



Study of second generation sugarcane bioethanol viability through integrated process optimization



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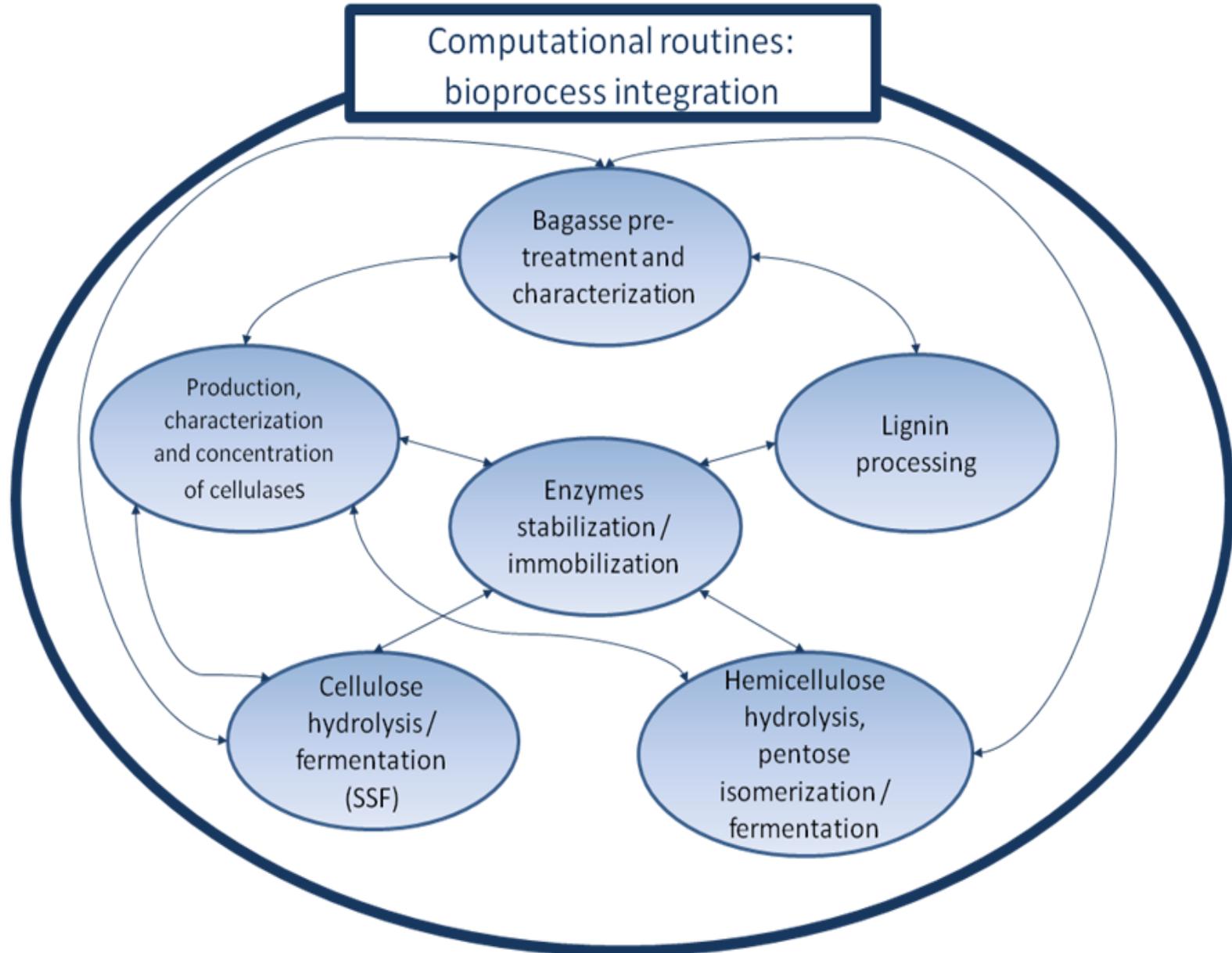
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BIOEN Project: Bioprocess Systems Engineering (BSE) Applied to the Production of Bioethanol from Sugarcane Bagasse (#2008/56246-0)



Sub-project 1: Development, implementation and validation of a user-friendly integrated computational environment

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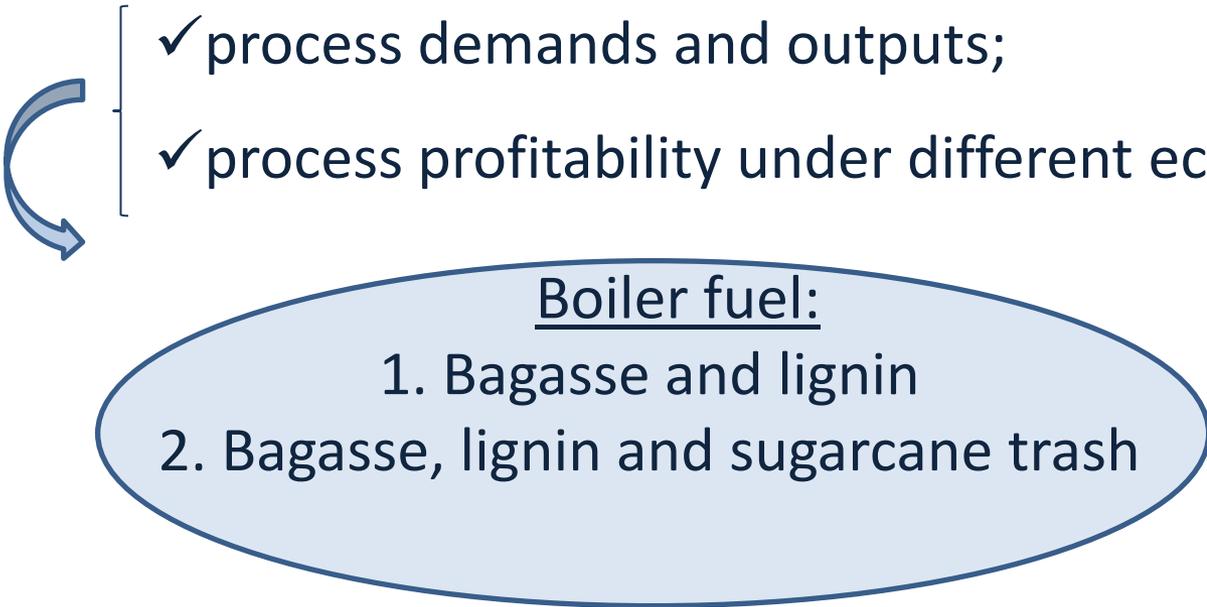
Objectives

