

POTENTIAL ROLE OF A SUPERHEATED STEAM DRYER IN AN ENERGY CANE / SWEET SORGHUM BIOREFINERY

L. S. Polanco, D. F. Day – Audubon Sugar Institute - AgCenter

V. Kochergin – Amalgamated Research LLC.

J. Alvarez – Sugar Cane Growers Cooperative of Florida

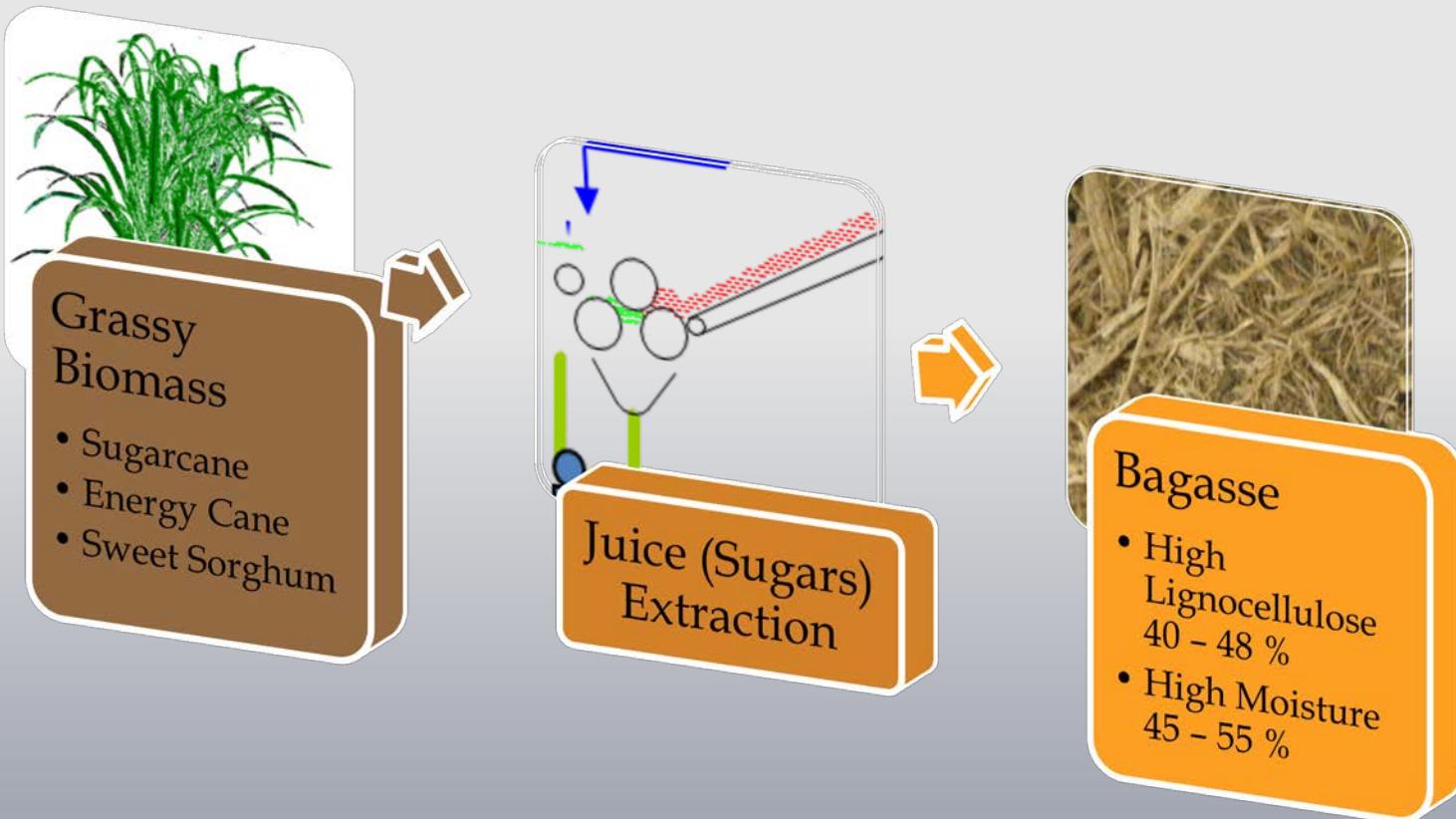
Sustainable Bioproducts Initiative – SUBI

