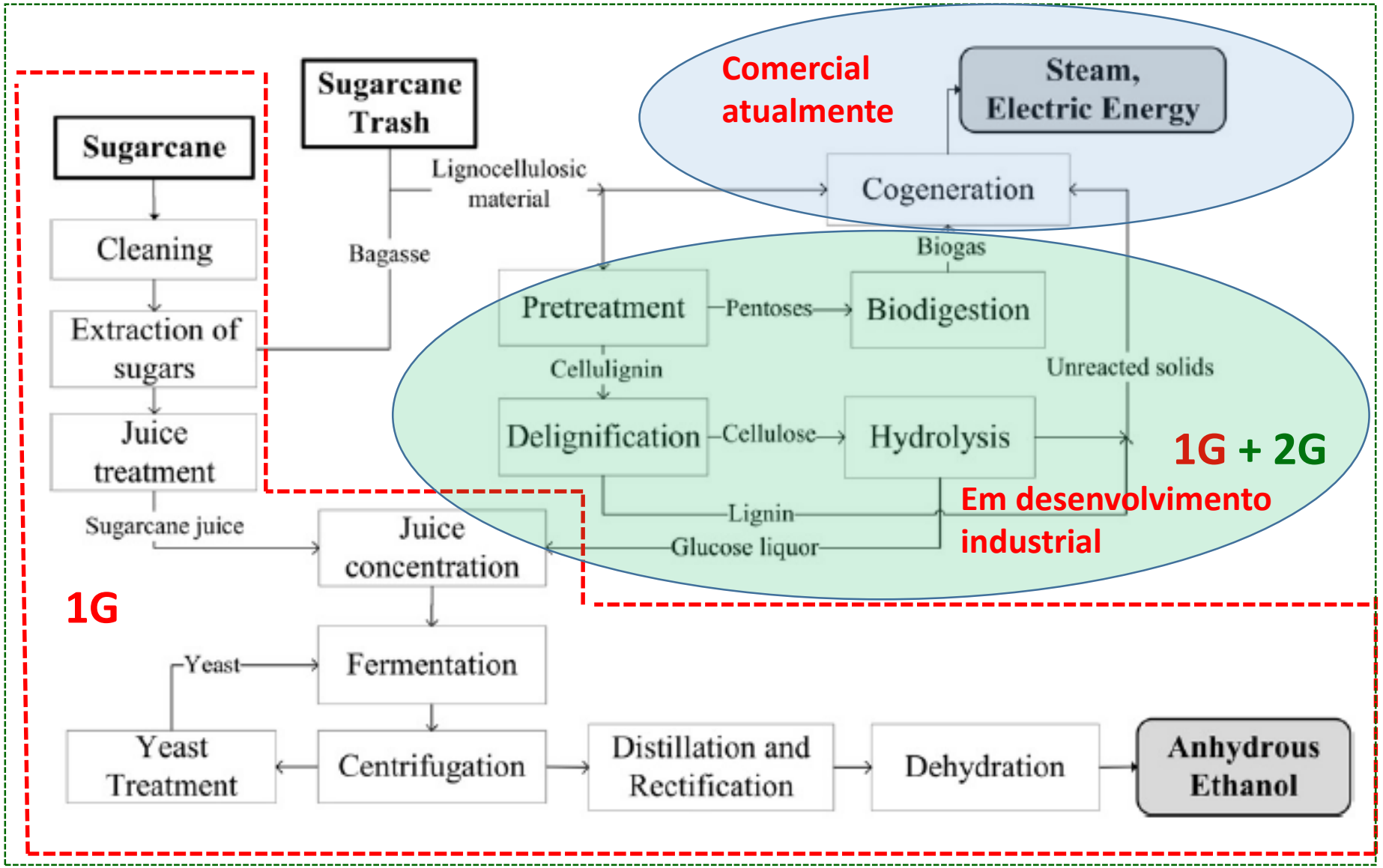
- Uma alternativa é o fracionamento da biomassa lignificada do bagaço para produção de diversos insumos dentro de um conceito de biorrefinaria.

***Pense* >> Como gerar monossacarídeos a partir dos polissacarídeos do bagaço de cana?**

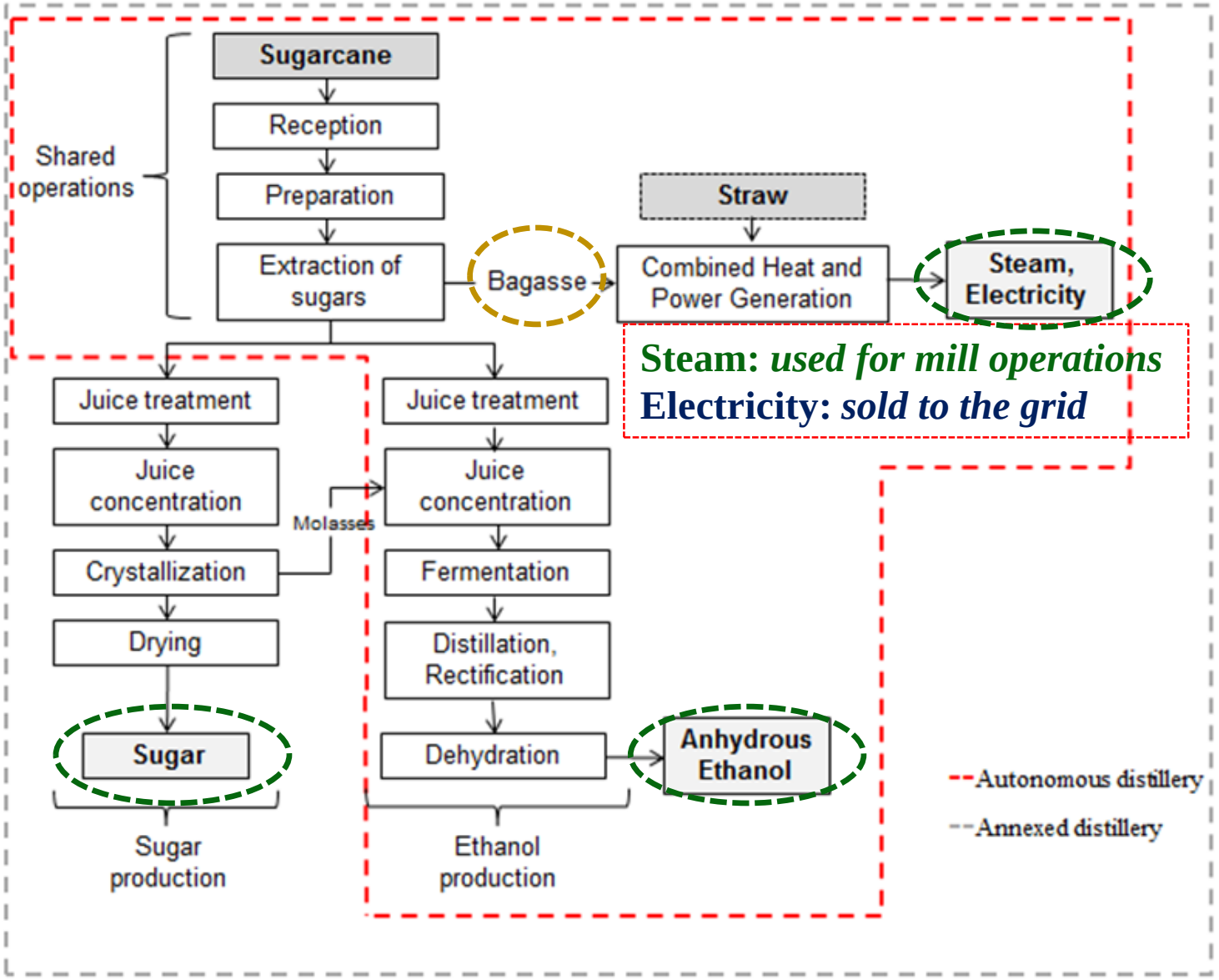
Hidrólise ácida?? Quais os problemas??
Hidrólise enzimática ?? Quais os problemas??

Deslignificação ajudaria??? Polpação kraft???
Quanto custa???

Integração de um processo de produção de etanol desde sacarose (1G) e de celulose e demais polissacarídeos (2G)



Traditional 1G-sugarcane biorefinery



Mendes et al., Chem Eng Res Design 125: 72-78, 2017

1G-production standards according to the sugarcane cultivar

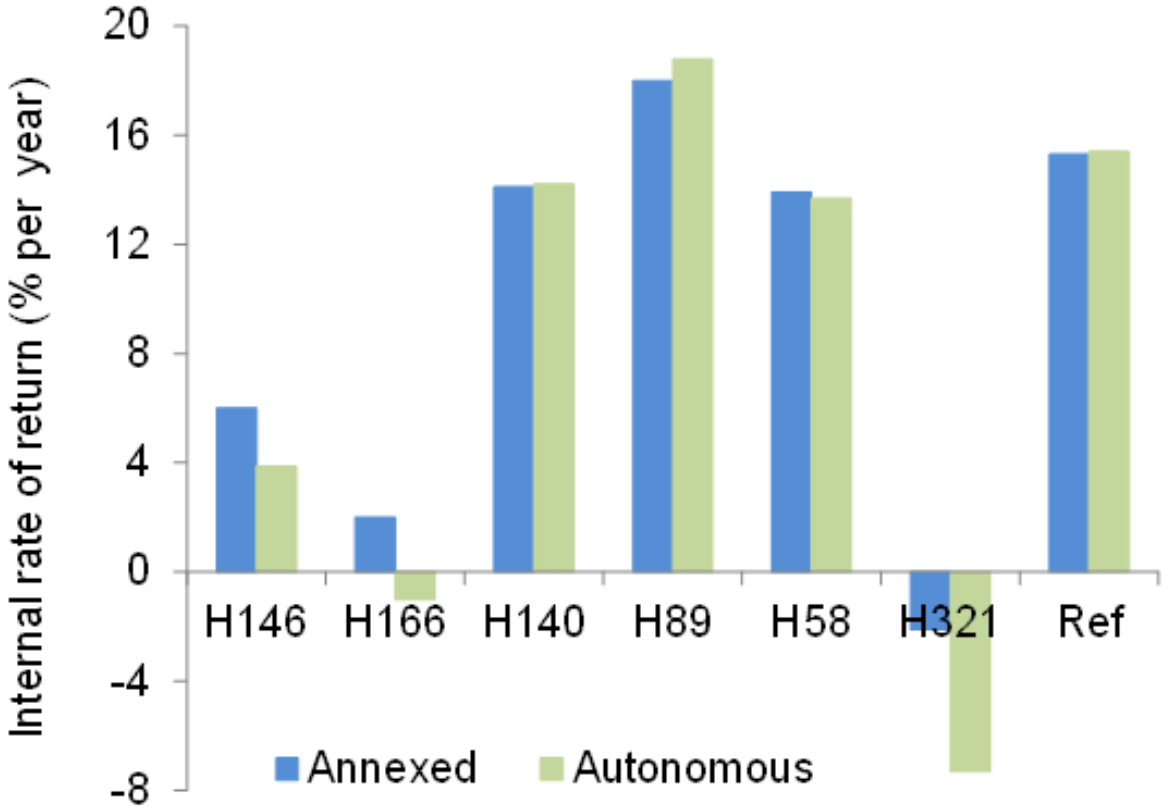
Simulation results for ethanol, sugar and electricity production for annexed and autonomous distilleries

