4th SMIBIO WORKSHOP

Small-scale biorefineries for bio-based products and biofuels production in Portugal

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Straubing, July 4th 2017

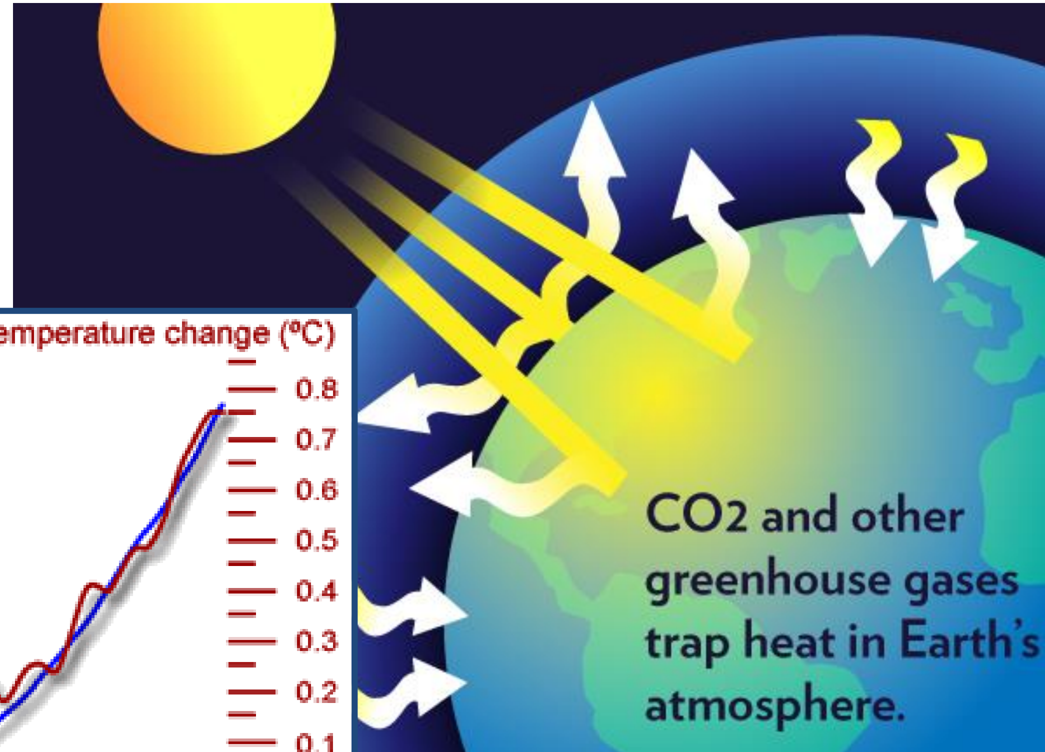
Introduction

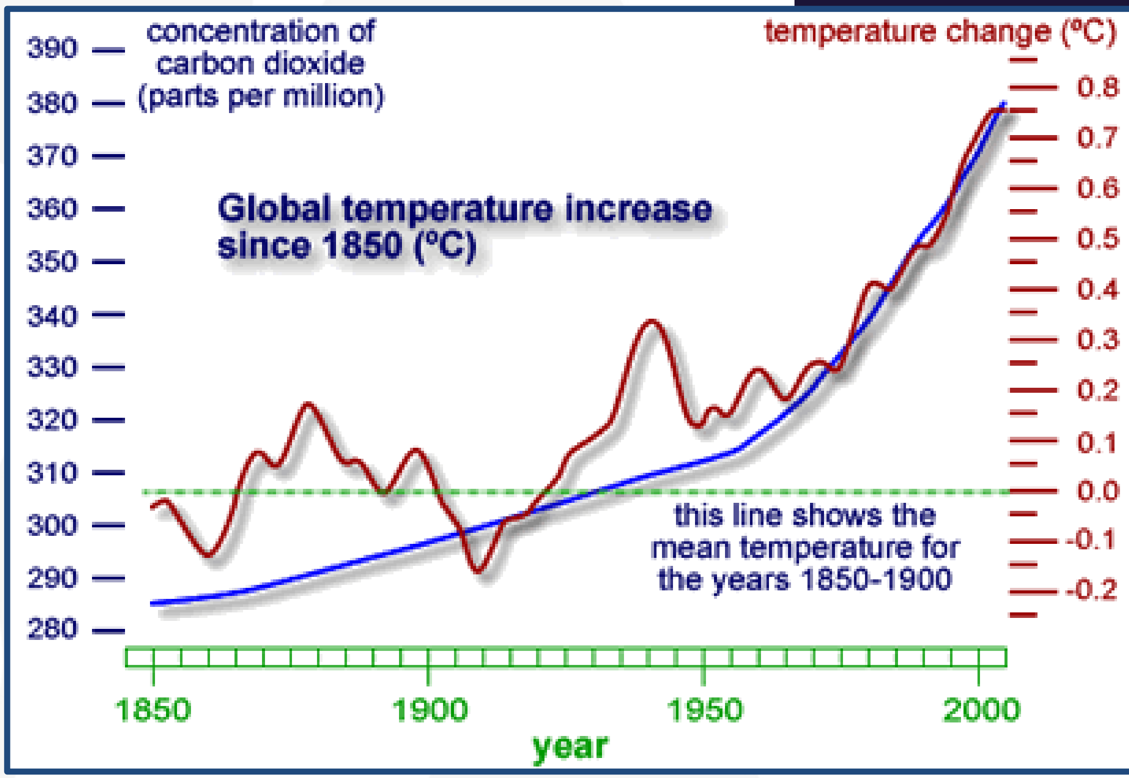
CLIMATE CHANGE

Norway; Source: National Geographic

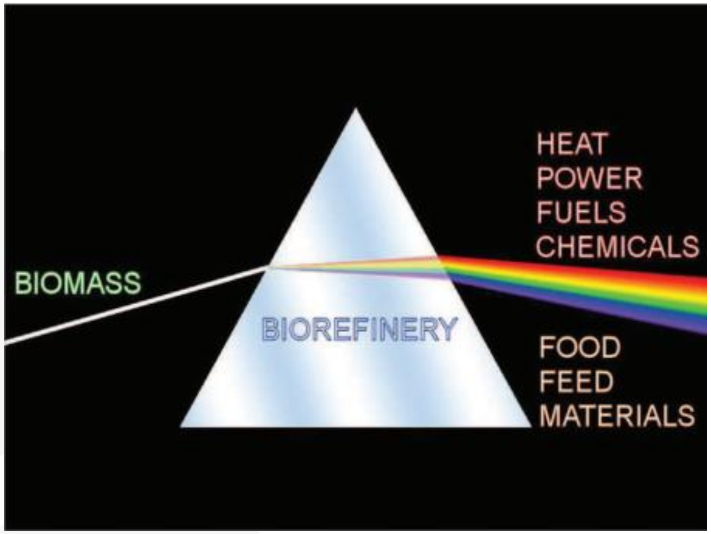
Introduction

GLOBAL WARMING





WHAT IS A BIOREFINERY?



"Biorefinery is the sustainable processing of biomass into a spectrum of marketable products and energy"

Source: IEA Bioenergy Task 42

Biorefineries

WHY SMALL-SCALE?

- Reduction of transportation costs of raw materials and intermediate products

- All-year supply of plant raw material within a suitable radius around the farm (up to 100 km)

- Decentralized location → stable regional sales market
- Industry and agriculture get linked by this process

- Refining "on the farm" allows very fast processing and can deliver high quality preproducts to decentralized biorefinery plants
- Residual material after refining (e.g. molasses, digestate) can be used as animal feed or source of energy, and soil fertilizer

Biorefineries

HOW TO ASSESS ITS ECONOMIC AND ENVIRONMENTAL VIABILITY?

ISSUE

- Process design
- Mass and energy balances
- Techno-economic analysis
- Sustainability assessment

SOFTWARE TOOLS

aspentech

SimaPro

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Biorefinery conceptual design and selection of business case studies

BIOREFINERY FEEDSTOCKS & PRODUCTS – PORTUGAL CASE STUDY

Feedstock:

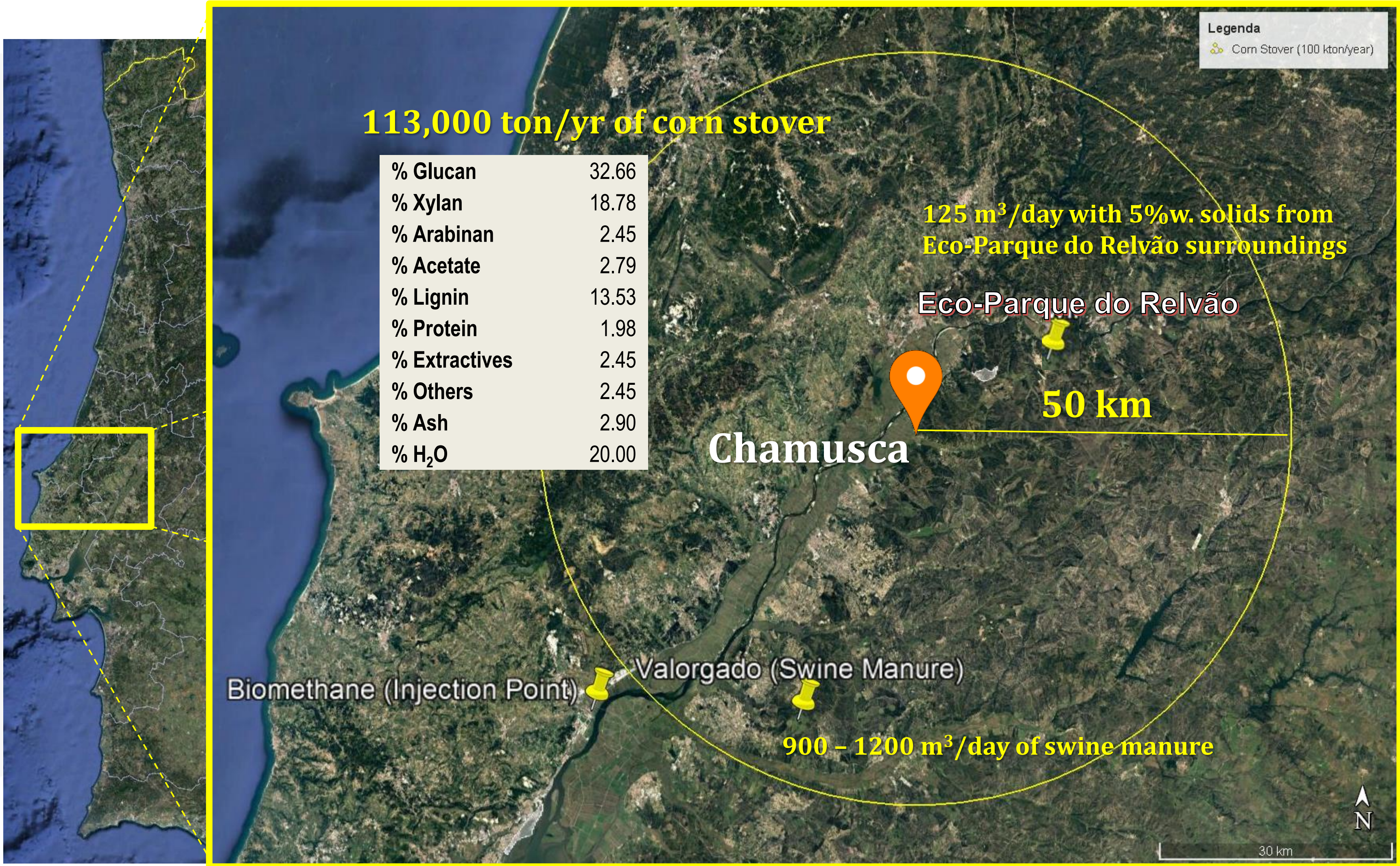
- Corn Stover (dry biomass)
- Swine Manure (wet biomass)

