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Biomass Resources and Conversion Efficiencies in the Cultivation and Processing of Sugarcane Ethanol and Electricity

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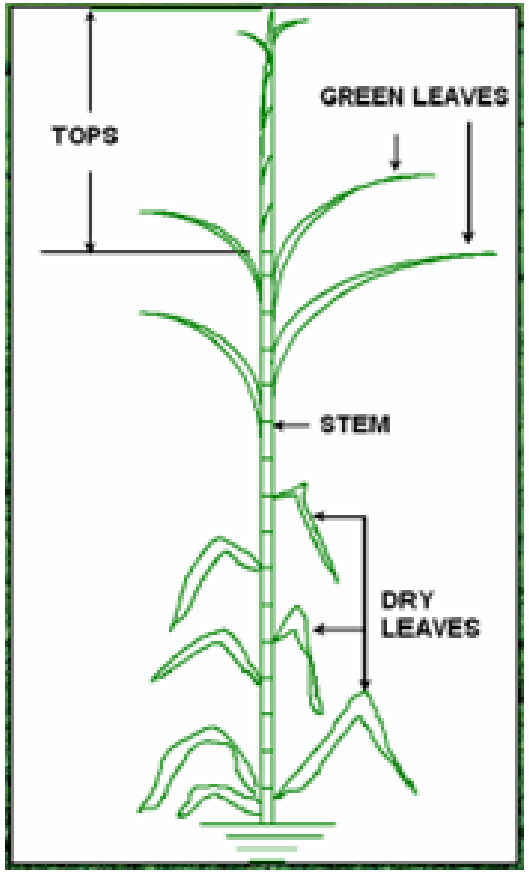
Sugarcane



Component	%mass
Water	65-75
Sugars	11-18
Fibers	8-14
Soluble solids	12-23

Trash Availability

Variety	Stage of Cut	Yield (t/ha)	Trash* (t/ha)	Trash/stalk ratio
SP79-1011	Plant cane	120	17.8	15%
	2nd ratoon	92	15.0	16%
	4th ratoon	84	13.7	16%
SP80-1842	Plant cane	136	14.6	11%
	2nd ratoon	101	12.6	13%
	4th ratoon	92	10.5	11%
RB72454	Plant cane	134	17.2	13%
	2nd ratoon	100	14.9	13%
	4th ratoon	78	13.6	17%
Average		104	14.4	14%

*Dry matter

Source:Hassuani et al., 2005

Trash - Proximate Analysis and HHV

Determination % weight(*)	Dry leaves	Green leaves	Tops	Bagasse
Moisture content	13.5	67.7	82.3	50.2
Ash	3.9	3.7	4.3	2.2
Fixed carbon	11.6	15.7	16.4	18.0
Volatile matter	84.5	80.6	79.3	79.9
HHV(Mj/kg)	17.4	17.4	16.4	18.1

(*) Dry basis

Source:Hassuani et al., 2005

Trash Ultimate Analysis

Determination % weight	Dry leaves	Green leaves	Tops	Bagasse
Carbon	46.2	45.7	43.9	44.6
Hydrogen	6.2	6.2	6.1	5.8
Nitrogen	0.5	1.0	0.8	0.6
Oxygen	43.0	42.8	44.0	44.5
Sulfur	0.1	0.1	0.1	0.1
Chlorine	0.1	0.4	0.7	0.002

Source: Hassuani et al., 2005

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Trash Ultimate Mineral Analysis

Determination	Dry leaves	Green leaves	Tops	Bagasse
Content(g/kg)*				
P_2O_5	0.5	2.0	2.5	0.5
K_2O	2.7	13.3	29.5	1.7
CaO	4.7	3.9	2.6	0.7
MgO	2.1	2.2	2.5	0.5
Fe_2O_3	0.9	0.5	0.2	2.3
Al_2O_3	3.5	1.4	0.5	2.3
Content(mg/kg)*				
CuO	<0.6	<0.6	<0.6	-
ZnO	9	15	35	-
MnO_2	169	120	155	62
Na_2O	123	128	119	45

*Dry Basis

Source: Hassuani et al., 2005

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Reference Sugarcane

Components	kg/tc[1]	Energy (MJ/tc)[2]
Sucrose	142	2360
Reducing sugars (glucose, fructose)	6	94
Stalk fibers	130	2340
Straw fibers	140	2520
Total		7,314

Notes:

