Towards Quality by Design to recover high-quality products from waste and wastewater streams

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LOOP
Laboratoire d'observation et d'optimisation des procédés
Process observation and optimization laboratory

Université Laval

Outline of the presentation

Introduction

Challenges

Proposed approach

Application example

Take-home message

INTRODUCTION

From linear to circular economy ...

VALORIZATION

Québec policy on organic waste management:
ban on organic waste incineration and disposal by 2022

Biomethanation: conversion of organic waste into bioenergy and bio-products

ORGANIC WASTE

ANAEROBIC DEGRADATION

BIOGAS

DIGESTATE

MINERAL FERTILIZERS AND OTHER BIO-PRODUCTS

Digestate processing

Digestate

Mechanical separation

Solid fraction:
Rich in organic matter, P, Ca, Mg

Soil conditioner

Liquid fraction:
Rich in N, K, (P)

High potential for nutrient recovery

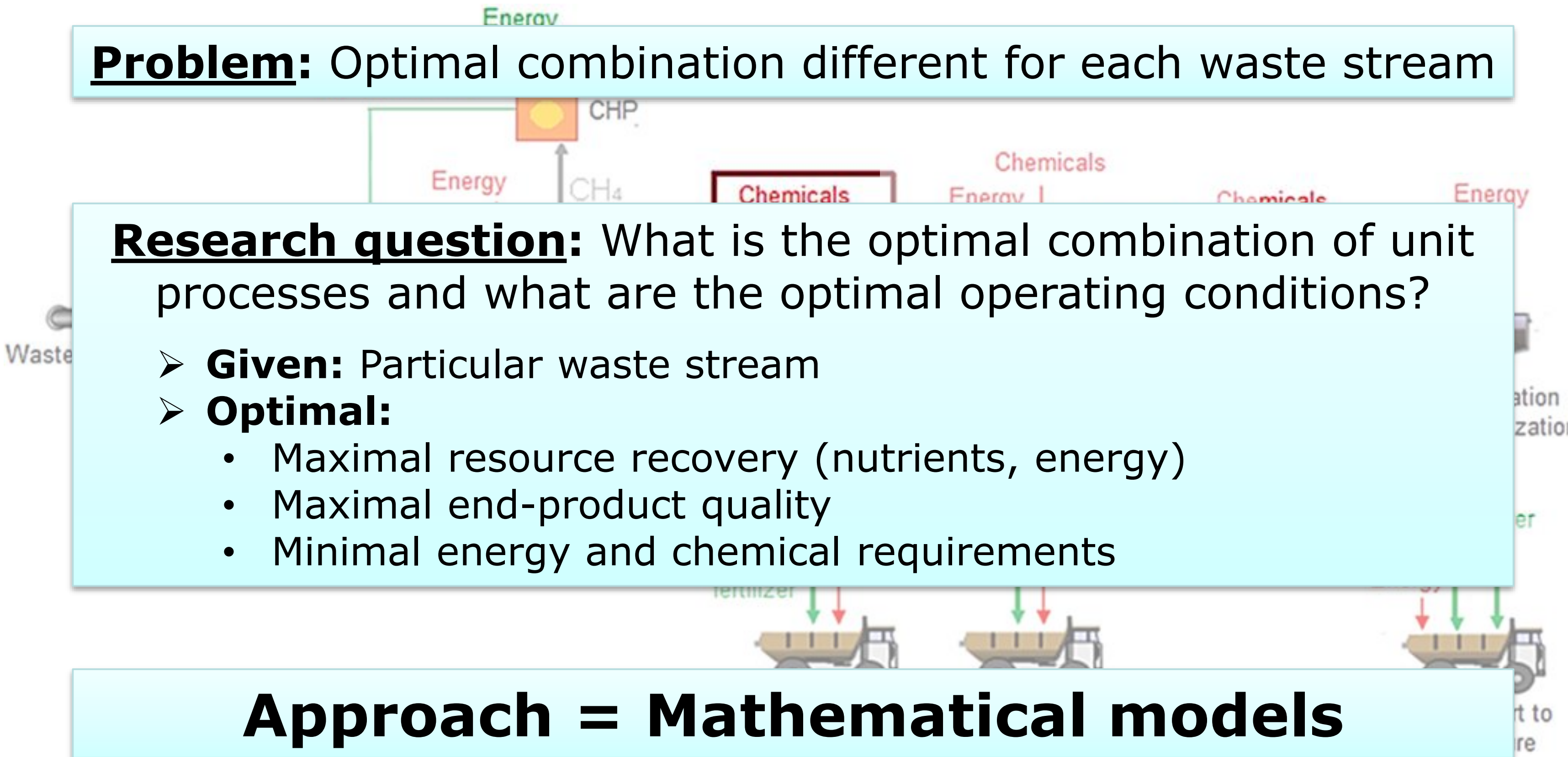
Nutrient recovery processes

1. Precipitation → struvite, calcium phosphates
2. Ammonia stripping → NH_3
3. Acidic air scrubbing → ammonium sulfates
4. M… ation → H_2O, N-K concentrates
5. B… tion and harvest → biomass

…

Mainly physico-chemical unit processes !

Potential flow diagram of a biorefinery for nutrient and energy recovery



Problem: Optimal combination different for each waste stream

Research question: What is the optimal combination of unit processes and what are the optimal operating conditions?

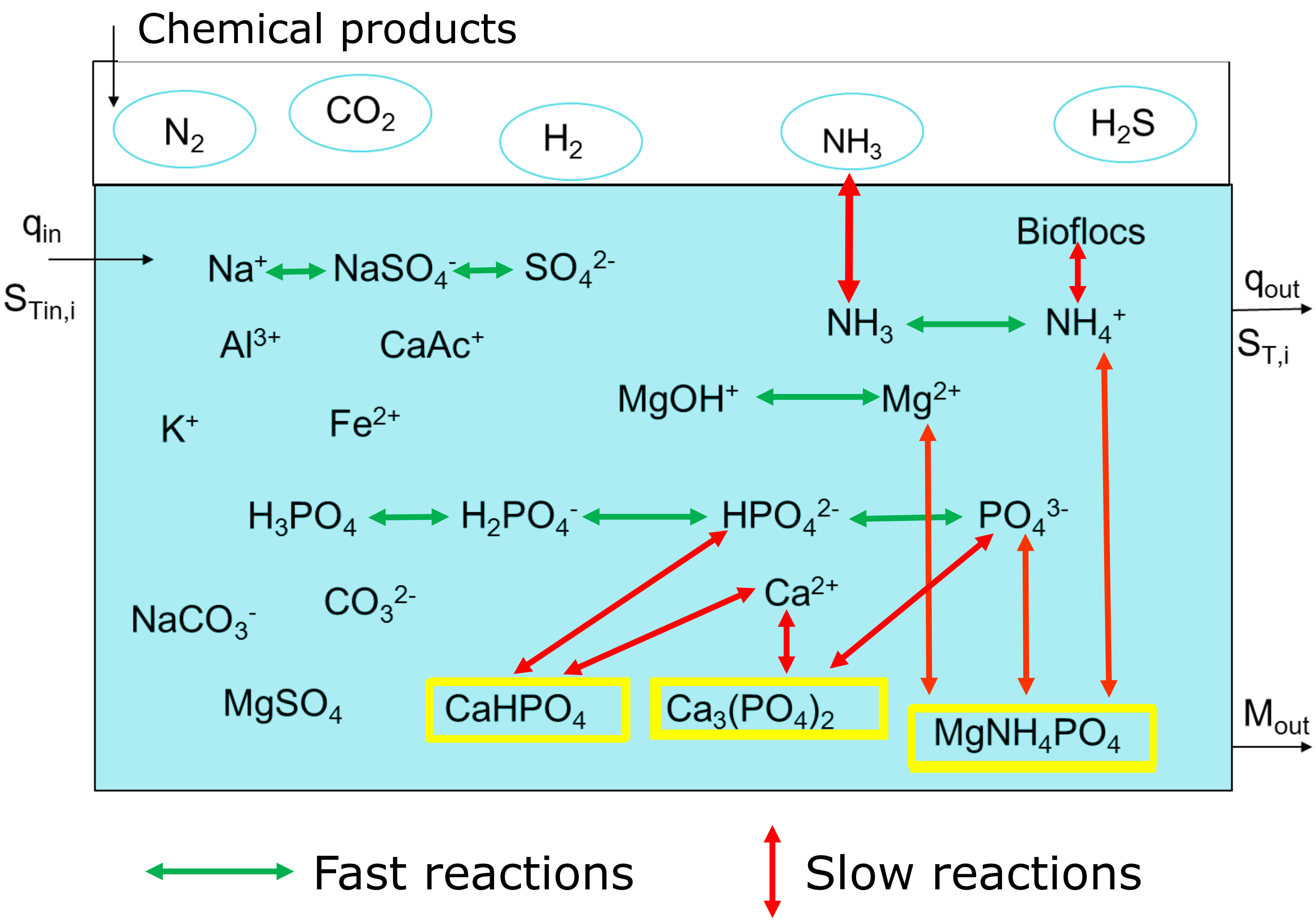
- **Given:** Particular waste stream
- **Optimal:**
  - Maximal resource recovery (nutrients, energy)
  - Maximal end-product quality
  - Minimal energy and chemical requirements

