Lignocellulosic Biofuels Co-Production And Co-Generation Using Integrated Biorefineries. A Solution for the Treatment of Agro-Industrial Wastes

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Motivation

- Biorefineries for the Mexican context
- Using **sustainability criteria** as design goals
  - Multi-feed using local agro-industrial wastes as feedstock
  - Co-production of bioethanol, biohydrogen and biogas
  - Electricity surplus
- A 500 ton/day solution for:
  - **Restricted availability of biomass**
  - **Local environmental pollution**
- Affordable design at local level but with higher TPC than CBP
- Explore further techno-economics

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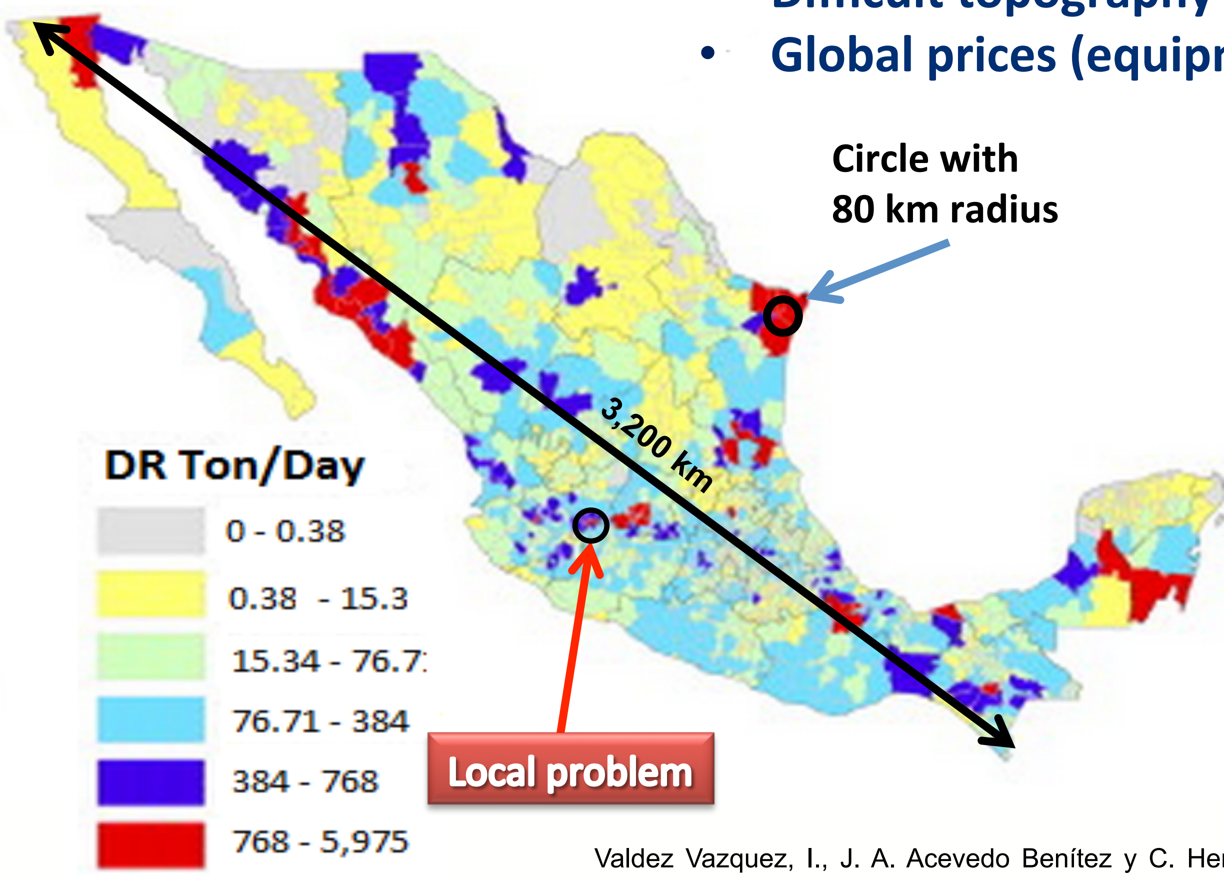
Availability of Agricultural Residues in Mexico