1. kg (db) per tonne of clean stalk (wb)
2. HHV

Sugarcane Participation in Brazilian Primary Energy Production

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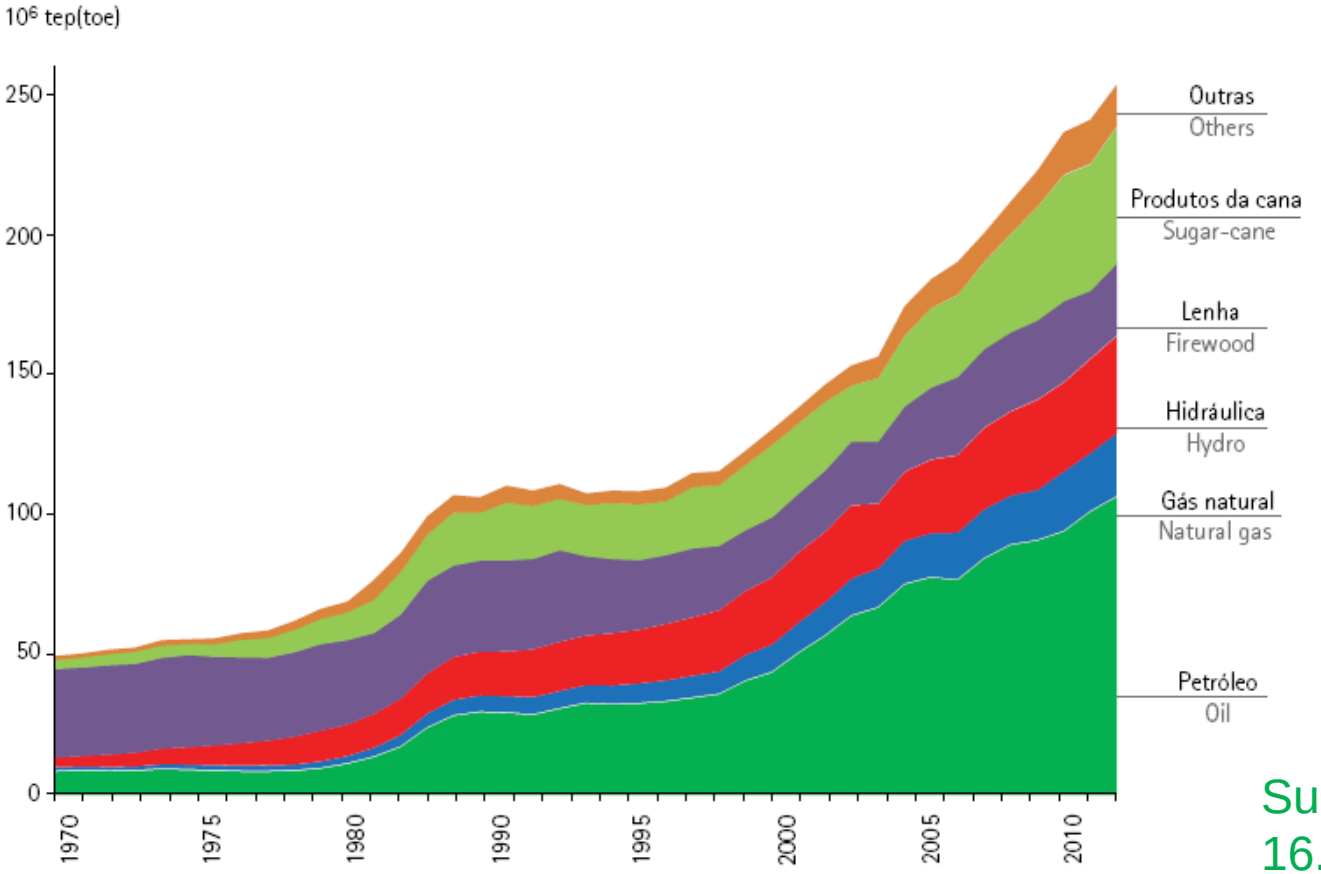
Chart 1.2.a – Primary Energy Production



Sugarcane represents 16.9% of the Primary Energy Production

Source: Brazilian Energy Balance 2012 (year 2011)