	Sugarcane sample	Anhydrous ethanol		Sugar		Surplus electricity	
		L/TC[a]	L/ha	kg/TC[a]	kg/ha	kWh/TC	MWh/ha
Annexed distillery	H146	55.8	2662	53.5	2816	129	6.8
	H166	52.7	2662	50.4	2546	163	8.2
	H140	46.8	4121	44.6	3927	247	21.7
	H89	52.4	5303	51.7	5235	243	24.6
	H58	49.8	4235	47.5	4038	200	17.0
	H321	45.7	2485	43.2	2350	166	9.1
	Reference	53.0	4508	50.8	4318	189	16.1
Autonomous distillery	H146	88.7	4669	-	-	132	7.0
	H166	83.7	4230	-	-	166	8.4
	H140	74.0	6545	-	-	249	21.9
	H89	85.5	8656	-	-	244	24.7
	H58	78.9	6703	-	-	200	17.0
	H321	72.2	3931	-	-	166	9.0
	Reference	84.3	7167	-	-	193	16.4

(a) TC means ton of sugarcane stalks as harvested in the field (wet basis)

Mendes et al., Chem Eng Res Design 125: 72-78, 2017

Internal rate of return for traditional 1G-processing



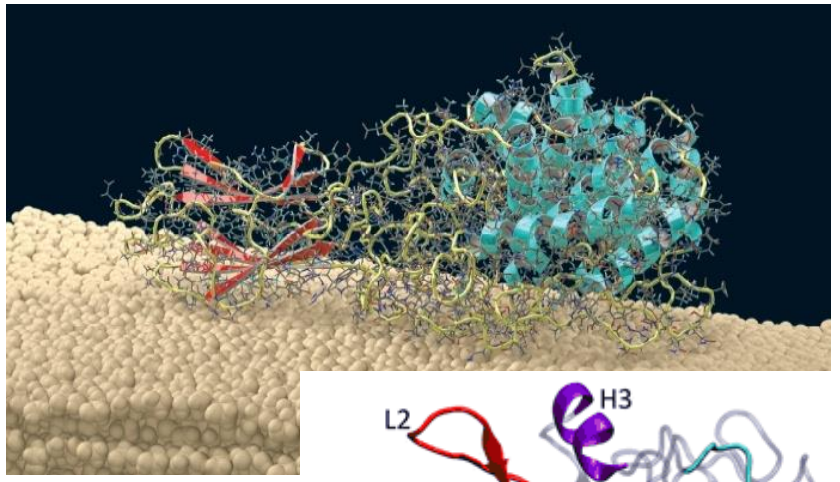
Mendes et al., Chem Eng Res Design 125: 72-78, 2017

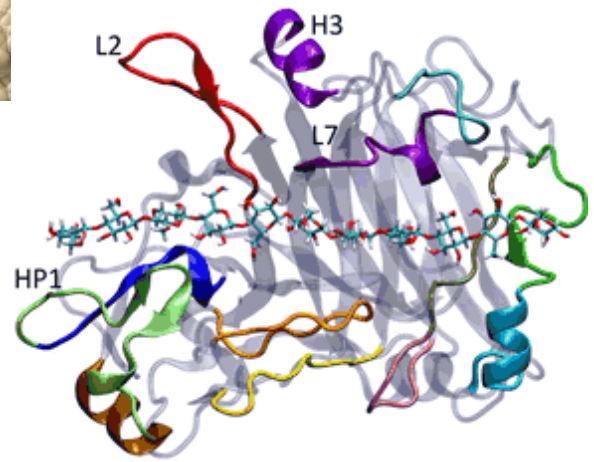
Using sugarcane bagasse for “new products”

1G-2G integration is the natural choice

Biomass polysaccharides → monosaccharides → 2G-ethanol

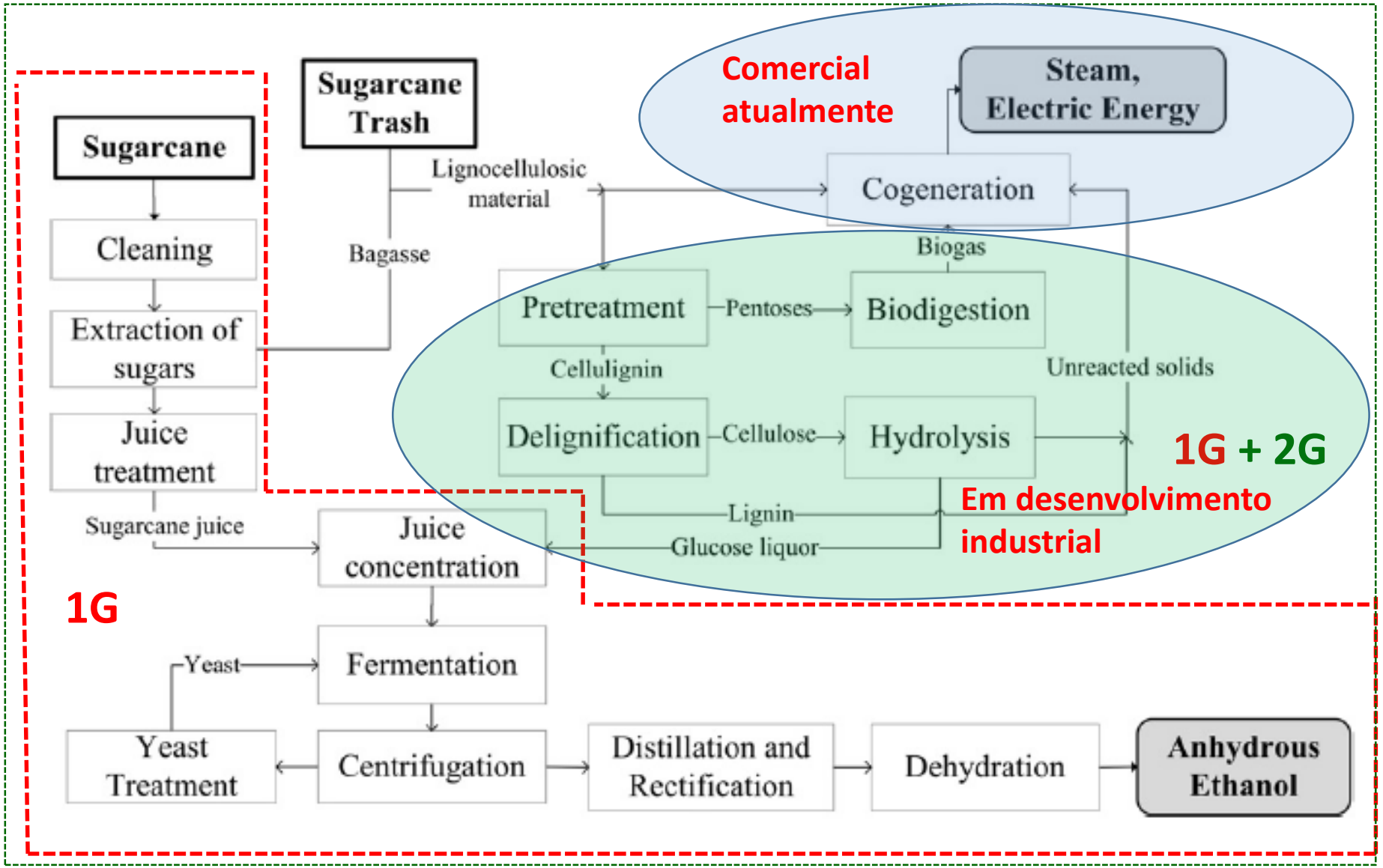
However, lignin and hemicellulose involve cellulose causing recalcitrance



