Advancing biorefinery design through the integration of metabolic models in superstructure optimization

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33RD EUROPEAN SYMPOSIUM ON COMPUTER-AIDED PROCESS ENGINEERING

GREEN AND SUSTAINABLE PROCESS SYSTEMS ENGINEERING IN THE DIGITAL AGE

#escape2023

The biorefinery concept

Challenges of biorefinery design

- Techno-economic viability & Scale up

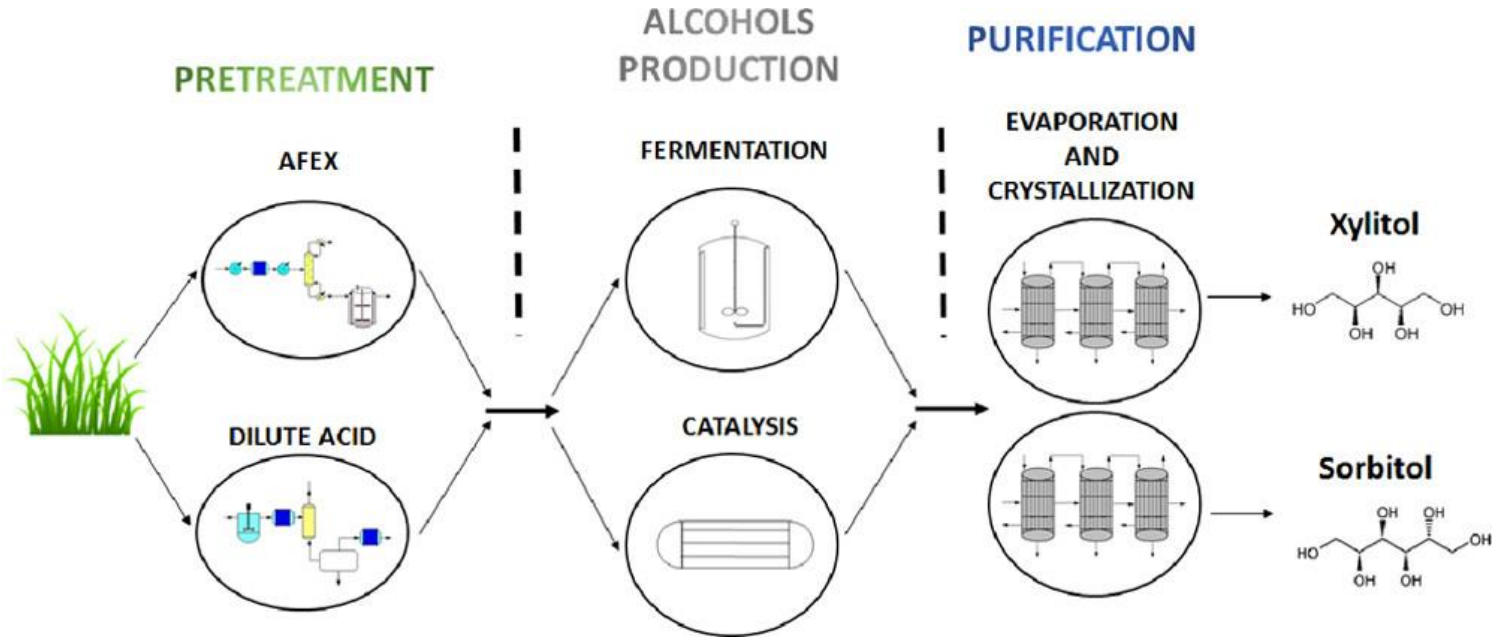
  Product Diversification

- Feedstock Availability and Variability

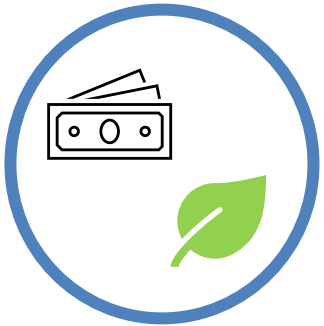
  Linking substrates to potential products

How do we assure investors to develop biorefineries?