Energy Recovery

1 tonne of clean stalks

Products	Energy (MJ)
86 L ethanol[1]	2,000
11.4 kg bagasse, db	205
Total	2,205

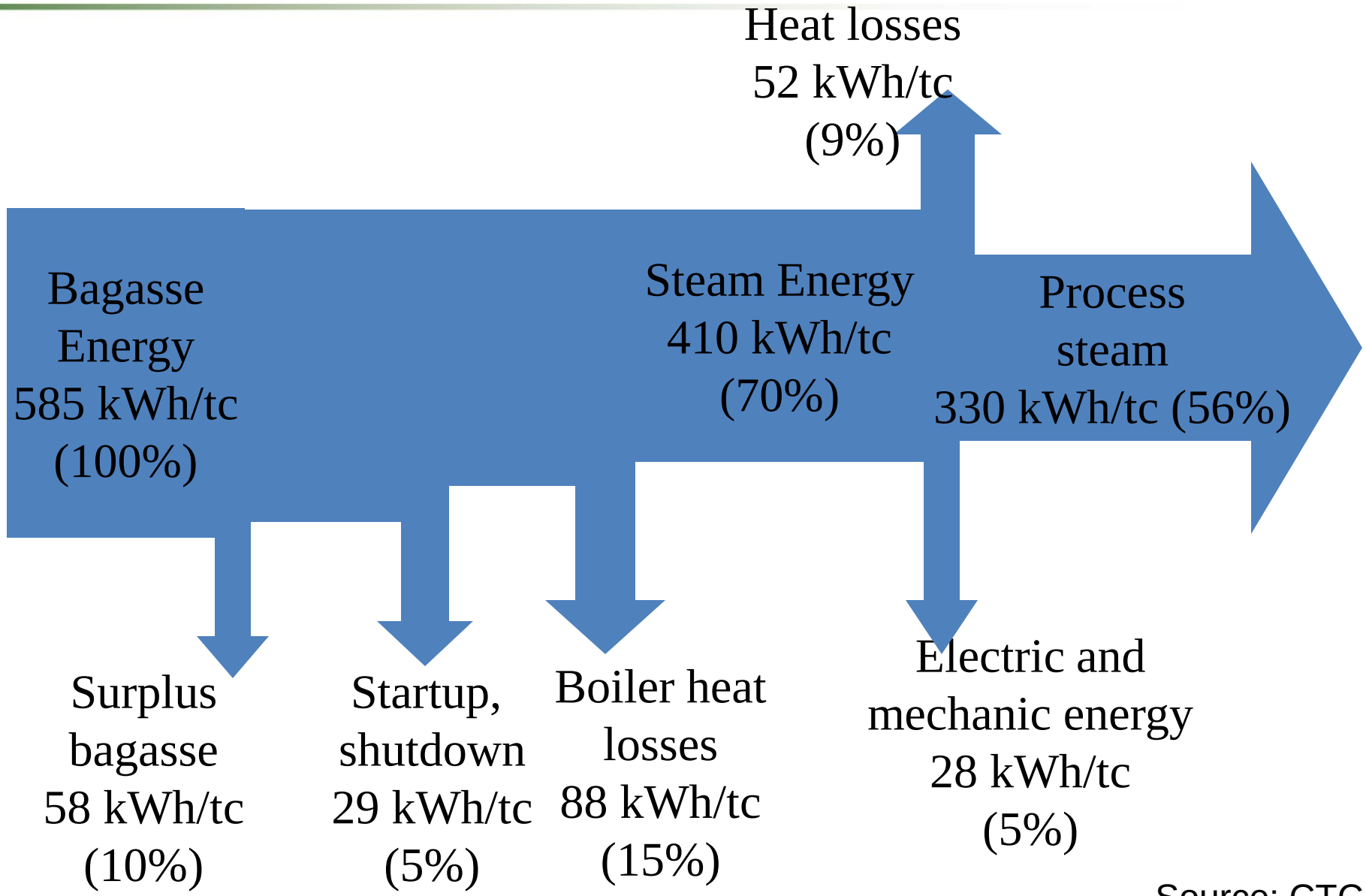
Recovery efficiency = 30.1%

How to Improve Sugarcane Energy Performance?

- **Increase conversion of primary energy to useful energy:** better distillery sugar conversion to ethanol and make better use of the fibers.