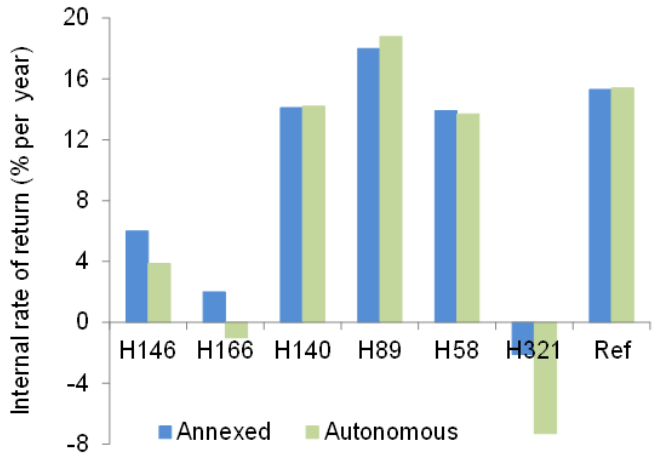


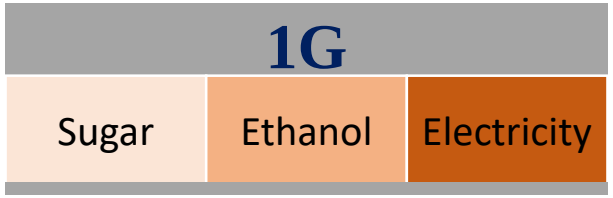
➡ **Pretreatment is required**

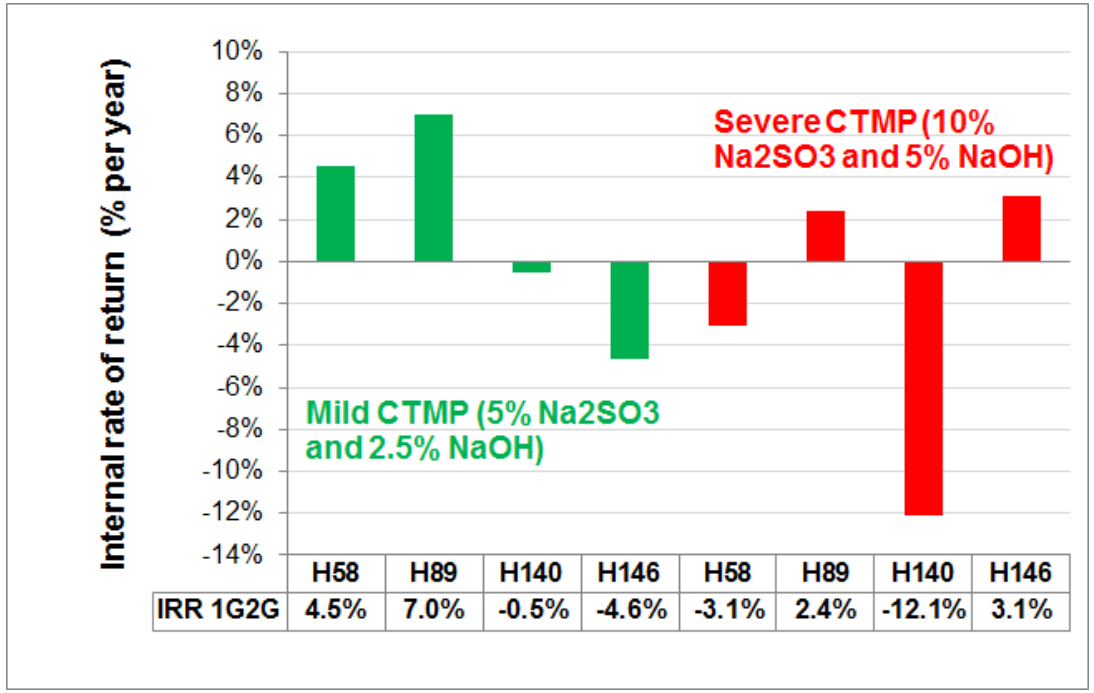
Integração de um processo de produção de etanol desde sacarose (1G) e de celulose e demais polissacarídeos (2G)



Internal rate of return for 1G-2G integrated sugar and ethanol production *(avoiding exciding electricity)*





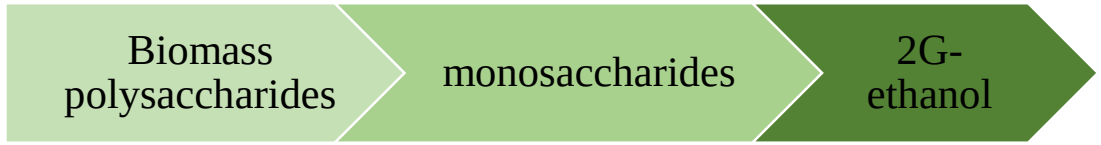


alkaline pretreatment:

similar to CTMP pulping

Integrated 1G-2G

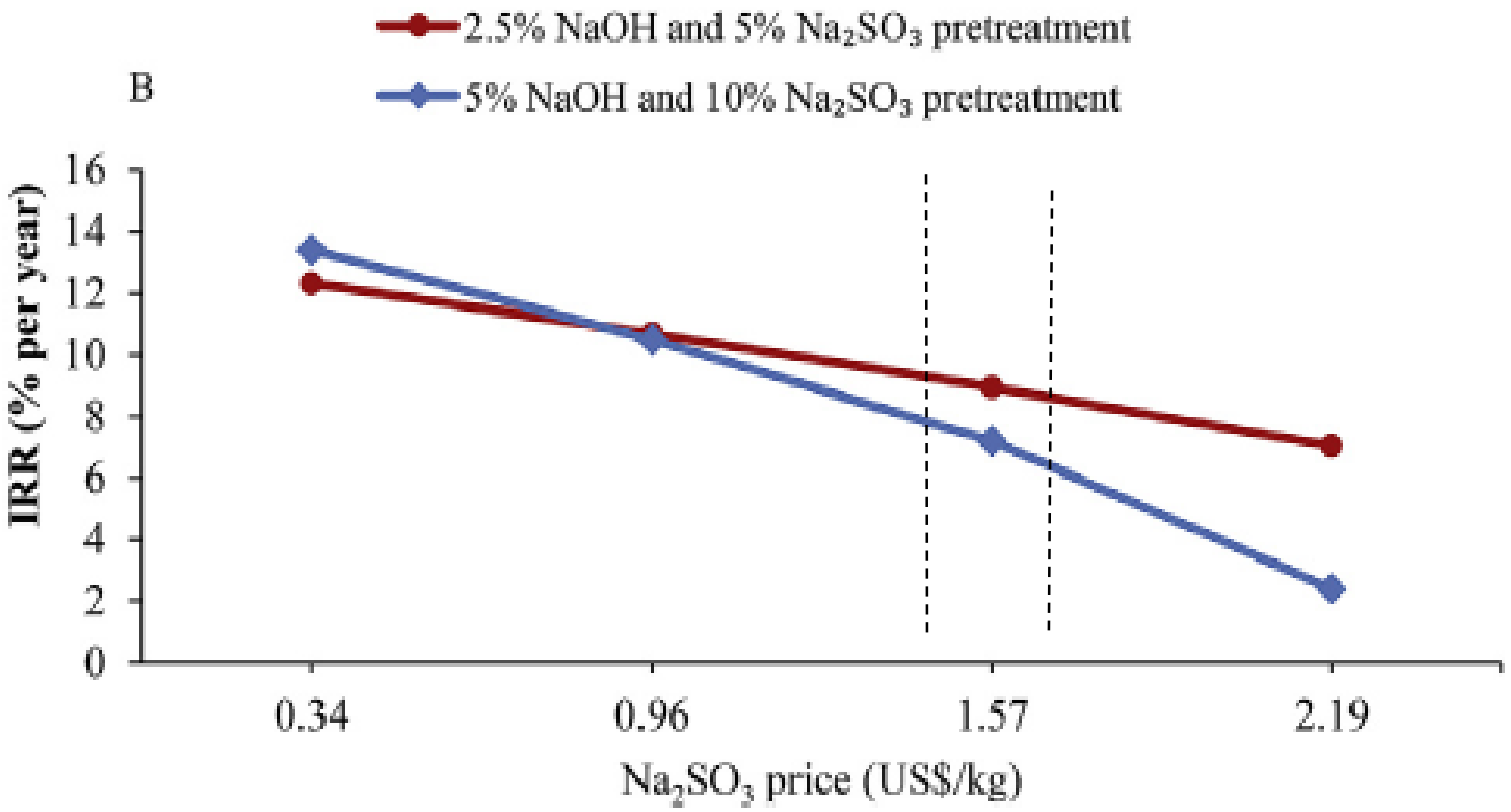
(for sugar and ethanol production)



Mendes et al., 2018. Biomass and Bioenergy 119 (2018) 314–321

Integrated 1G-2G

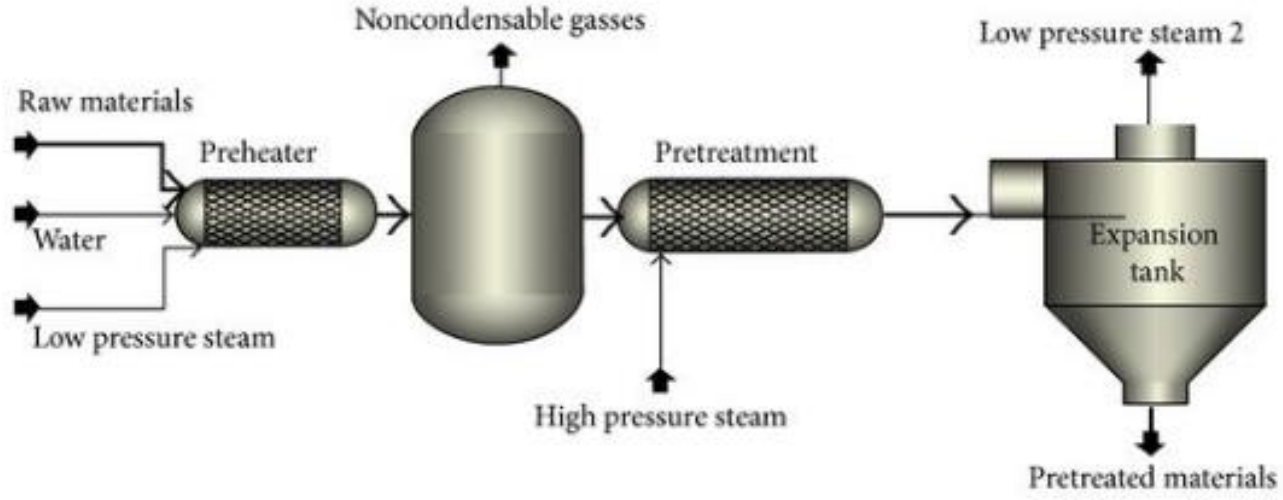
(for sugar and ethanol production): Technology is dependent on the pretreatment cost (CTMP pretreatment)



