Assessing the feasibility and sustainability of surfactin bioprocesses: a techno-economic and environmental analysis

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Introduction

Surfactant market

1. Soaps, carboxylates, lignosulfonates, 33%
   - Domestic soaps
   - Acids for industrial use
2. Synthetic detergents (sulfonate), 22%
   - Domestic use (solid and liquid)
   - Oil industry
   - Additive
   - Pharmaceutical use
3. Nonionic (ethoxylated or ethoxysulfates), 40%
4. Cationic (quaternary ammoniums), 5%

Oil-based process

Biotechnological pathways

Alternative solution for environmental mitigation

Introduction

Bacillus spp.

PGPR = Plant Growth Promoting Rhizobacteria
Production of lipopeptides
→ surfactin, fengycin and iturin

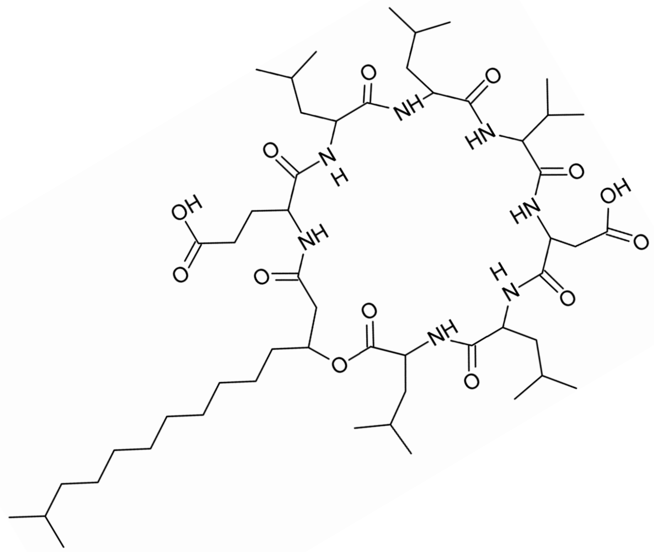
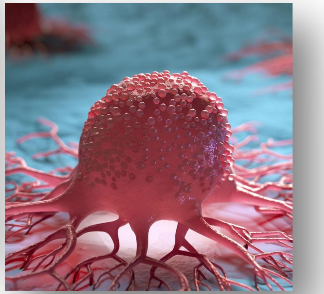


Fig1 Structure of surfactin (cyclic lipopeptide)

Properties and application possibilities of surfactants

Antifungal activity

Anticancer activity



Food preservative

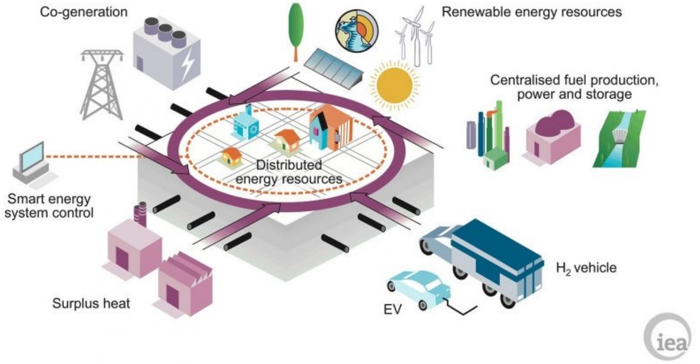
Foaming

Potential applications of biosurfactants/spores in the bioeconomic framework:

- Emulsifier (food sector)
- Ingredient for personal care product (cosmetic sector)
- Household detergent
- Microbial plant protection (*Bacillus* spp. spores; agricultural sector)

Problem statement

European energy crisis



2021
Electricity cost: 0.23 USD/kWh

2022
Electricity cost: 0.41 USD/kWh

→ Surfactin production

Experimental data → Simulation → Economic and Enviromental assessment

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Methodology

Experimental results: Laboratory of Bioprocess Engineering of the University of Hohenheim

Simulation and analysis: Institute of Biotechnology and Agribusiness, Universidad Nacional de Colombia sede Manizales