Biorefinery products:

- Ethanol/Isobutene
- Lignin and Biogas to CHP
- Bioproducts (oligosaccharides)

Biorefinery conceptual design and selection of business case studies

BIOREFINERY LOCATION



% Glucan	32.66
% Xylan	18.78
% Arabinan	2.45
% Acetate	2.79
% Lignin	13.53
% Protein	1.98
% Extractives	2.45
% Others	2.45
% Ash	2.90
% H_2O	20.00

Biorefinery conceptual design and selection of business case studies

HEURISTIC ANALYSIS Selection of 2 out of 4 scenarios

SCENARIO 1 Ethanol + Xylooligosaccharides (XOS) + CHP

XOS to be used as food or feed additive (1% wt.); e.g. prebiotic; World costumers

SCENARIO 2 Isobutene + XOS + CHP

Isobutene production from direct fermentation of C6 sugars; Industrial costumers

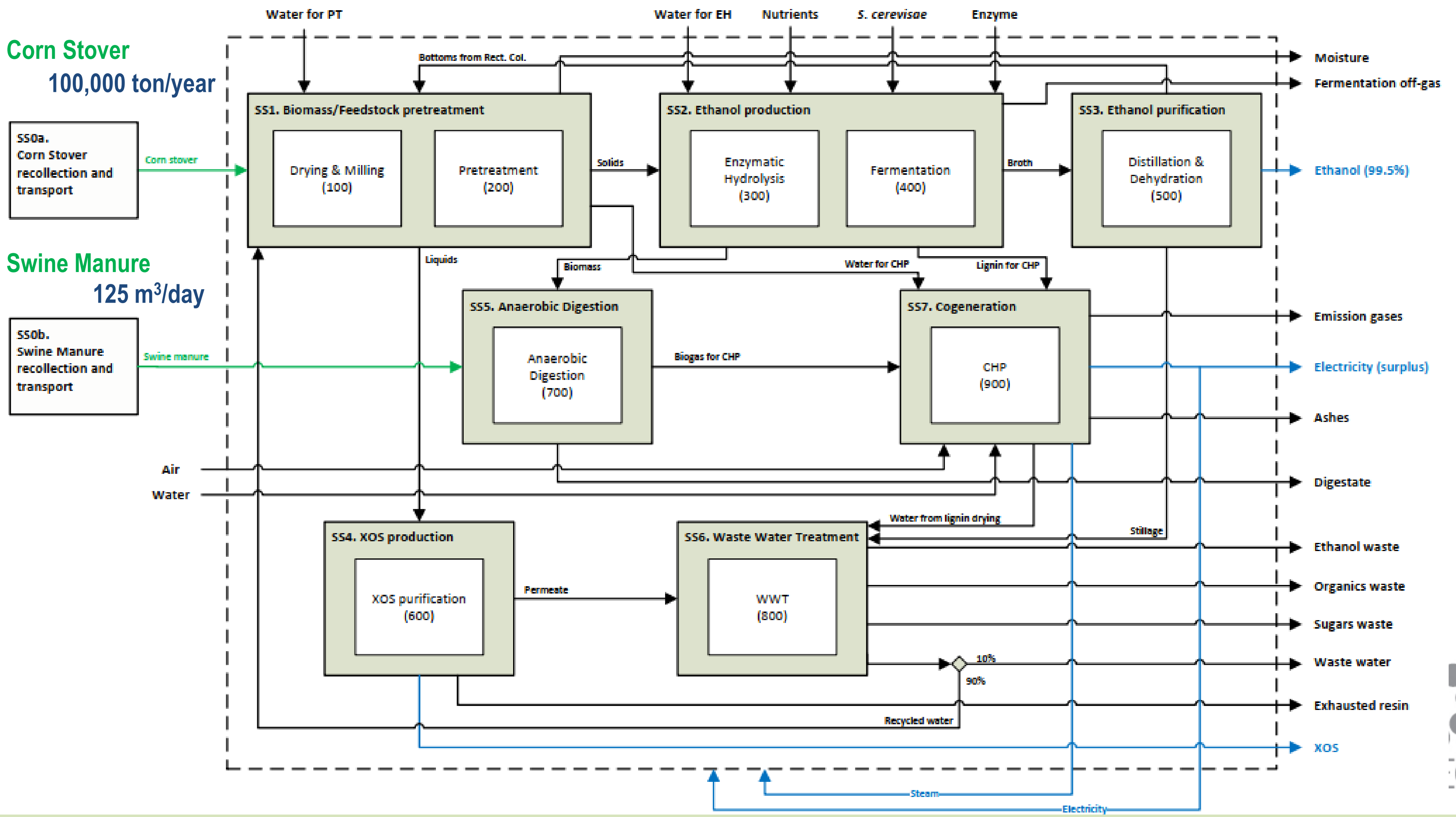
Process simulation of scenario #1

ASPEN PLUS **Mass & Energy balances**

SCENARIO 1 Ethanol + XOS + CHP

Corn Stover
100,000 ton/year

Swine Manure
125 m^3/day



Process integration and optimization of both platforms

ASPEN PLUS **Economic analysis**

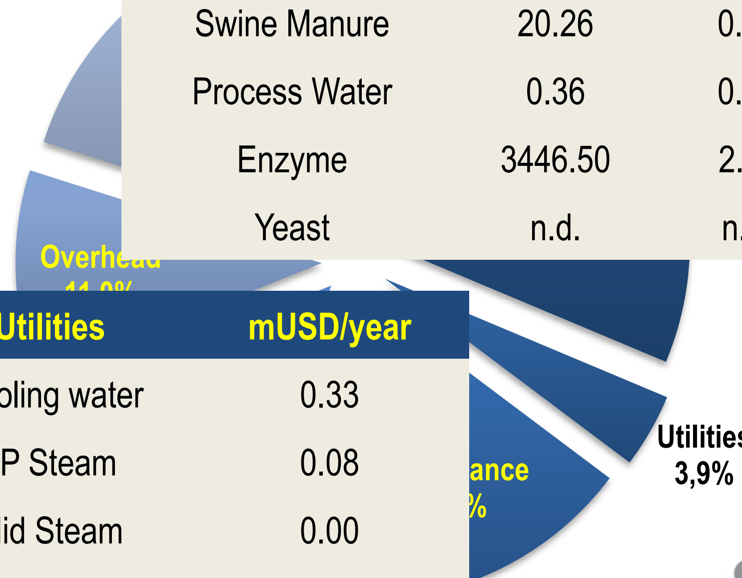
SCENARIO 1 Ethanol + XOS + CHP

Plant capacity: 100 kton corn stover per year

Fixed Capital Investment	78.9 mUSD

Total costs	mUSD/yr
Raw Materials	8.34
Utilities	1.04
Maintenance	5.49
Labor	0.11
Fixed & General	3.36
Overhead	2.92
Capital Depreciation	5.35
Other Costs	0.0
Total	**26.61**

Raw materials	USD/ton	mUSD/year
Corn Stover	52.10	5.21
Swine Manure	20.26	0.94
Process Water	0.36	0.07
Enzyme	3446.50	2.11
Yeast	n.d.	n.d.