Approach = Mathematical models

CHALLENGES

Modelling challenges

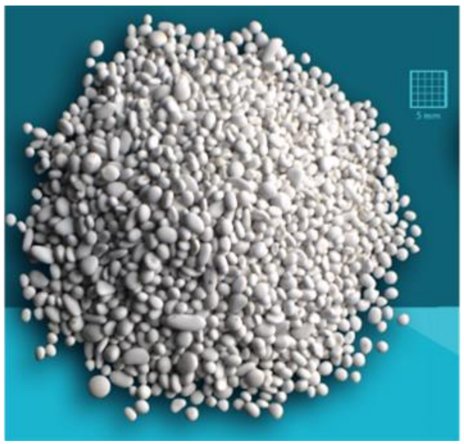
- Process complexity ! => Need for advanced process models



Control challenges

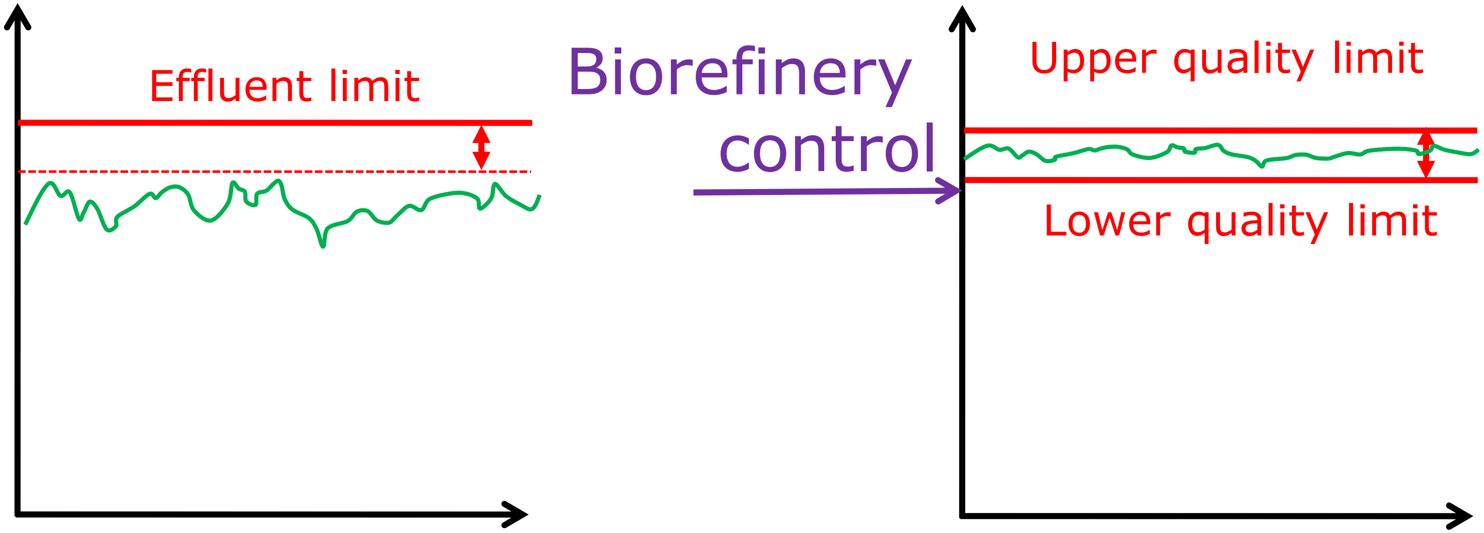
- Strict product quality specifications

- No selection of raw materials



Control challenges

- Need for a paradigm shift



Optimization challenges

Choice of the technologies
and operational settings?