Surfactin production using glucose as carbon source

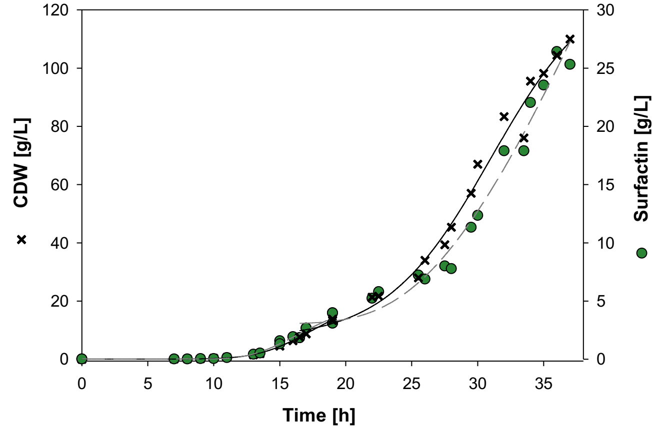

Fig2 Bioreactor fed-batch process employing strain *B. subtilis* 3NA *sfp*⁺ [2]

- **Sc1** Experimental results
  Base case
- **Sc2** Ideal process: 100% conversion
  Theoretical case
- **Sc3** Energy impact (fluctuations between 2021 and 2022)
  Energy case

✓ Glucose flow rate: 298.16 kg h^{-1}

✓ Thermodynamic properties:
  - NRTL -> Liquid phase
  - Redlich-Kwong (RK) -> Gas phase

✓ Continuous operation based on the residence time of each unit

[2] Klausmann, P., Hennemann, K., Hoffmann, M., Treinen, C., Aschern, M., Lilge, L., Morabbi Heravi, K., Henkel, M. & Hausmann, R. (2021). *Appl Microb Biotech*, *105*(10), 4141-4151.

Methodology
Economic and environmental assessment

Economic analysis

Operating costs (OpEx): Involve the cost of raw materials, utilities and labor.
Labor costs: Operator 13.47 USD/h (six operators)
Useful life of the plant **20** years
Depreciation method: Linear
Salvage value: 15%.

Fluctuation between 2021 and 2022

- Interest rate: 2%
- Raw material cost change 4.3%
- Utility cost change:
  - Steam: 34.5%
  - Cooling water: 4.5%
  - Electricity: 78.3%
  - Refrigerant: 1.5%

Environmental analysis

Objective: To compare the environmental impact of surfactin (2021 and 2022)
Functional unit: 1kg of surfactin
Scope: gate-to-gate
Analysis type: attributional
Indicators to evaluate: Recipe midPoint (e.g. Climate change).

Life cycle assessment (LCA)

SimaPro

Results
Techno-energetic assessment

- ✓ **Surfactin production:** 36% of theorical (Sc2)
- ✓ No significant difference in the **processing water**
- ✓ **Low-pressure steam**: increase of 50% compared with Sc2

Table 1. Summary of the overall mass and energy balances

Parameter	Scenarios		
	Sc1	Sc2	Sc3
Overall yield (kg/100 kg feedstock)	11.7	**32.4**	11.7
Processing water demand (m^3/day)		49.8	
Demand of low-pressure steam (kg/kg MP)	**1.42**	2.12	**1.42**
Demand of medium-pressure steam (ton/kg MP)		0.07	
Demand of cooling water (m^3/kg MP)	**0.85**	0.97	**0.85**