✓ Development of a computational tool coupling **simulation** of first and second generation bioethanol steady state production with a **global optimization algorithm**.

✓ Analyses of:

✓ process demands and outputs;

✓ process profitability under different economic scenarios.



Boiler fuel:

1. Bagasse and lignin

2. Bagasse, lignin and sugarcane trash

EMSO

- ✓ Environment for Modeling, Simulation and Optimization
(www.enq.ufrgs.br/trac/alsoc/wiki/EMSO)
- ✓ Equation-oriented;
- ✓ Own modeling language;
- ✓ Object-oriented and inheritance concepts;
- ✓ Open built-in models (inspection and extension);
- ✓ Solvers for algebraic and DAE systems;

EMSO

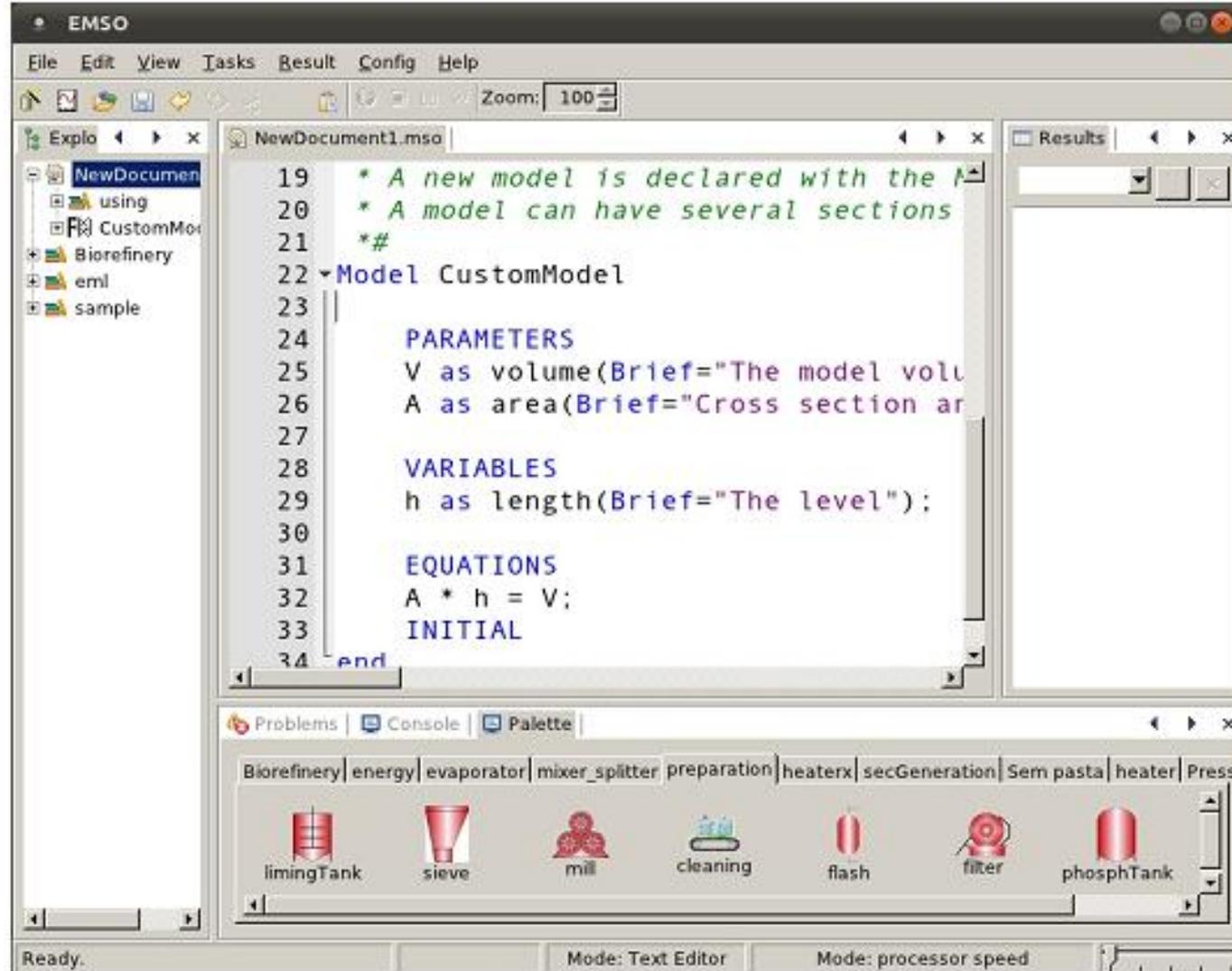


Fig. 1: EMSO interface (Soares and Secchi, 2003).