Superstructure optimisation: Sorbitol and Xylitol

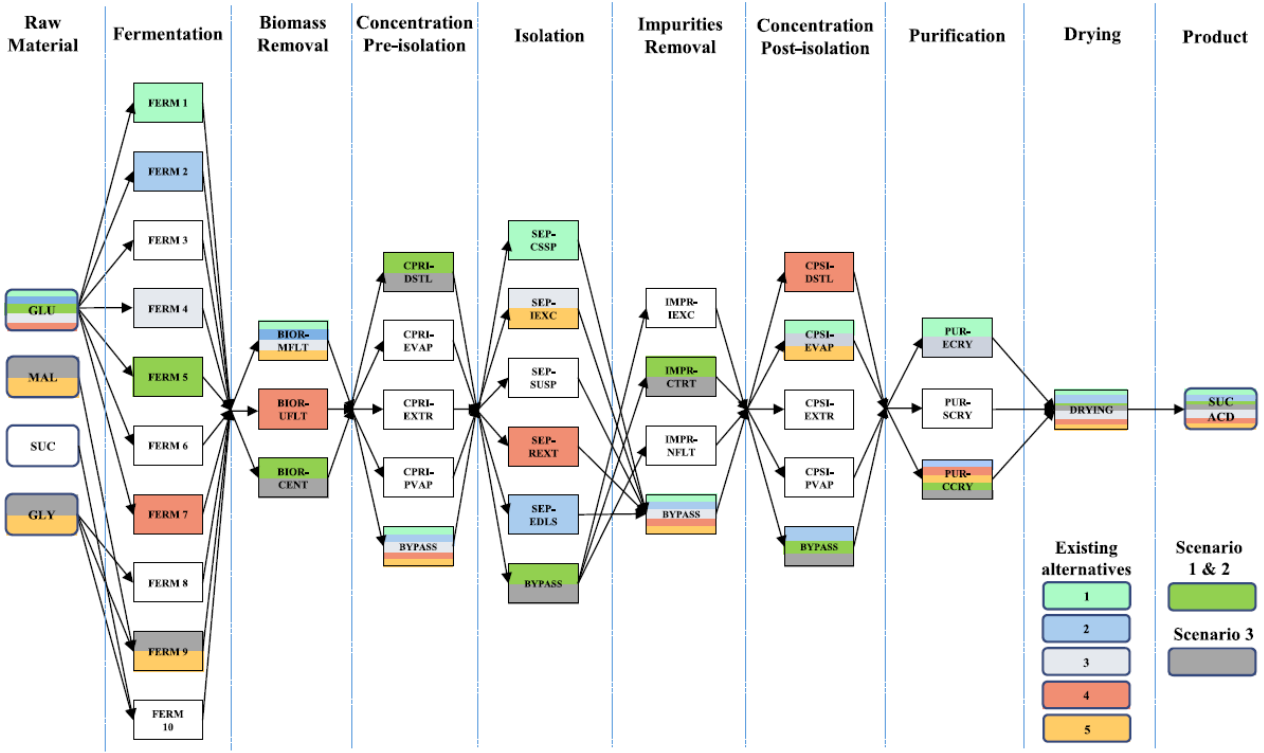


Objective

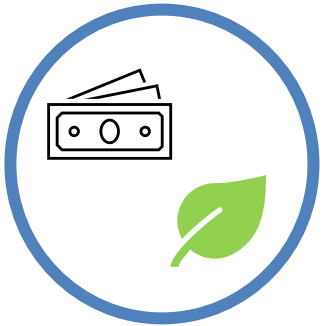


Galan et al. (2021)

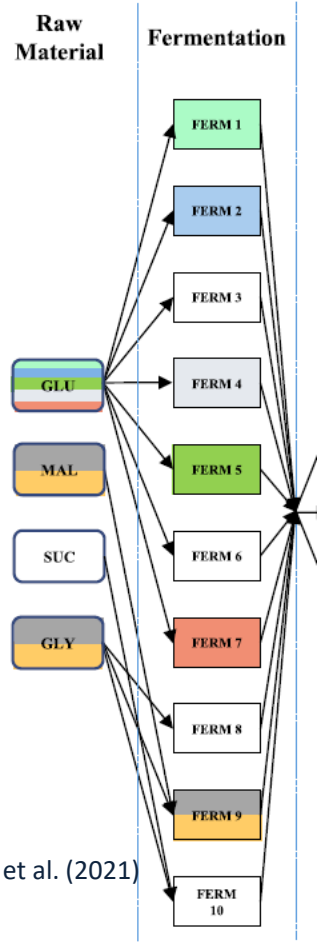
Superstructure optimisation: succinate acid



Objective



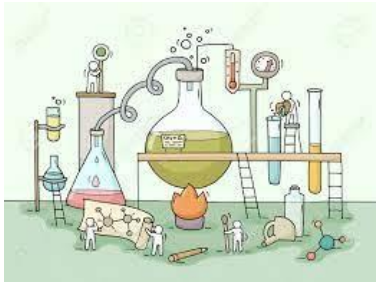
Galan et al. (2021)



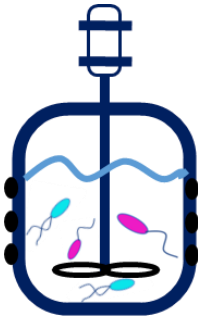
Galan et al. (2021)

Representation bio-reactor stage

Bio chemical conversion of substrates to products

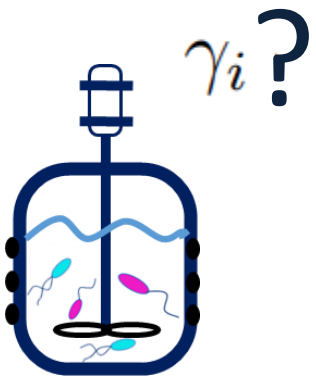


4 distinct microorganisms with well established fermentation outcomes



BUT Enormous Diversity of microorganisms for bioreactors and the potential substrates they can consume

Getting the bioreactions in superstructures



Research question:

How to integrate bioreactions of microorganisms in the most effective and efficient way in the superstructure?

