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Integrated production of sugar, bioethanol and poly-hydroxy butyrate from sugar cane

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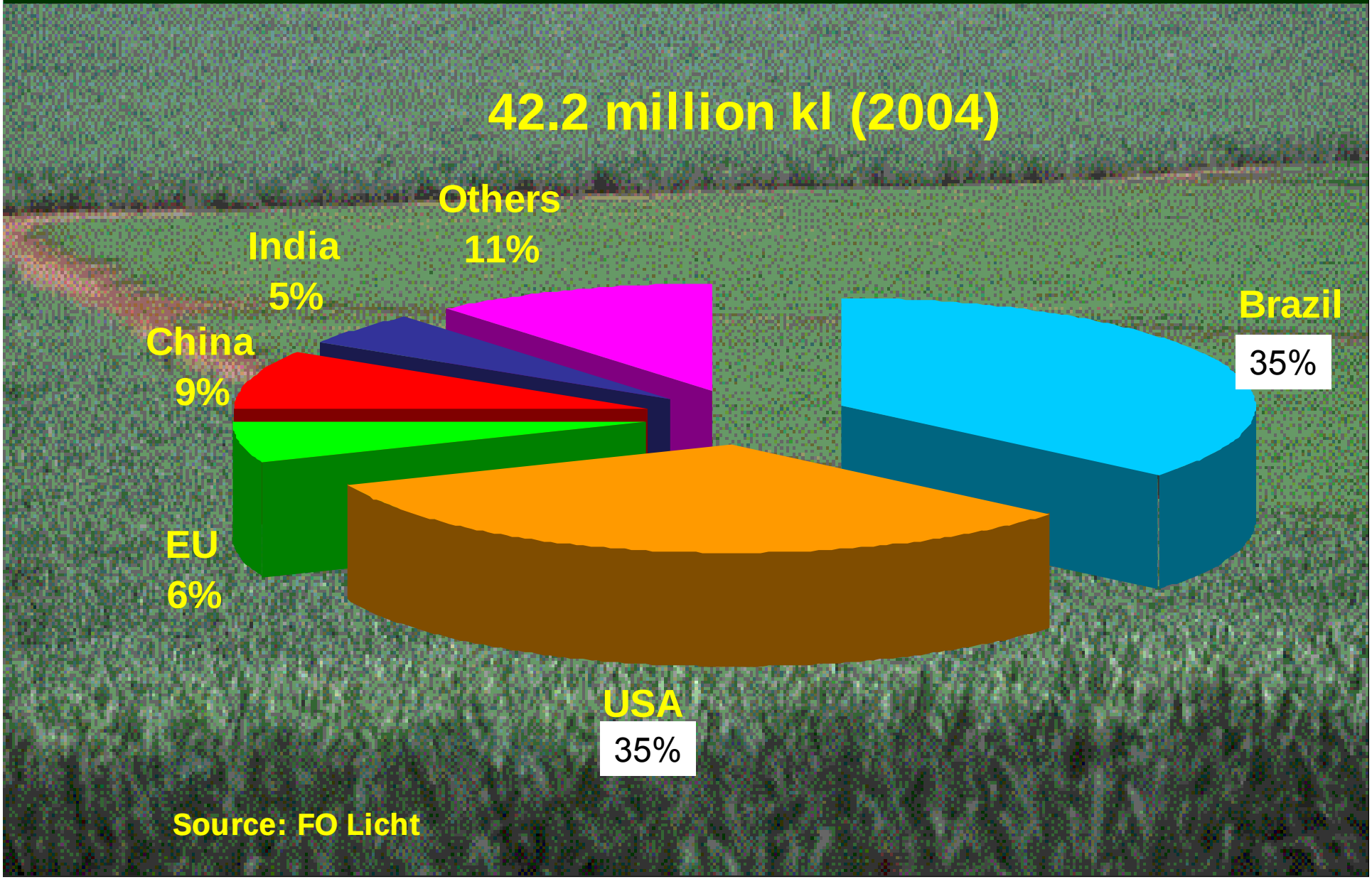
OUTLINE

- Overview about the present Brazilian situation of renewable feedstocks, bioethanol, bioenergy and biorefinery.
- Integrated production of sugar, bioethanol and poly-hydroxy butyrate from sugarcane

Present situation in Brazil

World Bioethanol Production



Bioethanol Productivity

Brazilian sugarcane ethanol is the biofuel presenting the highest productivity in the world (today: 6,000 l/ha.year) and the best renewable energy ratio:

8-9 l renewable energy/l fossil energy

US corn ethanol: 1.4-1.6

German biodiesel: 3.0

Adoption of innovative technologies will more than double present productivity to 14,000 l/ha.year

Bioethanol Fuel Around the World

- BRAZIL (E20 to E25, and E100)
- USA (E10 and E85)
- JAPAN (E3)
- CANADA (E10 and E85)
- SWEDEN (E10 and E85)
- INDIA (E5)
- AUSTRALIA (E10)
- THAILAND (E10)
- CHINA (E10)
- COLOMBIA (E10)
- PERU (E7)
- PARAGUAY (E18)

E20 is the default Fuel at petrol stats.

Comparative Energy Flow in Producing bioethanol

PROCESS	Corn[1]	Switchgrass[1]	Sugar cane[2]
	(GJ/ha.yr)	(GJ/ha.yr)	(GJ/ha.yr)
Crop production energy consumption	18.9	17.8	13.9
Biomass Energy	149.5[3]	220.2	297.1[4]
Agricultural energy ratio	7.9	12.3	21.3
Ethanol production energy consumption	47.9	10.2	3.4
Energy in ethanol	67.1[5]	104.4	132.5[6]
Total energy ratio	1.21	4.43	8.32

Notes:1- Source: ORNL, 2- Source: Copersucar/UNICAMP, 3-No credit for corn stover, 4- No credit for sugar cane leaves, 5- includes credits for co-products, 6- Includes credits for surplus bagasse 8%

Bioethanol: a new commodity

- Good business for tropical countries
- Challenges:

  - regularity and guarantee of supply

  -price stability, stock regulation, certifications...

Brazil - Production of Sugarcane, Sugar and Bioethanol

	Anhydrous Ethanol (Million kl)	Hydrous Ethanol (Million kl)	Total Ethanol (Million kl)	Sugar (Million ton)	Sugarcane (Million ton)
94/95	2.87	9.89	12.77	11.70	240.9
95/96	3.06	9.66	12.72	12.65	249.9
96/97	4.63	9.80	14.43	13.63	289.5
97/98	5.70	9.73	15.42	14.85	302.2
98/99	5.69	8.24	13.93	17.96	315.6
99/00	6.14	6.94	13.08	19.38	310.1
00/01	5.58	4.93	10.52	16.02	254.9
01/02	6.48	4.99	11.47	18.99	292.3
02/03	7.01	5.48	12.49	22.38	316.1
03/04	8.79	5.87	14.66	24.96	357.3
04/05	8.18	6.98	15.16	26.33	381.1
			17	(05/2006)	400
			20	(06/2007)	440