Annual Meeting

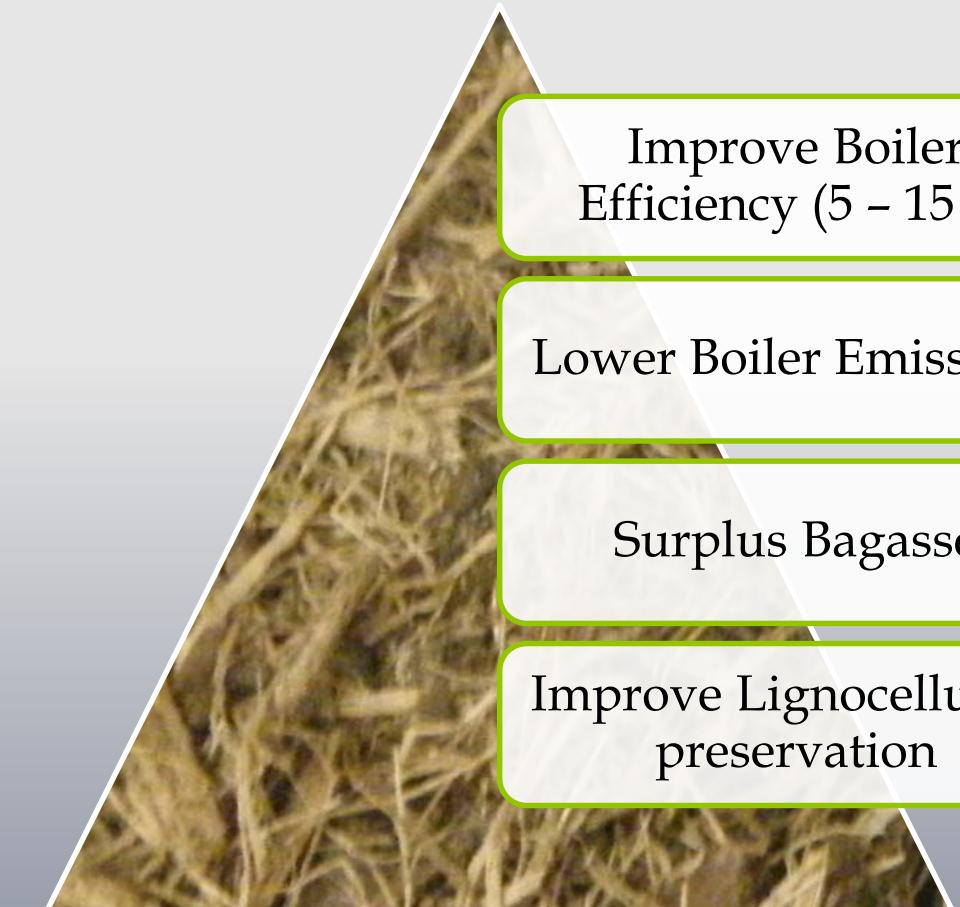
Baton Rouge LA, May 28, 2014



Bagasse Production



Why Dry Bagasse



Improve Boiler Efficiency (5 - 15%)

Lower Boiler Emissions

Surplus Bagasse

Improve Lignocellulose preservation

Wet Bagasse	Dry Bagasse
$\eta=60\% @ 52\% MC$ 1.6 kg steam/kg bagasse (19 bar, 269 °C) ⁽¹⁾	$\eta=74\% @ 37\% MC$ 2.0 kg steam/kg bagasse (18 bar, 265 °C) ⁽¹⁾
CO: 400–3300 ppm NOx: 0–154 ppm PM: 0–3600 mg/Nm ³ ⁽¹⁾	CO: 48–361 ppm NOx: 0–135 ppm PM: 0–855 mg/Nm ³ ⁽¹⁾
	12 – 18 % ⁽¹⁾
~25 % Fiber Losses @ 50 %MC (~7 weeks) ⁽²⁾	~7 % Fiber Losses @ 25 %MC (~18 weeks) ⁽²⁾

⁽¹⁾Colombres et. al 2011,

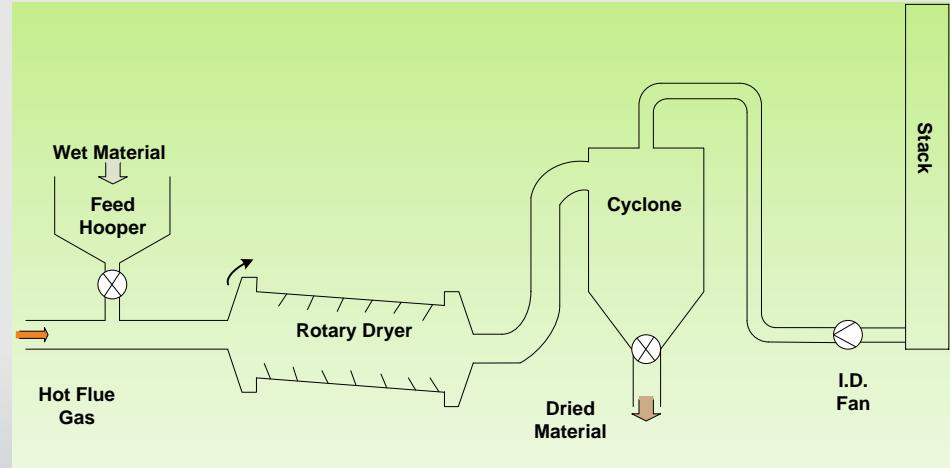
⁽²⁾Luangwilai et al., 2012)



Bagasse Dryers Review

Type and size	Capacity [ton/h]	Energetic source Gas Other	Year	Industry, place	Reference	Observations
Counter current flow	1.4	X	1910	Palo Alto Sugar Factory Donaldsonville, Louisiana	Boulet, W.P. (1975)	Pilot scale
Rotary dryer	30	X	1976	Atlantic Sugar Association, Florida	Furines, J.H. (1976)	$T_{g,o}=218\text{ }^{\circ}\text{C}$
Rotary dryer 3.6mx12 m	50	X	1976	St. Mary Sugar Co., Louisiana	Arrascaeta and Friedman (1987)	$T_{g,o}=315\text{ }^{\circ}\text{C}$
Rotary dryer	35	X	1979	Waialua Sugar Co., Hawaii	Kinoshita, C.M (1991)	$T_{g,o}=244\text{ }^{\circ}\text{C}$
Pneumatic Dryer	4.52	X	1980	Açucareira Santo Antonio, Brazil	Correia, L.E.M (1983)	$T_{g,o}=220\text{ }^{\circ}\text{C}$
Pneumatic Dryer	12	X	1981	Barra Grande sugar factory Lençois Paulistas SP, Brazil	Nebra, S.A. (1985)	
Pneumatic Dryer	9.7	X		Cruz Alta Plant, Olímpia, SP, Brazil	Sanchez, M.G. (2001)	
Rotary dryer 3.6mx9m	65		1980	Davies Hamakua Sugar Co., Paauilo - Hawaii	Kinoshita, C.M (1991)	
Rotary dryer 4.2mx9 m	10.7			Hilo Coast Processing Co., Pepeekeo, Hawaii	Kinoshita, C.M (1991)	pellets