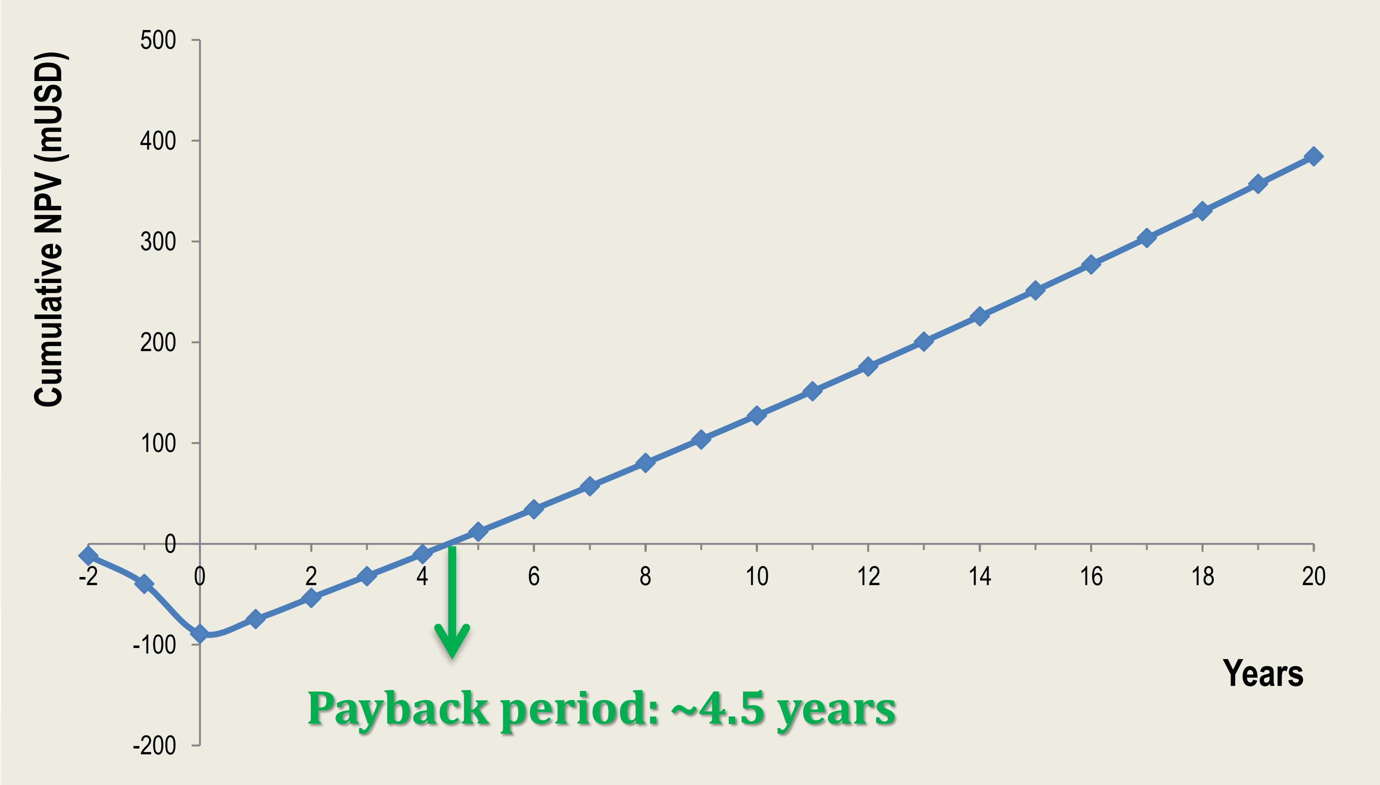
Utilities	mUSD/year
Cooling water	0.33
LP Steam	0.08
Mid Steam	0.00
HP Steam	0.63
Electricity	**0.00**

Process integration and optimization of both platforms

ASPEN PLUS **Economic analysis**

SCENARIO 1 Ethanol + XOS + CHP

NPV for 100,000 ton/year 384.5 mUSD (20 years plant lifetime)



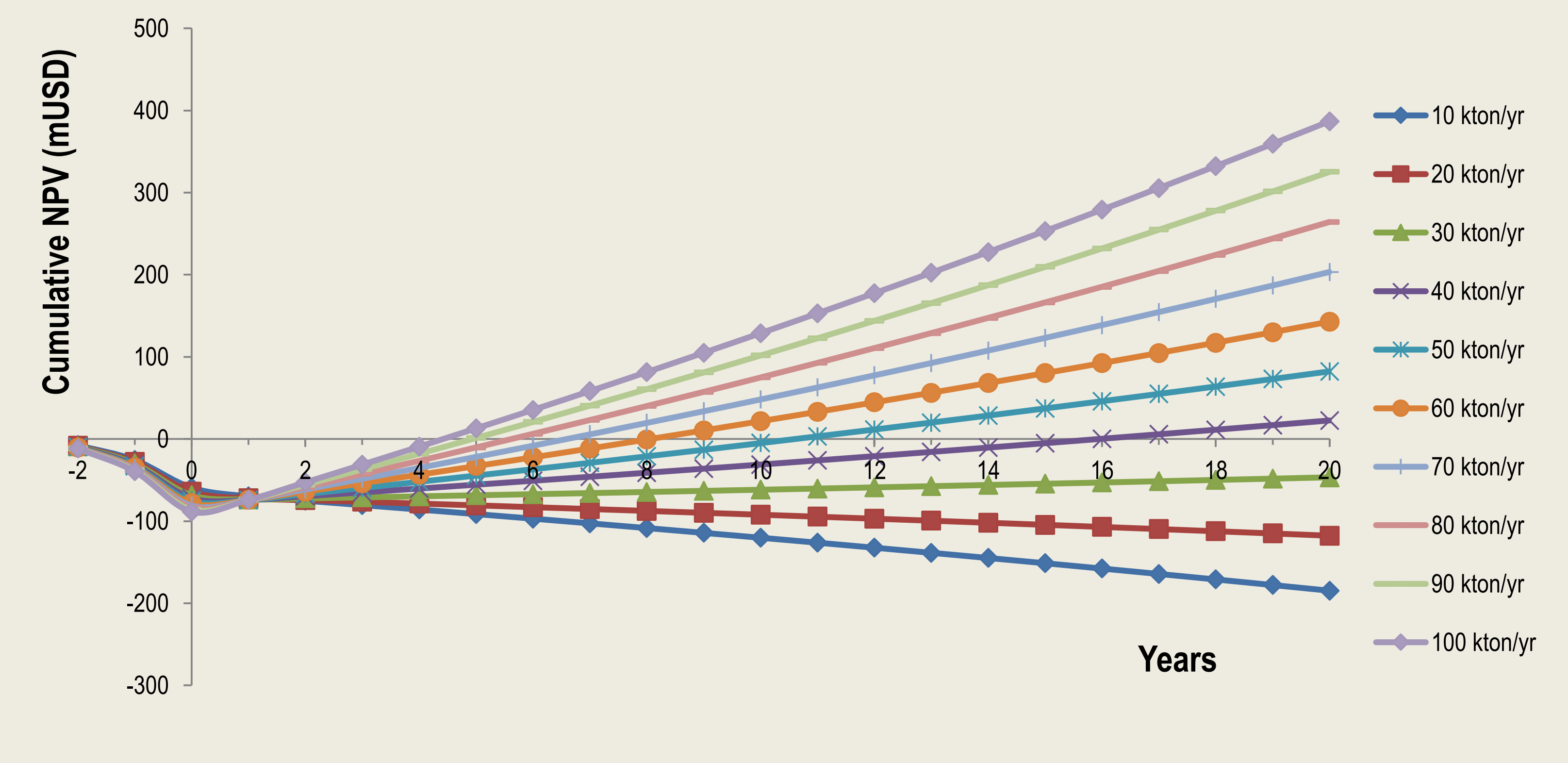
Market Price	USD/ton
Ethanol	950
XOS	4053

Process integration and optimization of both platforms

ASPEN PLUS **Economic analysis**

SCENARIO 1 Ethanol + XOS + CHP

Net Present Value vs. Plant Capacity



Process integration and optimization of both platforms

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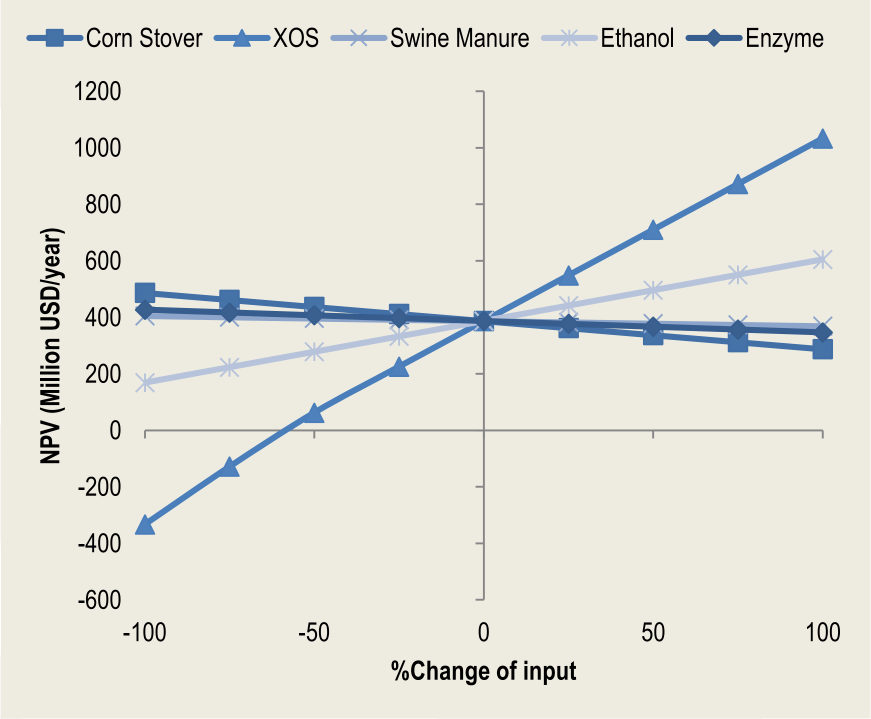
ASPEN PLUS **Economic analysis**