Source: DCAA/SPAE/MAPA

Brazil: ethanol exports 2005

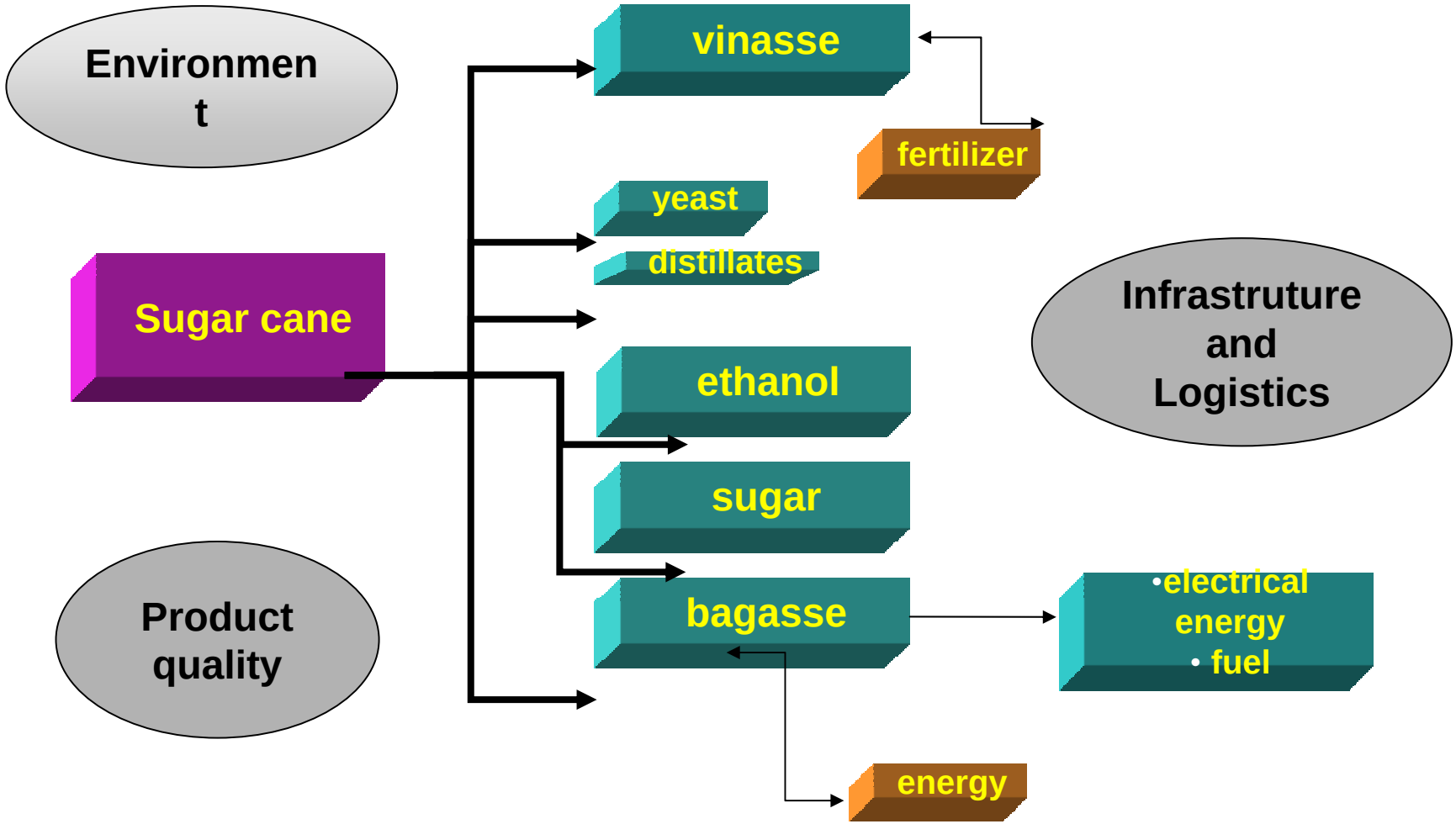
Countries	US$ FOB	kl
India	115,174,799	410,756
Japan	93,053,194	315,391
USA	77,462,430	260,714
Netherlands	79,575,786	259,402
Sweden	70,102,485	245,891
South Korea	63,899,736	216,356
Others	266,260,769	883,782
TOTAL	**765,529,199**	**2,592,292**

Source: SECEX-Brazilian Government

Present Situation in Brazil

- Ethanol production 20 million kl in 2006/07
- Ethanol Exports 2.6 million kl in 2005
- 340 mills in operation
- 89 new mills in different stages construction/planning
- New investments in mills US$ 10 billion – increase the production capacity by 7 million kl until 2010
- Ethanol competive with oil price above US$ 35/barrel
- *In 2007: flexible fuel vehicles represented 77% of light duty domestic market. More than 1.4 million sold*

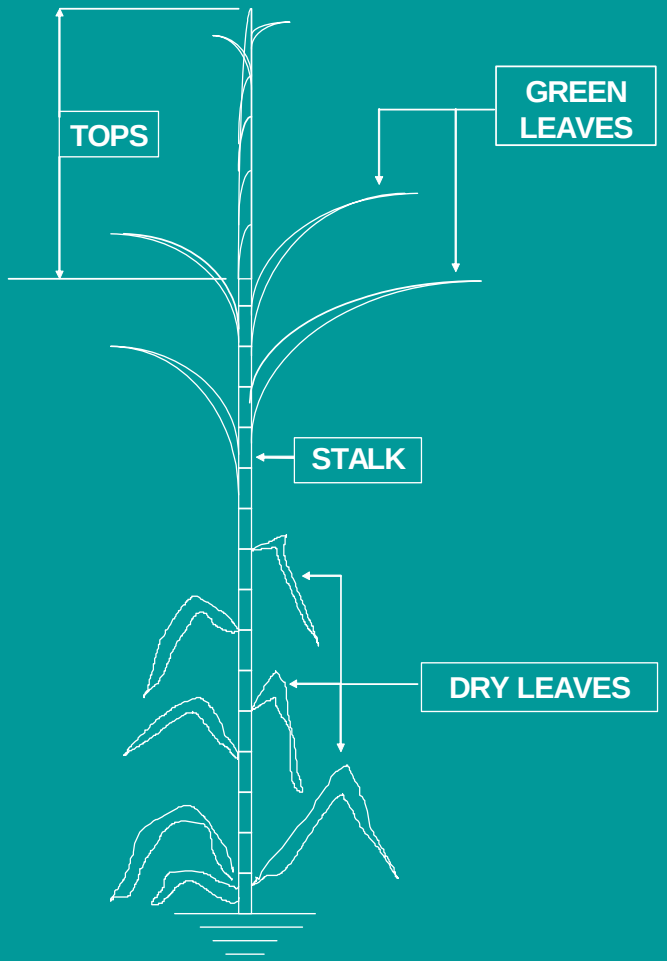
Current situation in Brazil first generation biorefinery



Present Location of Sugar-Etanol Mills in Brazil

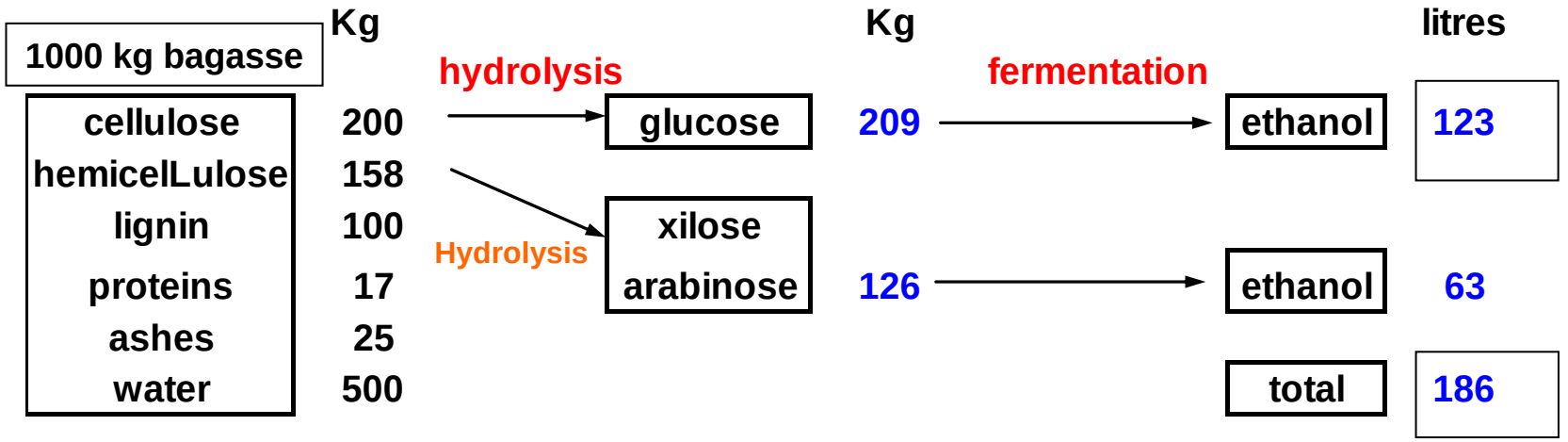
Towards the use of the whole sugargane

SUGARCANE TRASH (STRAW) YIELD



Variety	Cut	Average		
		Stalks (t/ha)	Trash (DM) (t/ha)	Trash % to Stalks
SP79-1011	1º C*	120,0	17,8	15%
	3º C	91,5	15,0	16%
	5º C	84,2	13,7	16%
SP80-1842	1º C*	135,8	14,6	11%
	3º C	100,5	12,6	13%
	5º C	91,6	10,5	11%
RB72454	1º C*	134,3	17,2	13%
	3º C	99,8	14,9	15%
	5º C	78,2	13,6	17%
Average		104,0	14,4	14%

Bio-processing of Sugarcane
ETHANOL YIELD from BAGASSE AND TRASH



	Kg	Kg	l
Cellulose	210	233	150
Hemicelulose	135	153	99
Lignin	110		
Extract	20		
ash	25		
water	500		

Convertion cellulose : glucose: 1,111 kg/kg

Hemicelulose: xylose: 1,136 kg/kg

glucose : etanol: 0,6475 l/kg

xylose : etanol: 0,6475 l/kg

C.E.V. ROSSEL

Figure 1a. Bagasse fiber

Figure 1b. Bagasse fiber (zoom)

Chemical composition of some common fibers Sugar Cane Bagasse and Trash

Cellulose	Lignin	Pentosan	Ash	Silica
32-48 %	19-24%	27-32%	1.5-5%	0.7-3.5%

[1] Rossel, C. *in* Franco, T.T. (ed). Proceedings Workshop *Industrial perspectives for bioethanol*. Instituto UNIEMP. Sao Paulo, april 2006

The success of Bioethanol from cellulose depends on:

1. Availability and cost of the raw material
2. Properties/characteristics of the raw material

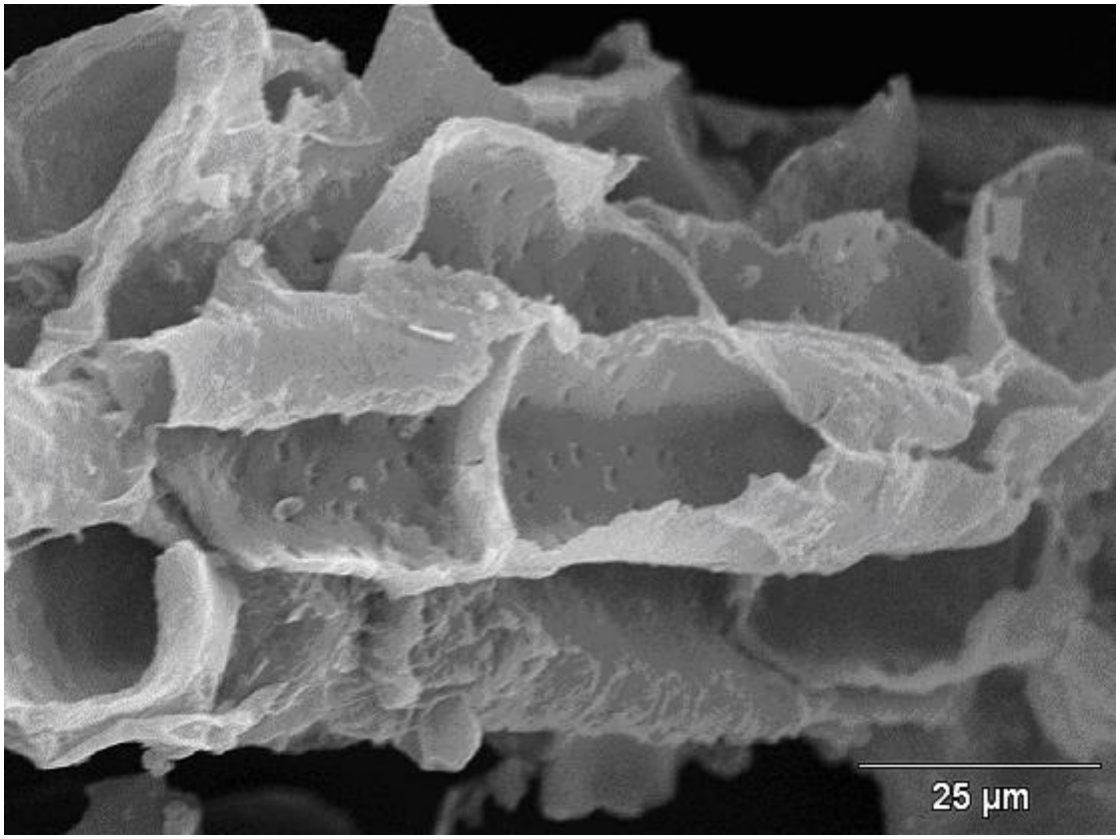
To minimize/simplify the pre-treatment operations

To simplify/minimize the hydrolysis process

To simplify the fermentation process

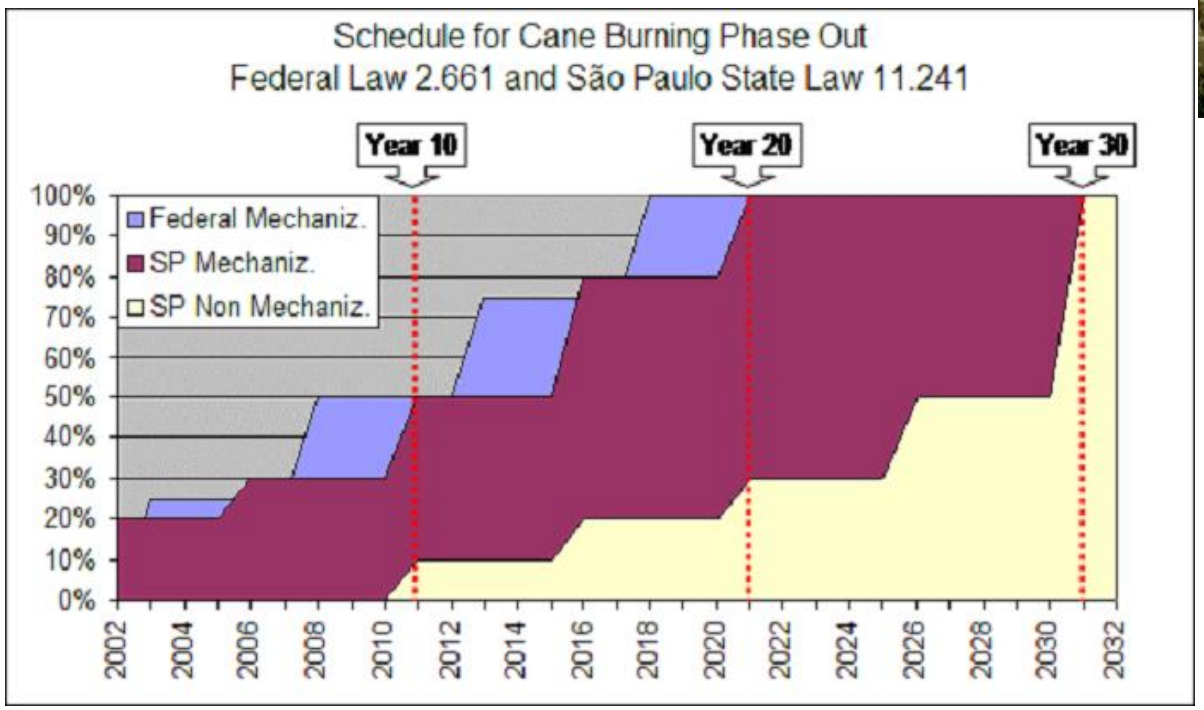
Advantages of the bagasse

1. It is already in the sugar/bioethanol mill
2. Its cost is already accounted
3. It has been previously treated in order to allow sucrose extraction (preparation and crushing)
4. Part of the sugarcane bagasse is made from cells walls (hole, large surface area)



Study of sugar cane bagasse characteristics: particle shape and size, free-settling velocity, and drag coefficient. Brazilian Chemical Engineering Journal. Silvia Nebra e Juan Harold Sosa-Arnao FEM UNICAMP 2006

SUGAR CANE BURNING PHASING OUT




Thick trash layer

Advantages of using the straw

1. The amount of available fibre can easily double;
2. Ending of the sugarcane burning;
3. Part of the straw is used to control pests (as cigarrinha);
4. The digestibility of sugarcane straw is better, when compared with corn stover, due to lower lignin content
5. The sugacane mill could theoretically burn the bagasse and use the straw hydrolysate and vice versa, as desirable;
6. The straw is already dried when arrives to the mill.

COST OF SUGAR CANE TRASH

GEF/UNDP/MCT Project BRA/96/G31 Biomass power generation: Sugar cane bagasse and trash

Items	Alternative 1	Alternative 2	Alternative 3
Deliver trash to mill	9.61	23.23	2.74
Loss of agricultural productivity	2.41	-	-
Opportunity cost of trash in field	5.59	5.37	6.50
Trash separation from cane	-	2.79	3.69
Trash processing	0.89	0.85	1.14
Difference of industrial results	-	-1.13	-0.37
Trash total cost U$/dry ton	18.49	31.12	13.70