Mendes et al., 2018. Biomass and Bioenergy 119 (2018) 314–321

Pré-tratamento em meio ácido, autohidrólise, ou explosão a vapor

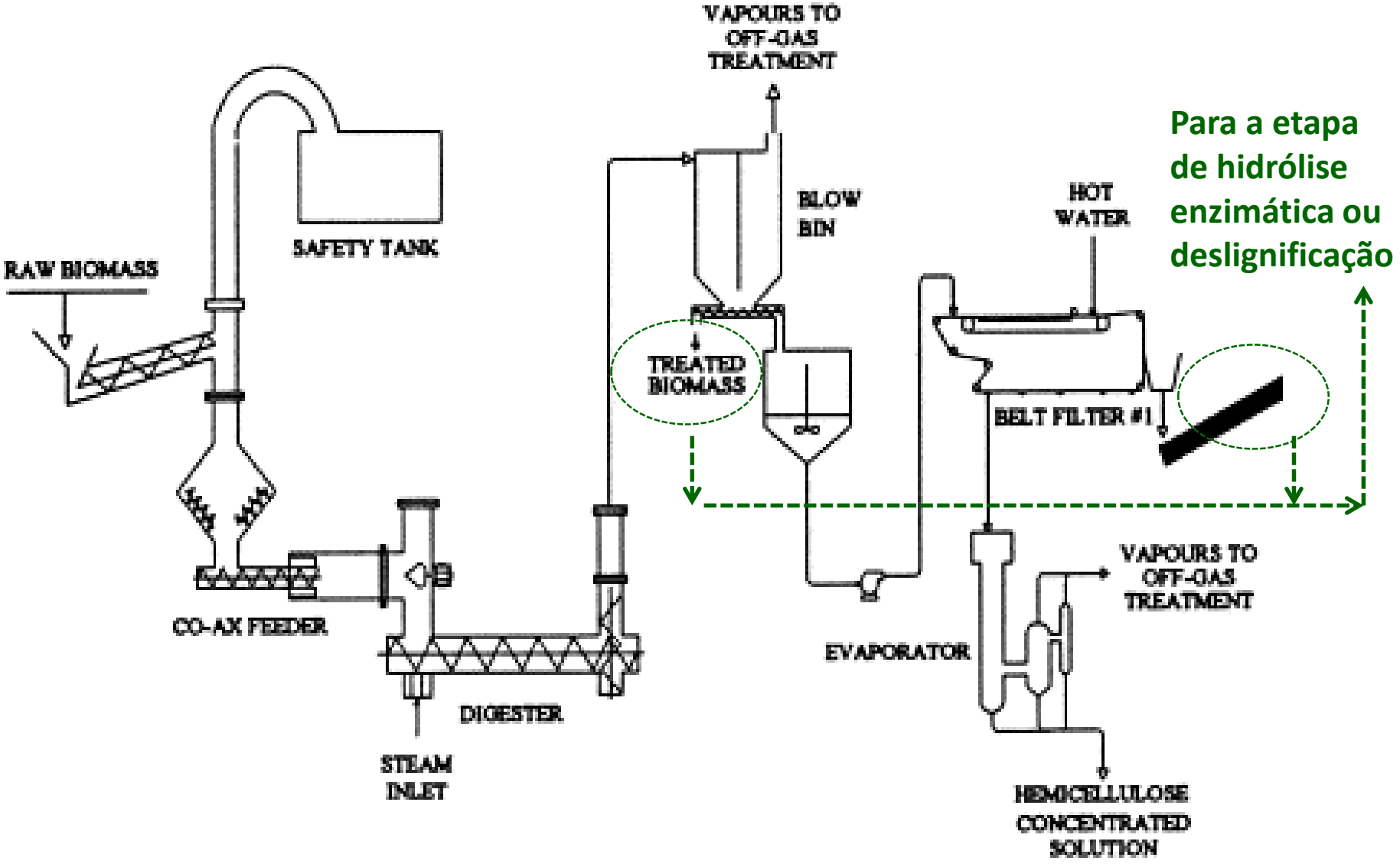
- O objetivo básico nesses sistemas é remover a hemicelulose seletivamente a partir de um processo de hidrólise “branda”. O licor gerado contém os monômeros ou oligômeros oriundos da hemicelulose. O resíduo sólido, contendo celulose e lignina, pode ser fracionado por deslignificação alcalina.



Fração aquosa: Rica em acúcares C5, provenientes da hemicellulose

Fração sólida: Praticamente toda a cellulose e lignina, porém com digestibilidade à enzimas aumentada

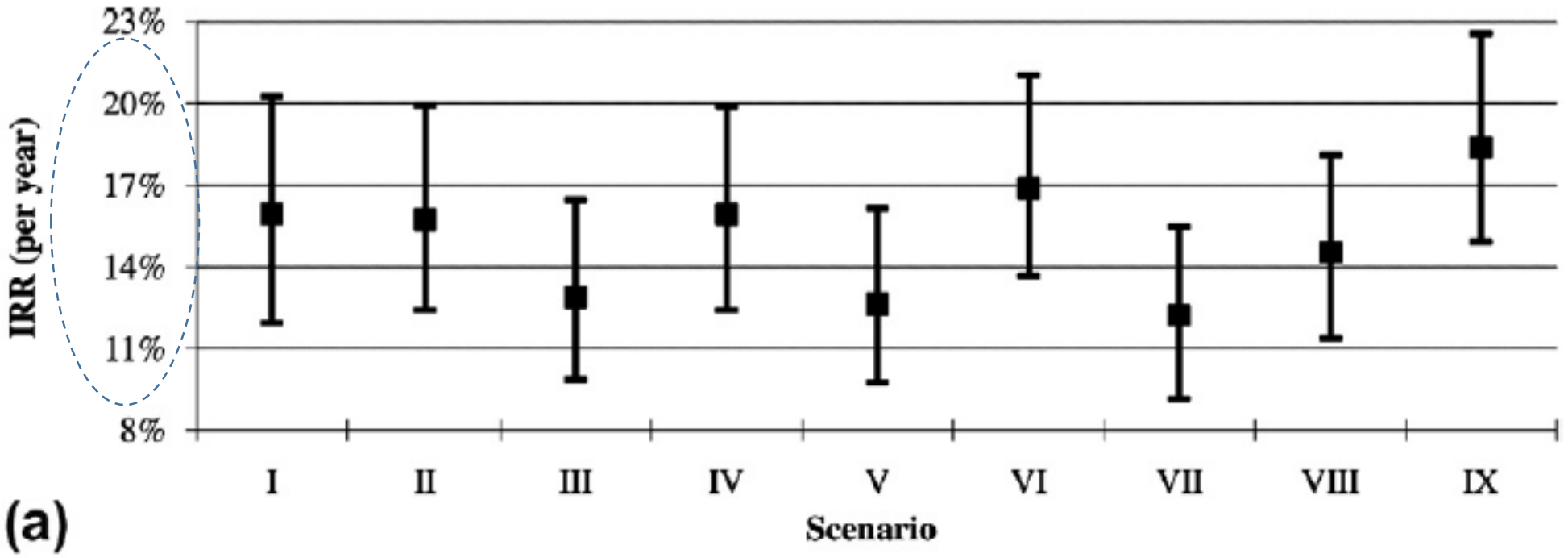
Planta piloto comercializada pela Stake Technologies - Canadá



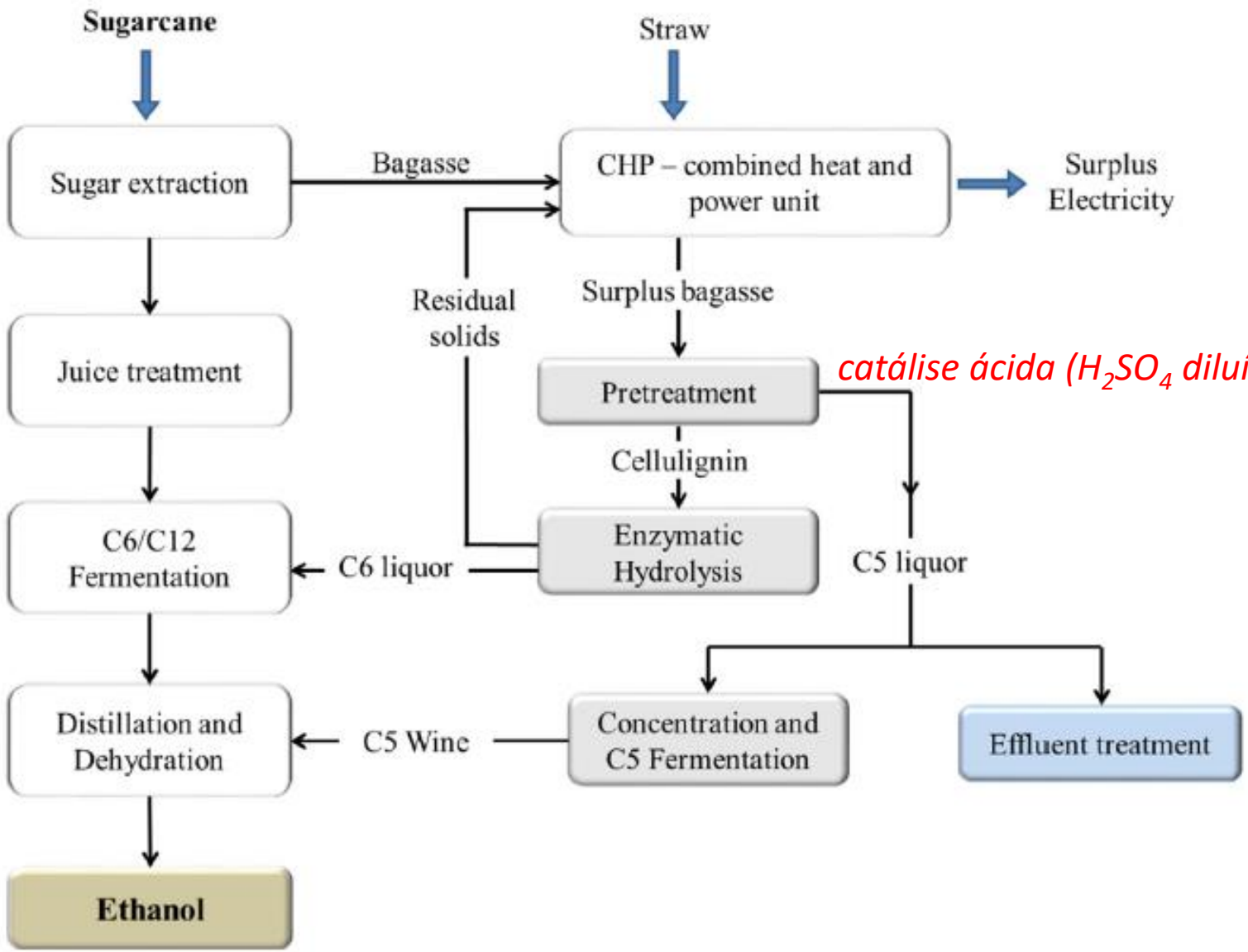
Para a etapa de hidrólise enzimática ou deslignificação