- Crop diversity
- "Large enough" amounts
- Scattered along vast territory
- Difficult topography ⟹ difficult collection
- Global prices (equipment, resources, logistics)

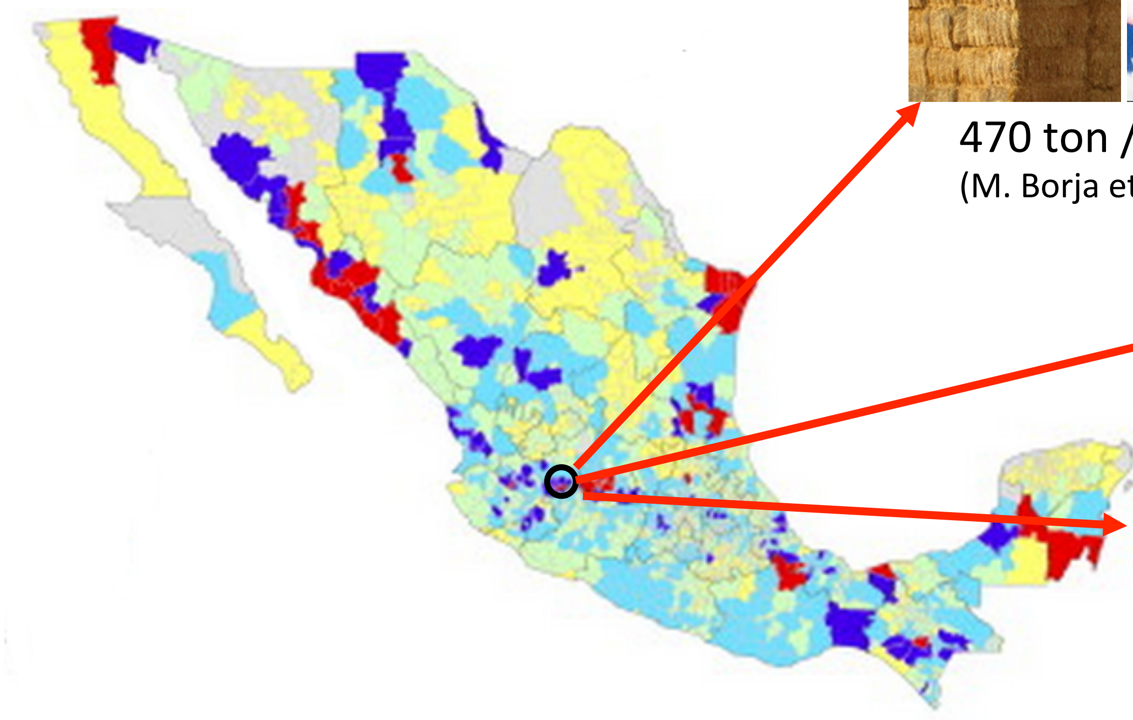


Crop	PCRI	Prod Mton/ year	Res prod Mton/year
Wheat	1.5	3.4	5.1
Corn	1.5	21.9	32.9
Sorghum	1.5	5.5	8.2
Sugarcane	0.15	50.6	7.6
Coffee Cherry (pulp)	0.24	1.5	31.5
Agave (bagasse)	0.12	1.2	1.5

Valdez Vazquez, I., J. A. Acevedo Benítez y C. Hernández Santiago. (2010) Distribution and potential of bioenergy resources from agricultural activities in México. Renewable & Sustainable Energy Reviews. 14(7): 2147-2153 p

Local Problem in a Western Region in Mexico

- Wheat straw and composted wheat straw
- Wastes from tequila and diary industries with high COD



Wheat straw

470 ton /day
(M. Borja et al. 2013)

Cheese whey

230 ton /day
(D.A. Lugardo et al. 2013)

Vinasses

3,900 ton /day
(A. Lopez-Lopez et al. 2010)