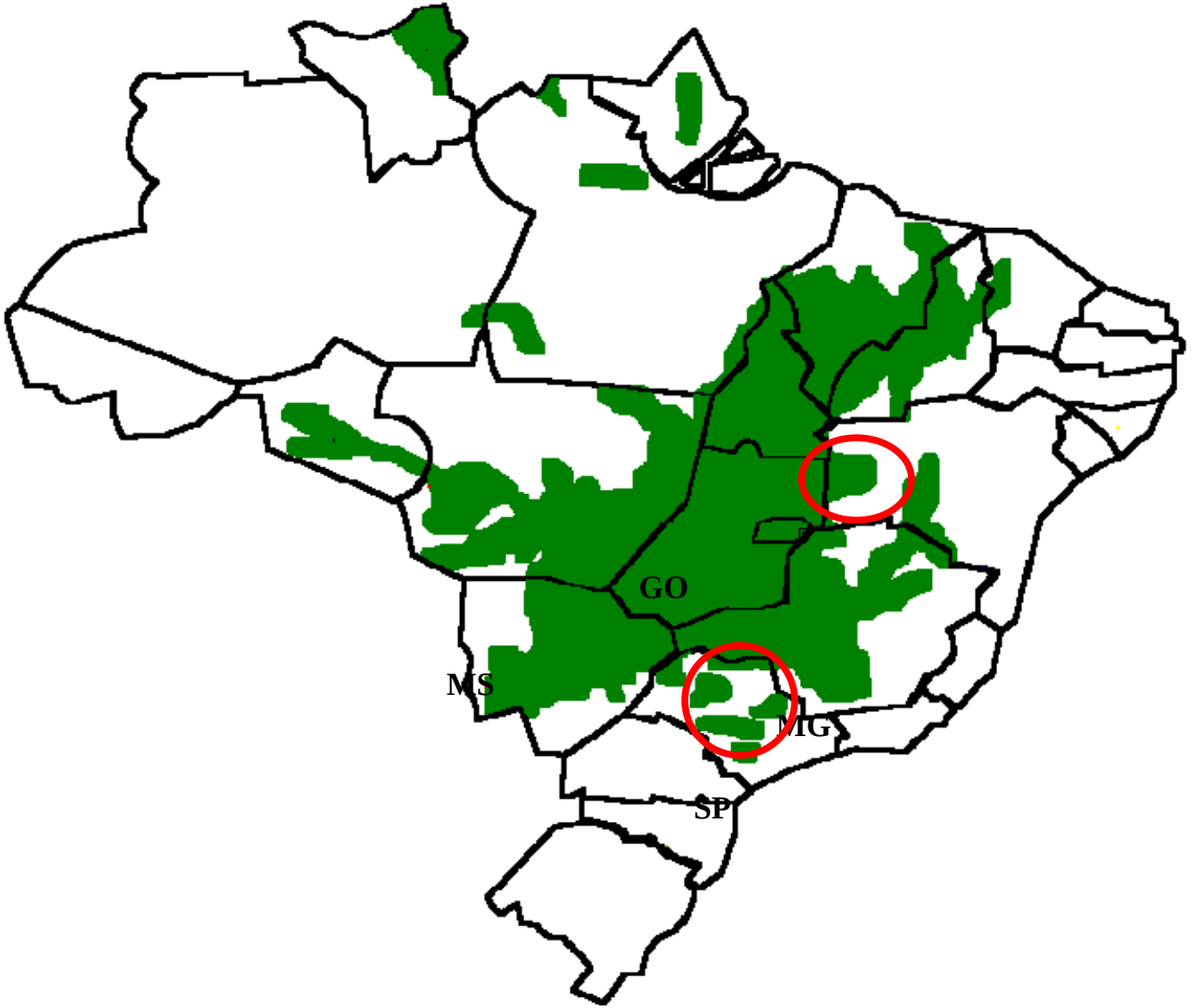
1 dry ton of trash ≈ 18 GJ

Alternative 1 – baling

Alternative 2 – no cleaning during harvesting, low density transportation

Alternative 3 –partial cleaning

New Areas for Expanding Sugarcane Production in Brazil: 90 million ha of available arable land



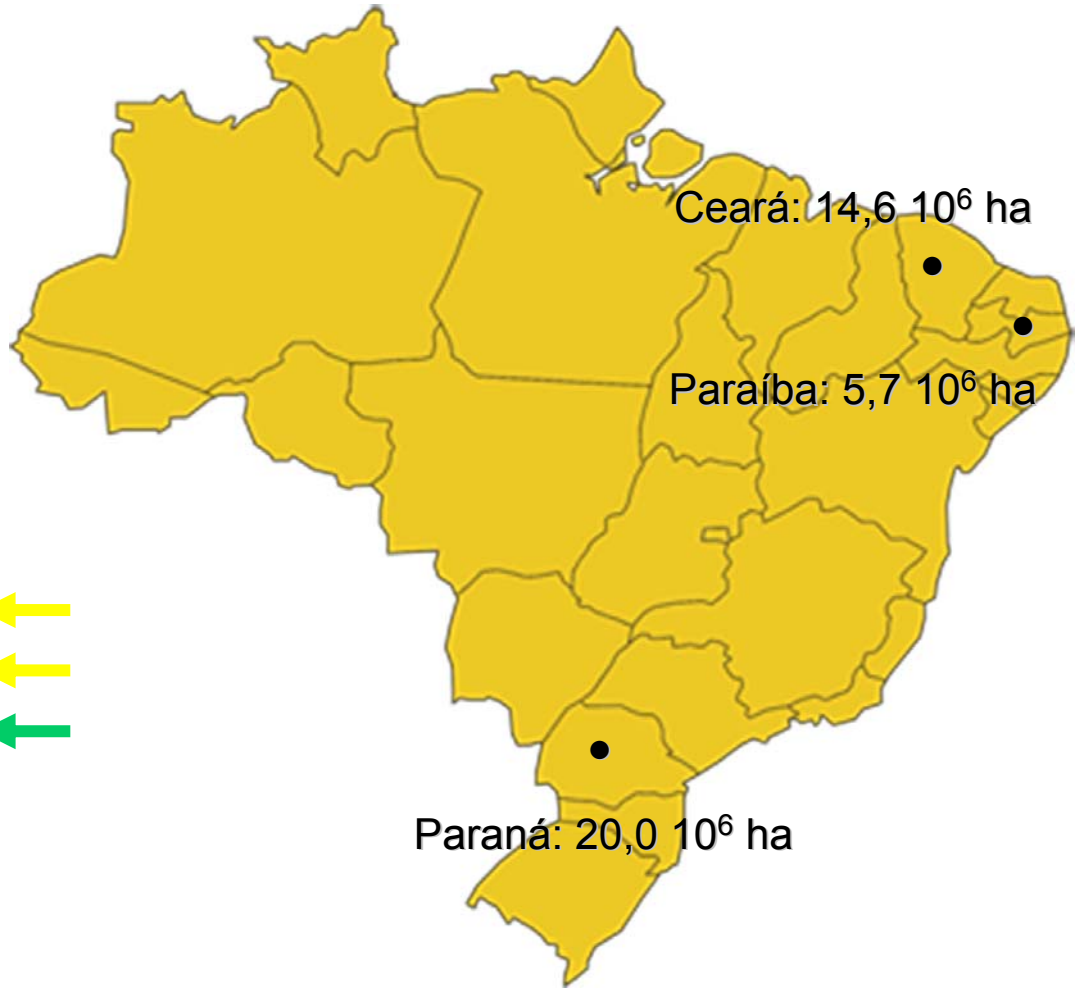
Sugarcane Expansion Potential

	Million ha
Brazil	850
Total arable land	320
Cultivated land:	
all crops	60.40
Sugarcane	5.34
Sugarcane for ethanol	2.66
Available area for crop expansion	90.0

Brazil: main crops 2004

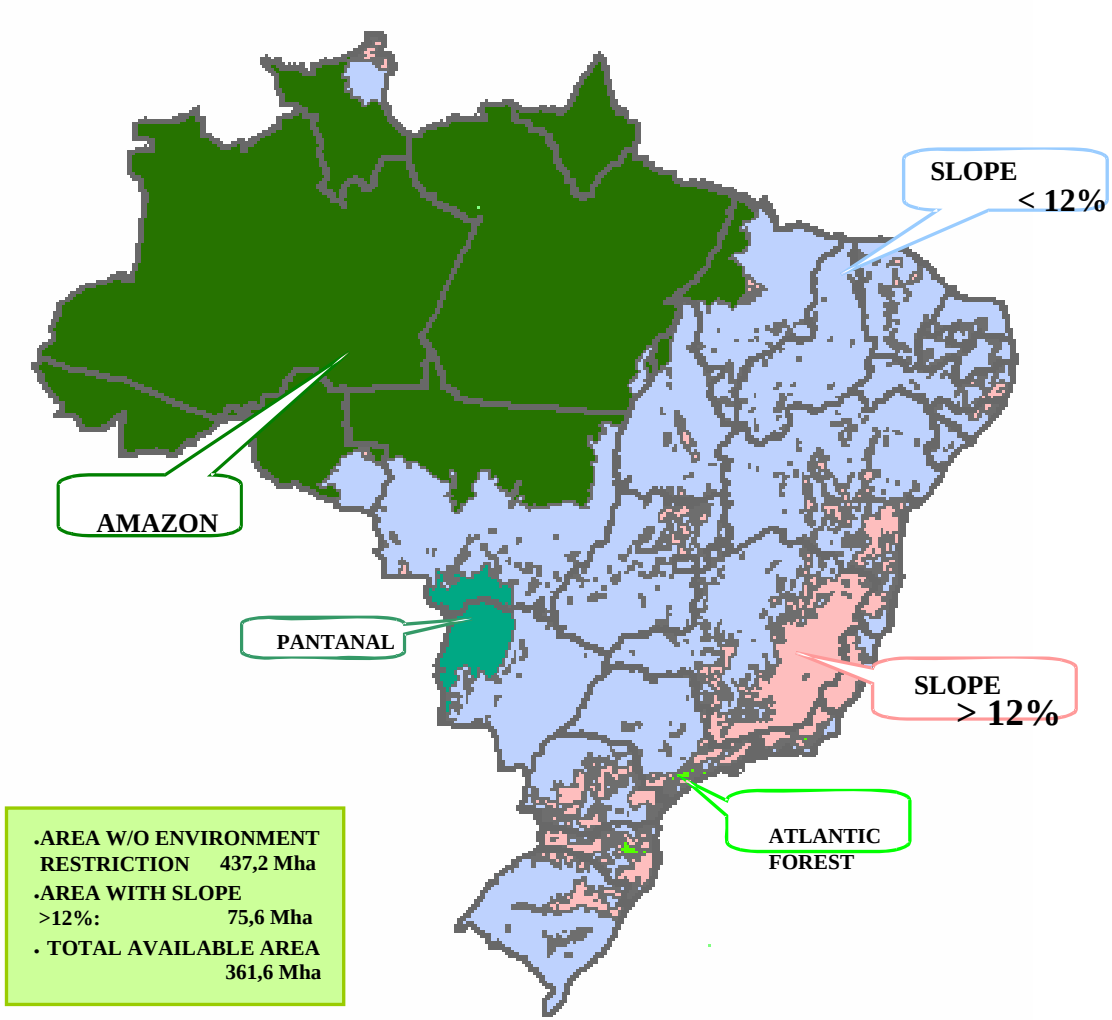
Brazil: 851 10^6 ha

	Surface [10^6 ha]
Pasture	150-200
Soya	21.5
Corn	12.3
Sugarcane	5.6
Agric. land	58.0