Pneumatic Dryer	72		1980	Paia Factory of HC&S Co., Maui, Hawaii	Kinoshita, C.M (1991)	
Pneumatic Dryer	24		1982	Central Azucarero Don Pedro, Batangas, Philippines	Arrascaeta and Friedman (1987)	
Rotary dryer 3.6mx12 m.	45	X		Central Aidsisa, Bacolod, Philippines	Arrascaeta and Friedman (1987)	$T_{g,o}=258\text{ }^{\circ}\text{C}$
Rotary dryer 2.4mx15.7 m	13			Central Victoria, Bacolod, Philippines	Arrascaeta and Friedman (1987)	
Pneumatic Dryer	2		1980	Sugar Research Inst., Mackay, Queensland, Australia	Edwards, B.P. (1981)	Pilot scale
Pneumatic Dryer			1983	Chun Cheng Sugar Factory, China	Arrascaeta and Friedman (1987)	Pilot scale $T_{g,o}=140\text{ }^{\circ}\text{C}$
Pneumatic Dryer	0.5	X	1983	Central Pablo Noriega, Quivicán, Cuba	Arrascaeta and Friedman (1987)	Pilot scale $T_{g,o}=200\text{ }^{\circ}\text{C}$
Through circulation (moving)		X	1983	Usina Paraíso Alagoas Pernambuco - Brazil	Massarani, G. (2004)	Industrial prototype
Pneumatic Dryer	7	X	1984	Central Pablo Noriega, Quivicán, Cuba	Arrascaeta and Friedman (1987)	$T_{g,o}=300\text{ }^{\circ}\text{C}$
Solar	3.18	X	1983	Consuelo factory, Dominican Republic	Anonimous (1985)	Hybrid active/passive system
Pneumatic Dryer	7.5	X	1984	Usina Itajubara - GIJS, Maranhão - Brazil	Augustinsky, J. (2004)	$T_{g,o}=330\text{ }^{\circ}\text{C}$
Pneumatic Dryer		X	1992	Ingenio Nuñorco, Tucuman, Argentina	Cardenas et al. (1994)	Industrial scale Prototype
Pneumatic Dryer	28	X	2003	Cia. Agroindustrial de Goiana - CAIG - Açúcar e Álcool - GIJS, Brazil	Augustinsky, J. (2004)	Building
Steam Dryer	0.3	X	2005	Queensland, Australia	Morgenroth and Batstone (2005)	Prototype
Pneumatic Dryer	29	X	2010	Ingenio El Carmen, Mexico	Colombres et al. (2010)	Industrial scale $T_{g,o}=338\text{ }^{\circ}\text{C}$