Particle Swarm Optimization (PSO)

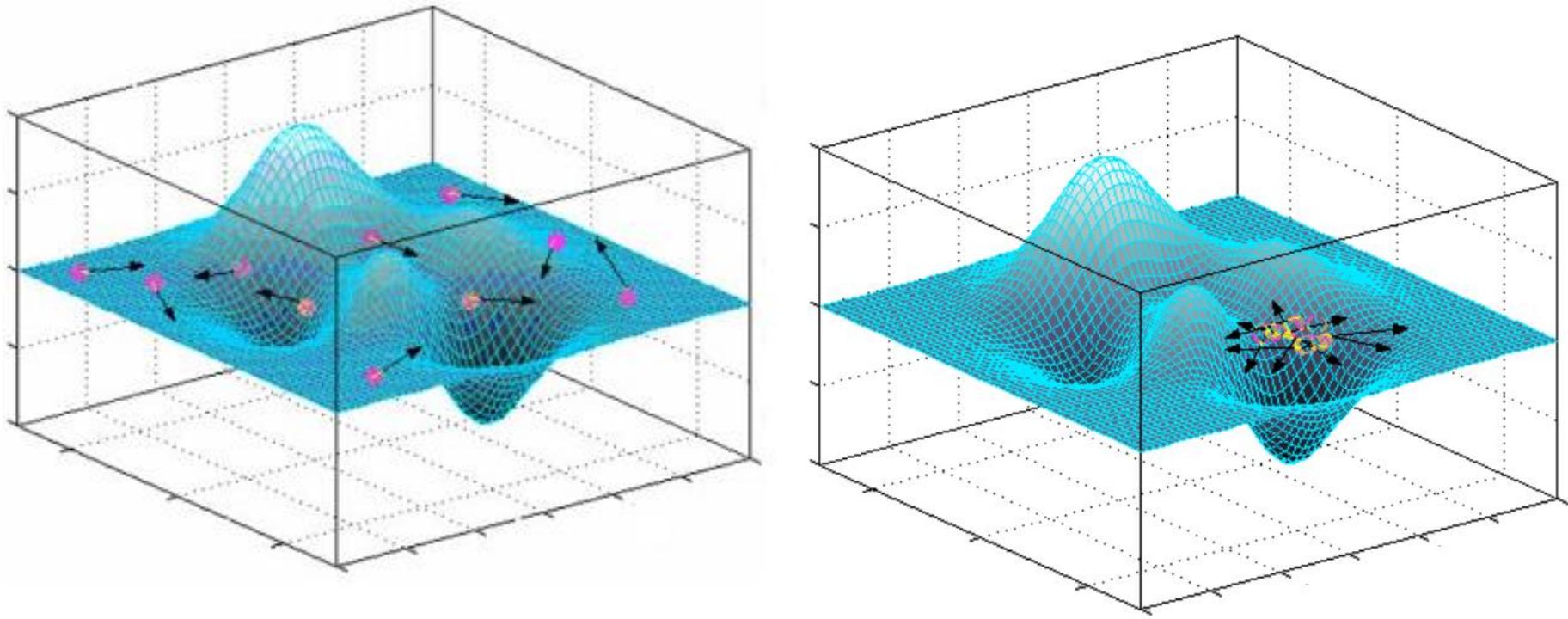


Fig. 2: PSO (Medeiros, 2005)