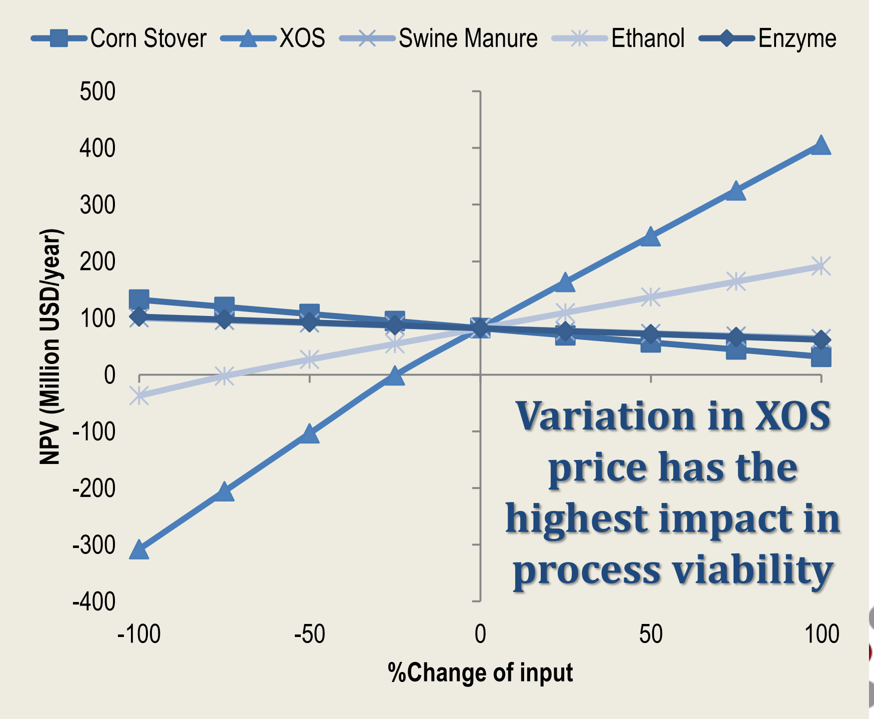
SCENARIO 1 Ethanol + XOS + CHP

Net Present Value vs. Price of Raw Materials/Products

100,000 ton corn stover/year



50,000 ton corn stover/year



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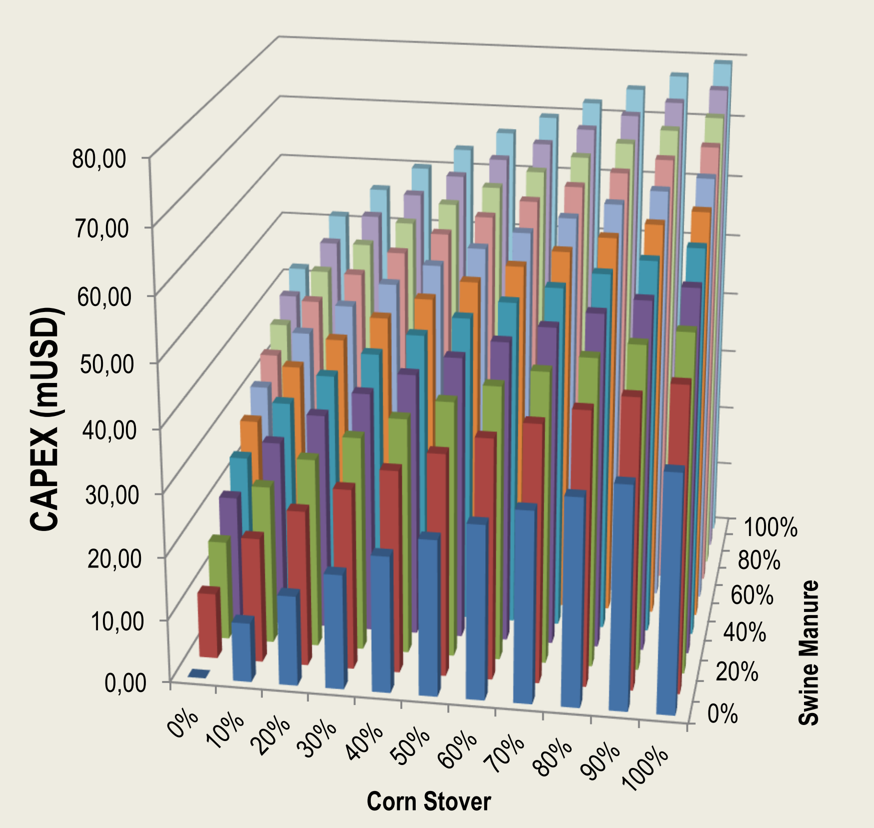
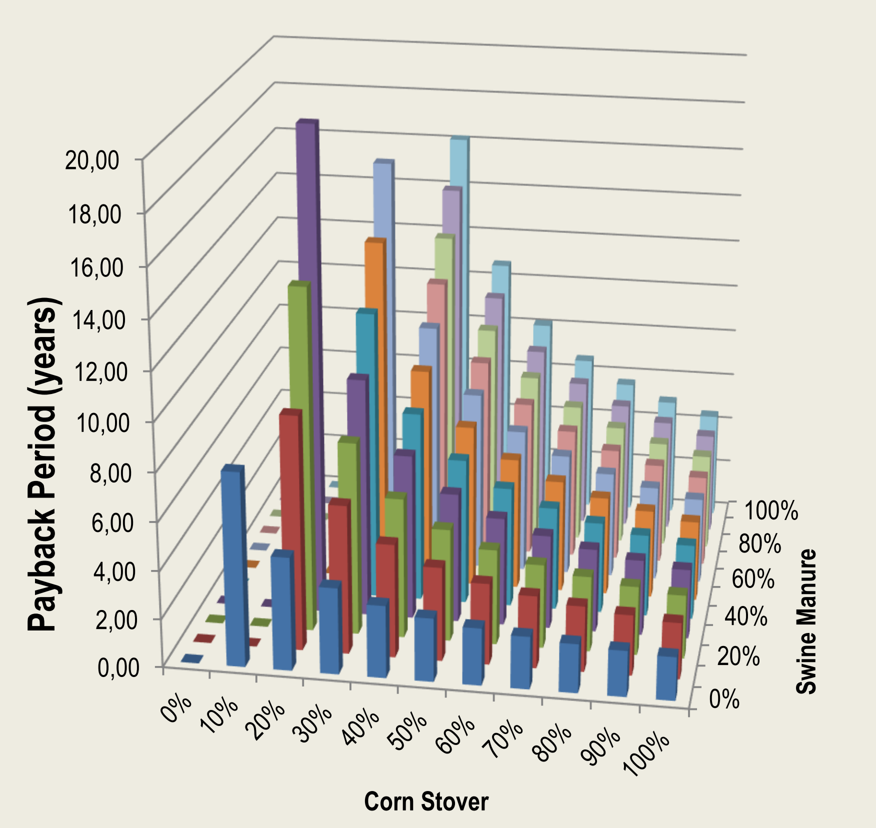
Process integration and optimization of both platforms

ASPEN PLUS **Economic analysis**

SCENARIO 1 **Ethanol + XOS + CHP**

Corn Stover (100,000 ton/yr) vs. Swine Manure (46,480 ton/yr)





Process integration and optimization of both platforms

ASPEN PLUS **Economic analysis**

SCENARIO 1 Ethanol + XOS + CHP

Corn Stover (100,000 ton/yr) vs. Swine Manure (46,480 ton/yr)

MP steam (ton/h)	Corn Stover (kton/year)										
Swine Manure (kton/year)	0	10	20	30	40	50	60	70	80	90	100
0	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.51	4.01	4.51	5.01
4.65	0.23	0.73	1.23	1.74	2.24	2.74	3.24	3.74	4.24	4.74	5.24
9.30	0.47	0.97	1.47	1.97	2.47	2.97	3.47	3.97	4.47	4.97	5.47
13.95	0.70	1.20	1.70	2.20	2.70	3.20	3.70	4.20	4.70	5.21	5.71
18.59	0.93	1.43	1.93	2.43	2.93	3.44	3.94	4.44	4.94	5.44	5.94
23.24	1.16	1.66	2.17	2.67	3.17	3.67	4.17	4.67	5.17	5.67	6.17
27.89	1.40	1.90	2.40	2.90	3.40	3.90	4.40	4.90	5.40	5.90	6.40
32.54	1.63	2.13	2.63	3.13	3.63	4.13	4.63	5.14	5.64	6.14	6.64
37.19	1.86	2.36	2.86	3.36	3.87	4.37	4.87	5.37	5.87	6.37	6.87
41.83	2.10	2.60	3.10	3.60	4.10	4.60	5.10	5.60	6.10	6.60	7.10
46.48	2.33	2.83	3.33	3.83	4.33	4.83	5.33	5.83	6.33	6.84	**7.34**

↳ **3 ton/h of steam at 7 bar available at Eco-Parque do Relvão**

Process integration and optimization of both platforms

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TECHNO-ECONOMIC ANALYSIS Main Conclusions

SCENARIO 1 Ethanol + XOS + CHP

- Ethanol production from corn stover is **economically viable for plant capacity higher than 50,000 ton/year** of lignocellulosic feedstock

- **XOS market price variation has the highest impact on process viability**; Process non-viable if XOS price is reduced in 50% for 100 kton/year and if reduced in 25% for 50 kton/year

- **Process is still viable if wet biomass is not used**; The use of swine manure increases the CAPEX and produces **surplus of electricity**; **No swine manure leads to electricity deficit**.