Integrated 1G-2G

(for sugar and ethanol production): Technology is dependent on the pretreatment cost (**Steam explosion pretreatment**)



Dias et al., 2011. Bioresource Technology 102 (2011) 8964–8971



M.H. Vasconcelos et al. / Energy 199 (2020) 117422

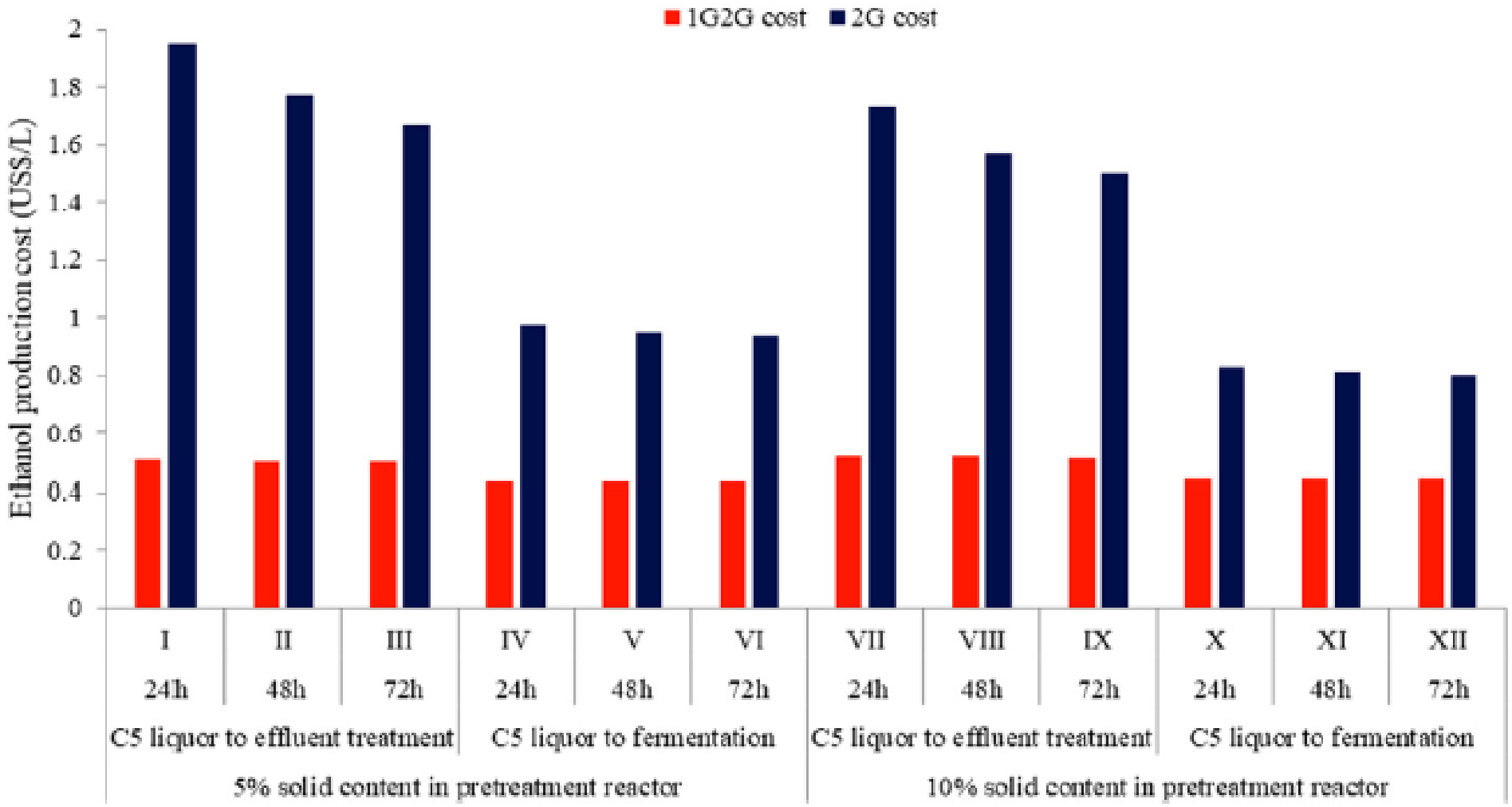
Table 2
Conditions considered for each evaluated scenario.

Scenario	Conditions		
	Solids content in the pretreatment reactor	Enzymatic hydrolysis incubation time	C5 Liquor destination
I	5%	24 h	Effluent treatment
II		48 h	
III		72 h	
IV	5%	24 h	Fermentation
V		48 h	
VI		72 h	
VII	10%	24 h	Effluent treatment
VIII		48 h	
IX		72 h	
X	10%	24 h	Fermentation
XI		48 h	
XII		72 h	

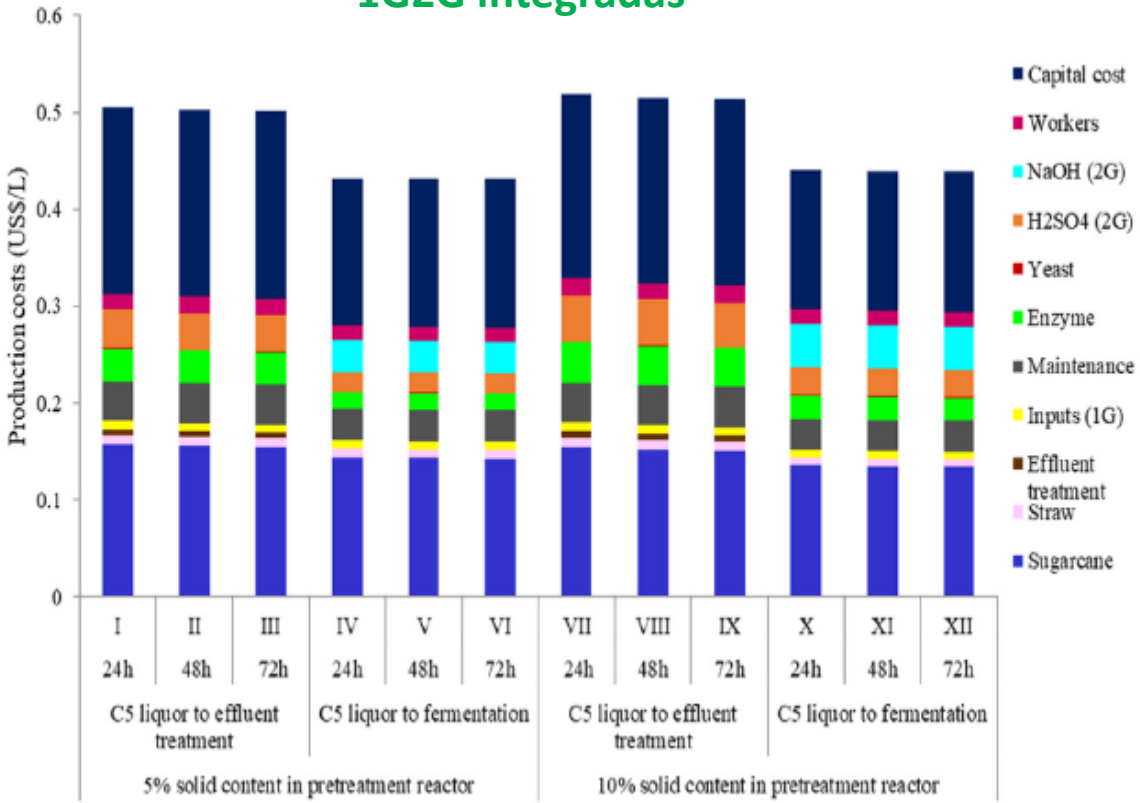
Table 5
Mass and energy balance for each simulated scenario.

Scenarios	Conditions			Fraction of burnt bagasse (%)	Steam (kg/TC[a])	Anhydrous Ethanol (L/TC[a])	Anhydrous Ethanol (L/ha[b])	Surplus electricity (kWh/TC[a])	Surplus electricity (kWh/ha[b])
	Solids content in the pretreatment reactor	Enzymatic hydrolysis incubation time	C5 Liquor destination						
I	5%	24 h	effluent	33.0	830.1	97.0	9816.4	100.3	10150.4
II		48 h	treatment	33.6	822.5	98.4	9958.1	99.1	10028.9
III		72 h		34.1	818.3	99.3	10049.2	98.4	9958.1
IV	5%	24 h	fermentation	62.0	953.6	103.6	10484.3	130.2	13176.2
V		48 h		62.2	949.6	104.3	10555.2	129.5	13105.4
VI		72 h		62.6	946.9	104.7	10595.7	129.1	13064.9
VII	10%	24 h	effluent treatment	15.1	754.4	100.1	10130.2	89.1	9016.9
VIII		48 h		16.5	748.2	101.8	10302.1	88.2	8925.8
IX		72 h		17.5	744.5	102.8	10403.4	87.6	8865.1
X	10%	24 h	fermentation	42.9	872.8	112.7	11405.3	115.2	11658.2
XI		48 h		43.8	868.1	113.6	11496.3	114.5	11587.4
XII		72 h		43.8	862.9	114.5	11587.4	113.6	11496.3