Second-generation ethanol

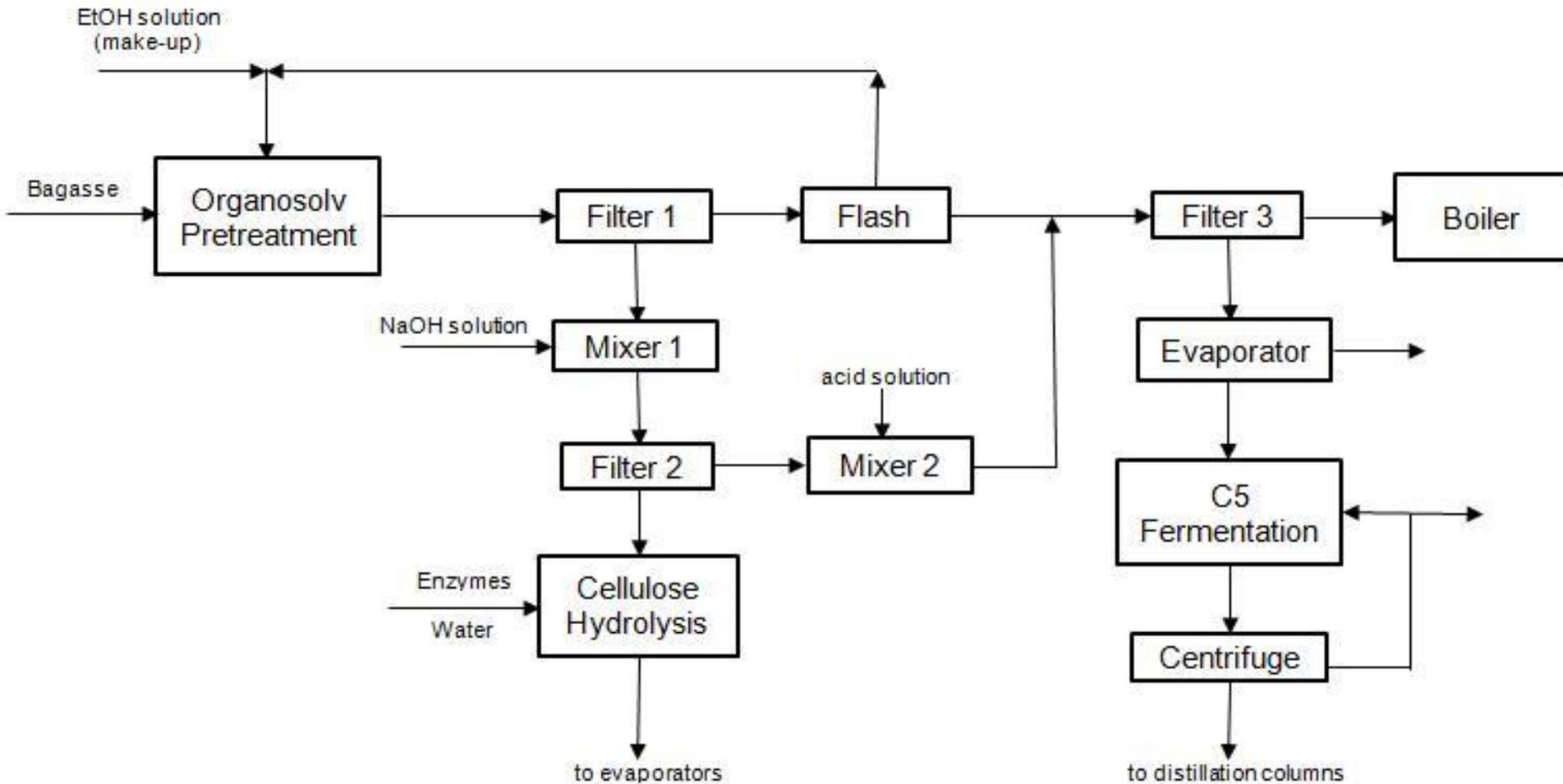


Fig. 3: Block diagram for second generation part of the modeled biorefinery.

Biorefinery

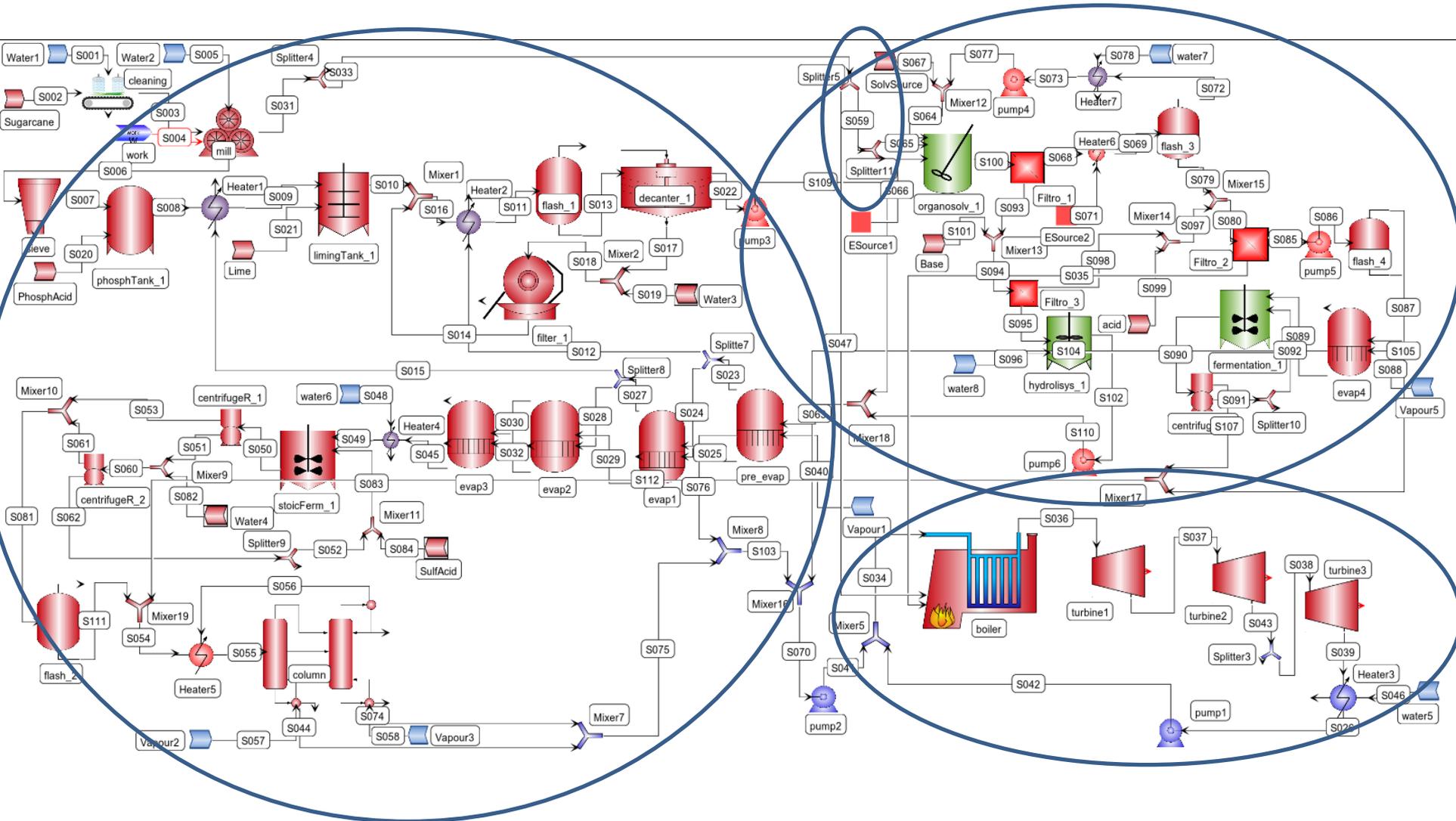


Fig. 4: Sugarcane biorefinery in EMSO software.