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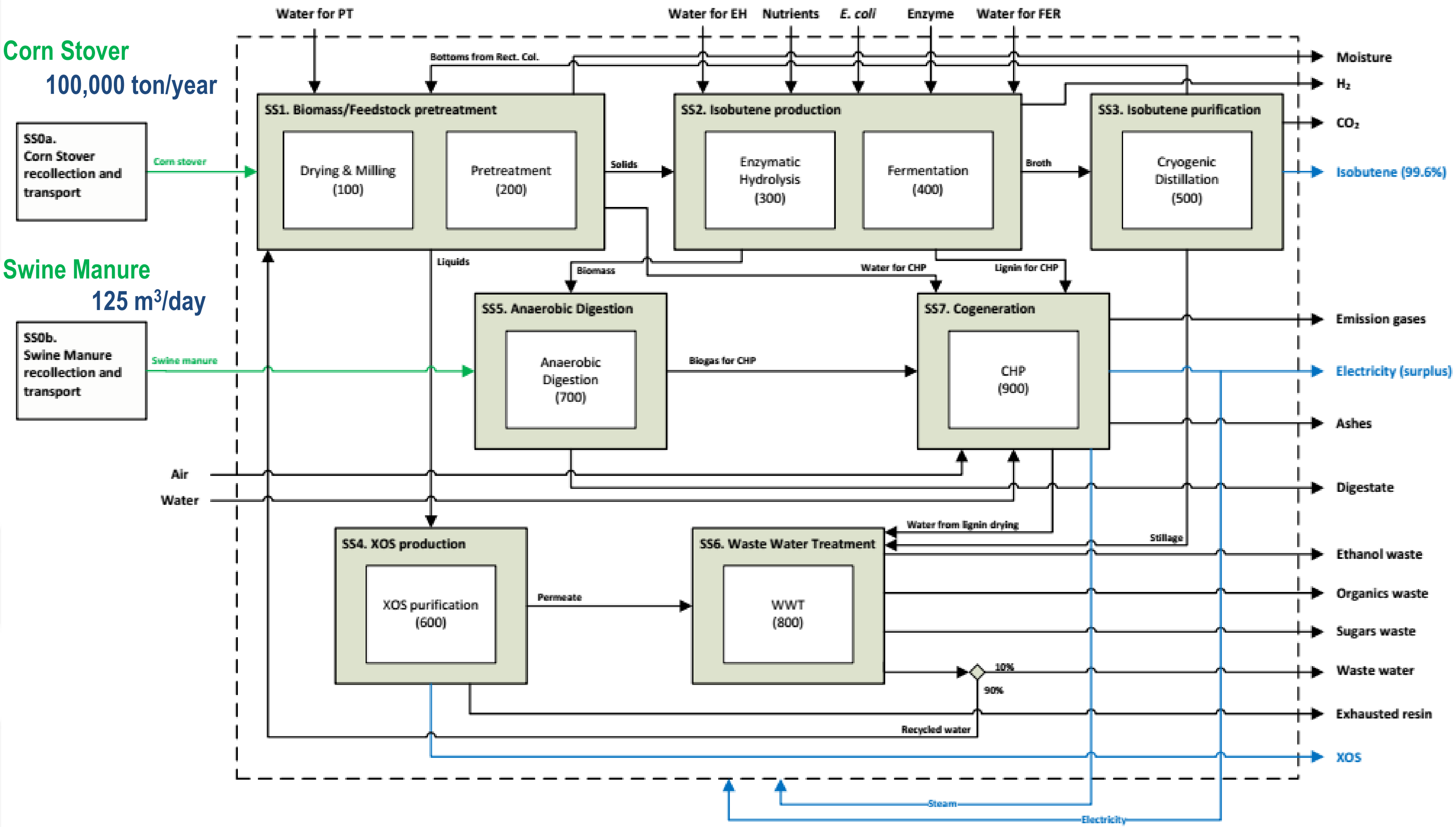
Process simulation of scenario #2

ASPEN PLUS Mass & Energy balances

SCENARIO 2 Isobutene + XOS + CHP

Corn Stover
100,000 ton/year

Swine Manure
125 m³/day



Process integration and optimization of both platforms

ASPEN PLUS **Economic analysis**

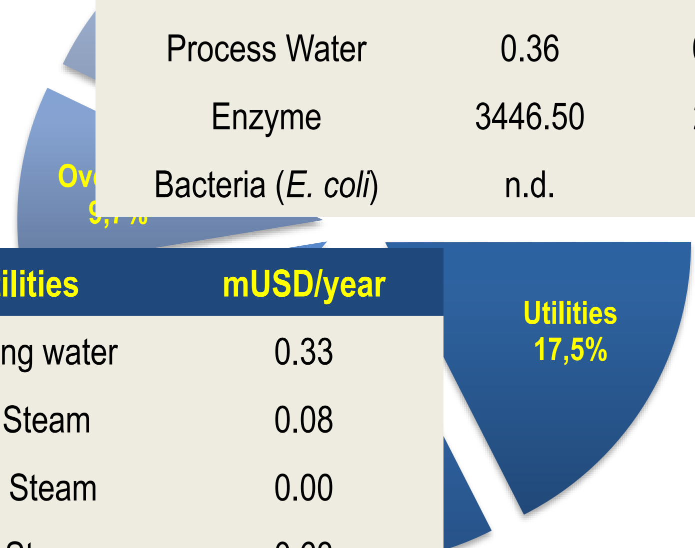
SCENARIO 2 Isobutene + XOS + CHP

Plant capacity: 100 kton corn stover per year

Fixed Capital Investment	89.5 mUSD

Total costs	mUSD/yr
Raw Materials	8.41
Utilities	5.90
Maintenance	6.17
Labor	0.11
Fixed & General	3.78
Overhead	3.28
Capital Depreciation	6.02
Other Costs	0.00
Total	**33.68**

Raw materials	USD/ton	mUSD/year
Corn Stover	52.10	5.21
Swine Manure	20.26	0.94
Process Water	0.36	0.14
Enzyme	3446.50	2.11
Bacteria (*E. coli*)	n.d.	n.d.



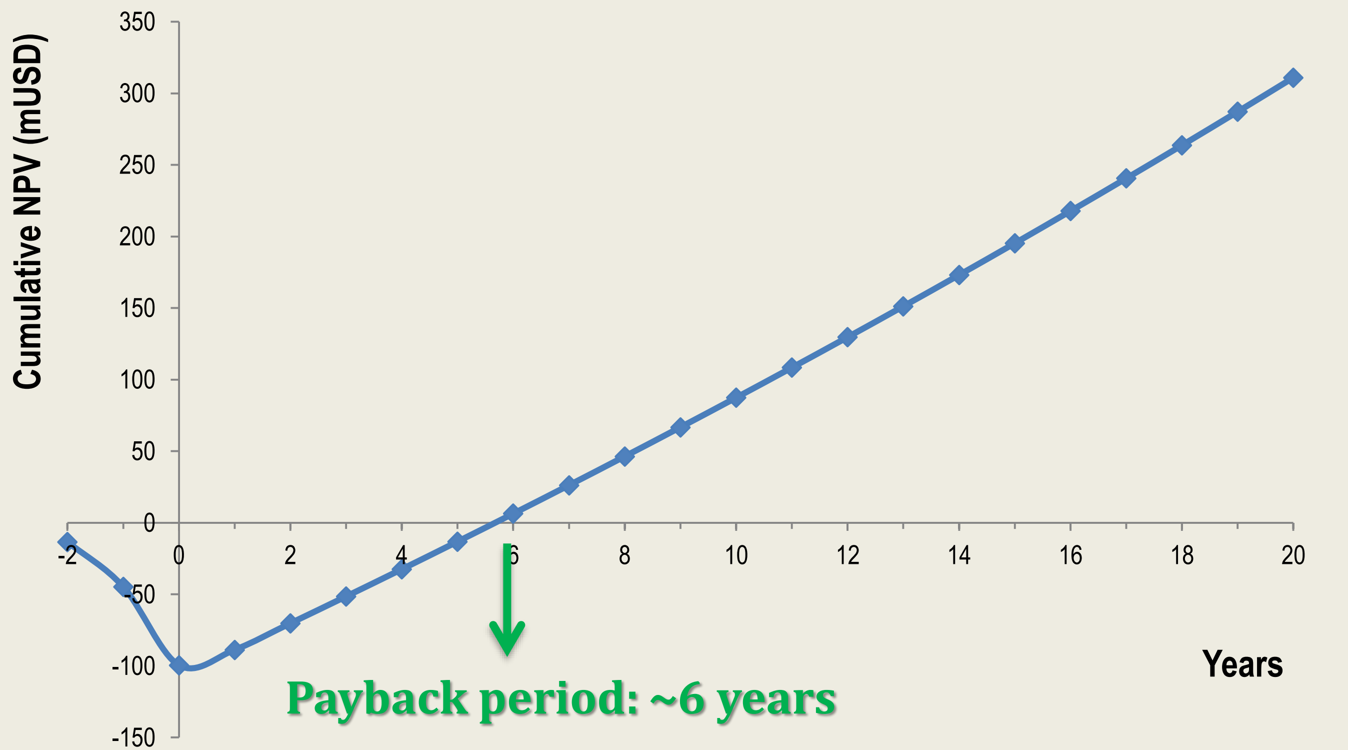
Utilities	mUSD/year
Cooling water	0.33
LP Steam	0.08
Mid Steam	0.00
HP Steam	0.63
Electricity	**0.00**

Process integration and optimization of both platforms

ASPEN PLUS **Economic analysis**

SCENARIO 2 Isobutene + XOS + CHP

NPV for 100,000 ton/year 311.0 mUSD (20 years plant lifetime)



Market Price	USD/ton
Isobutene	2017
XOS	4053

Process integration and optimization of both platforms

ASPEN PLUS **Economic analysis**

SCENARIO 2 Isobutene + XOS + CHP

Corn Stover (100,000 ton/yr) vs. Swine Manure (46,480 ton/yr)

MP steam (ton/h)		Corn Stover (kton/year)										
		0	10	20	30	40	50	60	70	80	90	100
Swine Manure (kton/year)	0	0.00	4.05	8.09	12.14	16.18	20.23	24.27	28.32	32.36	36.41	40.45
	4.65	1.88	5.93	9.97	14.02	18.06	22.11	26.15	30.20	34.24	38.29	42.33
	9.30	3.76	7.81	11.85	15.90	19.94	23.99	28.03	32.08	36.12	40.17	44.21
	13.95	5.64	9.69	13.73	17.78	21.82	25.87	29.91	33.96	38.00	42.05	46.09
	18.59	7.52	11.57	15.61	19.66	23.70	27.75	31.79	35.84	39.88	43.93	47.97
	23.24	9.40	13.45	17.49	21.54	25.58	29.63	33.67	37.72	41.76	45.81	49.85
	27.89	11.28	15.33	19.37	23.42	27.46	31.51	35.55	39.60	43.64	47.69	51.73
	32.54	13.16	17.21	21.25	25.30	29.34	33.39	37.43	41.48	45.52	49.57	53.61
	37.19	15.04	19.09	23.13	27.18	31.22	35.27	39.31	43.36	47.40	51.45	55.50
	41.83	16.92	20.97	25.01	29.06	33.10	37.15	41.19	45.24	49.29	53.33	57.38
	46.48	18.80	22.85	26.89	30.94	34.98	39.03	43.08	47.12	51.17	55.21	59.26