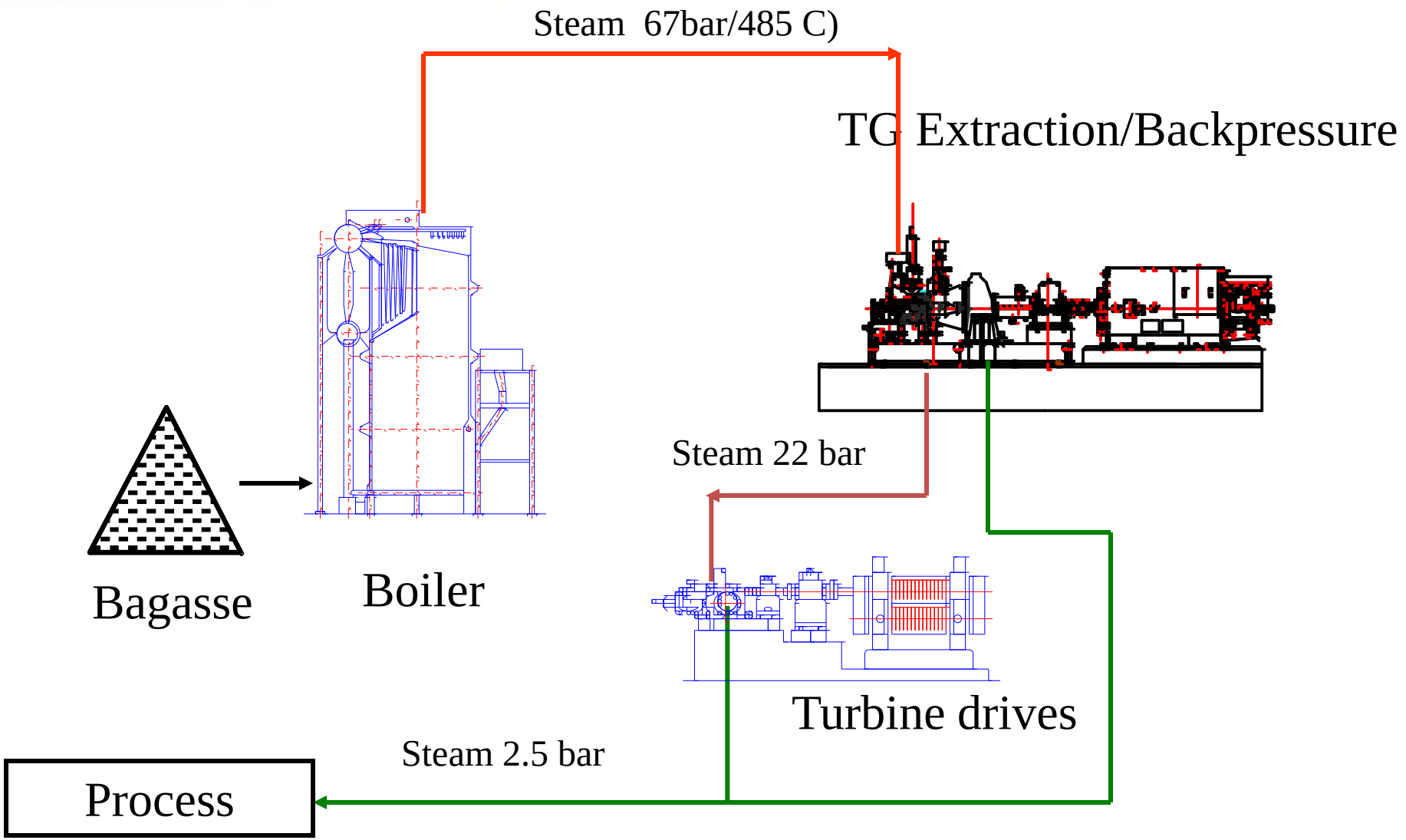
- **Develop a better energy feedstock:** breed cane for maximum primary energy per hectare, even at a cost of lower sugar content – energy cane.