Specifications

- ✓ 500 ton of sugarcane (TC) per hour;
- ✓ 13.92% of sugar in sugarcane;
- ✓ 97.5% of sugar recovered on the mills;
- ✓ Sugarcane bagasse with 50% (mass) of water;
- ✓ Dry sugarcane bagasse: 39% cellulose, 37% hemicellulose, 21% lignin and 3% ash;
- ✓ Glucose fermentation yield: 90% ;
- ✓ 72% of efficiency for the distillation column plates;
- ✓ Organosolv at 170°C and 22.15 bar;
- ✓ 13.4% of cellulose lost on pre-treatment;
- ✓ 10:1 ratio of liquid to solid mass in hydrolysis;
- ✓ Cellulose hydrolysis yield: 80%;
- ✓ Xylose fermentation yield: 65%;

Specifications

- ✓ Lignin recovery: 95.5%;
- ✓ Boiler outlet vapor pressure: 90 bar;
- ✓ High pressure turbine: $P_{out} = 22$ bar and $\eta = 0.68 - 0.72$;
- ✓ Medium pressure turbine: $P_{out} = 2.5$ bar and $\eta = 0.77 - 0.81$;
- ✓ Condensing turbine: $\eta = 0.66 - 0.70$;
- ✓ Bagasse lower heating value: 7.52 MJ/kg
- ✓ Lignin lower heating value: 12.20 MJ/kg
- ✓ Sugarcane trash lower heating value: 12.96 MJ/kg

Prices of materials and products

Table 1: Prices used for analyses.

Material / Product	Current value ¹	Hipotetical value
Sugarcane	US\$ 43.40 /t	US\$ 43.40/t
Ethanol	US\$ 0.88 /kg	US\$ 1.50/kg
Electric power	US\$ 95.64 /MWh	US\$ 25.00 /MWh
Enzyme	US\$ 2.25/kg	US\$ 0.6/kg
Yeast	US\$ 0.10/kg	US\$ 0.10/kg
Bagasse	US\$ 23.57/t	US\$ 7.50/t
Sugarcane trash transportation cost	US\$ 37.22/t	US\$ 37.22/t

Scenario 1 **Scenario 2**

Sugarcane trash: 140 kg/TC.

At least 50% of sugarcane trash must remain on the field.

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www.webartigos.com/articles/3770/1/Custo-Do-Vapor-Em-Agroindustria/pagina1.html

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www.unica.com.br

Optimization Studies

1. Maximization of profit:

$$\begin{aligned} \text{Profit} = & \text{[Ethanol Flowrate (kg/h)]} \cdot \$_1 + \text{[Surplus of} \\ & \text{electricity(MWh/h)]} \cdot \$_2 + \text{[Bagasse sold(kg/h)]} \cdot \$_3 + \text{[Yeast (kg/h)]} \cdot \$_4 \\ & - \text{[Enzyme (kg/h)]} \cdot \$_5 - \text{[Sugarcane (kg/h)]} \cdot \$_6 - \text{[Sugarcane trash} \\ & \text{(kg/h)]} \cdot \$_7 \end{aligned}$$

2. Maximization of ethanol production.

Decision variables

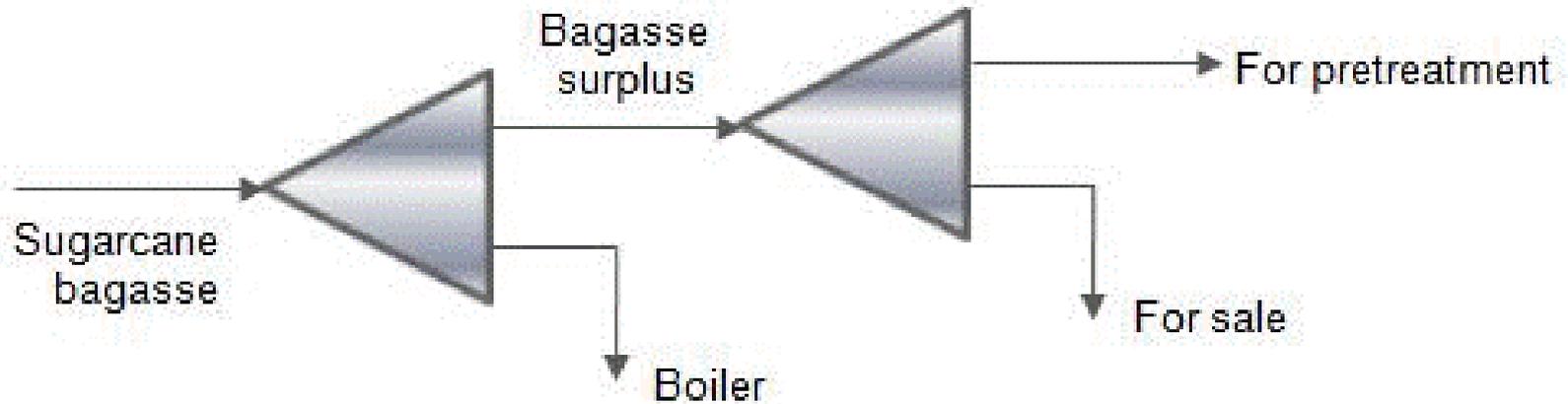


Fig. 5: Bagasse partition in the biorefinery.

$$\text{Splitter1} = \frac{\text{"Boiler"stream}}{\text{"Sugarcanebagasse"stream}}$$

$$\text{Splitter2} = \frac{\text{"For pretreatment"stream}}{\text{"Bagassesurplus"stream}}$$

Results

1. Scenario 1 (market prices)

A. Maximization of profit:

	With sugarcane trash		Without sugarcane trash (base case)
Splitter 1	1.000		1.000
Splitter 2	0.000		0.000
Ethanol production (L/TC)	85.7		85.7
Electric energy (MWh/TC)	572.5	55.4%	368.3
Vapor consumption (kg vapor/ kg ethanol)	4.3		4.3
Profit (US\$/h)	14300.4	10.4%	12953.2

Sensitivity analysis: enzyme costs have low impact in this scenario.