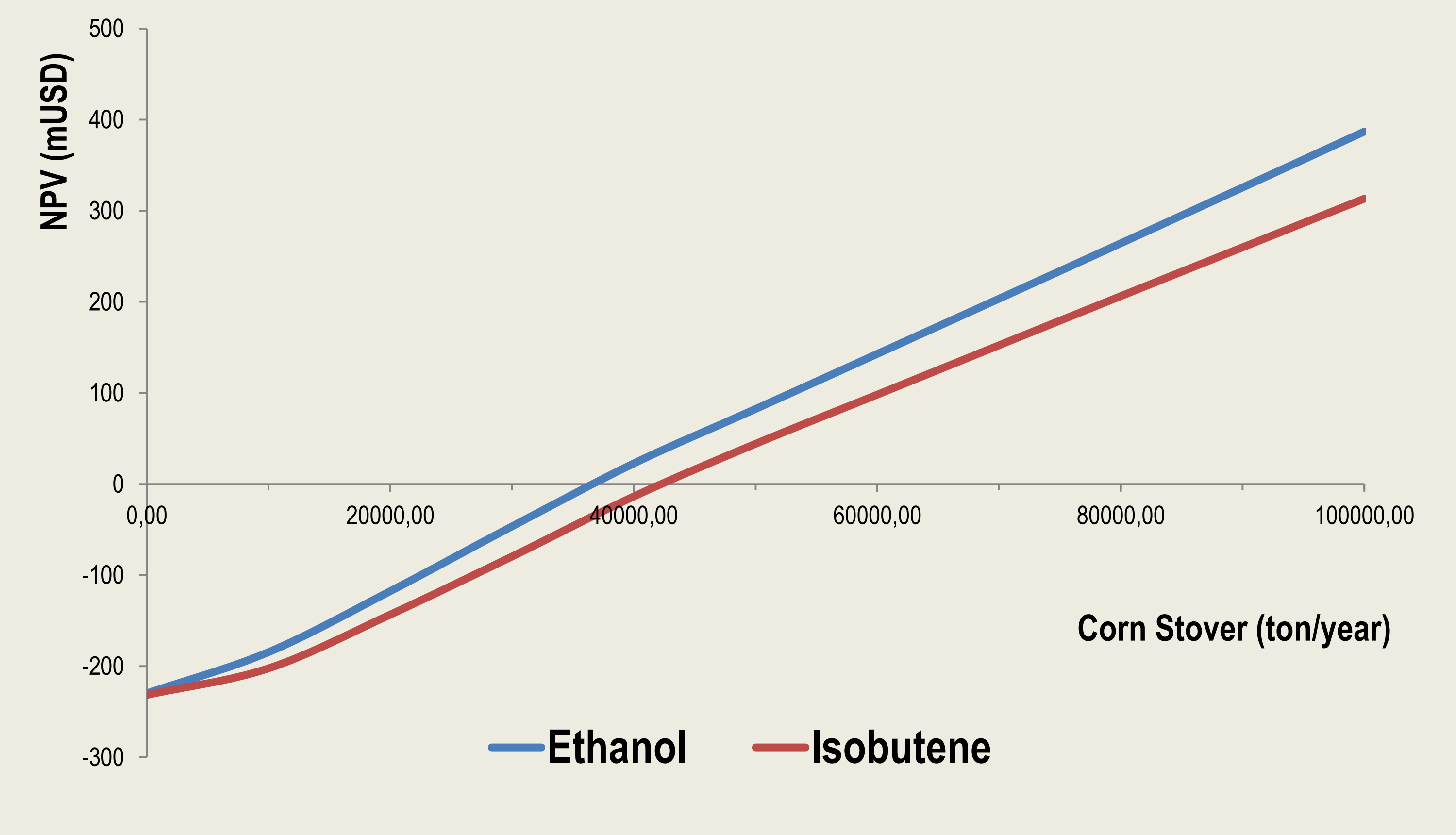
↳ **3 ton/h of steam at 7 bar available at Eco-Parque do Relvão**

Process integration and optimization of both platforms

ASPEN PLUS   Economic analysis

SCENARIO 1 vs. SCENARIO 2

Net Present Value vs. Plant Capacity



Process integration and optimization of both platforms

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TECHNO-ECONOMIC ANALYSIS **Main Conclusions**

SCENARIO 2 **Isobutene + XOS + CHP**

- Isobutene production from corn stover is **economically viable for plant capacity higher than 70,000 ton/year** of lignocellulosic feedstock

- **Higher CAPEX and OPEX than Scenario 1** due to the need of cryogenic distillation for isobutene purification; Higher steam demand due to the need of sterilization of streams before fermentation (with *E. coli*)

- The use of swine manure has the **same impact** as in Scenario 1

- Scenario 1 leads to **payback period lower than Scenario 2** for any viable plant capacity

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Process integration and optimization of both platforms

Life Cycle Assessment

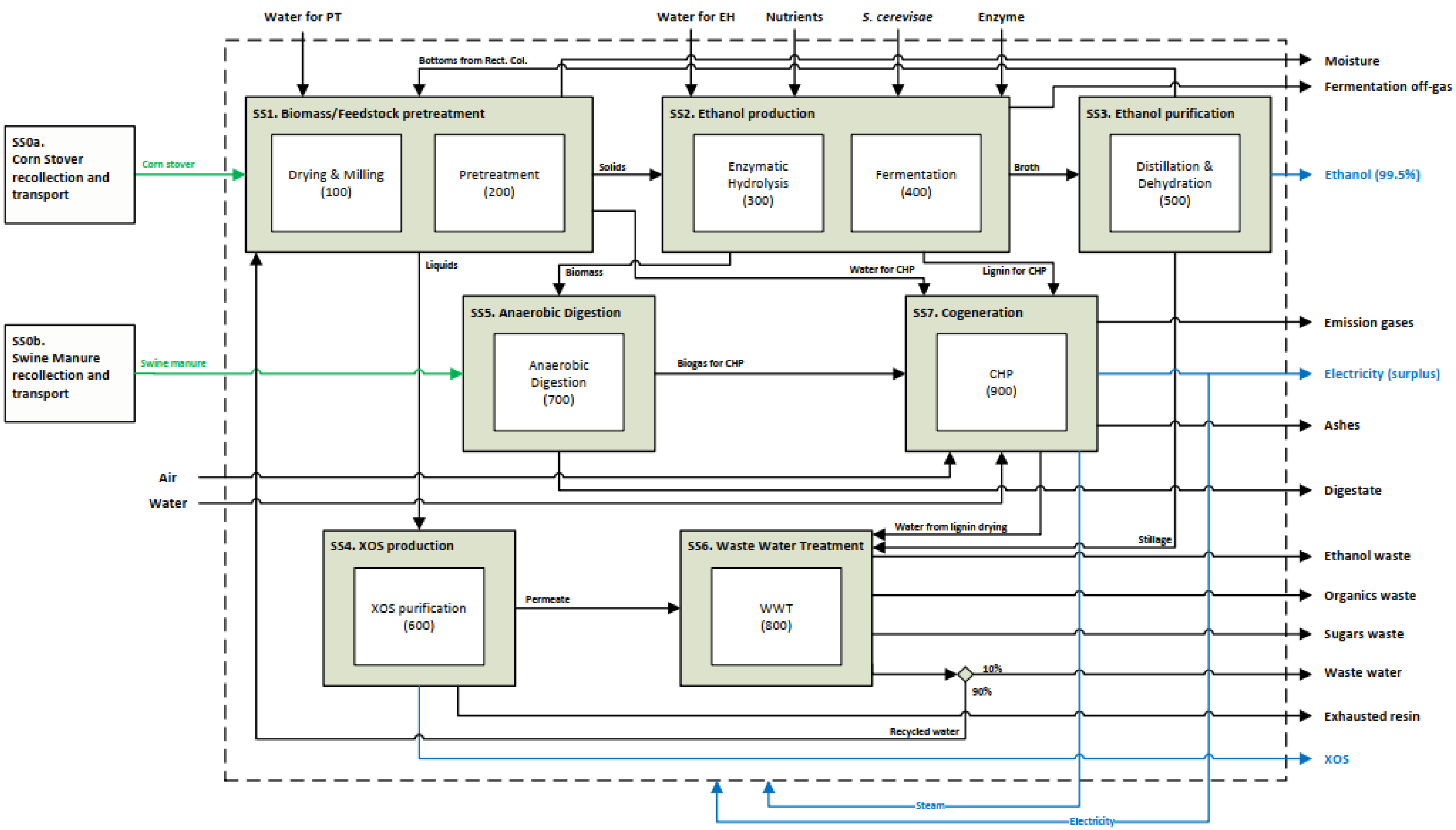
Goal and Scope:

- Assess the environmental impacts of producing biofuels/bioproducts under the developed scenarios for each country
- Functional Unit: **1 kg of lignocellulosic feedstock**
- System Boundaries: ***cradle-to-gate*** (feedstock as residues, only its transport was considered)
- Subsystems: To simplify the process and evaluate the impact of each system
- LCI: Data obtained from Aspen Plus simulations
- Databases: Ecoinvent v3 (SimaPro), literature data
- Methods for LCA: ReCiPe Midpoint (H)