Specific Objectives of the BIOETHANOL project:

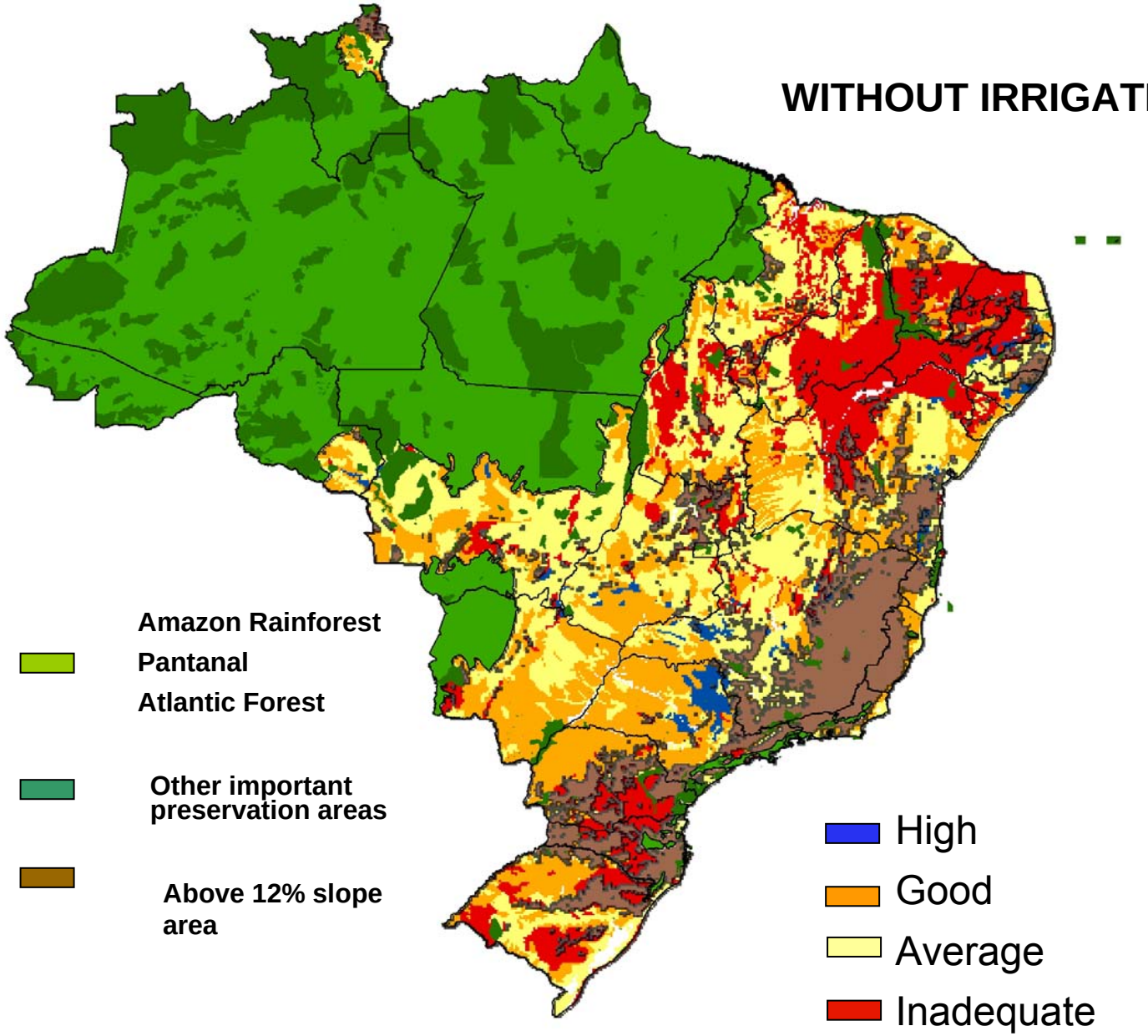
- **OE1**: **Present technology** and possible improvements
- **OE2**: Assessment of **new technologies**
- **OE3**: Selection of **potential suitable areas** for sugarcane production in Brazil
- **OE4**: **Infra-Structure: existing and need for improvement and expansion**
- **OE5**: Assessment of **socio-economic impacts**
- **OE6**: Construction of **ethanol production scenarios and socio-economic impacts**
- **OE7**: Assessment of **environmental impacts**
- **OE8**: **Legislation and policies** in diferent countries: producers and buyers



Main areas with environmental restriction and slope

Source: based on CTC (2005) data

POTENTIAL FOR SUGAR CANE PRODUCTION: SOIL AND CLIMATE



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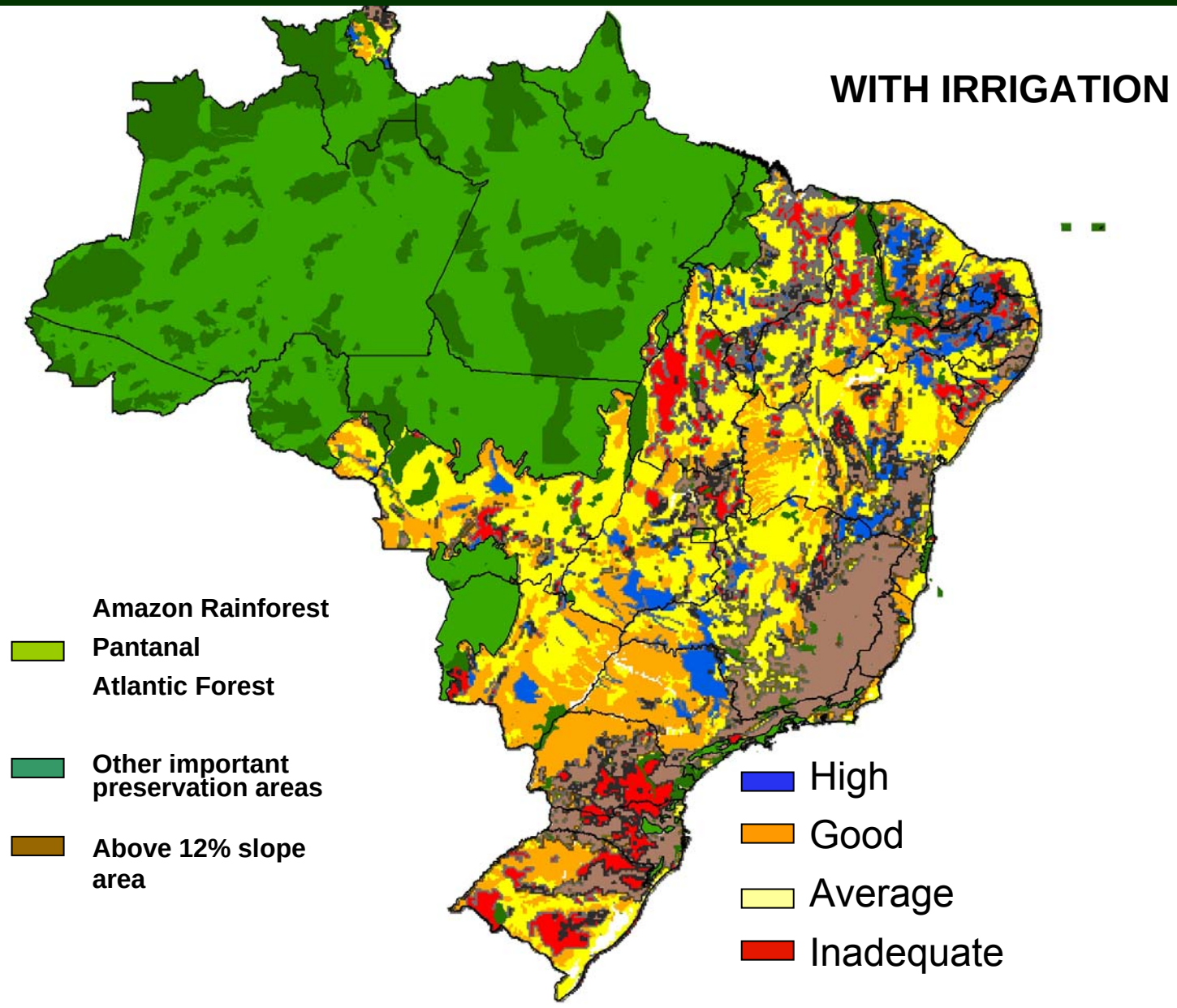