End-product distribution?

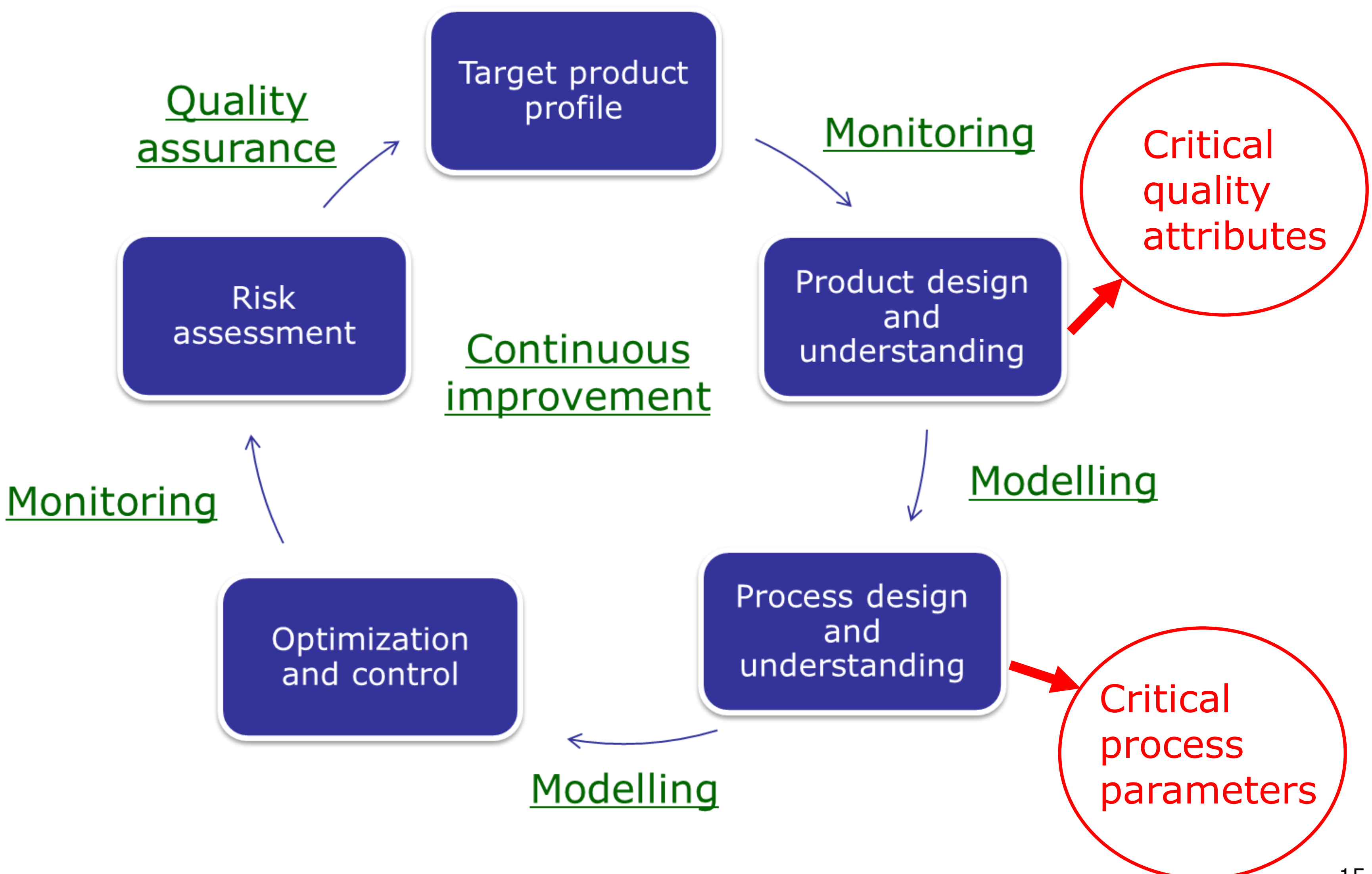
Location?