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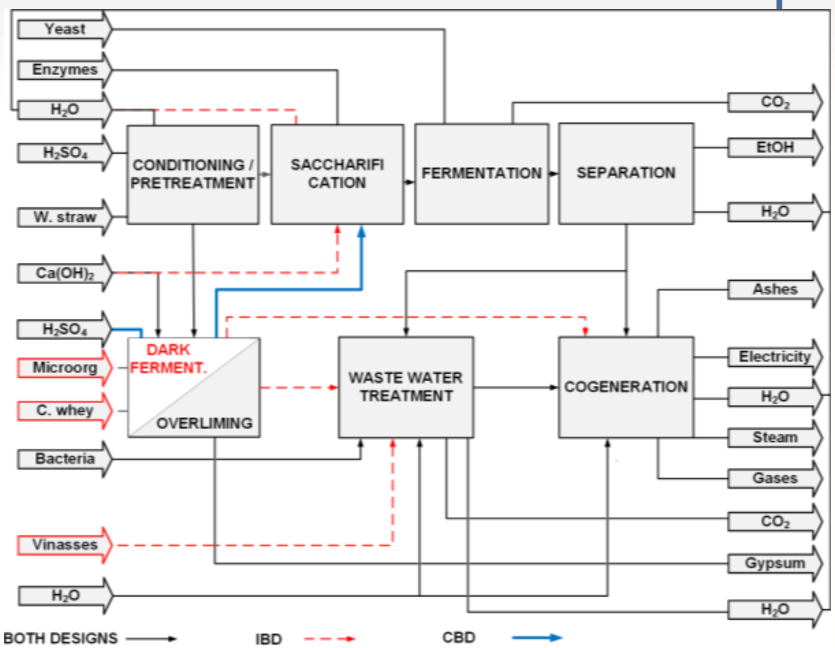
Local Problem in a Western Region of Mexico

AN ALTERNATIVE



Integrated Multi-feed, Coproduction Biorefinery

- **Sustainable design** ✓
- **Medium capacity (500 ton DB/day)** ✓
- **Solution for pollution problem** ✓
- **Smaller TPC, 1.20 $/L EtOH and 0.141 $/MJout for CBD than IBD10 (1.56 USD/L, 0.148 USD/MJ_{out})** ✗

This work: further exploration of the economics (preliminary results, 100% xiloses to dark fermentation)

- **Capital and TPC dependence on scale (capacity and feedstock price)**
- **(CBD + Vinasses + Cheese Whey Treatment) vs. IBD**

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Parametric Techno-economic Analysis Strategy

Energy Evaluation: EER
Tool: Energy integration
Pinch analysis for MER

Economic Evaluation:
DCF Analysis NPV=0 for TPC calculations

Patterson MG. What is energy efficiency? Concepts, indicators and methodological issues. Energy Policy 1996;24(5):377–90.

Seider W. J.D. Seader, D. R: Lewin, S. Widagdo Product and Process Design Principles: Synthesis, Analysis and Design, 3rd Edition (2008)

CBD and IBD Conceptual Designs with
100% hydrolisates to Dark Fermentation
SuperPro Designer v8.5

Plant Capacity
100 ton/day to 2,000 ton/day

Feedstock as a mixture of new and composted wheat straws

Feedstock price= f(polysacharides content (PC))

- **New wheat straw 60% PC-75 USD/ton**
- **Composted wheat straw 45%PC 6 USD/ton**

Discounted Cash Flow Analysis for NPV=0

$$NPV = CF\frac{[(1+i)^n - 1]}{(1+i)^n\, i} + \frac{WC}{(1+i)^n} - I = 0$$

CF = Incomes – Expenses	***CT*** = f(Production costs)
Expenses = Dir. Prod.Costs + taxes + financial costs	***I*** = Fixed Capital - Borrowing

Parameters	Value
Construction Period (years)	3
Project life time (years)	15
IRR (%)	4
Equity (%)	70
Global conversion (g etOh/g DB)	0.20

Borrowing payment period: 3 years, divided equally.

First paymment at production startup

Full production begins at the end of the construction.