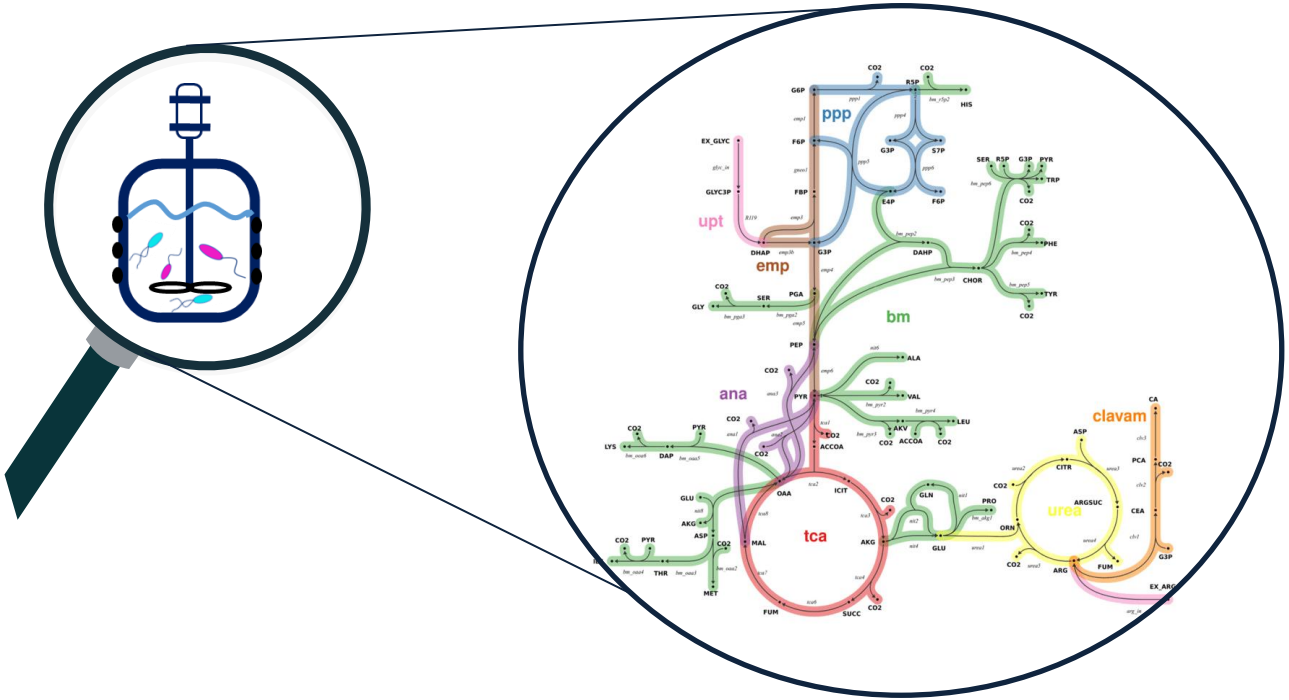
Or

How to unlock the full potential of microorganism in a superstructure framework?

Goal: Can we explore completely new designs linking new microorganisms to substrates and products?

Representing Bioreactors in Superstructures

Metabolic models



Advantages

- Predictive from omics data
- Able to handle multiple substrates

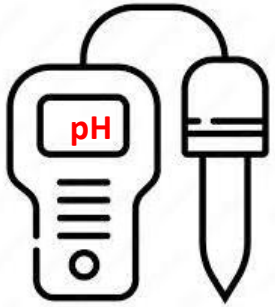
Considered biotransformations in bioreactors

Pure cultures
Genome Metabolic Models (GEMS)

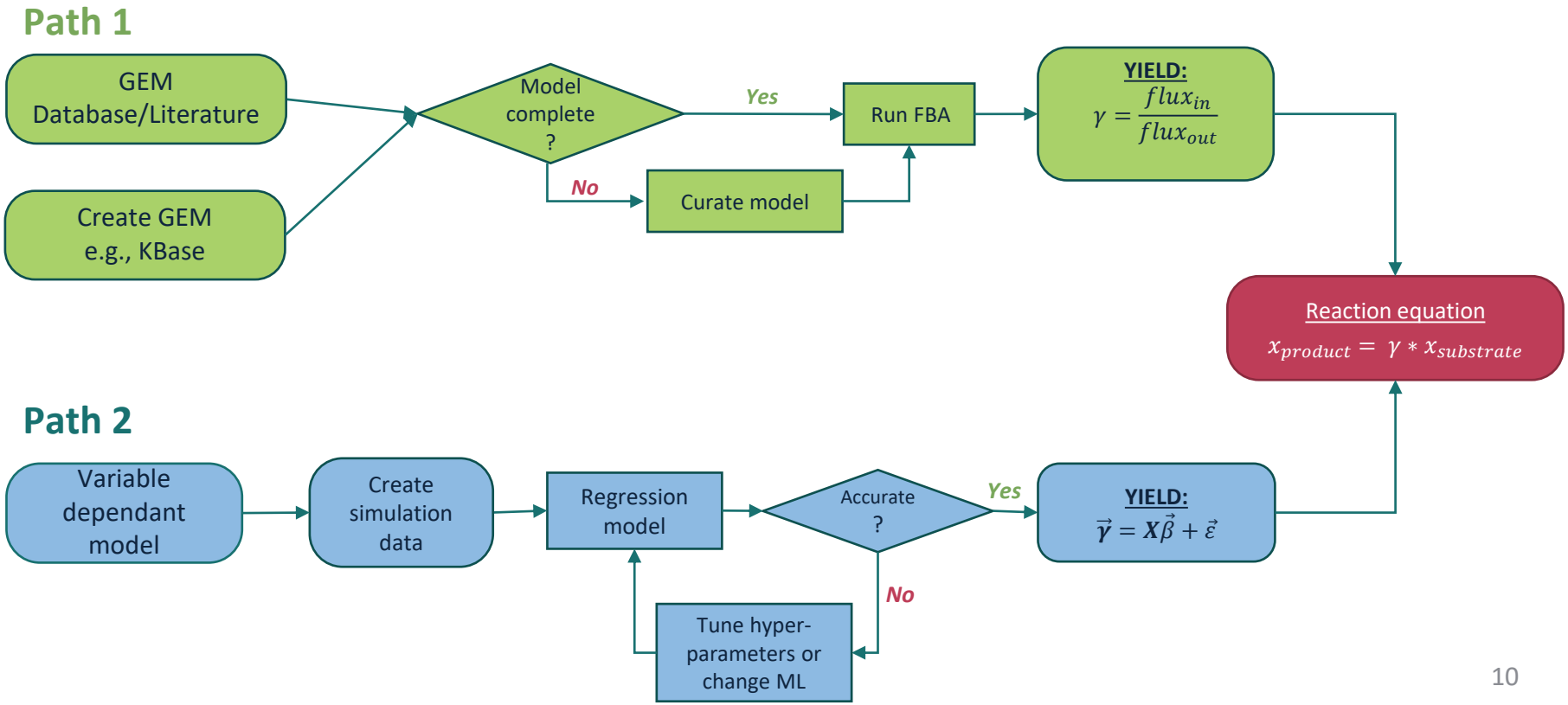
Recreation of the metabolic network, starting from the **genome**