Flue Gas Rotary Dryer

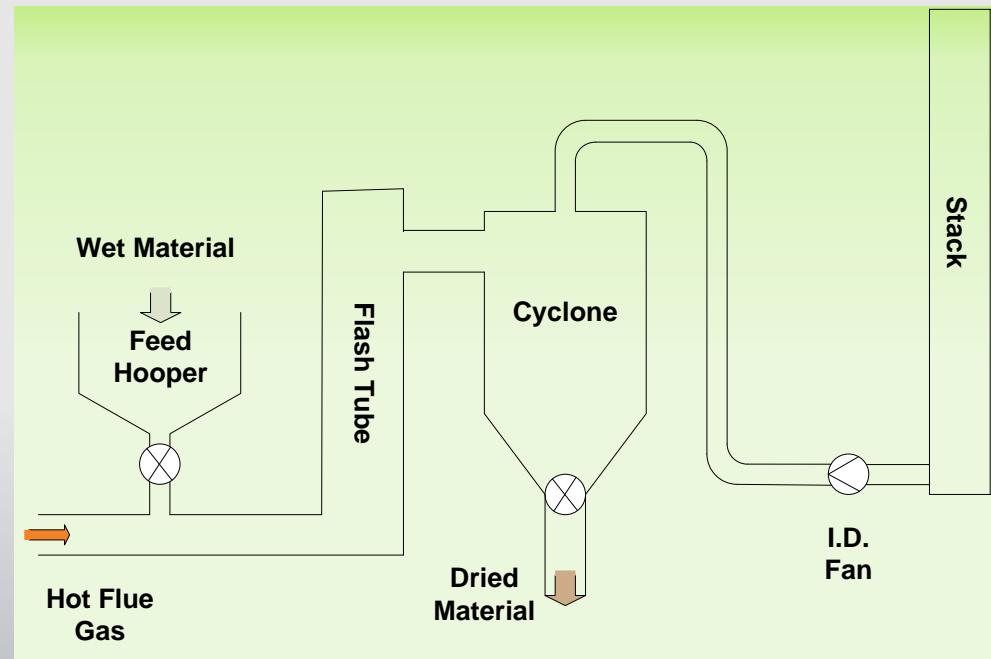


- Retention time depends on particle size (30 sec – 20 min)
- Not good control of moisture
- Fire and Explosion Hazard
- VOCs emissions
- High operation and maintenance costs

(Amos, 1998; Bruce and Sinclair, 2006; Worley, 2011)



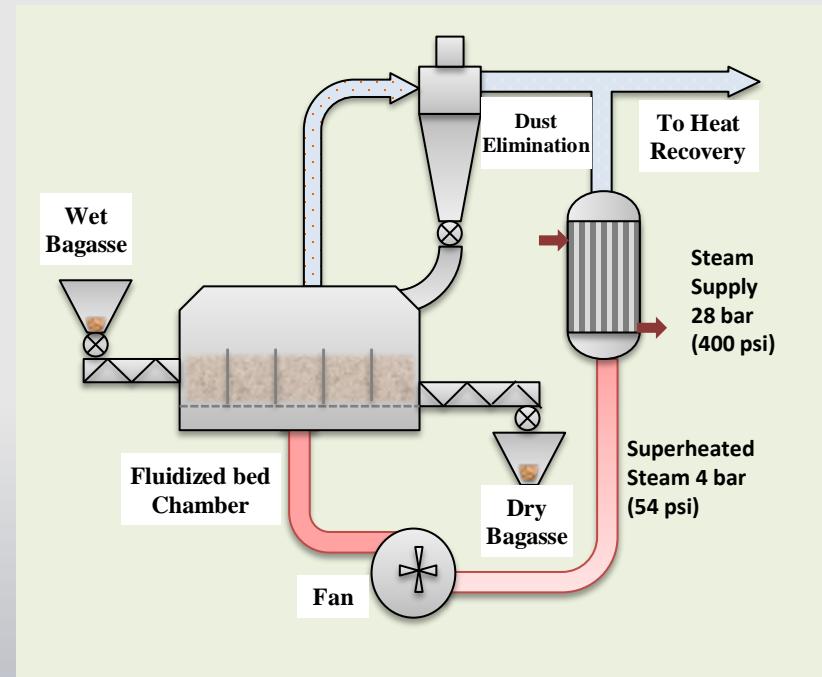
Flue Gas Pneumatic Dryer



- Shorter retention time (2sec - 10 sec)
- Easier moisture control and lower risk of fire in the dryer
- Higher risk of fire after the dryer due to high oxygen content
- Higher gas flow and higher volume of gas in the stack (more power for ID fan and problems for erosion and corrosion)
- More requirements for the system to control emissions in the boiler