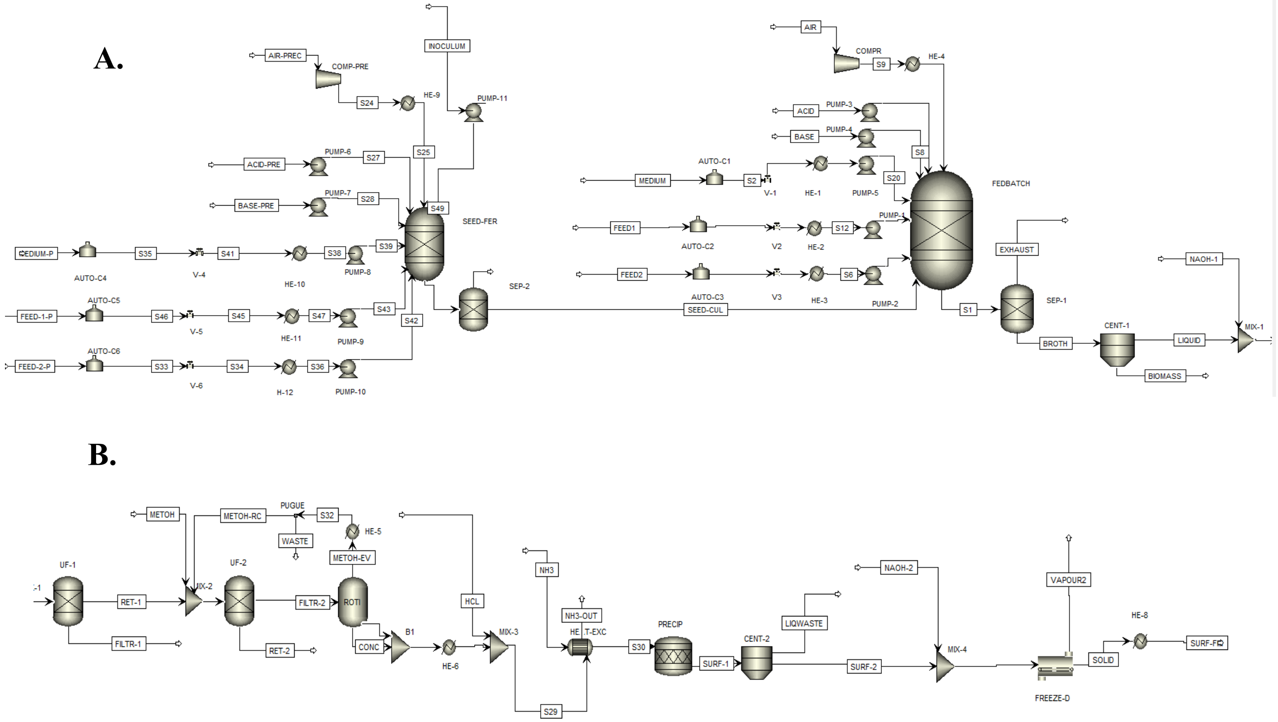

Fig3. Process diagram of surfactin production consisting of (A) conditioning and fermentation, and (B) downstream processing.

Results
Economic assessment

Analysis for the base case (Sc1)

- ✓ CapEx: 29% freeze-drying technology
- ✓ OpEx: 85% for the refrigerant (ammonia) in the freeze-drying
- ✓ Feasibility in less than one year of processing (NPV>0) because the high market price of surfactin (615 USD/kg)
- ✓ Feasibility: 35.2% of theorical

Table 2. Economic parameters for the surfactin production

Parameter	Escenario		
	Sc1	Sc2	Sc3
CapEx (M-USD)	6.63	6.67	6.63
OpEx (M-USD/year)	5.82	8.62	8.50
Production cost (USD/kg)	25.99	10.8	29.33
NPV in 20 años (M-USD)	2474.2	7028.81	1408.14
MPSEF (kg/day)*	88.7	12.1	140.8