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Energy Analysis Results
CBD and IBD

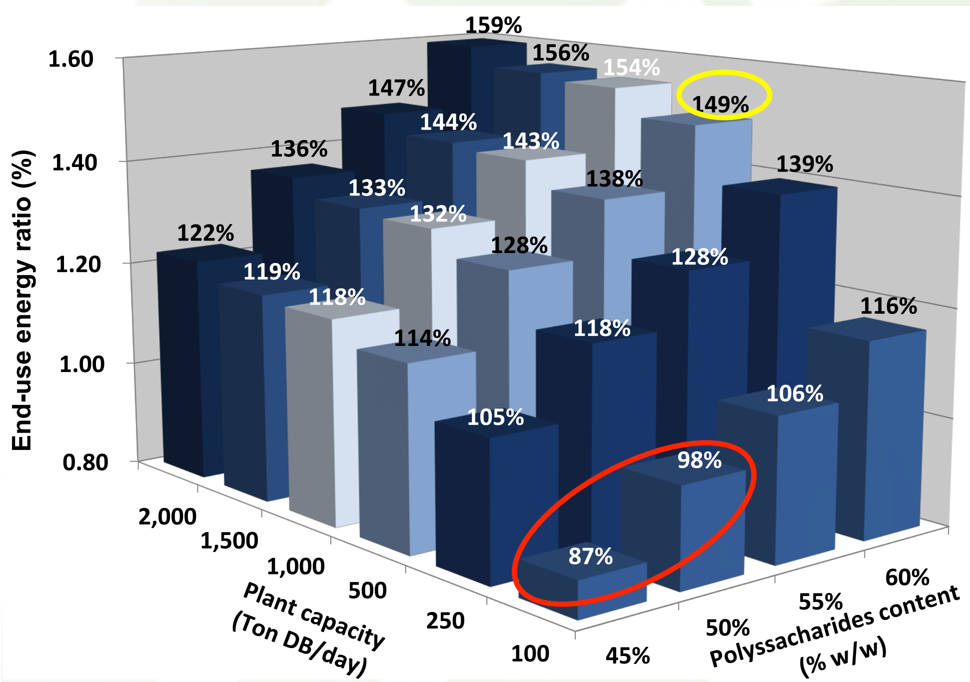
EER= ethanol+surplus electricity/electricity required+steam+cooling water

<1, Energy deficit
>1, Energy superavit

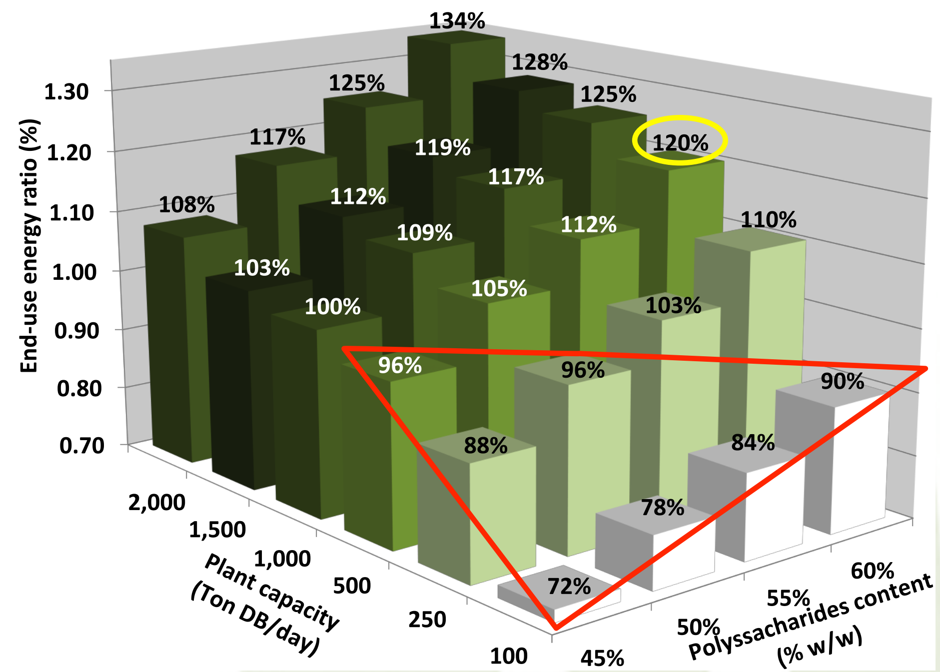
- *EER* ~ f(PC)

Surplus electricity if Plant Capacity (Ton DB/day)