Open mixed cultures
Bioenergetic model

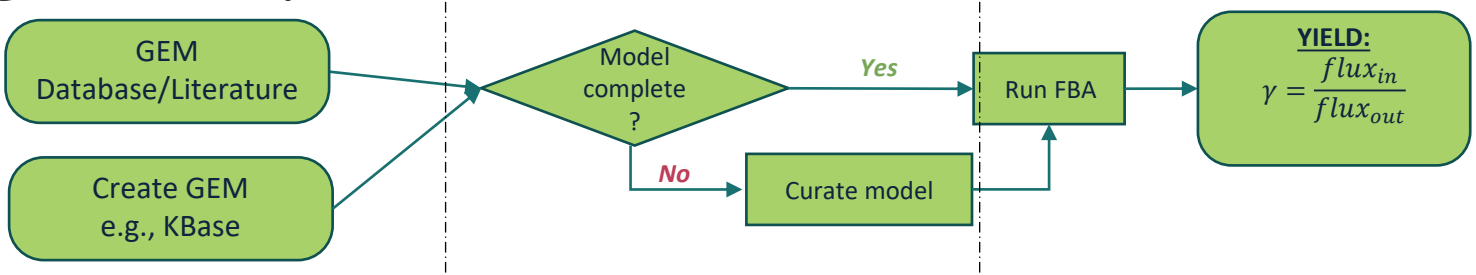
Recreation of metabolic networks, But dependent on **environmental influences**



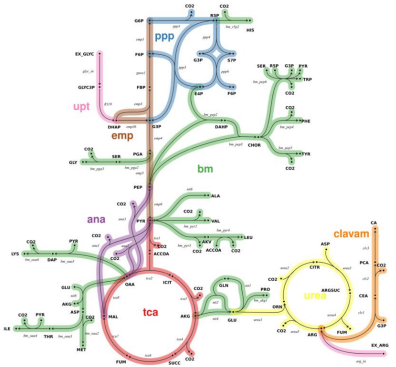
Making Surrogate models



Integration pure culture models



KBase
PREDICTIVE BIOLOGY



MEMOTE

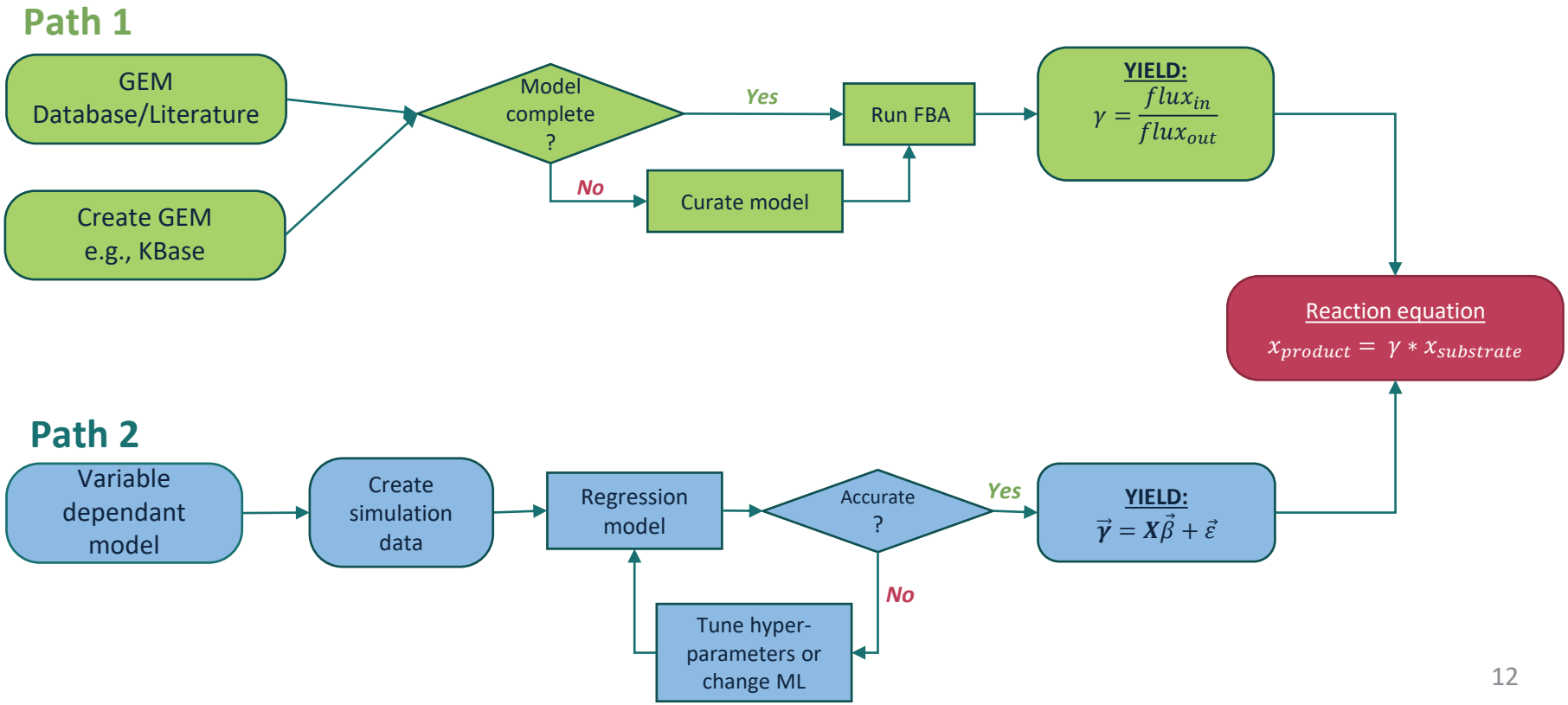
- Check mass and electron balances
- Check “dead end” metabolites
- Preform leak tests