(Bruce and Sinclair, 2006)

Fluidized Superheated Steam Dryer



(Jensen 2008)

- 10% MC possible because of the less risk of fire or explosion inside dryer
- No air emissions but VOCs in condensates (probably water treatment)
- Possible heat recovery (Evaporation process or by thermo-compression)



Dryer Type	Rotary Flue Gas	Flash or Pneumatic Flue Gas	Fluid Bed SSD Size G and H Steam (370 kPa : 4 bar : 54 psi)
Dryer Medium			
Evaporation, t/h	3 – 23	4.8 – 17	35 – 50
Capacity, OD t/h	3 – 45	4.4 – 16	14 – 20
Feed % MC	45 – 65	45 – 65	72
Discharge % MC	10 – 45	10 – 15	10
Pressure drop, kPa	2.5 - 3.7	7.5	
Thermal Requirements, GJ/t_{evap}	3.0 - 4.0	2.7 - 2.8	3.9 ⁽¹⁾ 0.4 ⁽²⁾ 0.1 ⁽³⁾
Capital Costs Equipment k\$/ODt/h	45 – 80	In - Out: 300-105°C 55- 40 %MC 4 - 35 t/h	70 – 180 In - Out: 300-105°C 55 - 15 %MC 4 - 35 t/h
Total Installed Cost (k\$/ODt/h)	<u>160 – 370</u>	<u>330 – 860</u>	<u>~510</u> <u>190 – 240</u> ⁽⁴⁾

Notes: OD- Oven Dry.

(1) Without heat recovery

(2) Latent heat recovery

(3) Blower power (GJ/tevap) – Operating pressure: 370 kPa abs (3.7 bar abs)

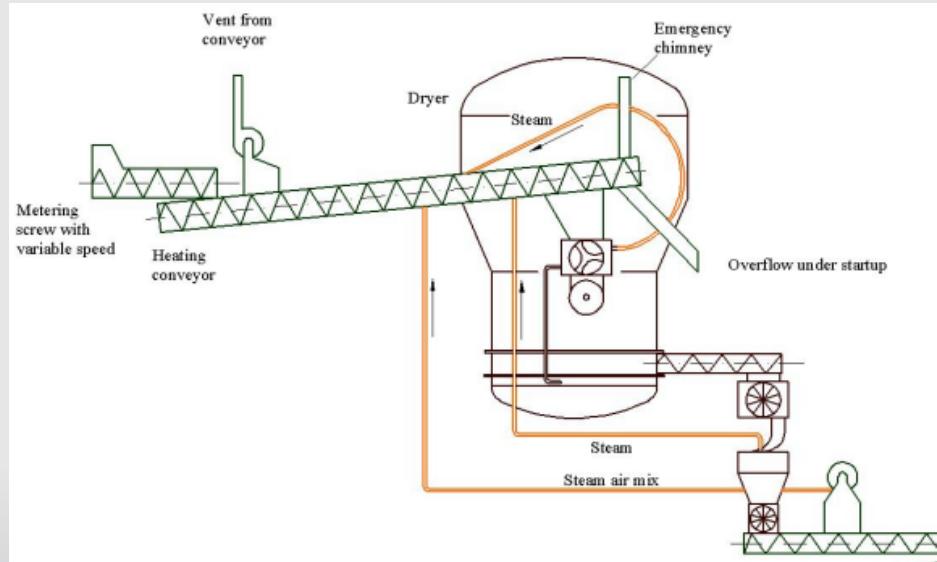
(4) Total installed cost (K\$/t_{evap}/h)

(Bruce and Sinclair, 1996; Jensen, 2001; Jensen, 2008)

Fluidized Bed SSD - Challenges

- Rotary valves (feed and discharge)
- Dust separation (fan)
- Steam leaks
- Bottom perforations and shape
- VOC emissions (smell) with non-condensable gases and waste steam
- Condensates treatment (VOC)

Jensen, 1995, 1997, 2003, 2008, 2011;
Kawlewski et al., 2007)



Volatile Organic Compounds – VOC (Beet)

Analyte	Untreated	Treated with NH ₄ OH
Acetic Acid	560	630
Propionic Acid	2.0	2.5
Isobutyric Acid	20	16
Butyric Acid	4.6	4.4
2-Methylbutyric Acid	1.0	1.0
Isovaleric Acid	1.9	1.4
Valeric Acid	1.0	1.5
Total Kjeldahl Nitrogen	39	250
Chemical Oxygen Demand	1,200	1,300
Conductivity, μmhos	400	1,500
Total Suspended Solids	2.0	2.0
pH, s.u.	3.9	8.5

Superheated Steam Dryer Research

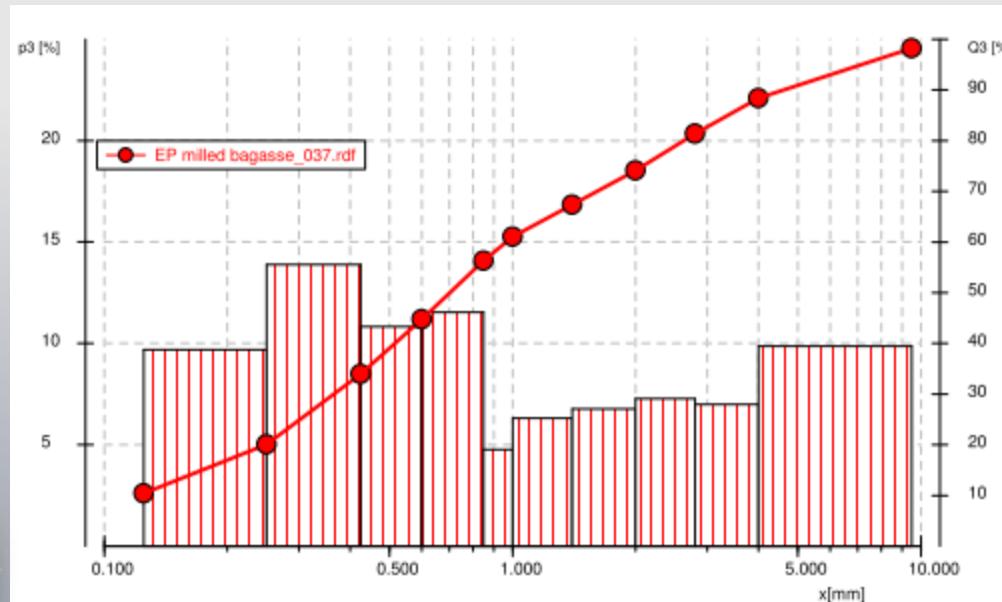
Research conducted by Sugar Cane Growers & Enerdry