Energy Flow in the Distillery

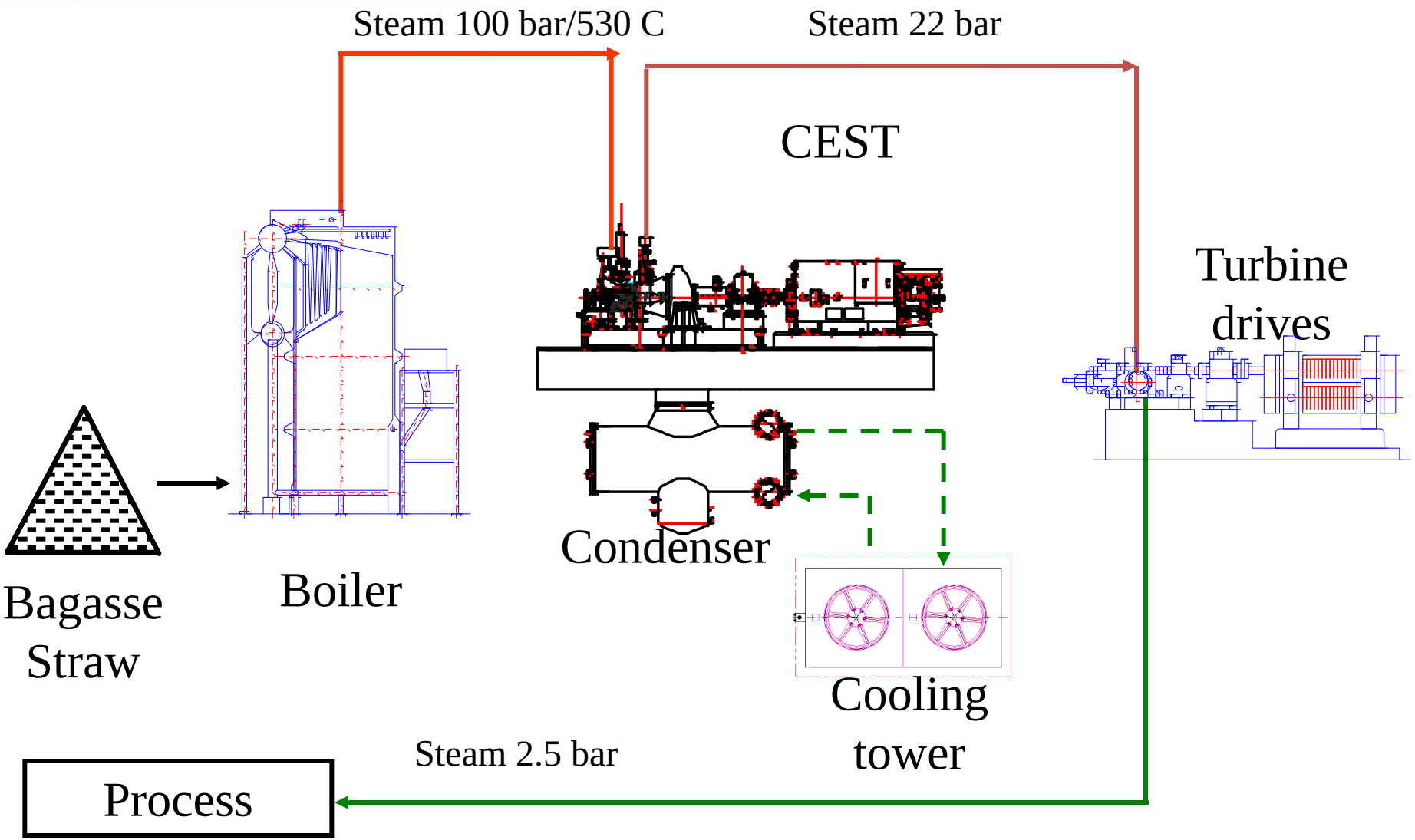


Source: CTC

Power Generation – BP TG



Power Generation - CEST



Energy Recovery with Electricity Cogeneration (backpressure TG)

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1 tonne of clean stalks

Products	Energy (MJ)
86 L ethanol	2,000
60 kWh	216
11.4 kg bagasse, db	205
Total	2,421

Recovery efficiency = 33.1%

Energy Recovery with Electricity Cogeneration (CEST)

1 tonne of clean stalks

Products	Energy (MJ)
86 L ethanol	2,000
100 kWh	360
Total	2,360

Recovery efficiency = 32.3%

Energy Recovery with Electricity Cogeneration (CEST)

1 tonne of clean stalks + 50% straw

Products	Energy (MJ)
86 L ethanol	2,000
155 kWh	558
Total	2,558

Recovery efficiency = 35.0%

Energy Recovery with Electricity Cogeneration (CEST)