Possible Gains in Productivity

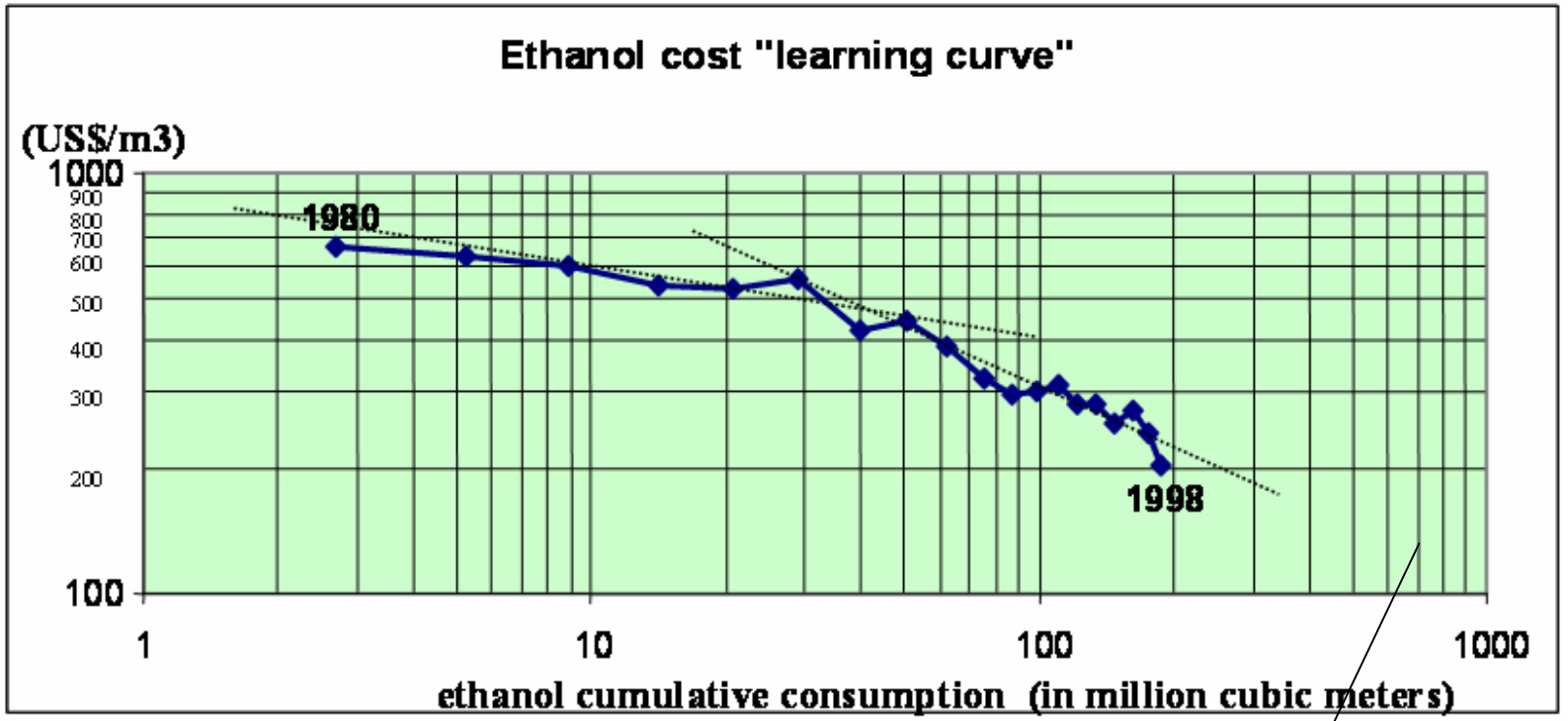
* **Hydrolysis if fibers (bagasse and trash)**
* **Raw sugarcane harvesting – trash recovery**

	2005		2015		2025	
Technology	l/tc	l/ha	l/tc	l/ha	l/tc	l/ha
Conventional	85	6,000	100	8,200	109	10,400
Hydrolysis	---	----	14	1,100	37	3,500
Total	85	6,000	114	9,300	146	13,900
Area Needed for 205 billion l		**34 M ha**				**15 M ha**

Guarantee of Supply

- Negotiation of long term contracts for exports that allow to plan ethanol production in Brazil and program deliveries
- Possible areas for bilateral cooperation: production and trade of ethanol, logistics for transport and new technologies

Learning Curve – Brazilian Ethanol



Goldemberg, J.

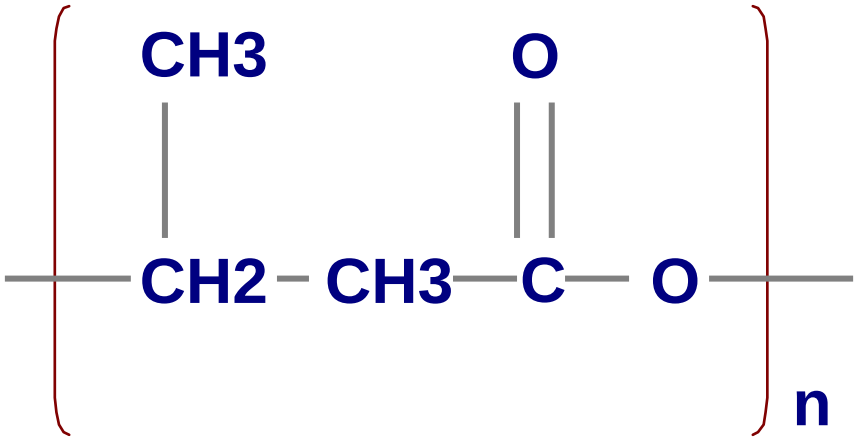
?

Future situation

- **Better varieties: bioethanol sugarcane varieties, energy sugarcane?**
  - **Lower lignin content, due to sugarcance genome?**
  - **Lignocellulose balance content?**
  - **Structural changes?**
  - **Native cellulases maximized?**
- **Bioethanol photosynthesis conversion?**
- **Termochemical BTL (biomass-to-liquids) or gaseification + fermentation? Feasible?**

Integrated production of sugar, bioethanol and poly-hydroxy butyrate from sugar cane

PHB Chemistry



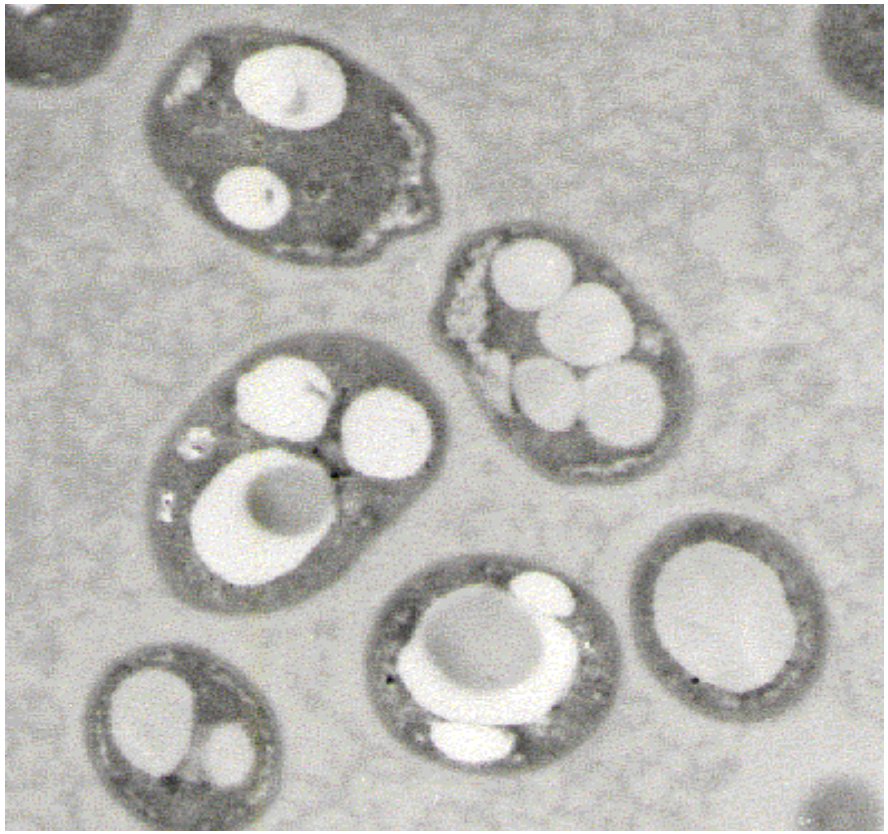
POLY-3-HYDROXYBUTYRATE (PHB)