*MPSEF: Minimum processing scale for economic feasibility

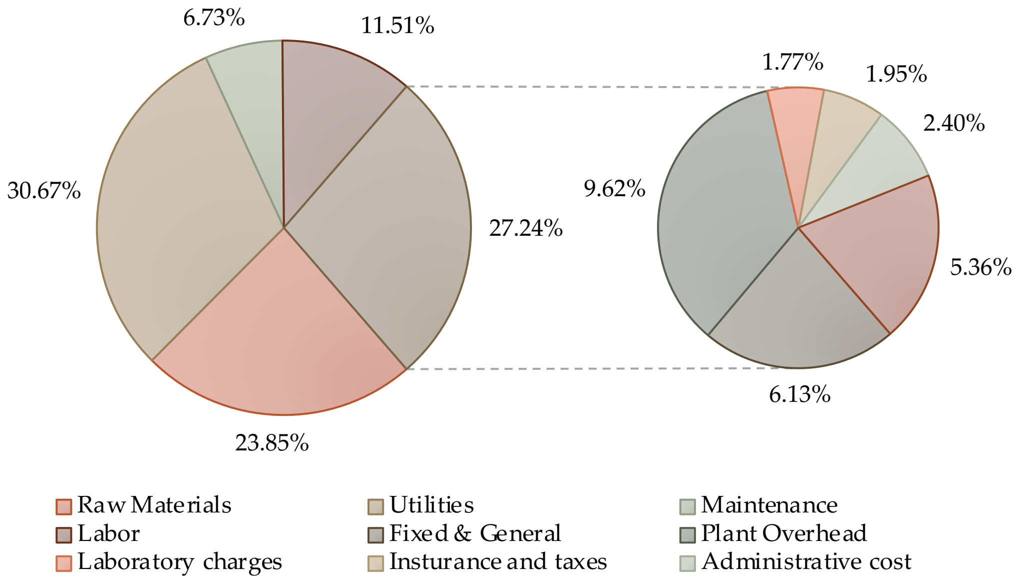

Fig4. Distribution cost for the base case scenario.

Comparison between scenarios

- ✓ CapEx: slight increase with the ideal case (Sc2) of 0.6%
- ✓ OpEx: 46% increase due to energy crisis (Sc1 and Sc3)
  - o Refrigerant: 35.2%
  - o Electricity: 59.1%
- ✓ Production cost increase of 12.9%(Sc1 and Sc3)
- ✓ Gross income reduction of 43%(Sc1 and Sc3)