FBA

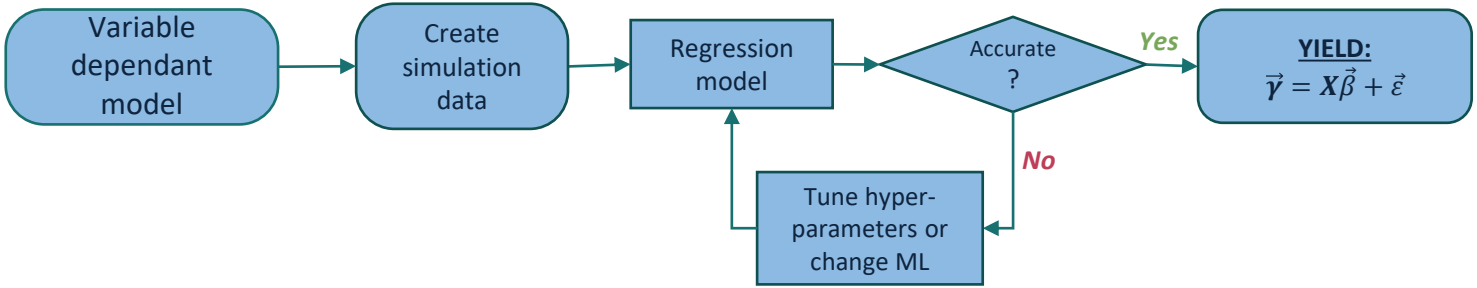
$$\frac{d}{dt}\begin{pmatrix} A \\ B \\ C \\ D \\ E \end{pmatrix} = \mathbf{Sv} = \mathbf{S}\begin{pmatrix} v_1 \\ \frac{v_2}{b_1} \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{pmatrix} = \mathbf{0}$$