Fermentation of Ralstonia eutropha for PHB production

- *Aerobic Fermentation:*

✓*Cells growing*
✓*PHB accumulation*

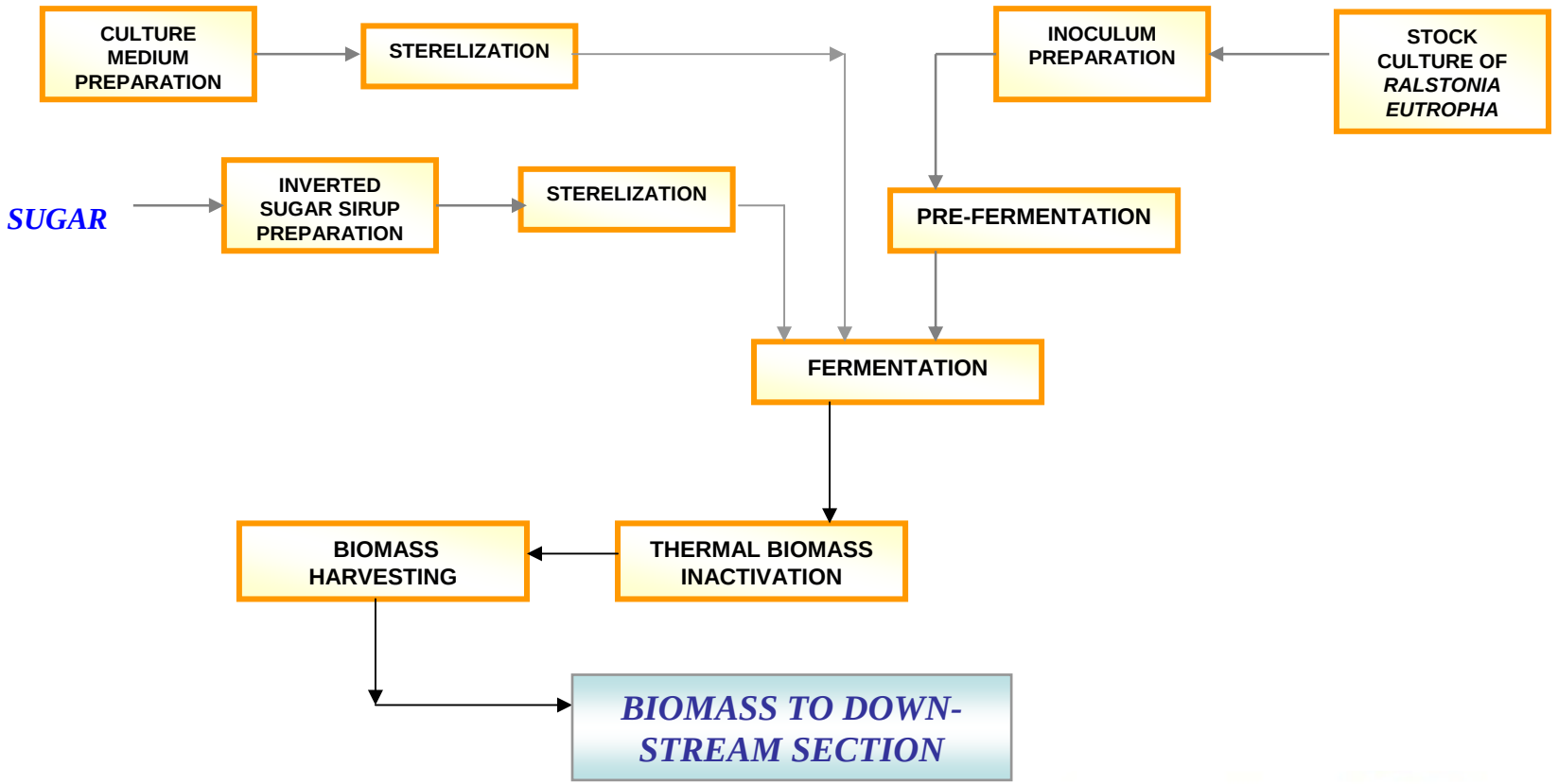
- *Picture shows Cells stroring PHB*
- *40 - 50% of total dry biomass stored as PHB*
- *Electronic Microscope picture magnified X 10000*



PHB Production Process - Technical Coefficients

Sugar consumption:	**3,0 kg/kg of PHB**
Biomass yield (dry basis):	**150kg/m3 of fermentation wine**
Fraction of PHB in biomass	**- 75%**
fermentation time:	**-60 hours**
Yield related to PHB extraction:	**-near 95%**
Energy consumption:	**-3,6 KWh/kg PHB (provided by cane bagasse remaining after sugar extraction)**
Steam consumption:	**35 kg/kg de PHB (provided by cane bagasse remaining after sugar extraction)**
Investment:	**U$S 4000-6000 per ton of PHB/year**

PHB FERMENTATION - FIRST STEP



PHB DOWNSTREAM STEP

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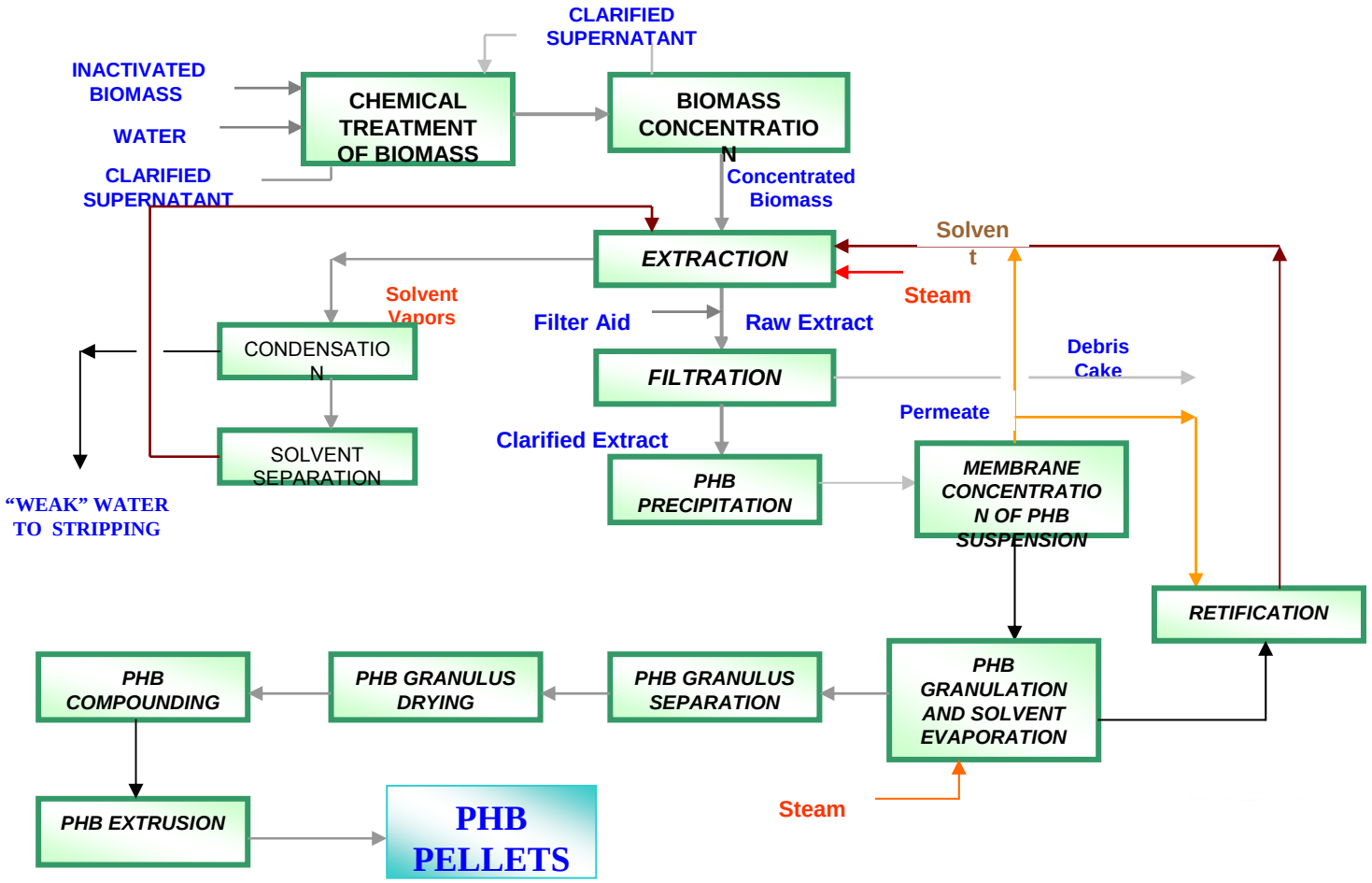