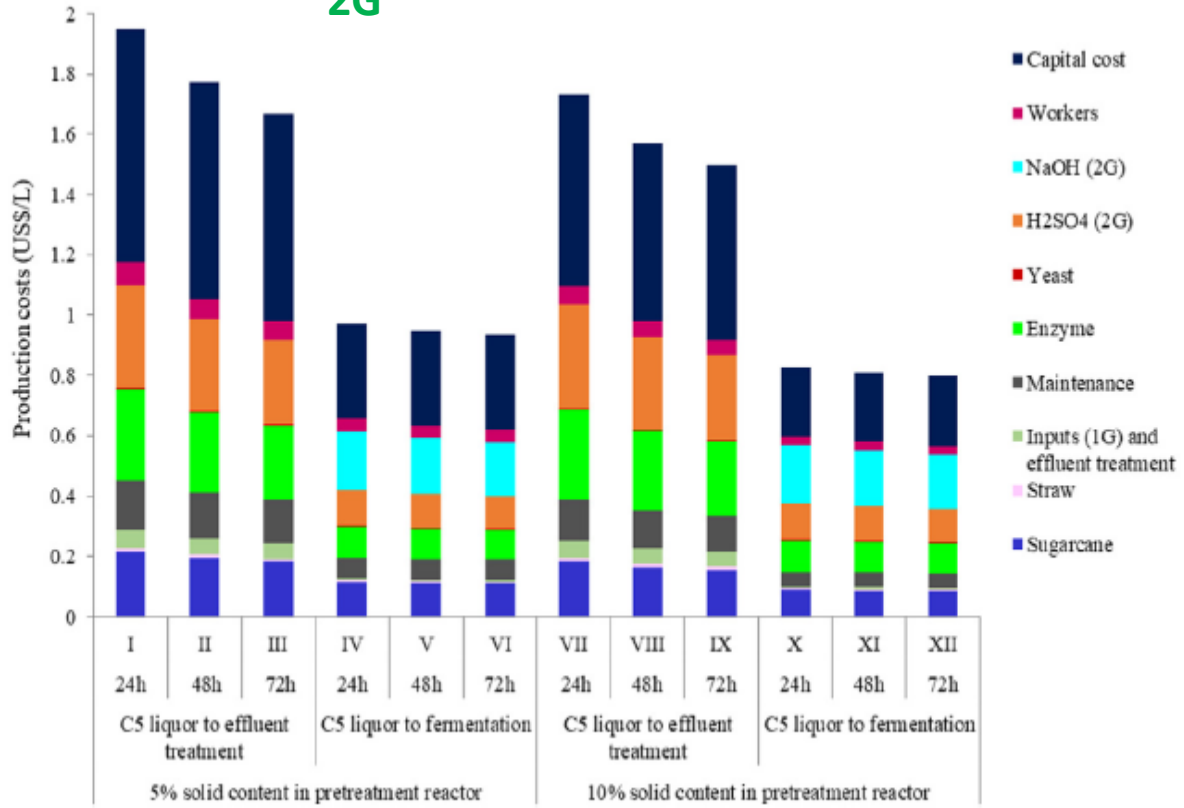
[a] TC = Metric tons of sugarcane stalks.
[b] ha = hectare.


1G2G cost
2G cost
Ethanol production cost (US$/L)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
24h
48h
72h
24h
48h
72h
24h
48h
72h
24h
48h
72h
C5 liquor to effluent treatment
C5 liquor to fermentation
C5 liquor to effluent treatment
C5 liquor to fermentation
5% solid content in pretreatment reactor
10% solid content in pretreatment reactor

1G2G integradas



2G



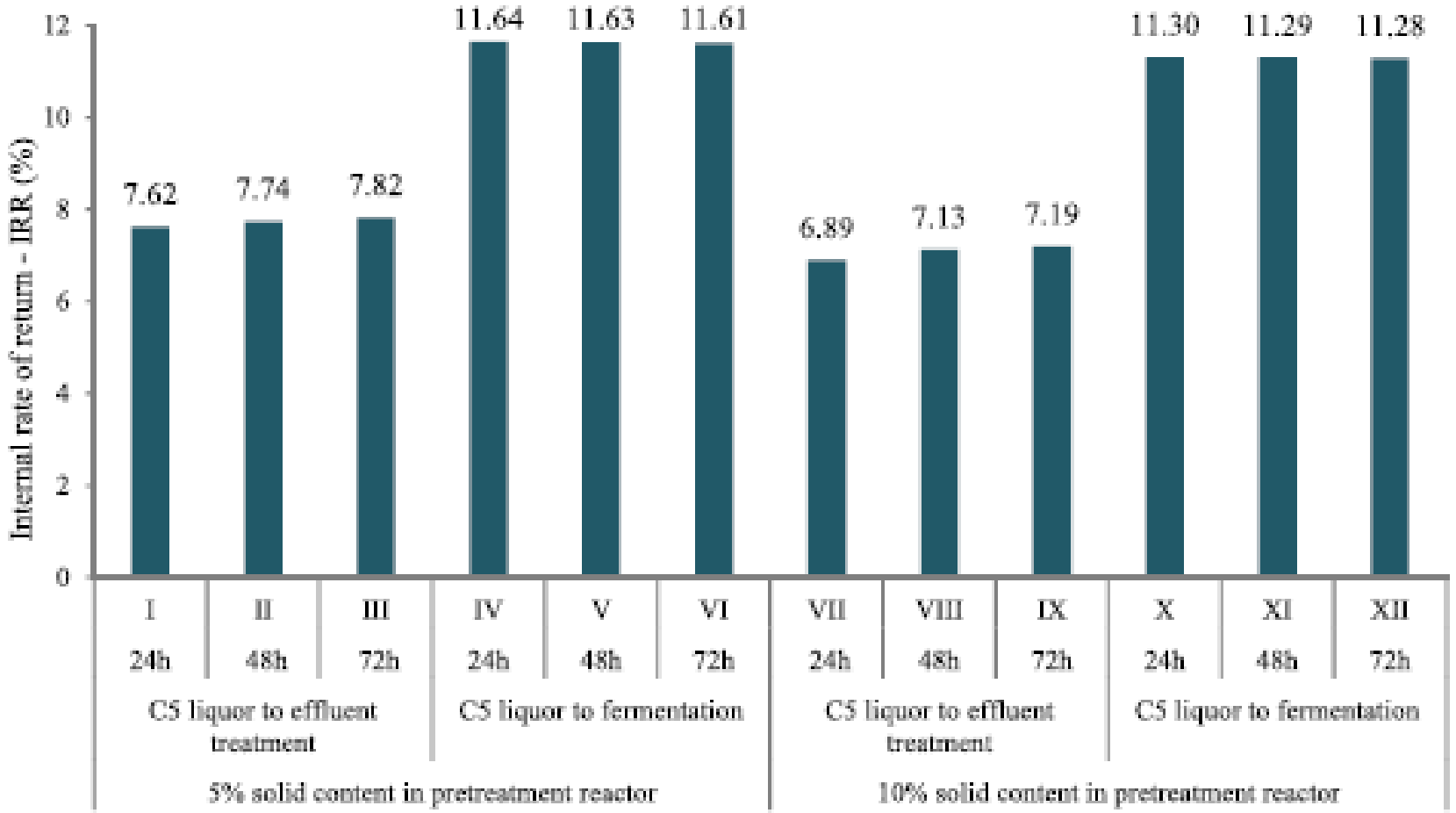


Fig. 4. Internal rate of return (IRR) for each 1G2G integrated scenario. 24, 48, and 72 h are the incubation times of enzymatic hydrolysis.

Etanol do milho (1G*milho*)