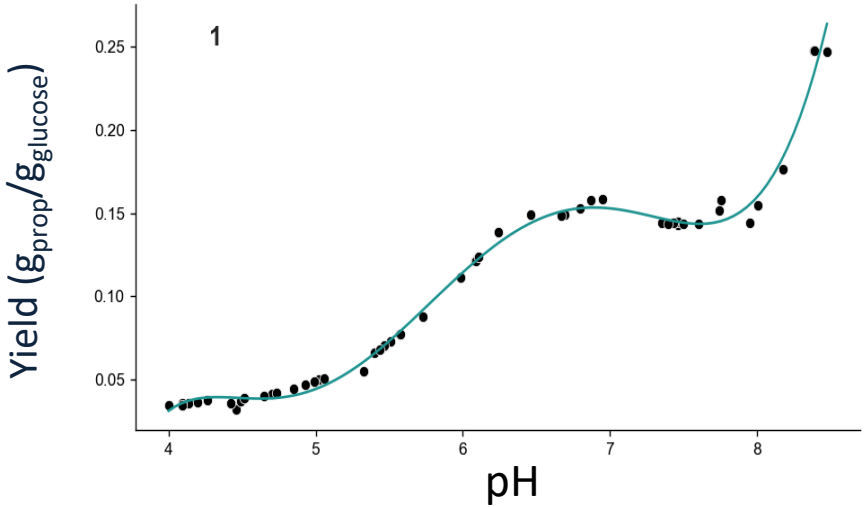
Steady State Mass balance

Making Surrogate models



Mixed culture models

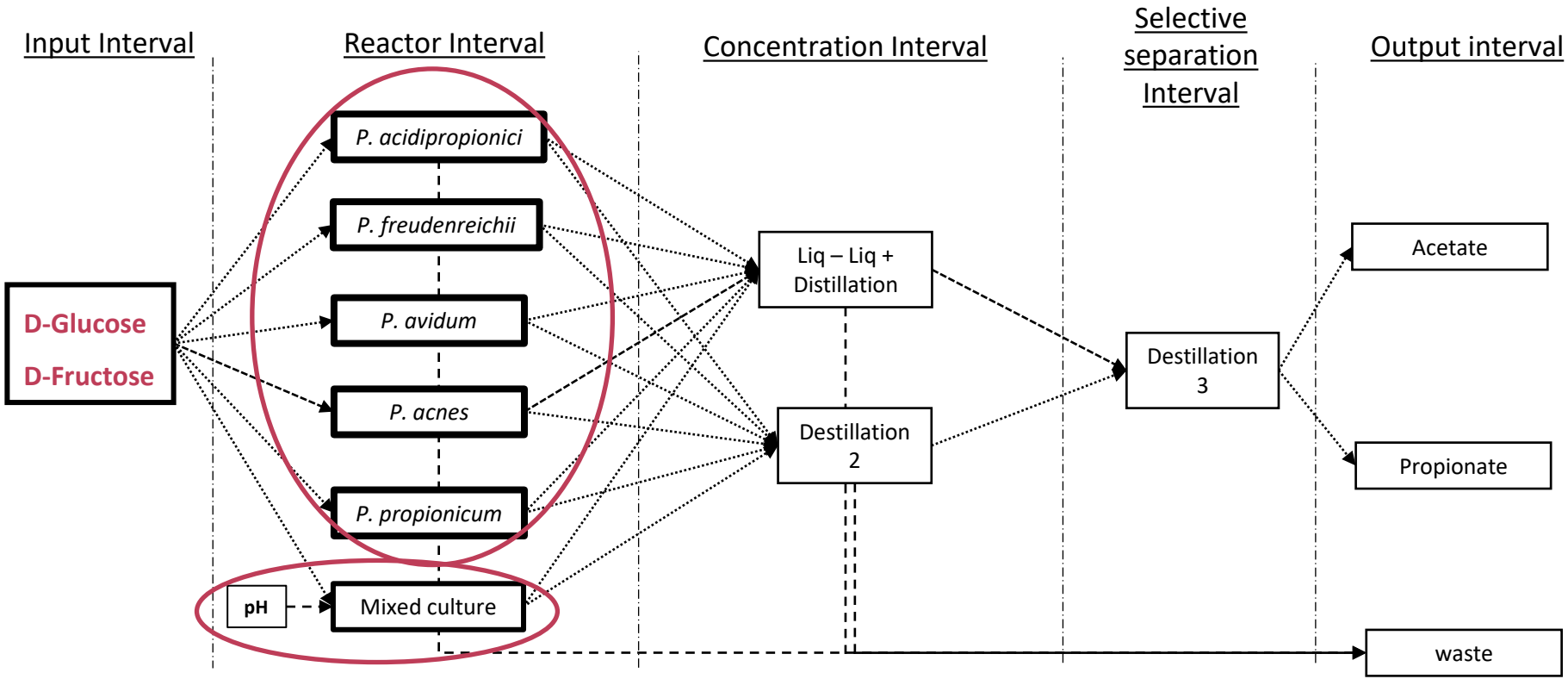




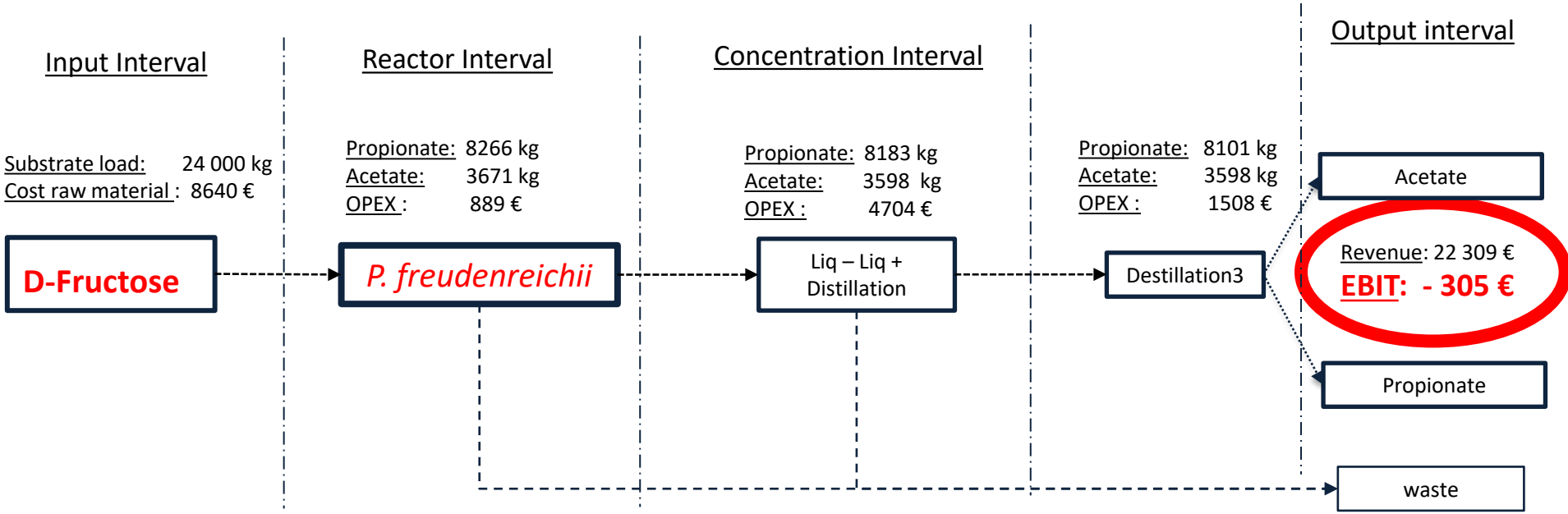
$$\vec{\gamma} = \boldsymbol{pH} \cdot \vec{\beta} + \vec{\varepsilon}$$