Physicochemical Properties of PHB

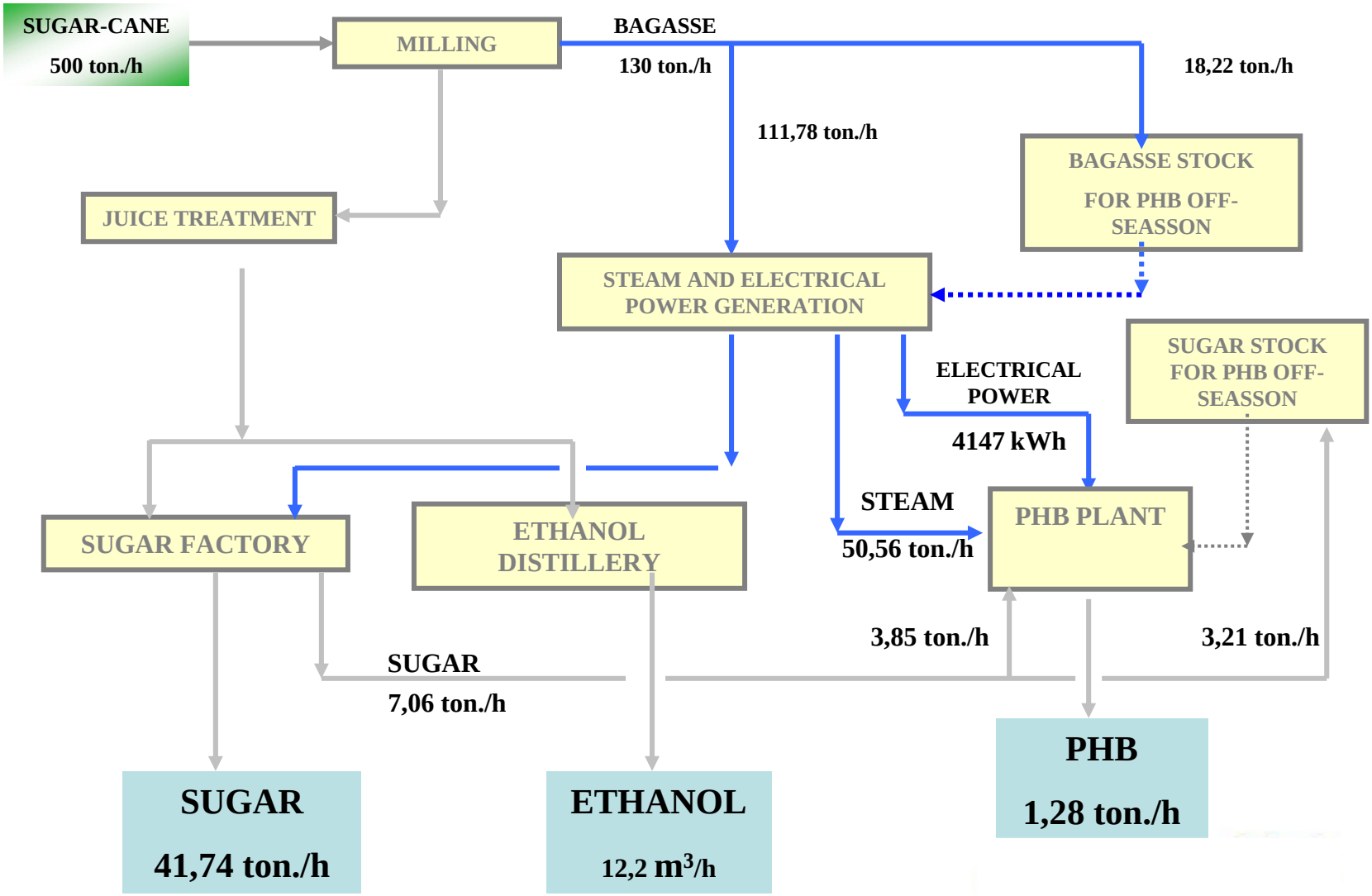
Properties	Values
Molecular Weight range (Da)	250.000 – 600.00
Specific Gravity 25°C (g/cm^3)	1,25
Melting point (°C)	168,0 – 172,0
Vitreous transition point (°C)	1,0 – 5,0
Decomposition temperature (°C)	250,0
Cristallinity (%)	60,0 – 70,0
Specific Heat (J/kg.°C)	1,32 – 1,36

PHB content:	**99.8%, dry basis**
Nitrogen content:	**< 0.05%, dry basis**
Ash content:	**< 0.1%, dry basis**
Residual solvent:	**2-5 ppm**
Moisture:	**< 0.15%**
Appearance:	**Yellowish white granulated solids**

Integrated Production of PHB, SUGAR and ETHANOL

Premisses	
Sugar and ethanol season:	***180 days***
PHB production:	***300 days***
PHB:	***10,000 Ton/year***
Cane Milling:	***2,160,000 Ton/season***
Sugar:	***180,000Ton/season***
Ethanol:	***52,575 m^3/season***

Integrated Production of PHB, SUGAR and ETHANOL (10.000 ton./year of PHB)



PHB PILOT PLANT

PHB INDUSTRIAL S/A

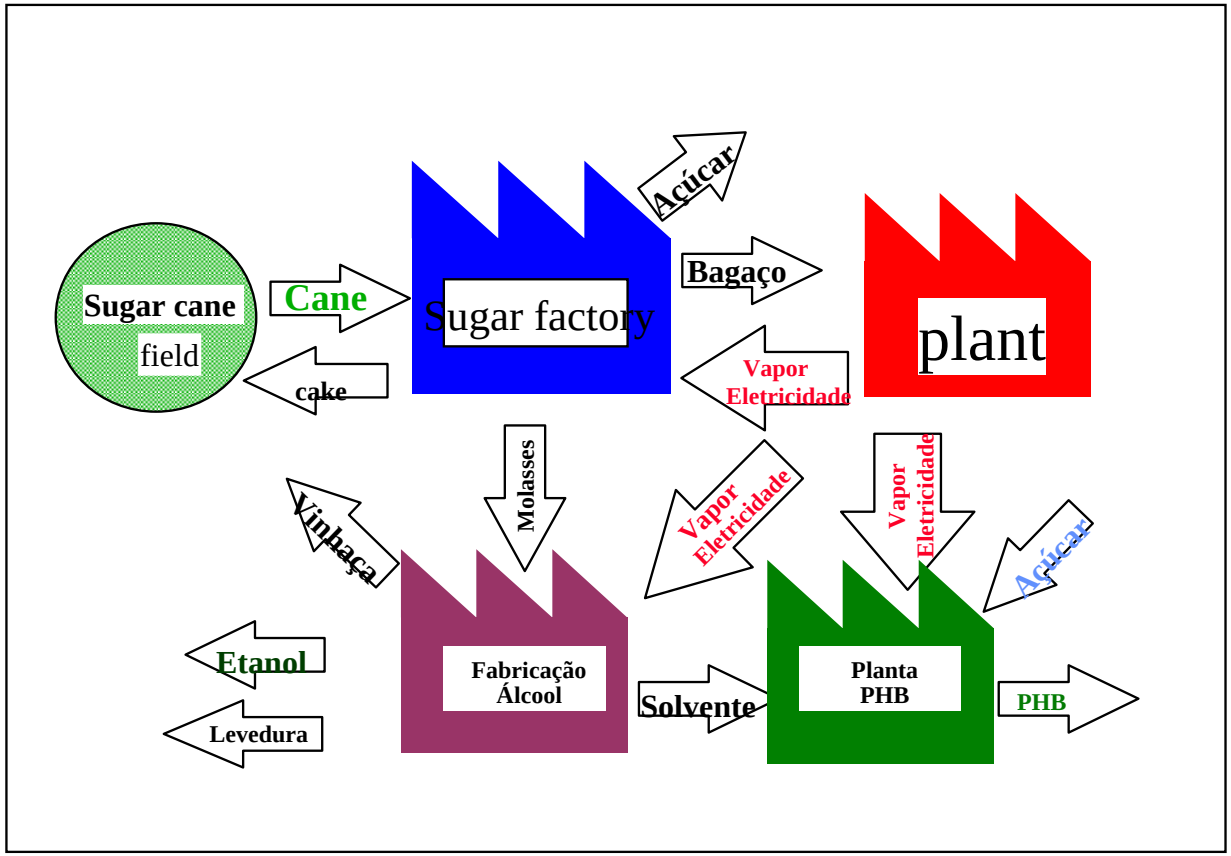
SERRANA-S.PAULO

BRAZIL

Capacity: 50 ton./year

Advantages of integrated production sugar, bioethanol and PHB

- Sugar substrate
- Sugar-mill facilities:
- heating & cooling,
- electric power,
- water, efluent treatment & disposal



Very recent improvements

- *Achieved*
- PHB from xylose and from sugar cane hydrolisates → "perfect" yield by 3 natural strains (~60 g/L biomass with 60% PHB),
- Improvement of rigidity was achieved by producing PHA of medium-chain length (C6-C12), lower final yield of polymer, but able to produce films.

- *To be optmized:*
- the whole process can be improved, as energy consuption, downstream, better and more selective solvent,

PHB Granules after Downstream Processing

PHB Pellets after final compounding

Samples prepared by injection moulding of PHB resin

Thank you

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