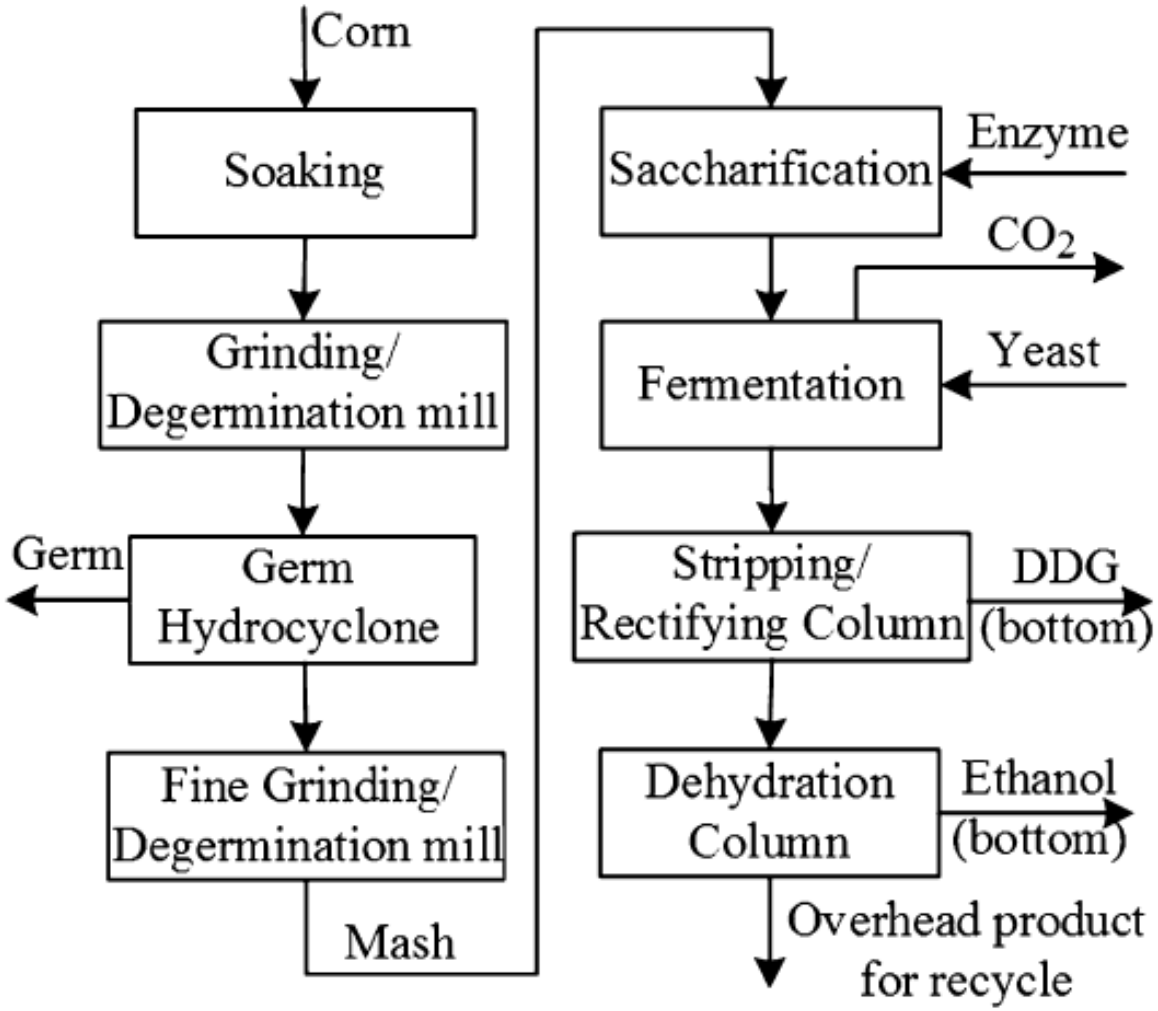
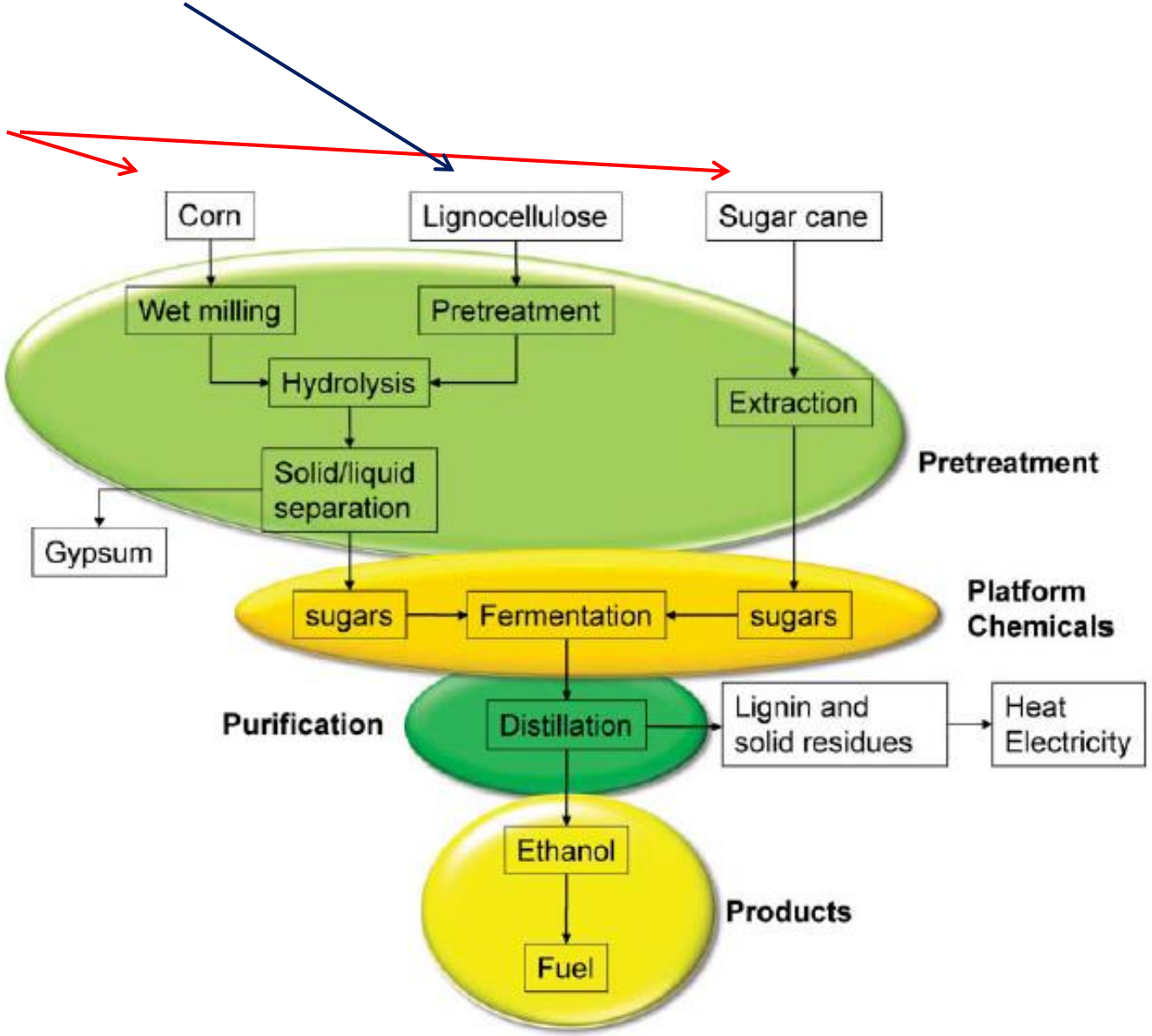


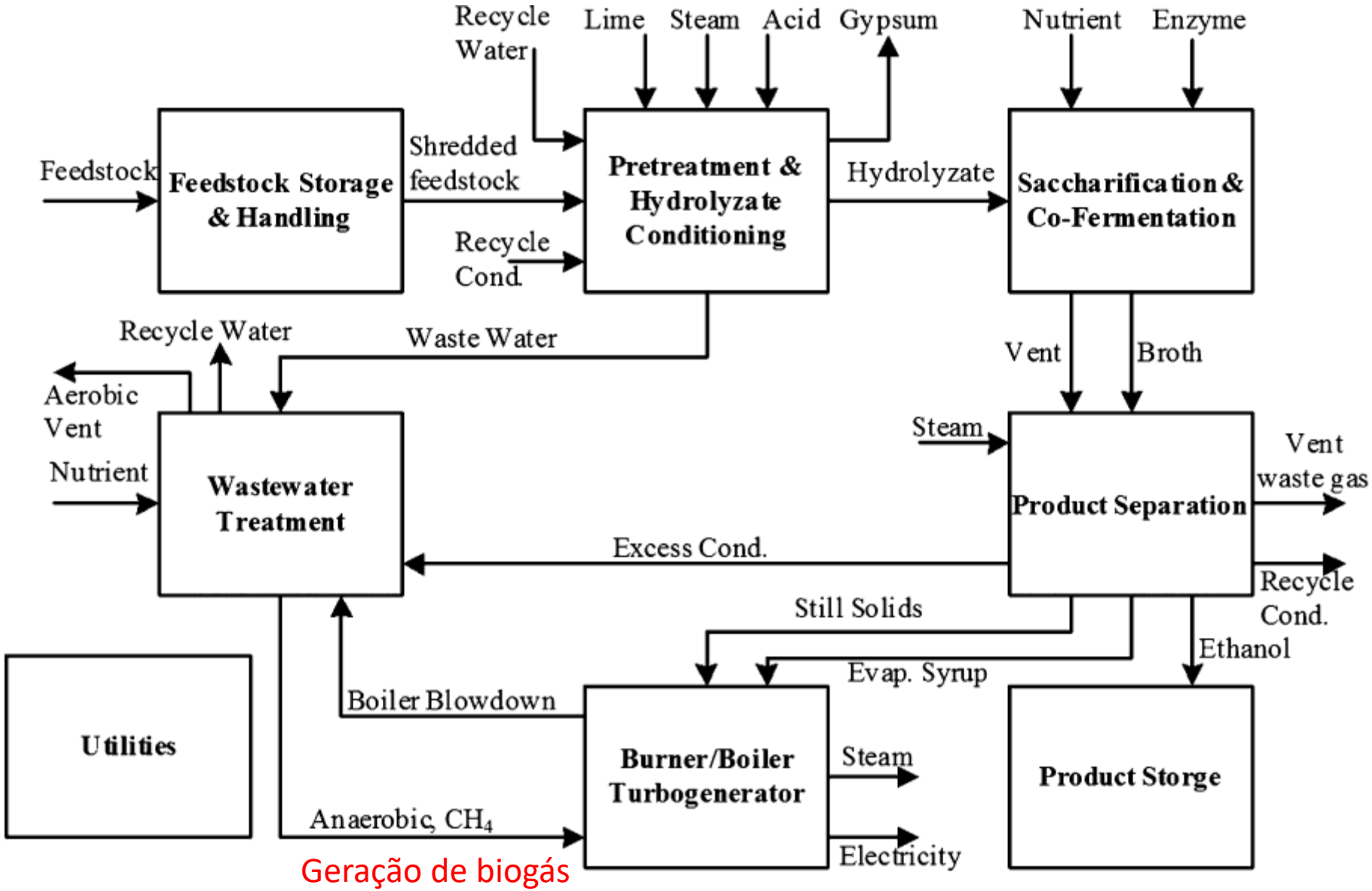
Fig. 1. Modified corn dry-grind ("Quick Germ") process [3].

Biorefinarias - Rotas bioquímicas para uso de biomassa lignocelulósica (*processos atuais em escala industrial*)



Outras matrizes encontradas na literatura

Substratos diversos (muitas vezes hipotéticas)



Geração de biogás

Fig. 3. Overall process block diagram for a basic lignocellulose to ethanol biorefinery [7].

2. Pre-extraction of hemicellulose and other value-added chemicals

Pré-extração em meio ácido

(Hemicellulose, Celulose, Lignina)