Results

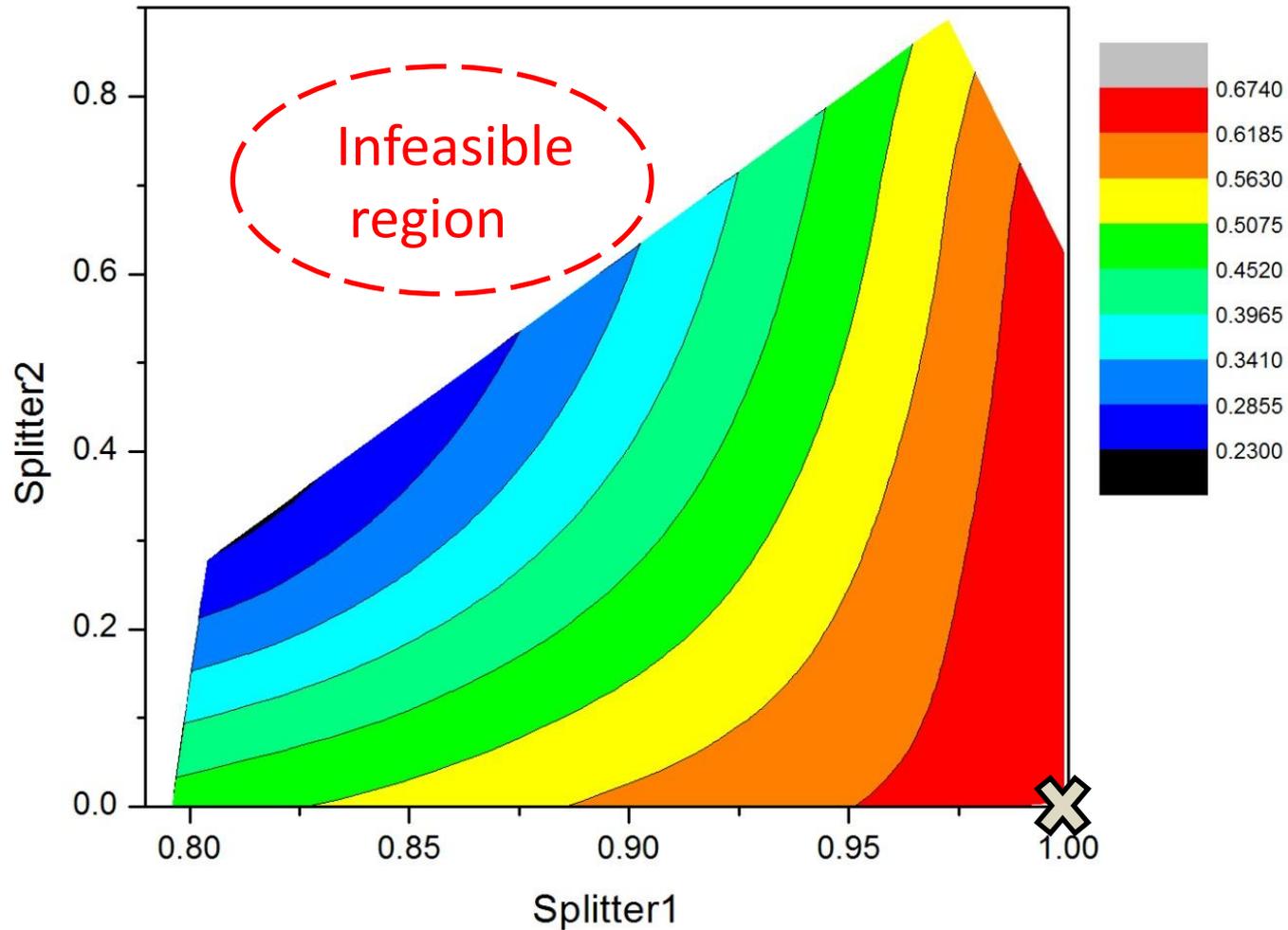


Fig. 7: Contour plot of dimensionless profit NOT considering the use of sugarcane trash (Scenario1).