Economic optimization?

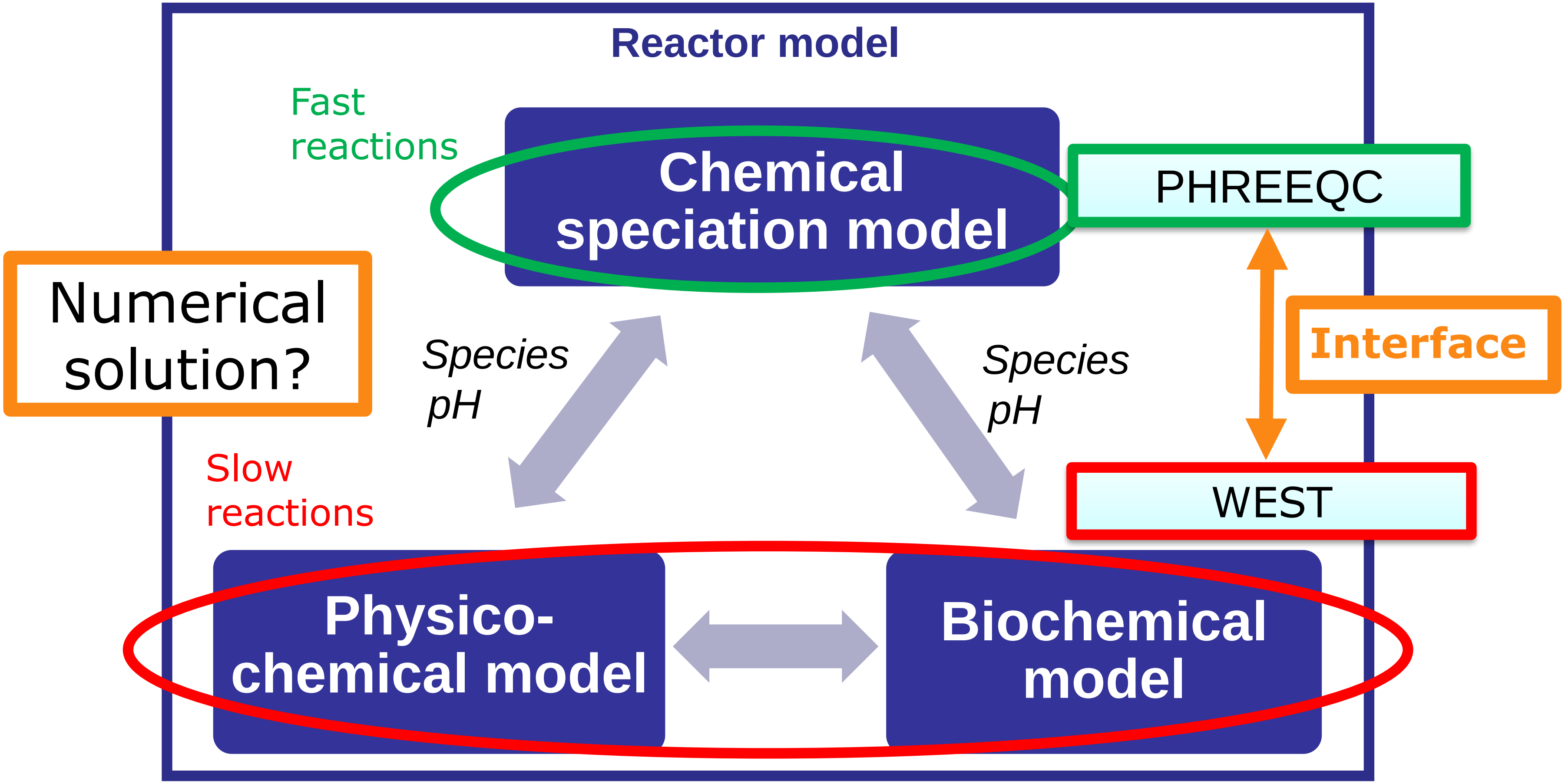
⇒ Need for a holistic end-user focused approach to planning and optimization of resource recovery projects !