Process integration and optimization of both platforms

Life Cycle Assessment Scenario 1 : Ethanol + XOS + CHP

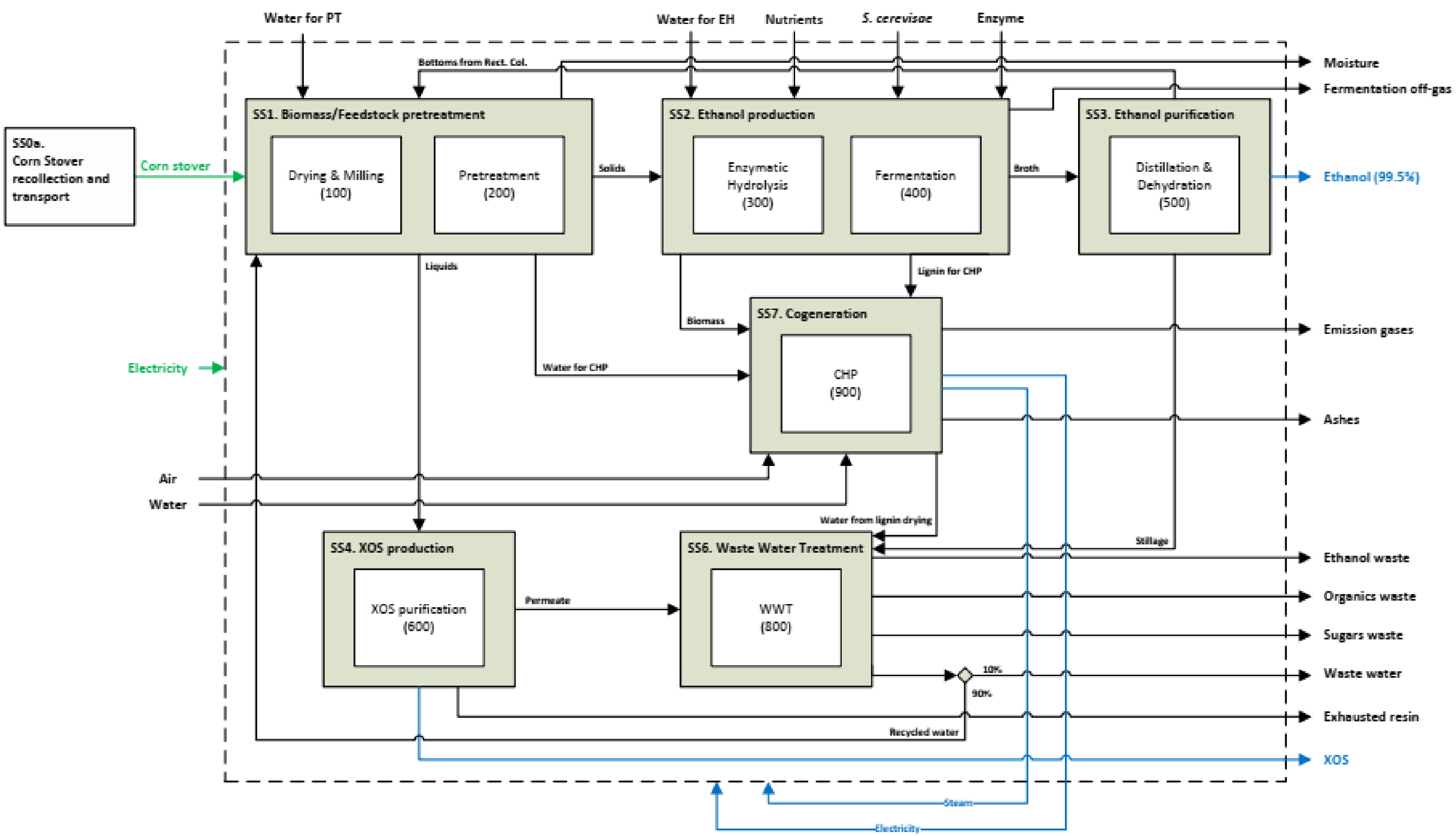
Corn Stover + Swine Manure



Process integration and optimization of both platforms

Life Cycle Assessment Scenario 1 : Ethanol + XOS + CHP

Without Swine Manure



Process integration and optimization of both platforms

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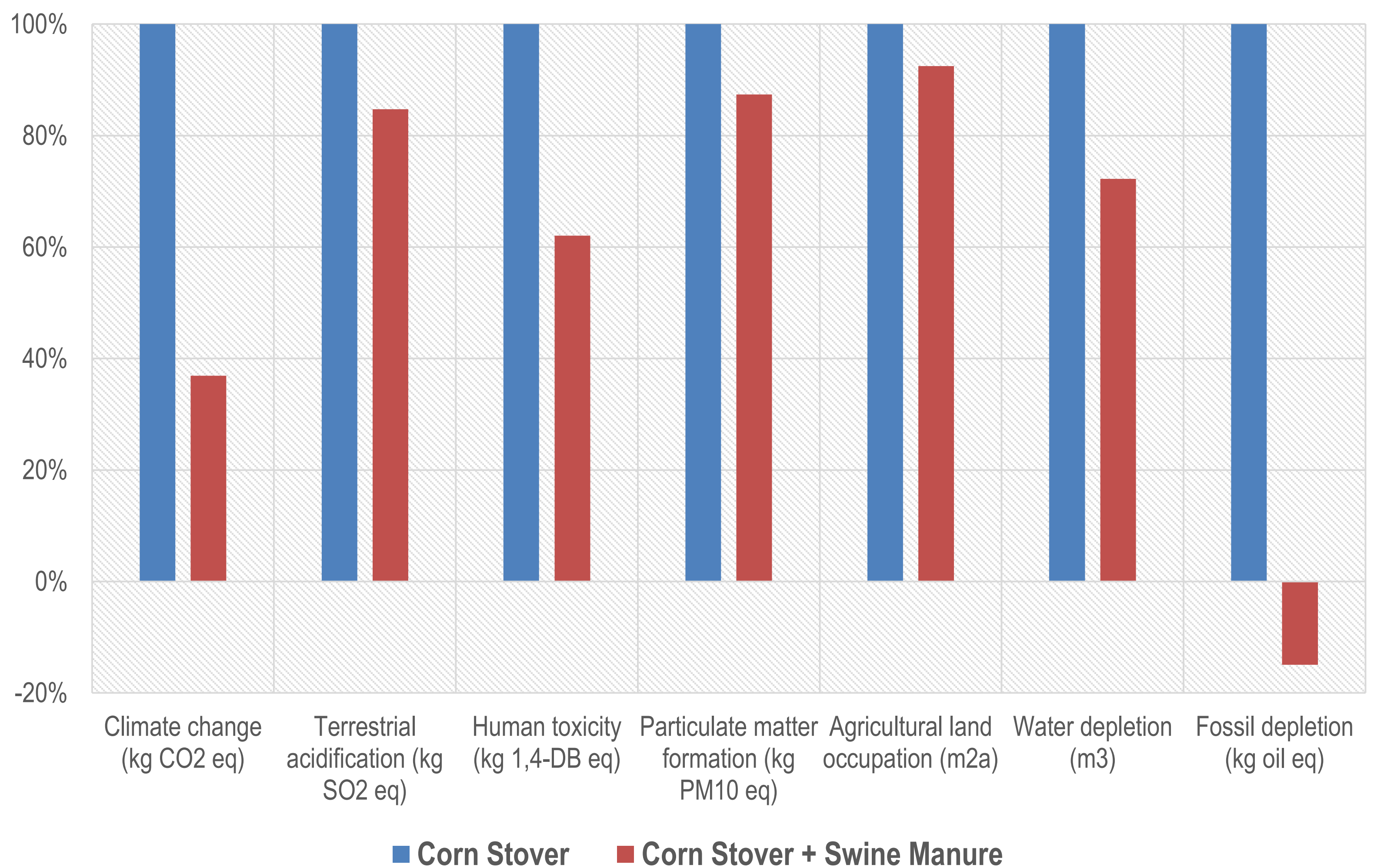
Life Cycle Assessment   Corn Stover + Swine Manure vs. CS only



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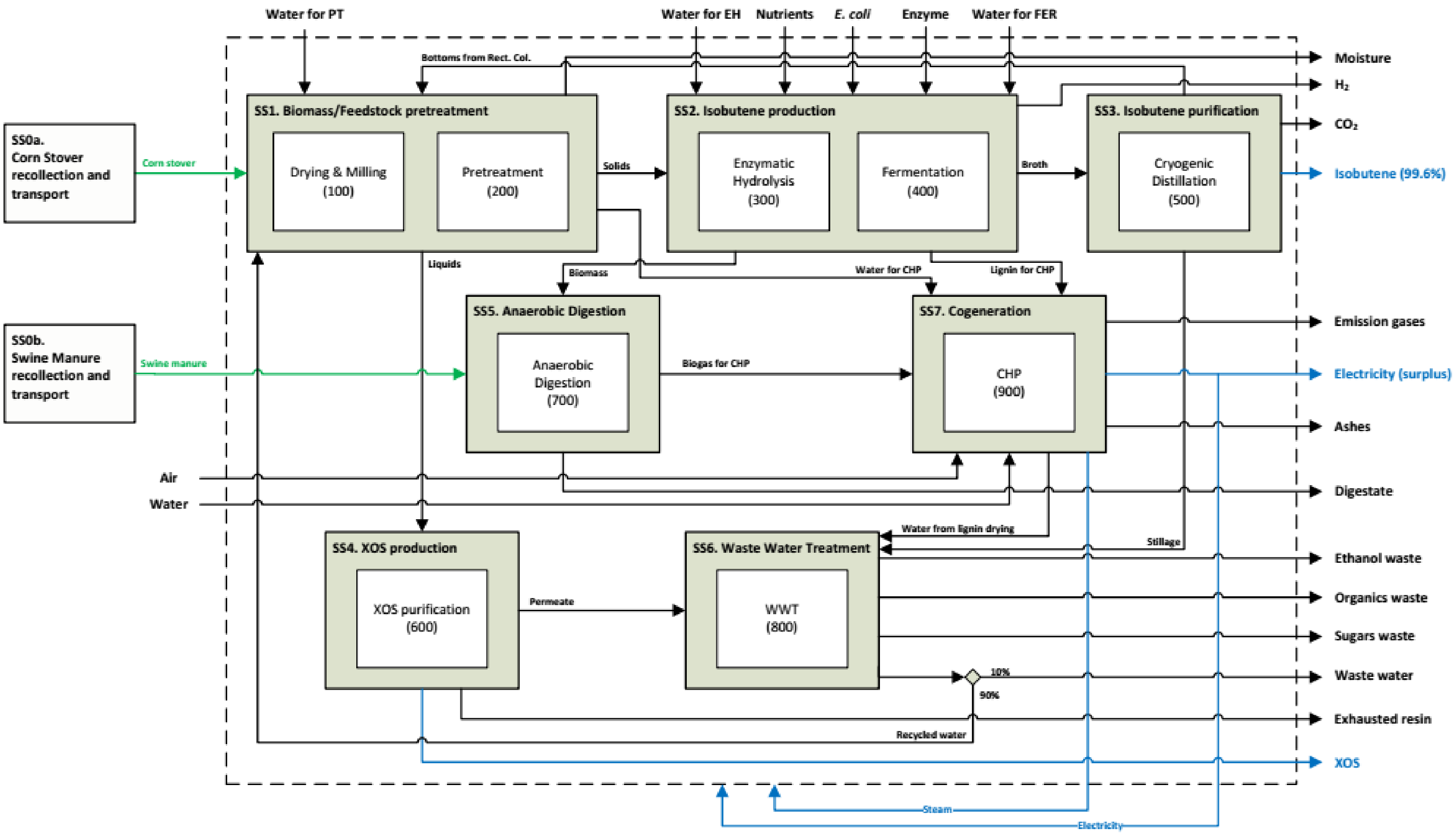
Process integration and optimization of both platforms