1 tonne of clean stalks + 100% straw

Products	Energy (MJ)
86 L ethanol	2,000
210 kWh	756
Total	2,540

Recovery efficiency = 37.7%

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Summary of Alternatives

Useful energy (MJ/tc)	No surplus EE	Surplus EE (BP TG)	Surplus EE (CEST)	Surplus EE (50% straw)	Surplus EE (100% straw)
Etanol	2000	2000	2000	2000	2000
Surplus bag.	205	205	0	0	0
Surplus EE[1]	0	216	360	558	756
Total	2205	2421	2360	2558	2756
Energy eff. (%)	30.4	33.1	32.3	35.0	37.7
Energy/ha[2] (GJ/ha)	**154**	**169**	**165**	**179**	**193**

Notes:

1. Souce Olivério (2008) with author adaptations
2. Sugarcane yield 70 tc/ha/yr

Comments on Energy Recovery

- The partial recovery (50% here) and use of straw for surplus power generation adds considerable gains in energy efficiency, but it is still low; 100% recovery is not possible nor desirable
- The sale of this additional surplus electricity has a significant impact in the economics of the distillery;

Straw Recovery in Brazil

- In Brazil the process is still incipient
- Two basic routes have survived the initial trials
  - **Integral cane**: the straw and cane are brought together to the mill and separated there in a dry cleaning station and then is processed and mixed with bagasse in its way to the boilers
  - **Baling**: the straw is windrowed, baled, transported to the mill and processed and mixed with bagasse in its way to the boilers

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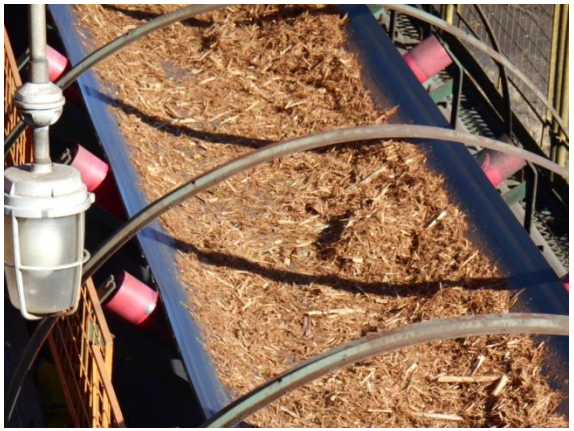
Mechanical Harvesting of Green Cane

Integral Cane

Dry Cleaning Station



Straw conveyor

Mineral impurities removal and straw shredding

Baling

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Bale Transport

Straw Recovery Problems

- **Integral cane**
  - Decrease in cane load density: higher transport costs
  - Low efficiency of the dry cleaning station: higher fiber in milled cane resulting in lower milling rate, higher sugar carryover, higher energy consumption, other
- **Baling**
  - Large amount of mineral impurities
  - Bale storing and processing at the mill need improvement
  - Soil compaction and ratoon damage (decrease yields)
  - Higher recovery costs except for longer distances

Critical Issues

- Quality: high levels of mineral impurities
- Agronomic impacts of straw removal: SOC, erosion control, soil emissions, fertilizer efficiency, weed control, pests, water balance, fire hazard, ratoon sprouting, frost
- Use in bagasse fired boilers: lack of experience (corrosion, deposits, slagging, efficiency)
- Storage and transport cost in the mill
- Last but not least: how much is needed in the field

Energy Cane

- It is an old concept dating from the 1970s, but never reached a true commercial stage;
- Lately, the interest has revived in USA (Florida), Barbados, Mauritius, Reunion, Brazil;
- There are several varieties in this category;
- There are no available information on harvesting and processing this type of cane.

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Energy Cane Varieties

Variety	Yield (tc/ha)	Sugar (%)	Fiber (%)	Straw%cane	GJ/ha
R779[1]	88.1	13.1	14.8	14	648
R92/0804[2]	123.2	12.6	19.0	16	1034
B77602[3]	77.6	17.3	14.8	17.8	678
WI814456[4]	125.4	8.9	23.9	17.3	1115

Notes:

1. Reunion commercial variety
2. Reunion energy cane variety
3. Barbados commercial variety
4. Barbados energy cane variety

Comments on Energy Cane

- The primary energy per hectare is really impressive and well above the commercial varieties;
- The conversion efficiency of the primary energy into useful energy is expected to be lower since sugars are more efficiently converted to fuel while the conversion of fiber to electricity is subjected to the 2nd Law of Thermodynamics