- ✓ Demonstrated the optimal fluidizing velocity and good moisture reduction in a full scale trial
- ✓ Further research is needed in the feeding and discharge system for the dryer, and quality of the condensates on heat recovery



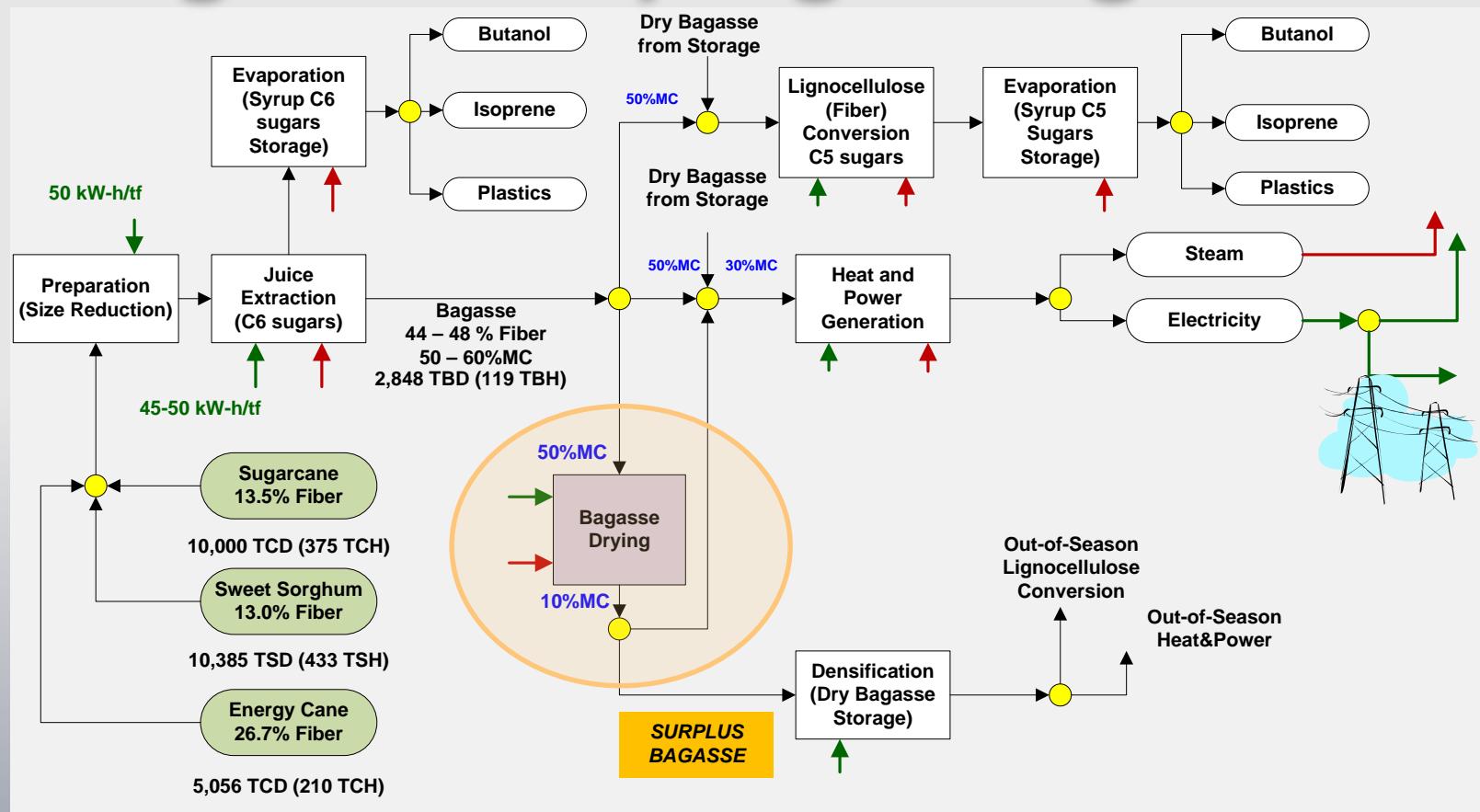
Bagasse Particles Characteristics

- Heterogeneous: Shape and wide particle size distribution

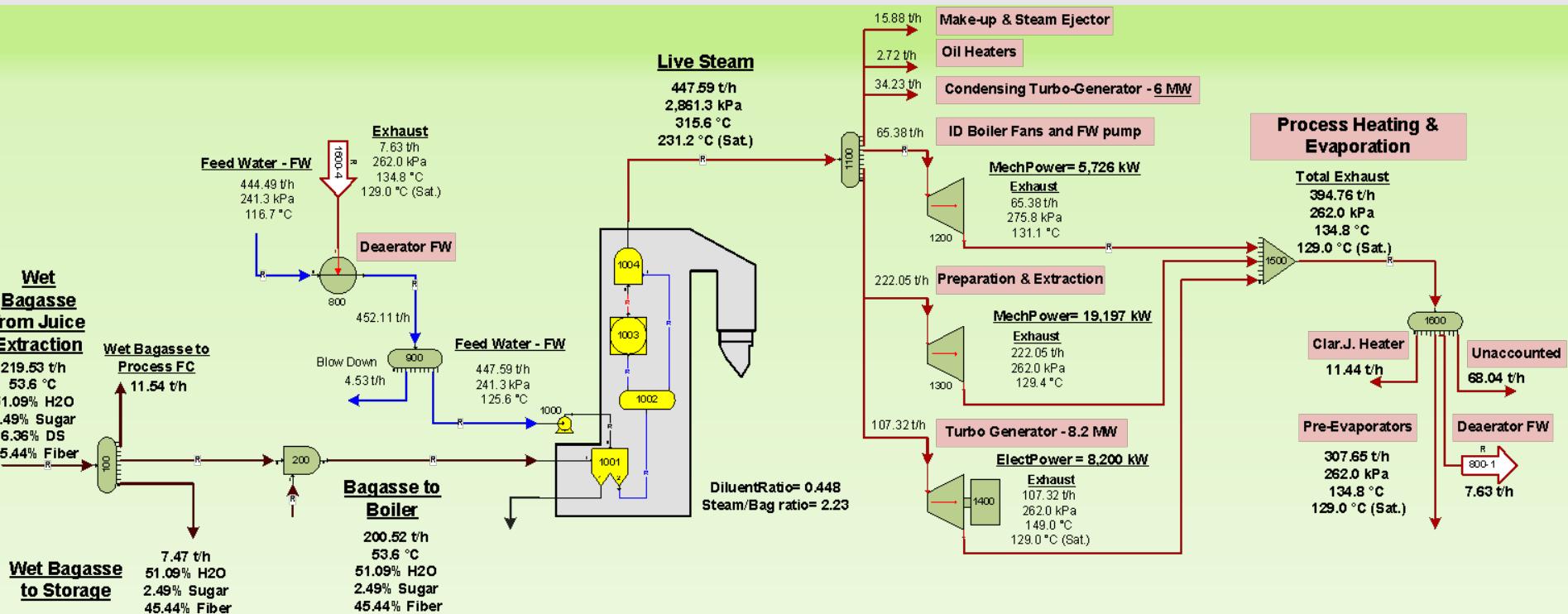


(Polanco et al. 2013)

Bagasse Drying Integration



Sugarcane Factory Model (SCGC)



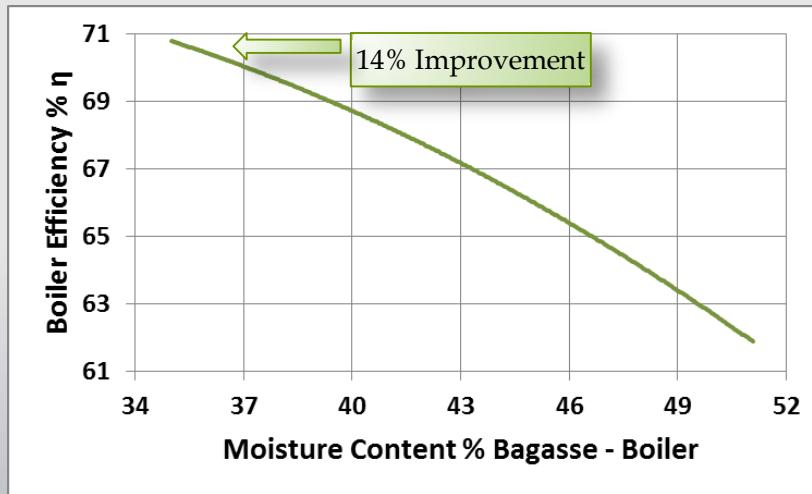
(Weiss et al. 2005)

- ✓ Grinding Rate : 980.4 t/h (23,500 t/d)
- ✓ Fiber : 12.9 % Cane
- ✓ Bagasse (50MC) : 21.9 % Cane
- ✓ Live Steam : 46 % Cane
- ✓ Exhaust Vapor : 40 % Cane
- ✓ Power (M&E) : 40 kW/tc
- ✓ Bagasse Storage (50MC) : 3.40 % total bag.