Case study

Objective: EBIT = GREV - OPEX

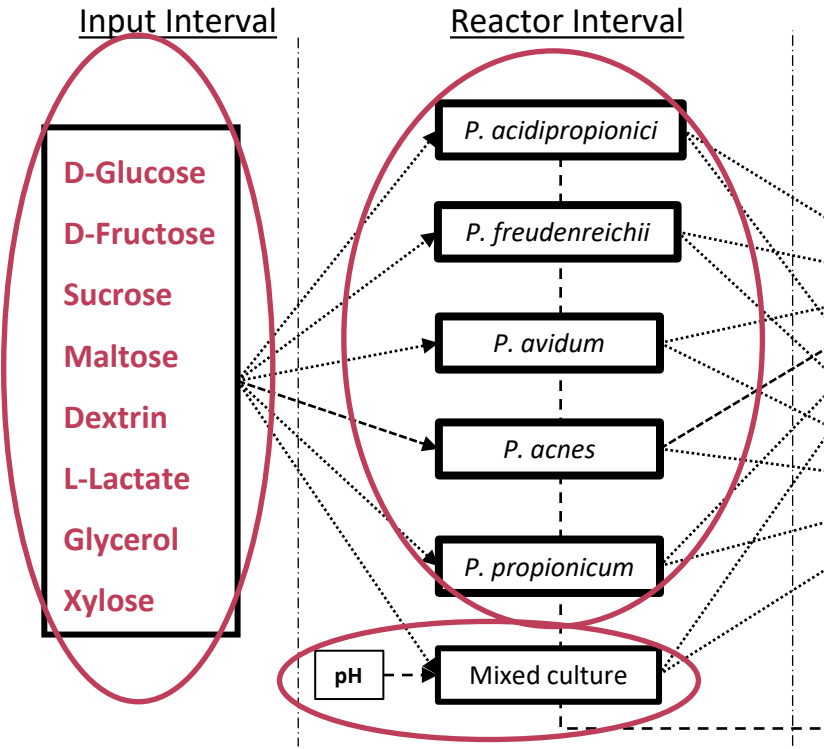


Results


Input Interval
Reactor Interval
Concentration Interval
Output interval
Substrate load: 24 000 kg
Cost raw material : 8640 €
Propionate: 8266 kg
Acetate: 3671 kg
OPEX : 889 €
Propionate: 8183 kg
Acetate: 3598 kg
OPEX : 4704 €
Propionate: 8101 kg
Acetate: 3598 kg
OPEX : 1508 €
D-Fructose
P. freudenreichii
Liq – Liq + Distillation
Destillation3
Acetate
Revenue: 22 309 €
EBIT: - 305 €
Propionate
waste

Case study

Objective: EBIT = GREV - OPEX



How to identify substrates:

1. Identify Exchange reactions in the GEM

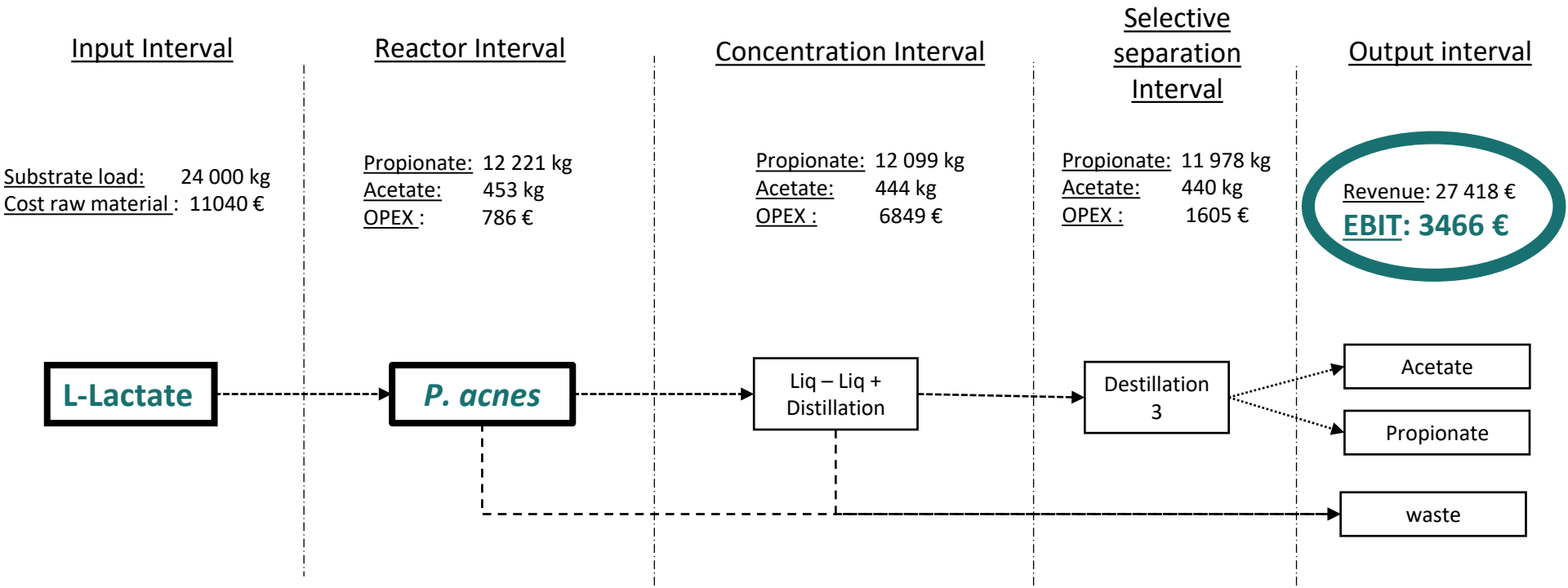
2. Filter out proteins

3. A minimum production of the target products required

4. Final manual selection

→ substrate – microorganism

Results


Input Interval
Substrate load: 24 000 kg
Cost raw material : 11040 €
Reactor Interval
Propionate: 12 221 kg
Acetate: 453 kg
OPEX : 786 €
Concentration Interval
Propionate: 12 099 kg
Acetate: 444 kg
OPEX : 6849 €
Selective separation Interval
Propionate: 11 978 kg
Acetate: 440 kg
OPEX : 1605 €
Output interval
Revenue: 27 418 €
EBIT: 3466 €
L-Lactate
P. acnes
Liq – Liq + Distillation
Destillation 3
Acetate
Propionate
waste

Conclusion

An efficient **workflow** was created to **integrate metabolic models** for representing bioreactor processes **in superstructure optimization problems**

The surrogate models are capable of

1) **Predicting operation conditions** for optimal yields
2) **Predictive from genome data**
3) Predicting yields from **various substrates**