Results

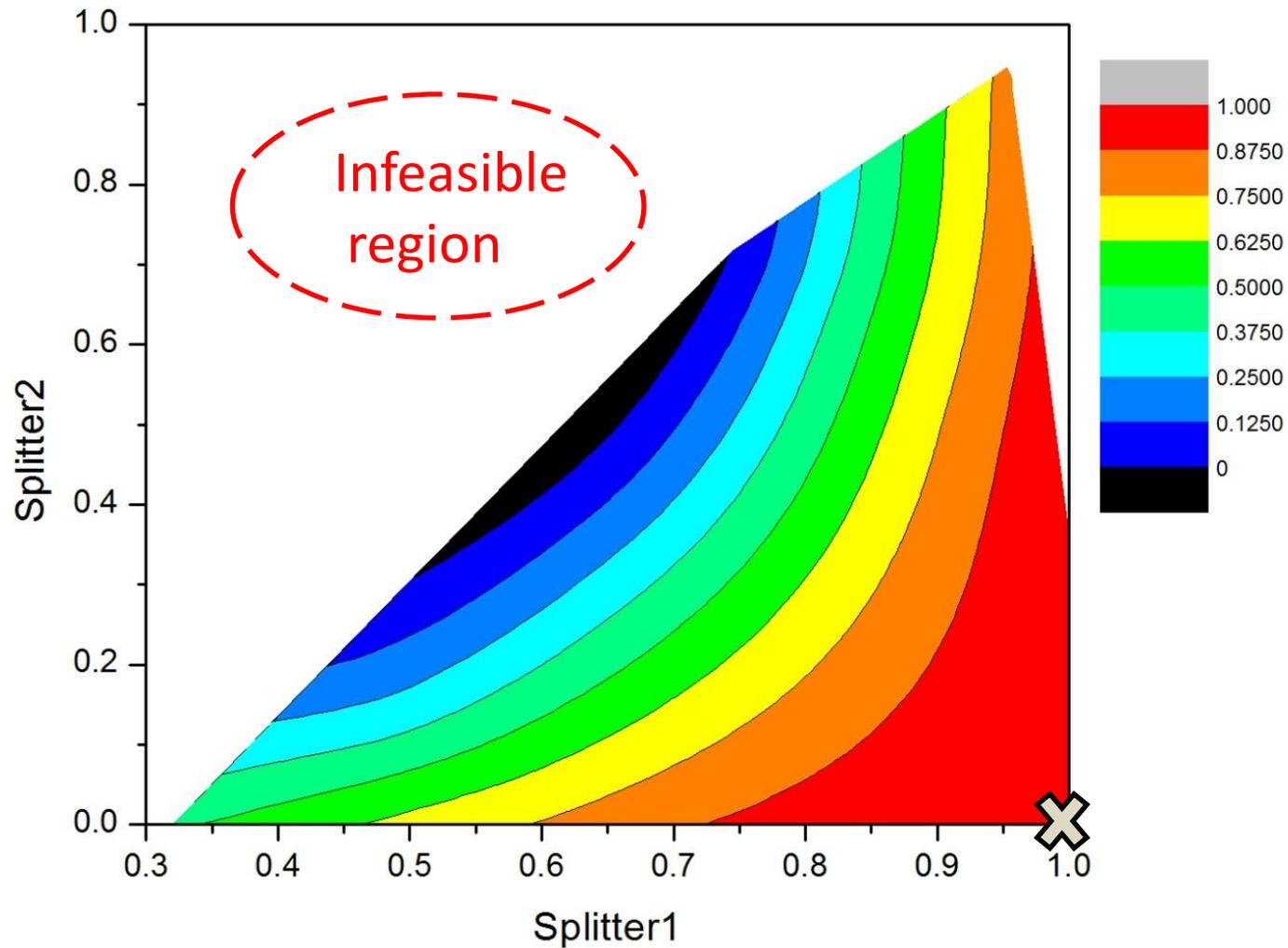


Fig. 6: Contour plot of dimensionless profit considering the use of sugarcane trash (Scenario 1).

Results

1. Scenario 1 (market prices)

B. Maximization of ethanol production:

	Without sugarcane trash		With sugarcane trash		Base case
Splitter 1	0.888		0.693		1.000
Splitter 2	1.000		1.000		0.000
Ethanol production (L/TC)	88.3	+ 3.0%	91.8	+7.1%	85.7
Electric energy (MWh/TC)	331.1	-10.1%	498.5	+35.3%	368.3
Vapor consumption (kg vapor/ kg ethanol)	5.6	+30.2%	7.9	+83.7%	4.3
Profit (US\$/h)	10356.1	-20.0%	7643.1	-41.0%	12953.2

Results

2. Scenario 2

B. Maximization of profit:

	With sugarcane trash		Without sugarcane trash
Splitter 1	0.696		0.886
Splitter 2	1.000		1.000
Ethanol production (L/TC)	91.8	+ 4.4%	87.9
Electric energy (MWh/TC)	499.3	+51.0%	330.6
Vapor consumption (kg vapor/ kg ethanol)	7.9	+37.9%	5.7
Profit (US\$/h)	32501.2	+1.4%	32042.2