CBD, Plant Capacity > 250 Ton DB/day



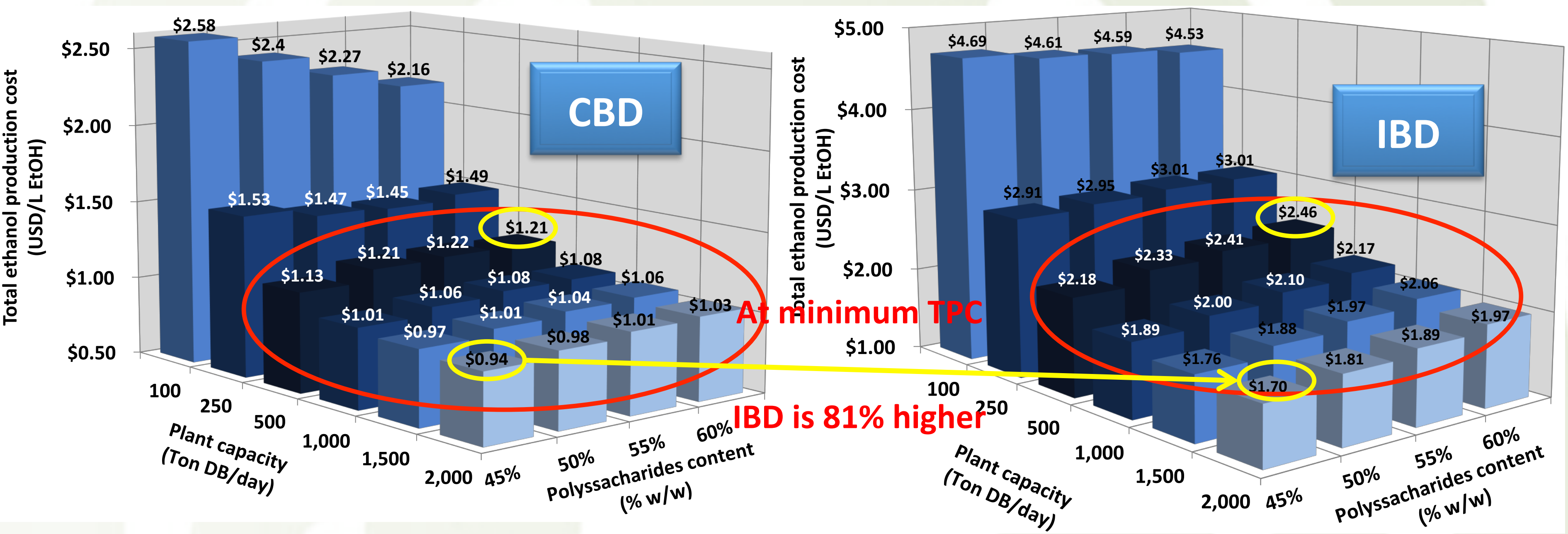
IBD, Plant Capacity > 500 Ton DB/day



Total Production Cost
CBD and IBD

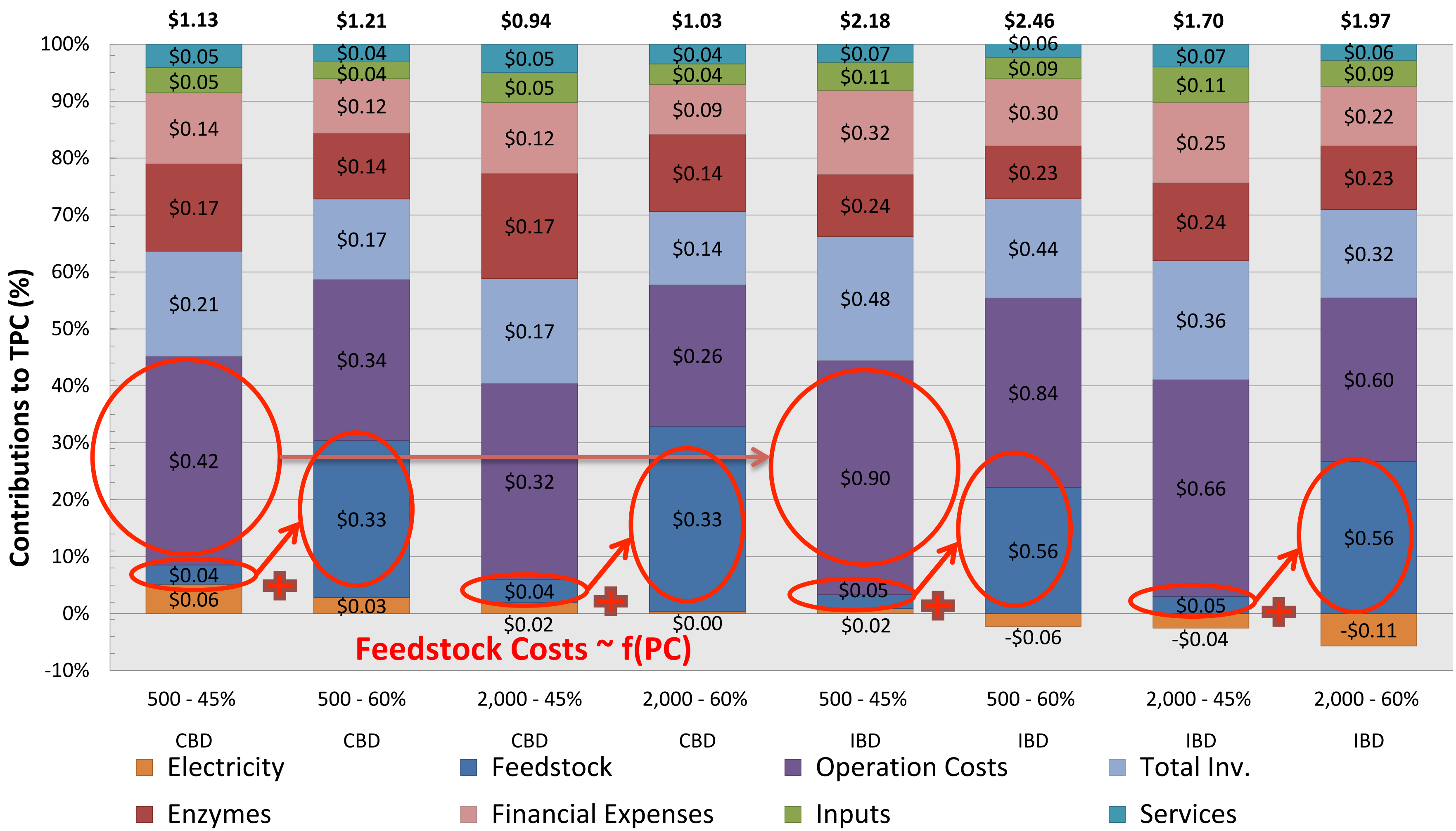
Conceptual Design 500 ton DB, 45% w/w	TPC ($/L EtOH)	Bioethanol produced (kg/h)	Cogeneration (kW-h/h)
CBD	$ 1.13	2562	2402
IBD	$ 2.18	1872	5120
Comparison	93%	-27%	113%

100% of hydrolysates are sent to H_2 coproduction (Dark Fermentation), means less bioethanol produced but higher electricity cogeneration