PROPOSED APPROACH

Quality by Design

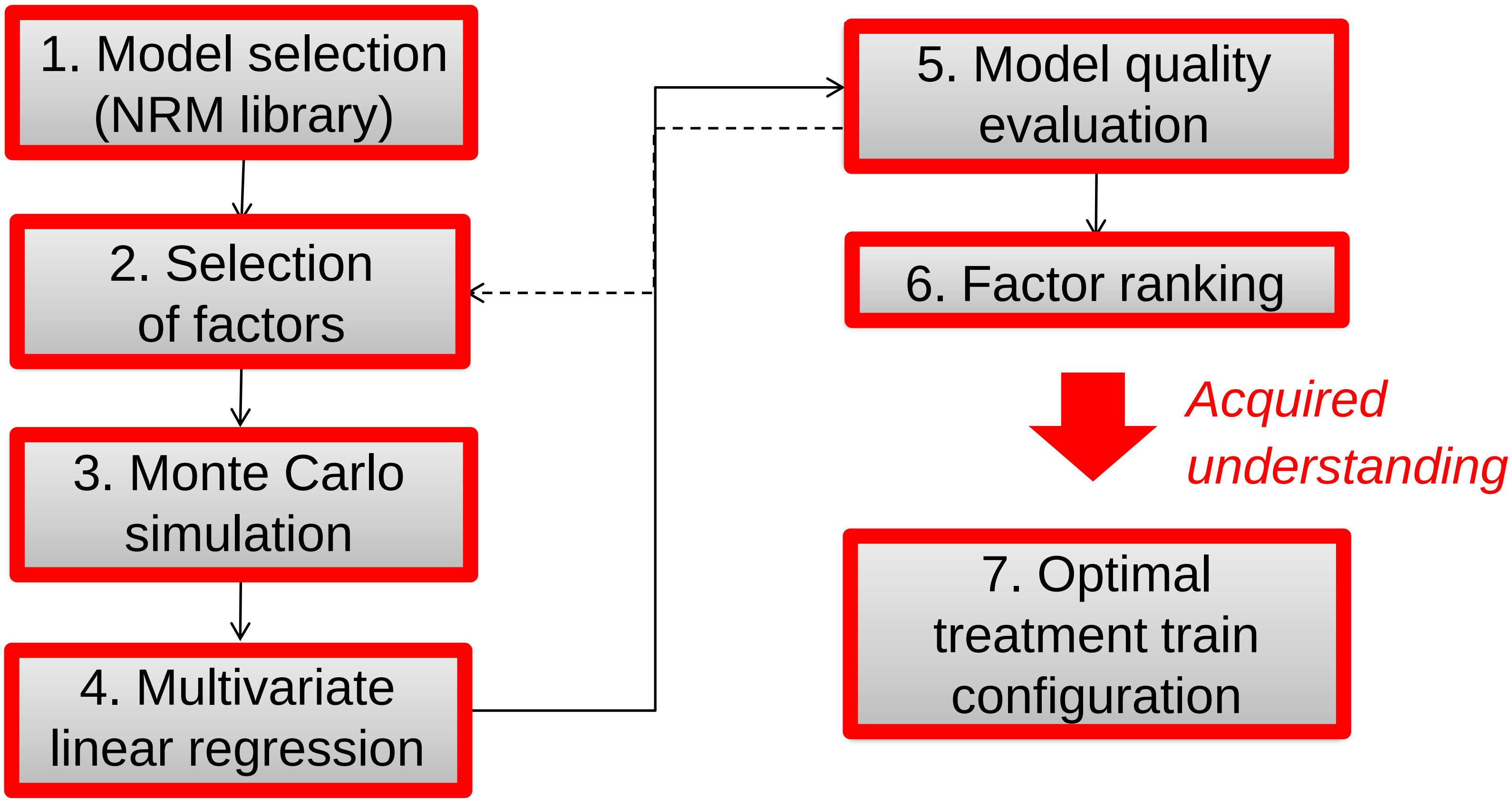


Combined three-phase physicochemical-biological process models



=> Improved potential to predict end-product quality

Global sensitivity analysis (GSA) for optimal treatment train configuration



Increased process insights
=> Control strategies and risk assessment

Monitoring and quality control

- Real-time measurement of critical process parameters and critical quality attributes

=> Towards a regulatory Process Analytical Technology (PAT) framework ?