Life Cycle Assessment   Scenario 2 : Isobutene + XOS + CHP



Process integration and optimization of both platforms

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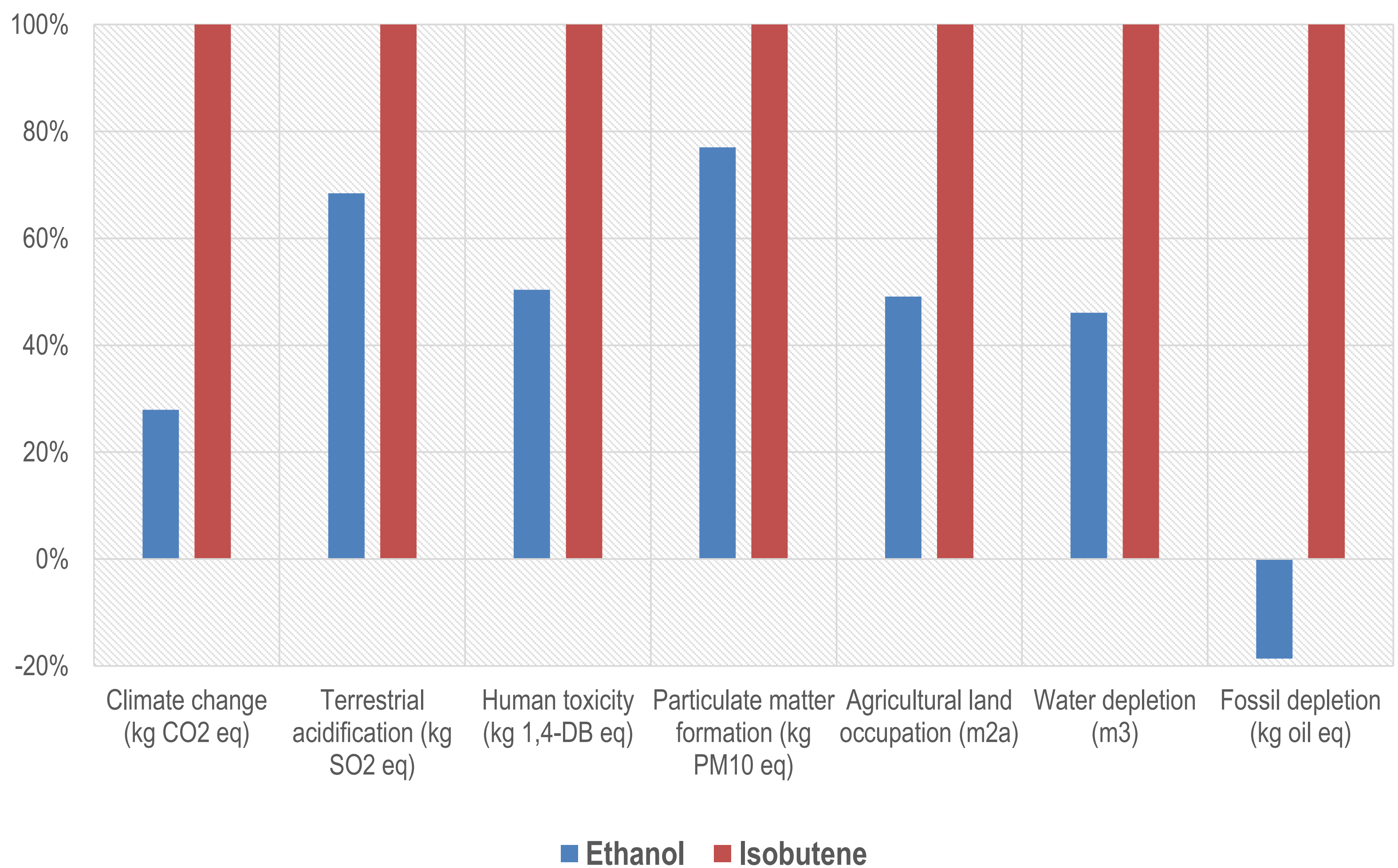
Life Cycle Assessment Scenario 1 vs. Scenario 2



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Process integration and optimization of both platforms

Life Cycle Assessment Scenario 1 vs. Scenario 2

Impact category	Ethanol (corn stover)	Isobutene (corn stover)
	Per kg of lignocellulosic feedstock	
GWP (kg CO_2 eq)	0.6296	2.2571
Agricultural land occupation (m^2a)	1.3019	2.6515
Water depletion (m^3)	0.0090	0.0195
Fossil depletion (kg oil eq)	-0.0405	0.2174

Values for scenarios 1 and 2 using 100,000 ton/year of corn stover and 46,485 ton/year of swine manure

Process integration and optimization of both platforms

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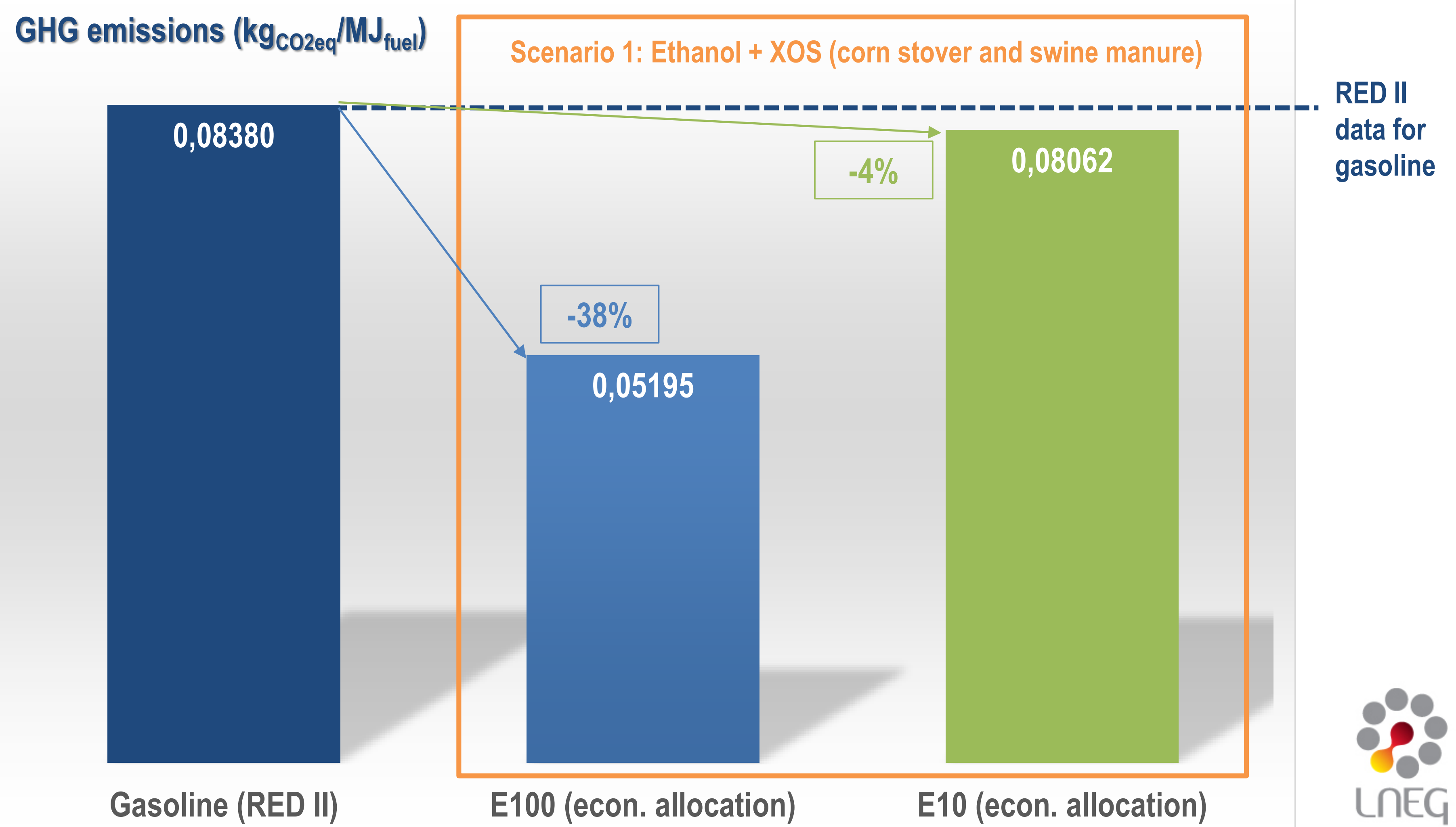
Life Cycle Assessment   Comparison with fossil fuels



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Process integration and optimization of both platforms

Life Cycle Assessment   Main Conclusions

- In scenario 1, SS2 (Ethanol production) has the **highest contribution for climate change and agricultural land occupation**; This is due to the impacts related to yeast production
- The use of swine manure has **a positive impact due to electricity surplus**, leading to a more sustainable process
- **Scenario 1 (Ethanol) is more environmentally sustainable than Scenario 2 (Isobutene)**; This is due to the higher demands of electricity and steam, and the impact related to the use of *E. coli*
- Ethanol from corn stover (E100), under this biorefinery scenario where XOS is also produced, has **less GWP than gasoline from oil (RED II)** if an economic allocation is considered

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Thank you for your attention

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