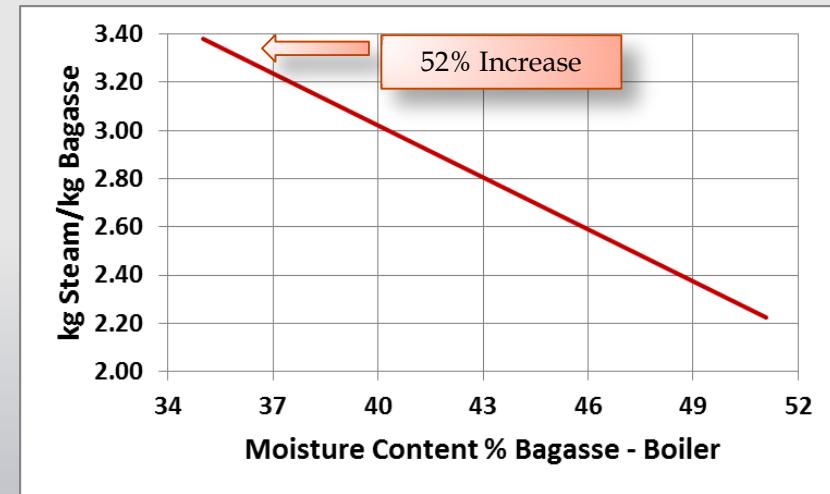


Boiler Efficiency & Steam Production versus Bagasse Moisture

Efficiency



Steam/Bagasse Ratio

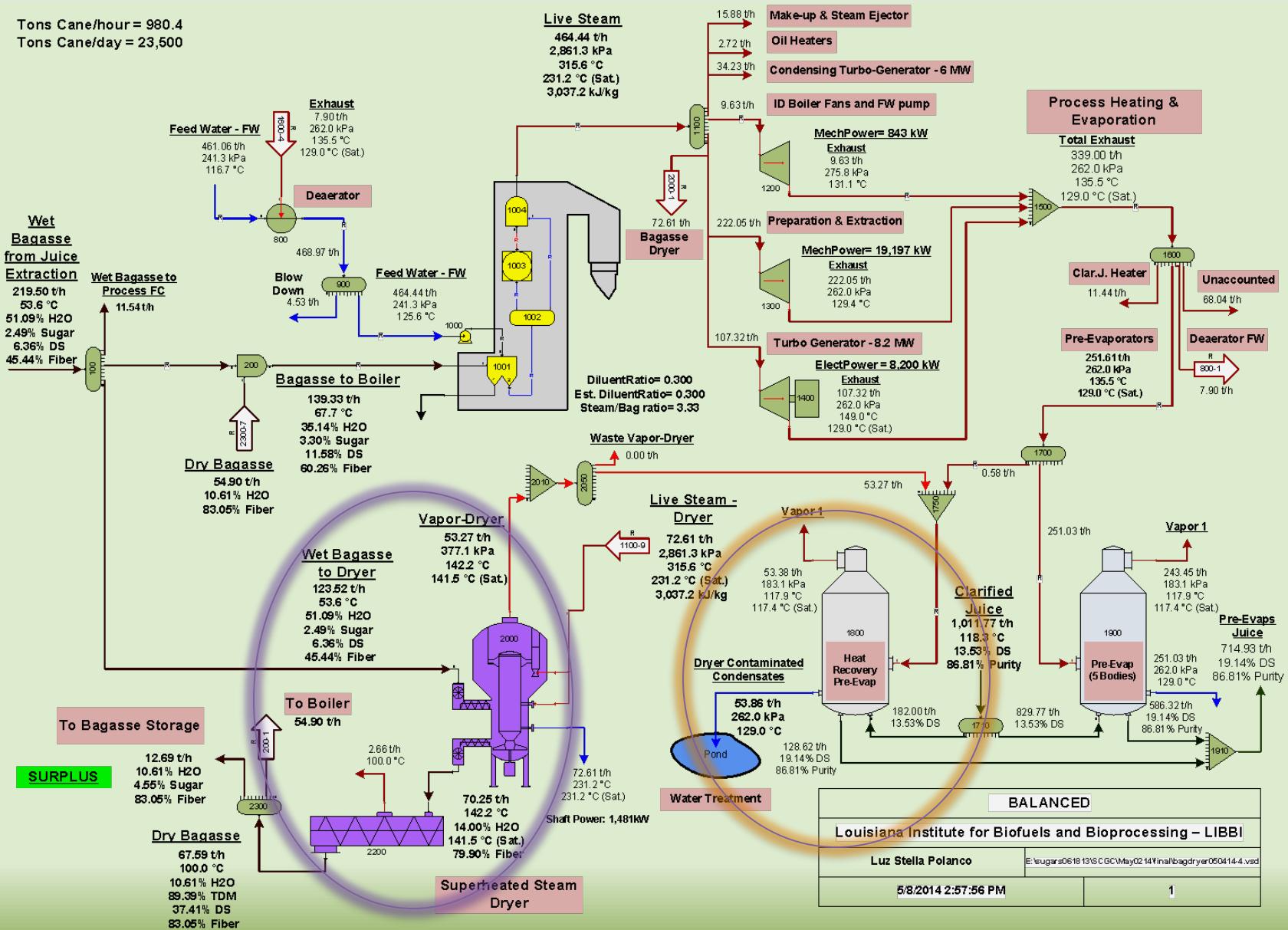


- Estimated from bagasse analysis (Moisture, Pol and Ash % Bagasse)
- Ash (assumed) : 5 % Fiber
- Feed Water at 125.6 °C (258 °F)
- Live Steam at 2861 kPa (415 psi), 316 °C (600 °F)