Sugarcane Renewable Electricity (SUCRE) Project

- Objective: create the necessary conditions to increase surplus power generation by the sugarcane mills using straw to supplement bagasse.
- How:
  - helping 3 mills to establish the commercial scale use of straw in power generation by eliminating the barriers identified: technological, financial, information and regulatory.
  - Disseminating the results and using the 3 mills as examples of success. Make feasibility studies for 7 additional mills.
  - Making the project results widely available.
- Project duration: 5 years

Project Structure

- Supporter: Global Environment Facility (GEF)
- Implementing Agency: UNDP
- Executing Agency: CTBE
- Budget (US$)

GEF	7,800,000
CTBE	3,750,000
Mills (3)	55,800,000
UNICA	100,000
Total	67,450,000

Main Barriers Identified

- **Technological**: lack of a commercial technology widely accepted to recover, transport, process and use.
- **Financial**: the lack of a proven commercial technology decreases the confidence of investors and banks.
- **Information**: there are no reliable and accescible information about the required investments, performance indeces, agronomic impacts and impacts on the mill.
- **Regulatory**: the existing regulatory framework does not favor the sale of electricity produced by the mills (the mills have to bear all the costs of the interconnection including the transmission lines, competition from wind power at the same conditions, etc.).

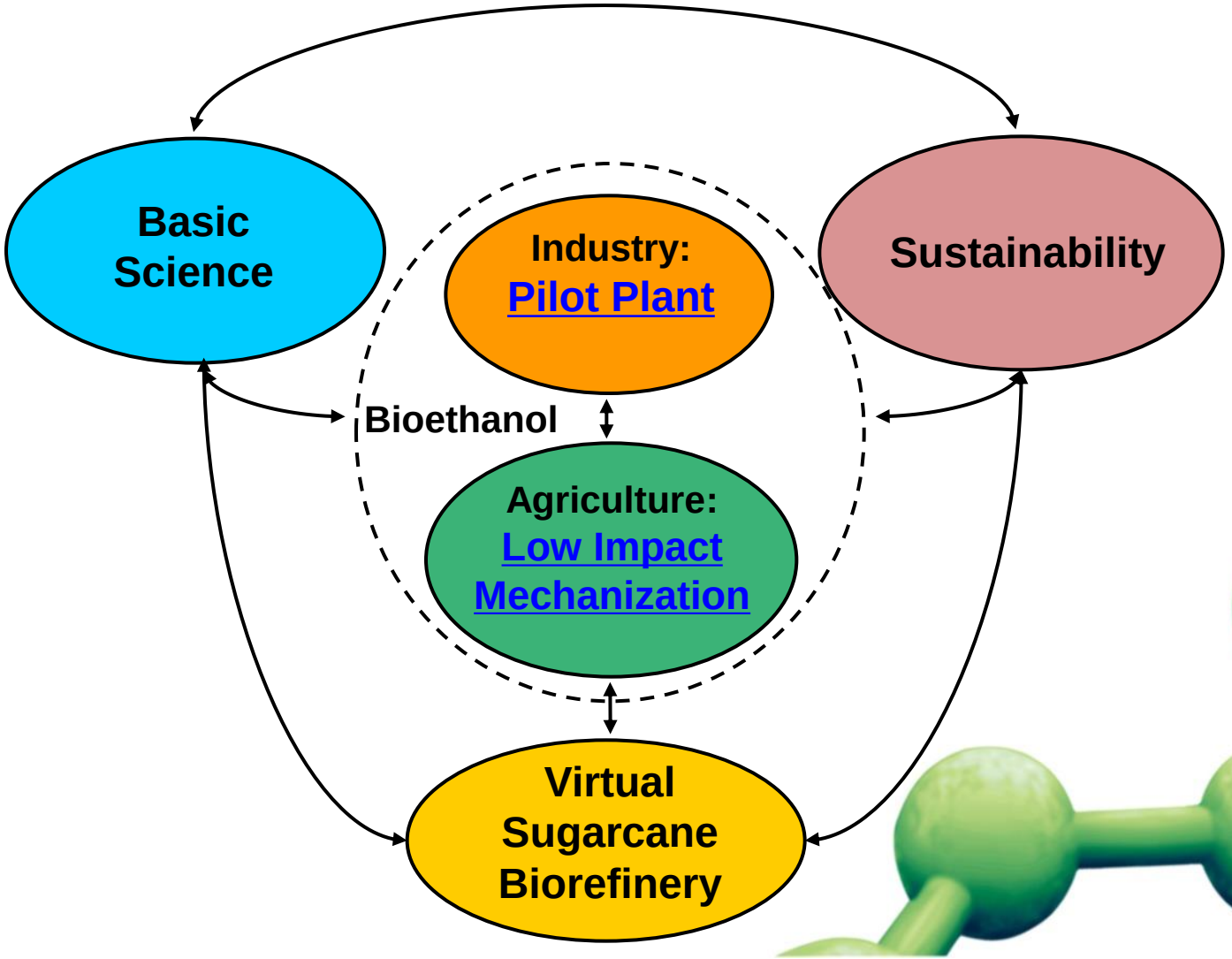
Final Comments

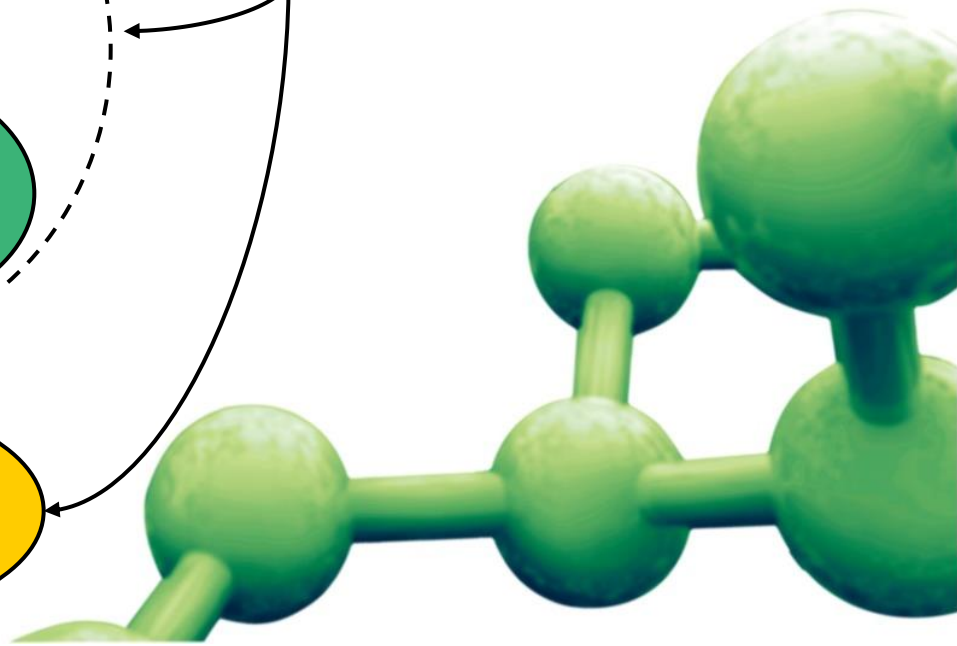
- Sugarcane has an enormous potential as an energy crop;
- This potential is today largely untapped due to, mainly, the inefficiency in the conversion of the cane primary energy to useful forms of energy (ethanol and electricity);