Results
Environmental assessment through LCA

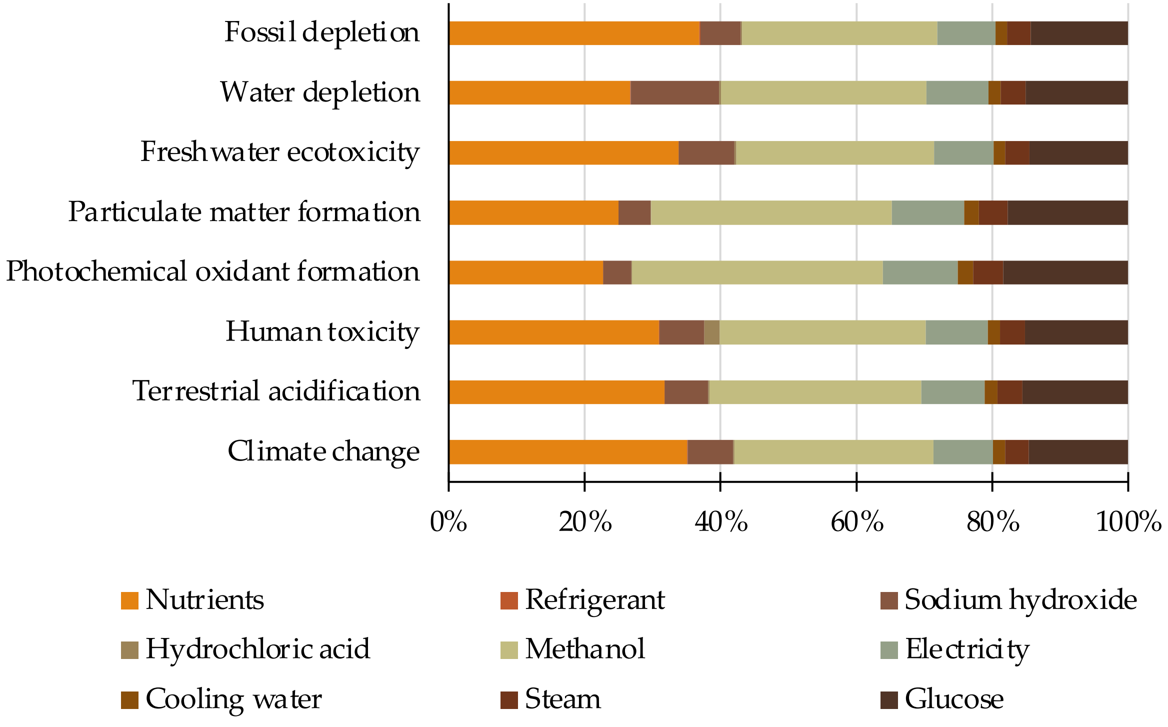

Fig5. Normalization of environmental impact categories for the base case scenario (Sc1)

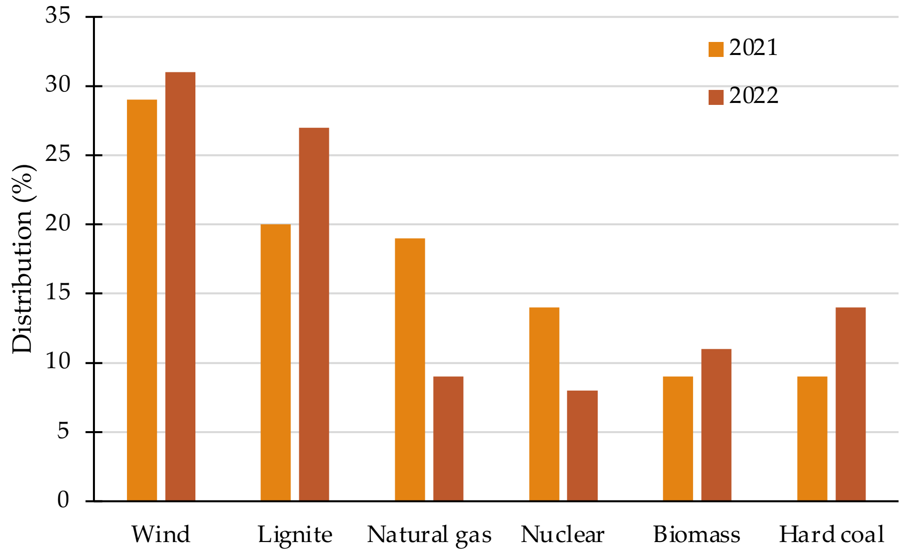

Fig6. Distribution of energy sources used for electricity generation in Germany.

Table 1. Comparison of the total environmental impact between 2021 and 2022 scenarios

Impact category	Unit	Scenario	
		2021	2022
Climate change	kg CO_2 eq kg^{-1} FU	11.71	10.57
Terrestrial acidification	kg SO_2 eq kg^{-1} FU	0.05	0.04
Human toxicity	kg 1,4-DB eq kg^{-1} FU	0.42	0.38
Photochemical oxidant formation	kg NMVOC kg^{-1} FU	0.04	0.03
Particulate matter formation	kg PM10 eq kg^{-1} FU	0.03	0.02
Freshwater ecotoxicity	kg 1,4-DB eq kg^{-1} FU	0.17	0.15
Water depletion	m^3 kg^{-1} FU	0.18	0.16
Fossil depletion	kg oil eq kg^{-1} FU	3.05	2.76

Conclusions

- ✓ The energy crisis in Europe drastically affected the performance of surfactin production, decreasing the gross income by 43%. However, there was environmental mitigation due to the shortage of natural gas, reducing the environmental impact by 9.7%.

- ✓ The economic viability of surfactin production depends on the economic variations of the country as a result of the social and political dynamics of the European Union and its suppliers.

Acknowledgments

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SISTEMA de INFORMACIÓN Hermes de la Investigación, Extensión y Laboratorios

El conocimiento es de todos Minciencias

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Thank you

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