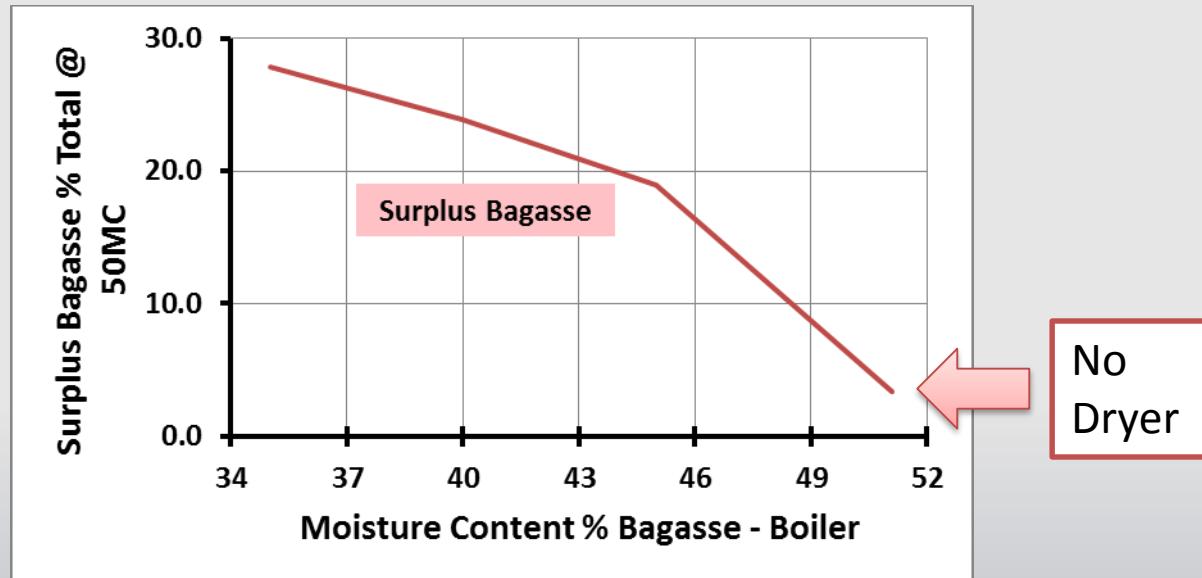


Dryer Integration Simulation

Tons Cane/hour = 980.4
Tons Cane/day = 23,500



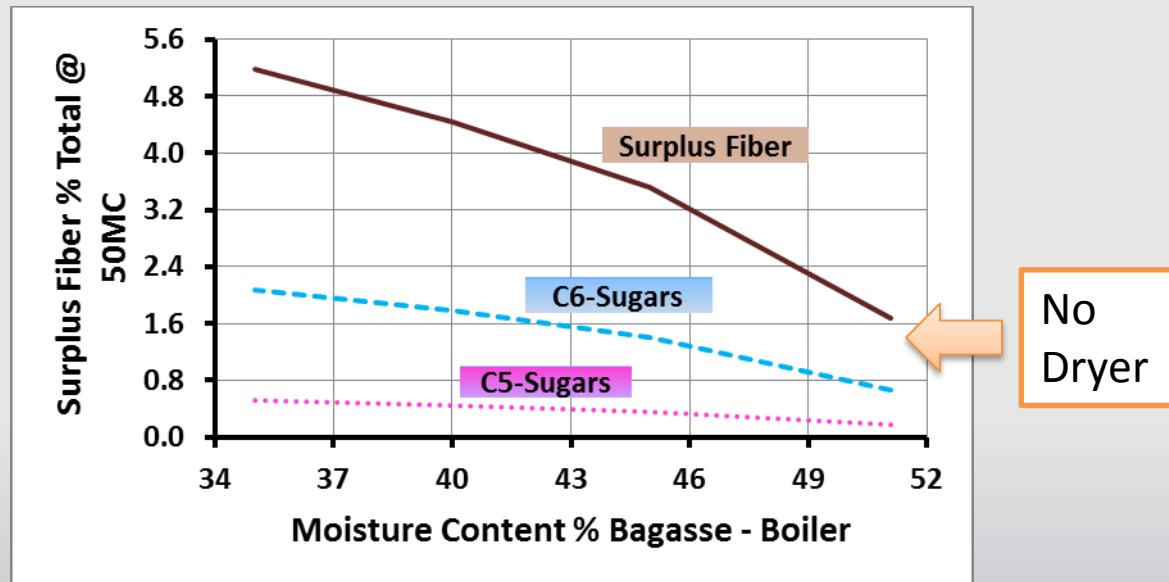
Surplus Bagasse



- Simulation: blending wet bagasse (51.09%MC) & dry bagasse (10.61%MC) to final moisture content : 45, 40 and 35 %MC (for Steam Generation)
- Heat Recovery Dryer: One pre-Evaporator body



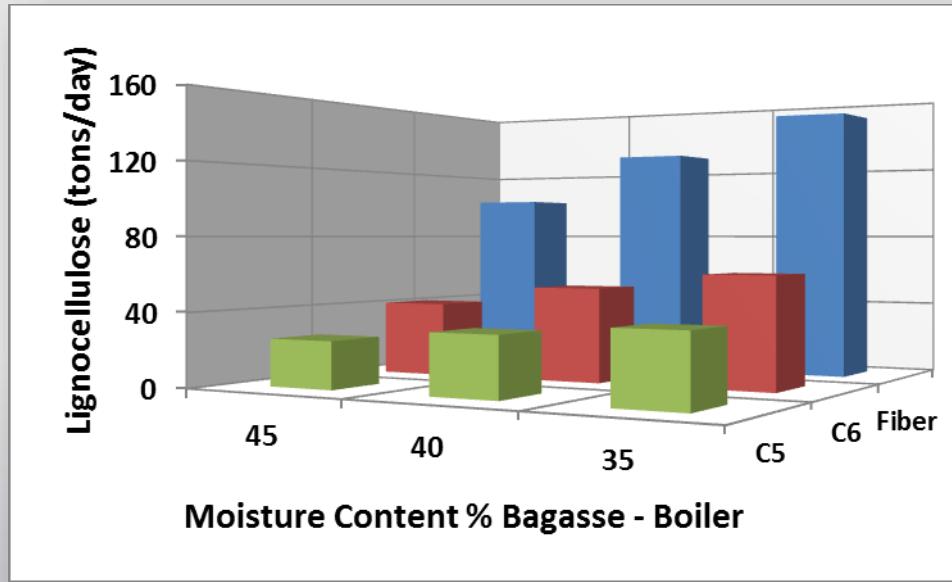
Surplus Fiber



- Simulation: blending wet bagasse (51.09%MC) & dry bagasse (10.61%MC) to final moisture content : 45, 40 and 35 %MC (for Steam Generation)
- Heat Recovery Dryer: One pre-Evaporator body
- Fiber Composition: ~40% Cellulose (C6-Glucose) & ~25% Hemicellulose (C5-Xylose)



Surplus Sugars per Day (10,000 t/d)



- Blending to final moisture content : 45, 40 and 35 %MC (for Steam Generation)
- Heat Recovery Dryer: One pre-Evaporator body
- Fiber Composition: 40% Cellulose (C6-Glucose) & 25% Hemicellulose (C5-Xylose)
- Grinding Rate : 10,000 tons/day , Bagasse Production : 3000 tons/day



Simulation Summary

Parameter	Unit	w/o Dryer	w/ Dryer	%Δ
Bagasse to Boiler@50MC	% Cane	20.0	13.9	-31
Bag. Moisture - Boiler	% Bag	51.1	35.0	-31
Live Steam	% Cane	45.7	47.4	4
Live Steam/Fuel Ratio	t-Steam/t-Bag	2.2	3.3	49
Exhaust	% Cane	40.3	34.6	-14
<u>Dryer</u>				
Bag. Moisture - Dryer	% Bag	—	10.6	—
Live Steam - Dryer	% Cane	—	7.4	—
Bagasse to Dryer (Oven Dry)	% Cane	—	6.2	—
Steam Efficiency Dryer	t-Steam/t-Evap	—	1.4	—
Shaft Power	kW-h/t-Evap	—	28	—



Conclusions

- Drying biomass is required to improve boiler efficiency and to preserve the fiber during storage
- The main advantages of the superheated steam dryer are high evaporation capacity and lower fire hazards allowing to reduce moisture content on bagasse to ~ 10%
- Preliminary simulation of the integration of a superheated steam dryer shows improvement on boiler efficiency up to 14% and increase on surplus fiber up to 210%
- For a grinding rate of 10,000 tons per day, a rough estimation gives a surplus of 60 and 15 tons per day of C6 and C5 sugars respectively, for a bagasse blend of 35 % moisture content going to the boiler



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