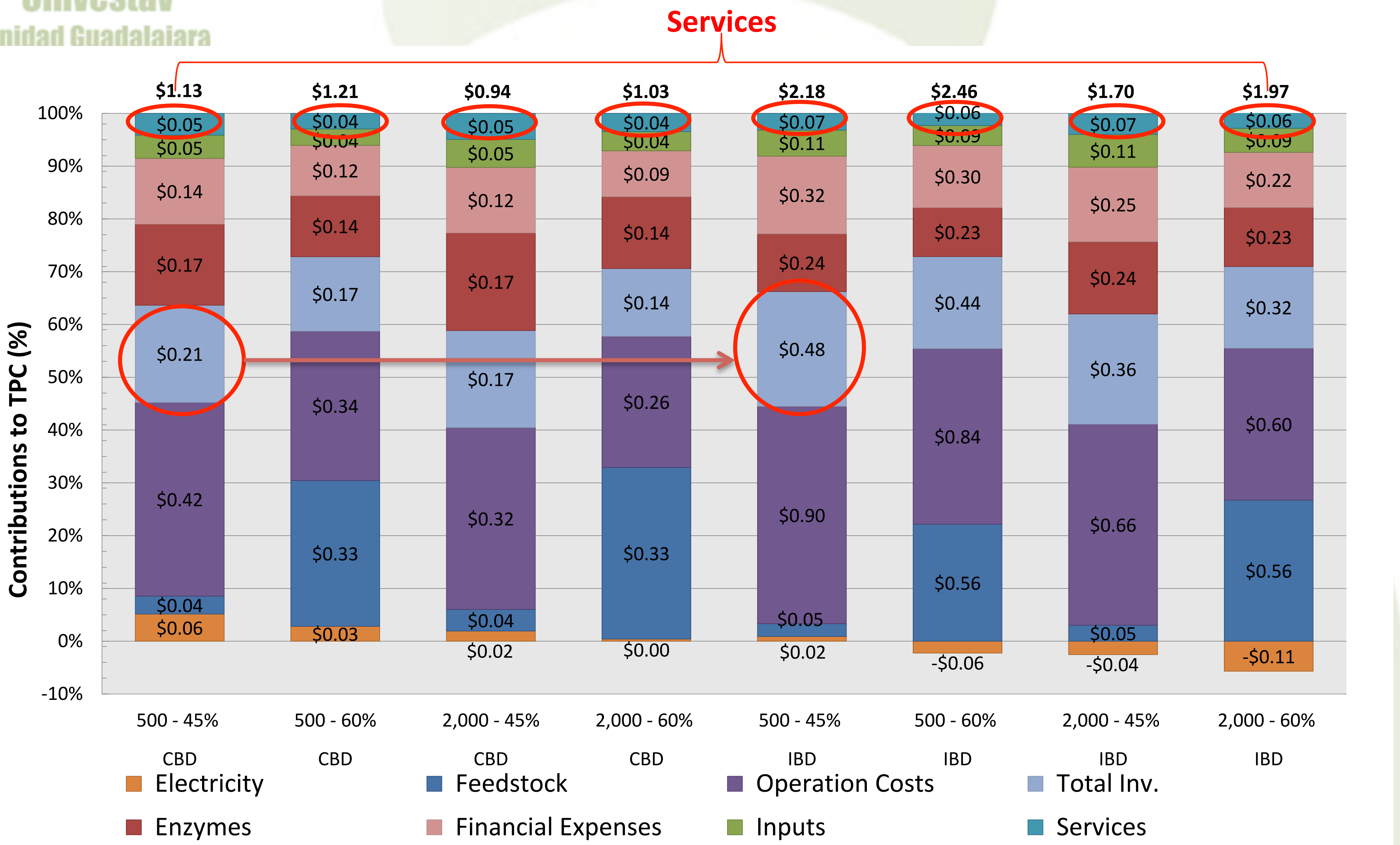
Contributions to TPC

(CBD and IBD)



Contributions to TPC

(CBD and IBD)



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Waste Treatment Analysis

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(Cheese Whey + Vinasses + CBD) vs IBD
Always better to do it all together

Conceptual Design @500 ton DB, 45% w/w	Total Capital Investment x10^3	Total Operational Cost ($/yr) x10^3	Power Demand (kW-h/h)	Cogeneration (kW-h/h)
CBD	$ 90,506	$ 42,649	4293	2402
Vinasses WWT	$ 57,806	$ 15,526	292	488.4
Cheese Whey WWT	$ 25,940	$ 10,421	81	108.5
CBD + WWTs plants	$ 174,252	$ 68,596	4666	2999
IBD	$ 149,350	$ 56,858	5584	5120
Comparison against IBD	**17%**	**21%**	**-16%**	**71%**

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Conclusions

- A quasi-linear TPC dependence with plant capacity and feedstock price (low sensitivity)
- **Total Capital Investment** and **Operational Costs** higher for CBD + WWTs plants than IBD
- Although IBD TPC is higher…
- IBD 10% hydrolisates to DF as sustainable as CBD

Conceptual Design 45% w/w	TPC ($/L EtOH)	
	@500 ton DB	@1000 ton DB
CBD	$ 1.13	$ 1.01
IBD	$ 2.18	$ 1.89
Comparison	**93%**	**87%**

- **Inclusion of other design criteria beyond economics?**

Conceptual Design 500 ton DB, 60% w/w	TPC		% hydrolysates to Dark Fermentation
	($/L EtOH)	($/MJout)	
CBD	$ 1.20	$ 0.14	10%
IBD	$ 1.56	$ 0.15	10%
	$ 2.18	-	100%

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THANK YOU

Acknowledgements

RED TEMÁTICA DE BIOENERGÍA

AGARED

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