- One key issue in this inefficiency is related to the bad use of the cane fibers: bagasse is used to provide all energy required to operate the plant with little concern with plant efficiency (mainly process steam consumption); straw resulting from unburned cane harvesting is normally left in the field to decay.
- There is a growing interest in recovering the straw to generate more electricity by supplementing the bagasse and the new mills are coming with an efficient process and high pressure boilers and TG's;
- There is no proven technology to recover and process the straw economically and reliably in spite of several mills attempting different solutions;
- The regulatory framework for power sales is inhibiting investments toward increase of surplus power generation.

CTBE Projects Related to Straw Recovery

- CTBE – Brazilian Bioethanol Science and Technology Laboratory;
- It is a National Laboratory funded by the Ministry of Science, Technology and Innovation;
- Fully dedicated to sugarcane ethanol.

CTBE Research Programs





Main Activities

- **Sustainability**: field measurements and model simulations of the impacts of removing different amounts of straw from the field in the soil C and emissions, water balance, cane yields, weed, pests and diseases.
- **Agricultural**: new mechanization technology to harvest cane with straw recovery with reduced fossil energy consumption and soil compaction.
- **Industrial**: characterization of straw and bagasse, characterization of ashes, use of straw and bagasse for 2G ethanol production.
- **Basic Science**: plant CO_2 conversion to biomass or sugars, yields and traits, enzyme production, straw decay dynamics.
- Virtual Biorefinery: simulations with different recovery rates and commercial uses (2G ethanol or EE)

Questions?

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