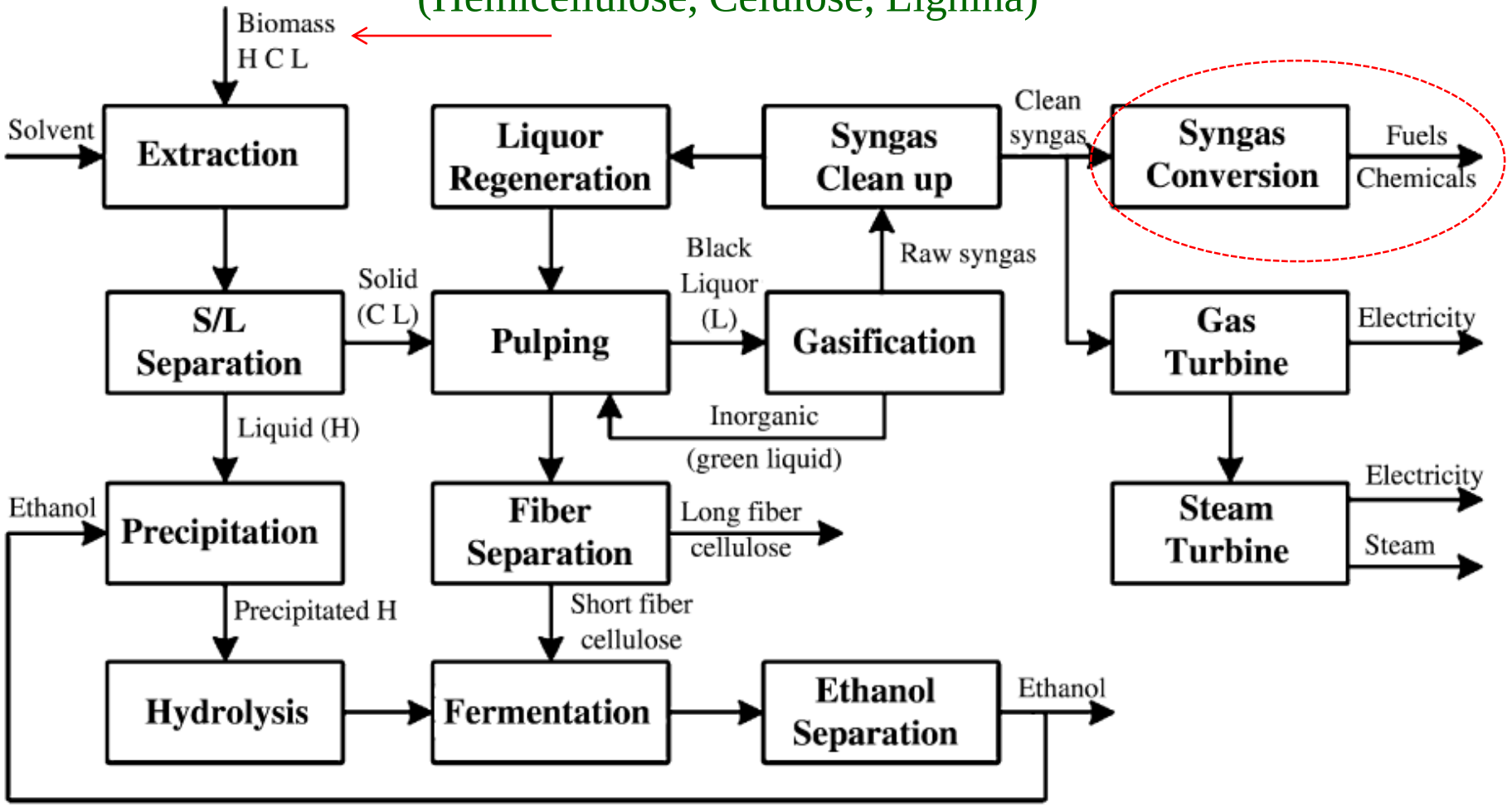
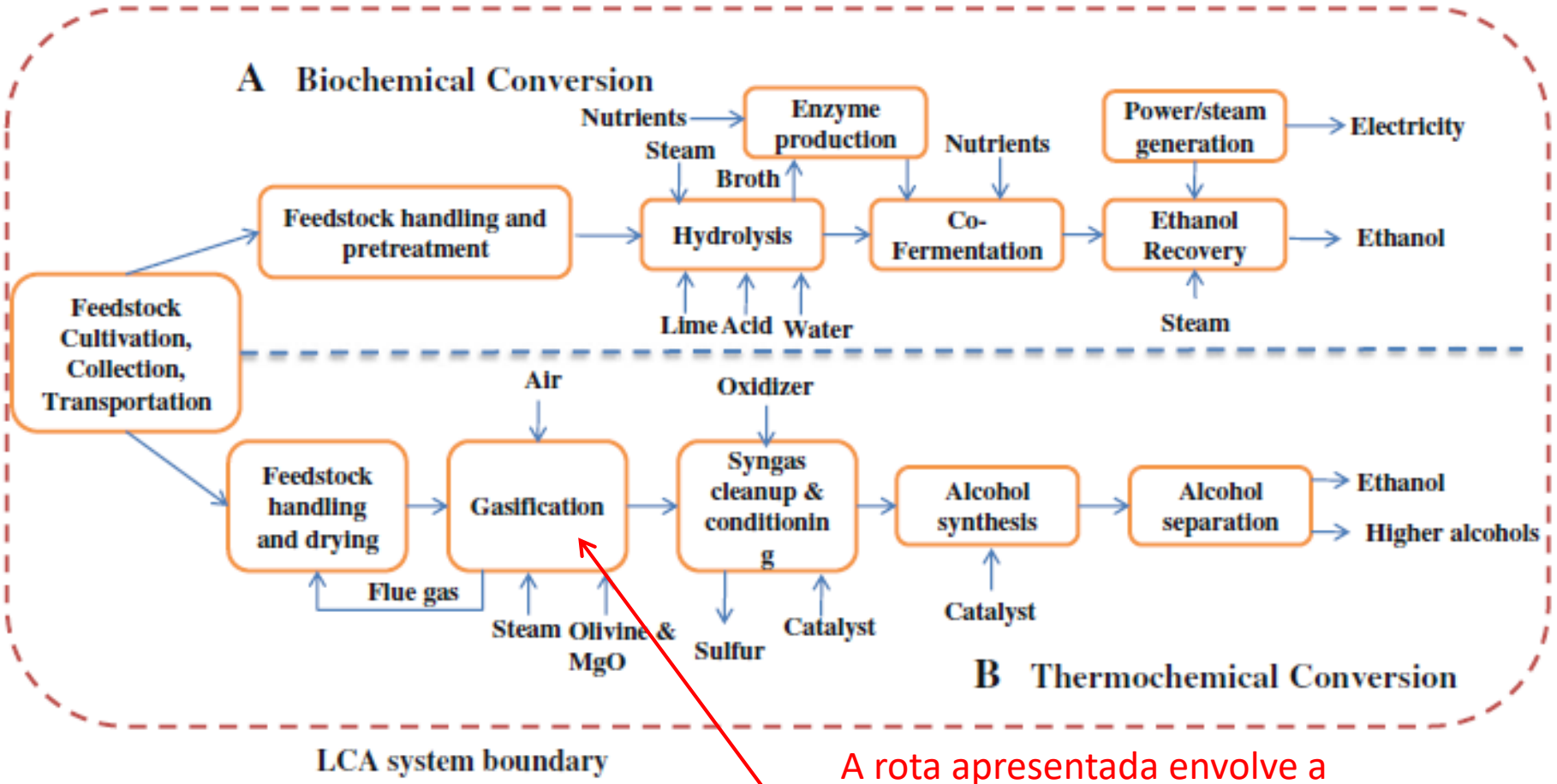


Fig. 4. Process block diagram of an integrated forest biorefinery.

Rotas termoquímicas e bioquímicas comparadas

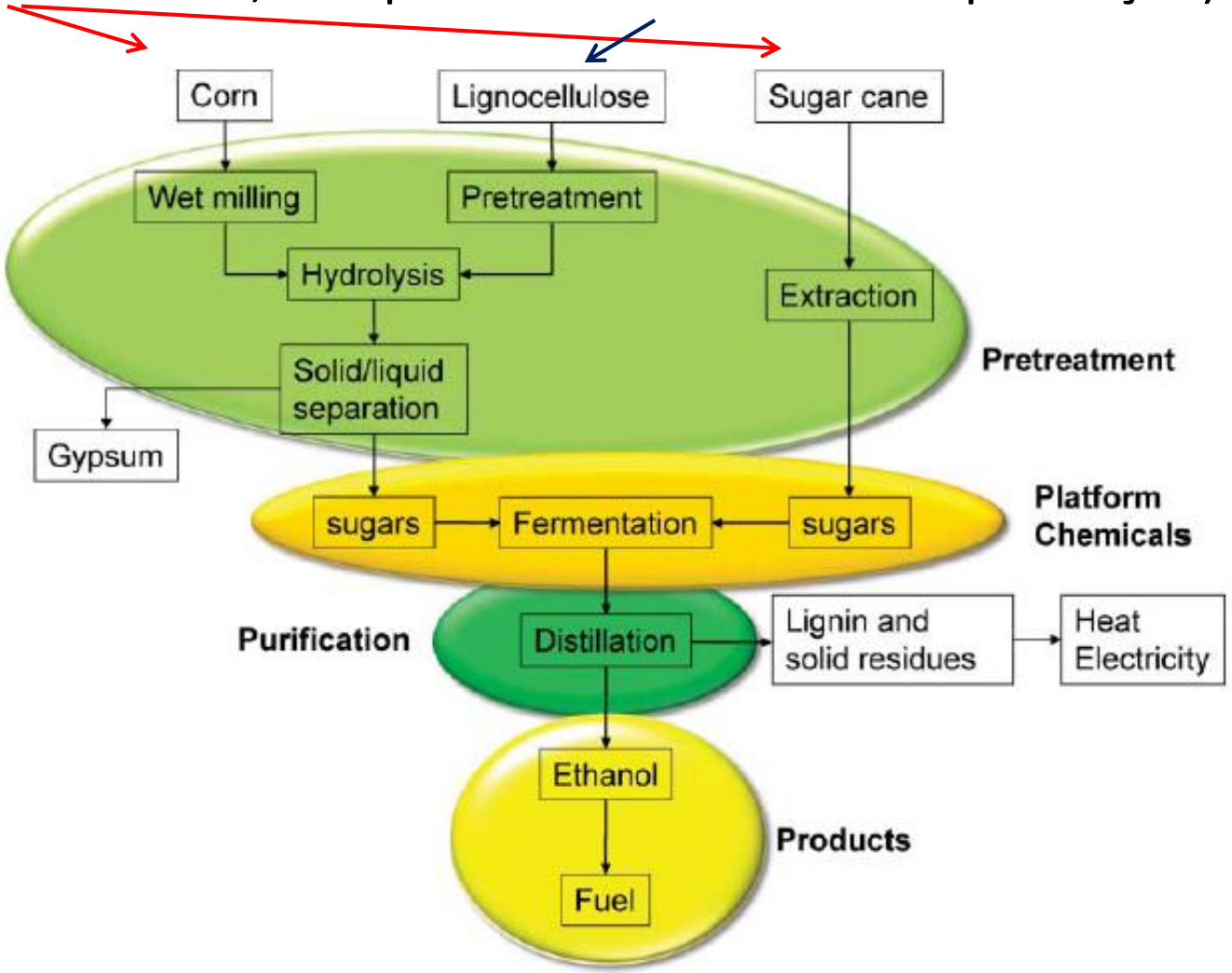


A rota apresentada envolve a maximização da gaseificação.
Há outras vias possíveis, incluindo bio-óleo e carvão

Biorefinarias

Rotas bioquímicas

(plantas comerciais; complexos industriais em implantação)



Rotas termoquímicas possíveis