Case studies demonstrate how superstructure optimization using metabolic models **can identify economically viable combinations of substrates and microorganisms.**

HAVE A NICE DAY

THANK YOU

EMAIL

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Acknowledgments

AGENCIA ESTATAL DE INVESTIGACIÓN

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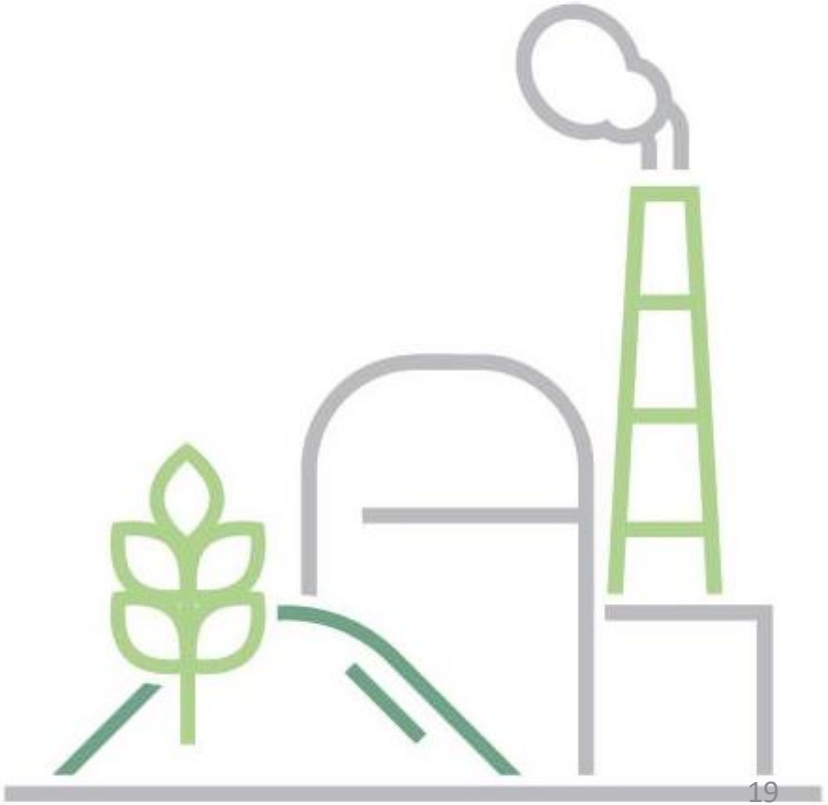
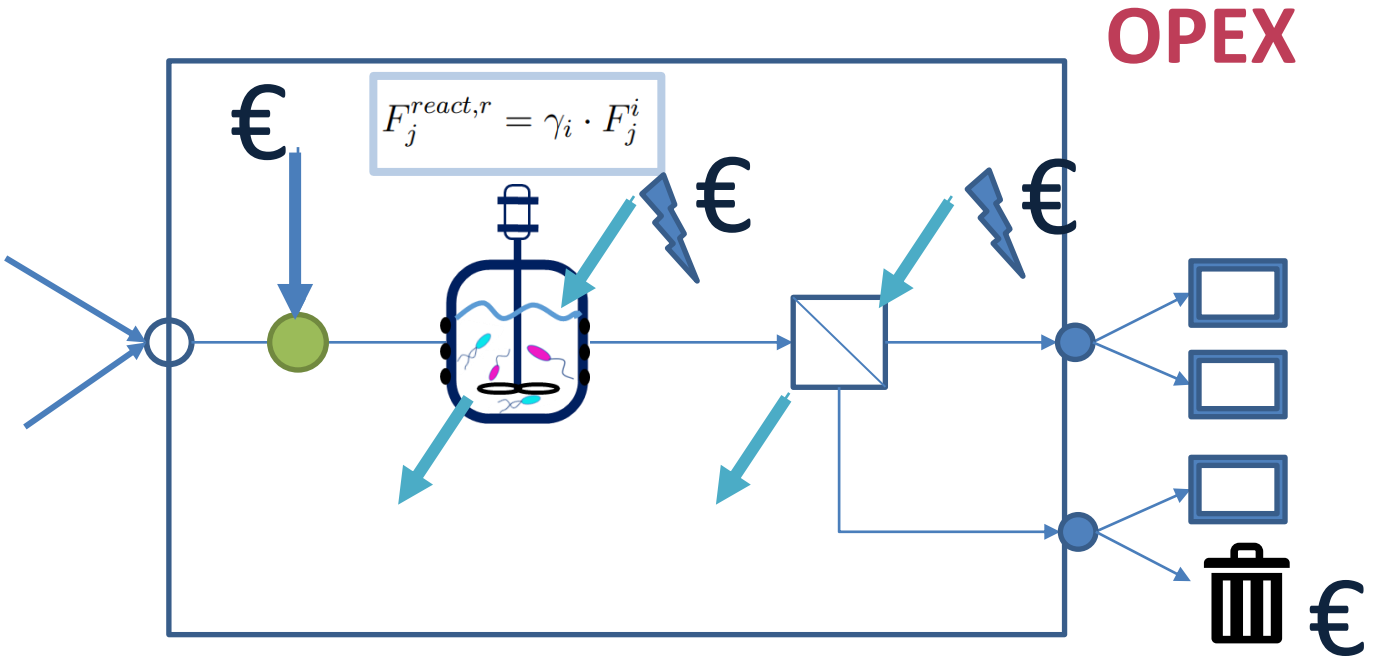


EXTRA

Representation of unit processes

- Flow divider
- Mixer
- Mixer utilities (chemicals)
- (Bio)Reactor
- Separator
- Flow of mass
- Flow energy
- Next process unit or waste



Quaglia et al (2015), Bertran et al. (2017)