Results

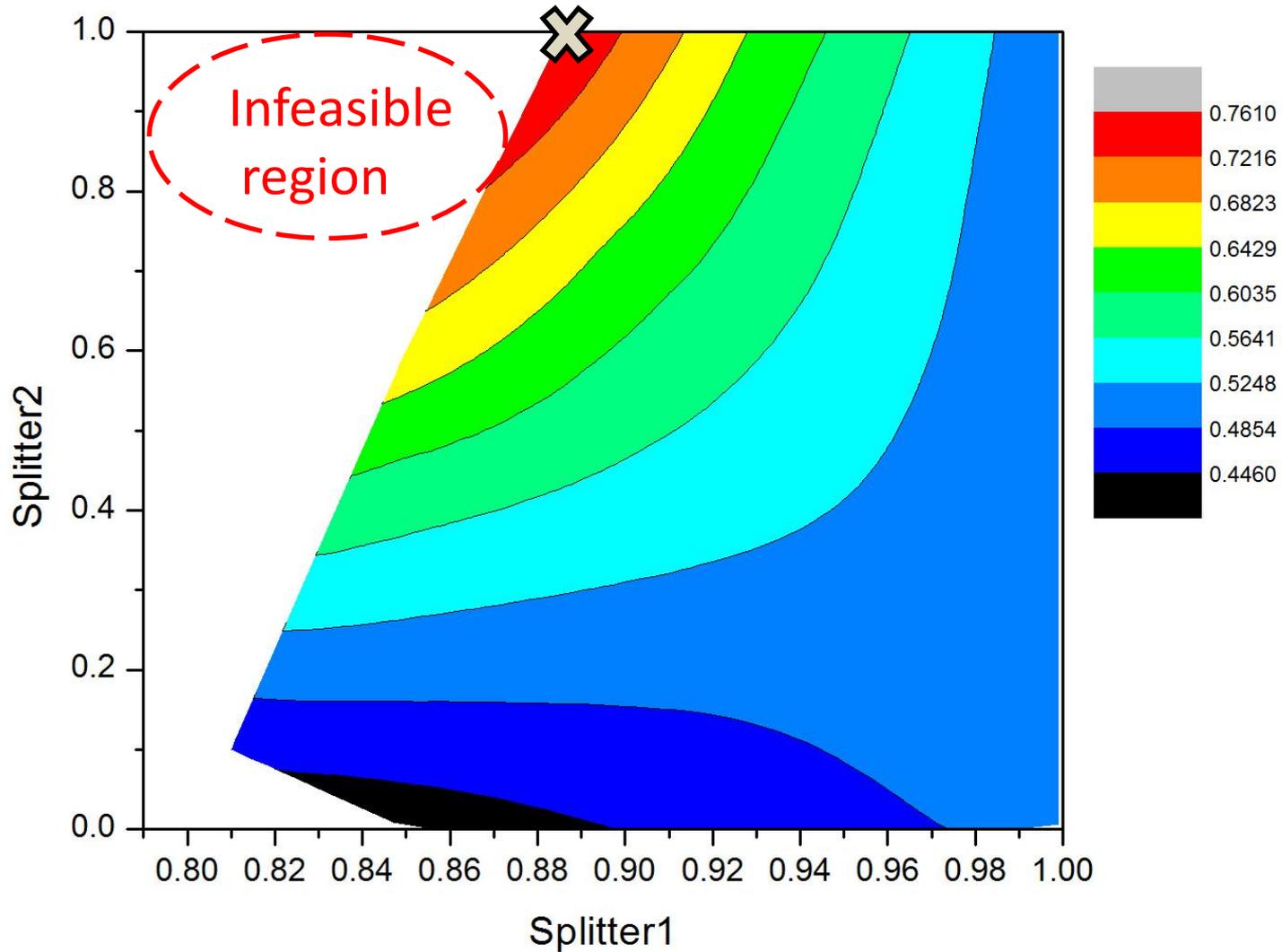


Fig. 8: Contour plot of dimensionless profit NOT considering the use of sugarcane trash (Scenario 2).

Results

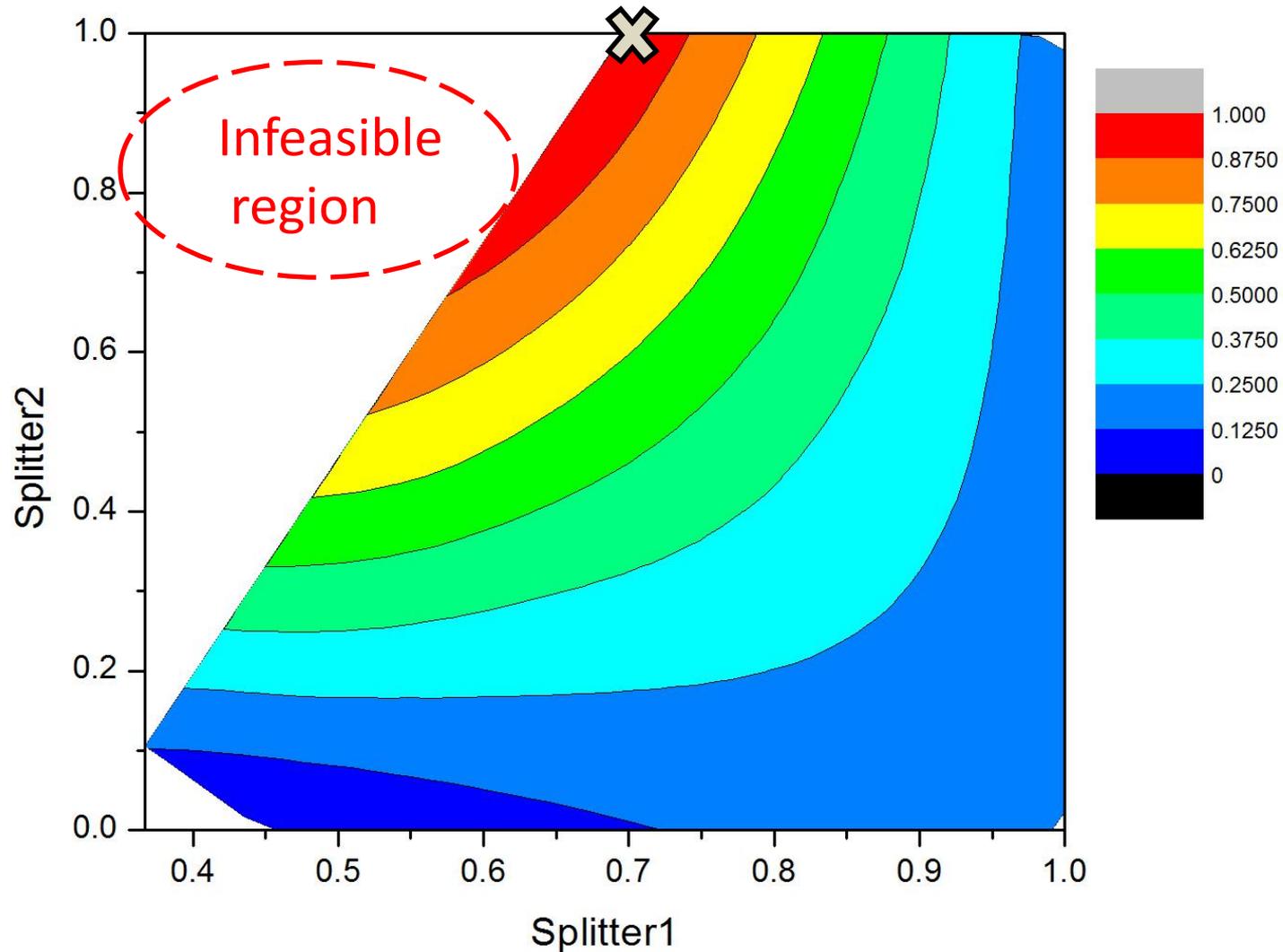


Fig. 9: Contour plot of dimensionless profit considering the use of sugarcane trash (Scenario 2).

Conclusions

- Optimization of the use of bagasse and calculation of process demands and outputs for the best situation (best = dependent on stipulated objective function) was possible using our tool;
- For current prices, maximization of ethanol production leads to lower profit;
- Use of sugarcane trash is not profitable for second generation ethanol production, but it is for electric power generation (Scenario 1: current market prices);

Conclusions

- Energy demand for second generation ethanol production cannot be supplied only by burning lignin (extra bagasse is needed);
- If electric power and bagasse prices decrease around 70% and ethanol price increases 70%, second generation ethanol would become an interesting option, and the use of sugarcane trash would help to increase profit even more (**governmental action?**).

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THANK YOU