Multi-dimensional decision-support systems (DSS) for holistic optimization: optim-

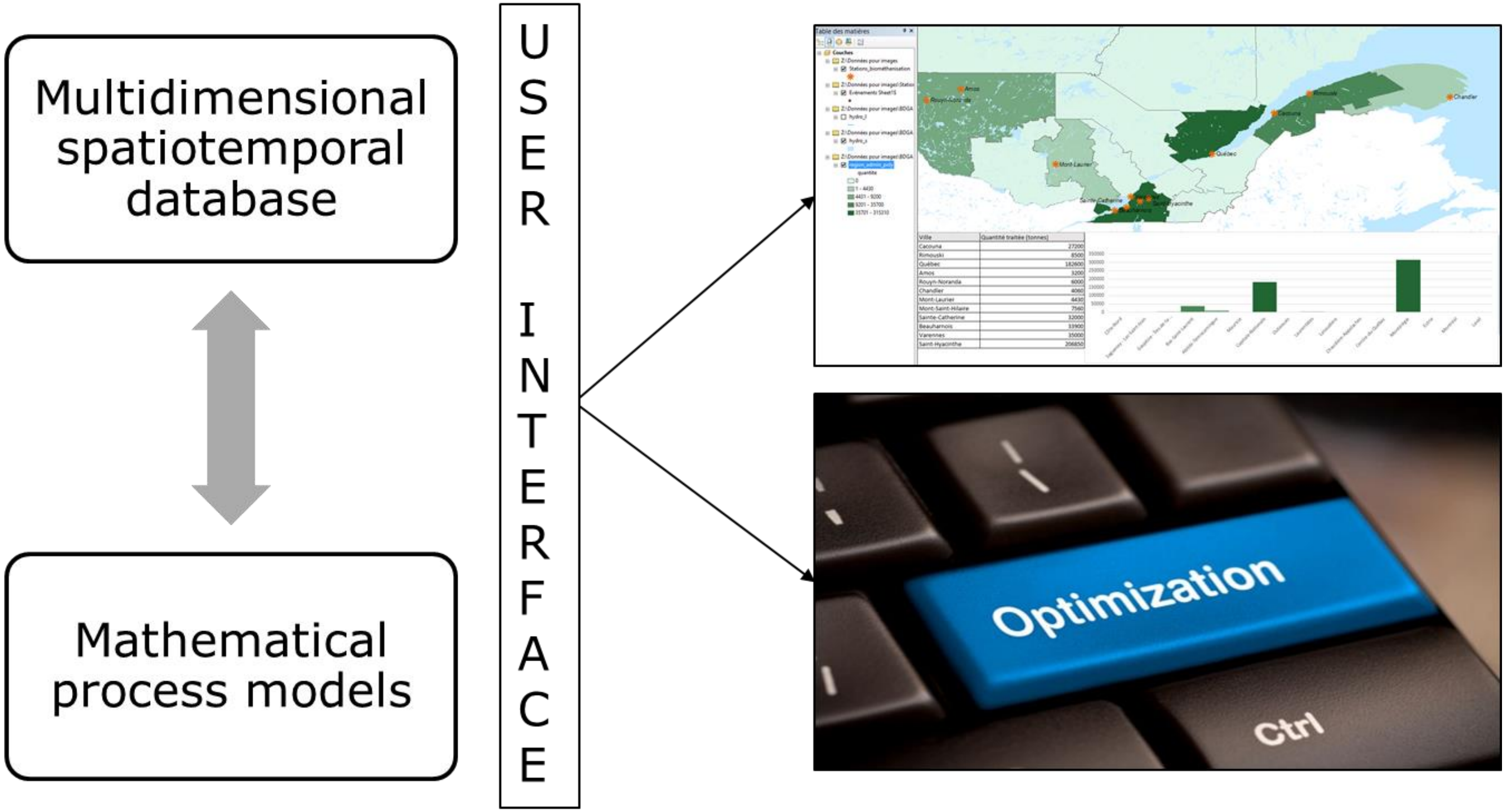
Decision support tool for organics valorization

Waste collection

Waste treatment

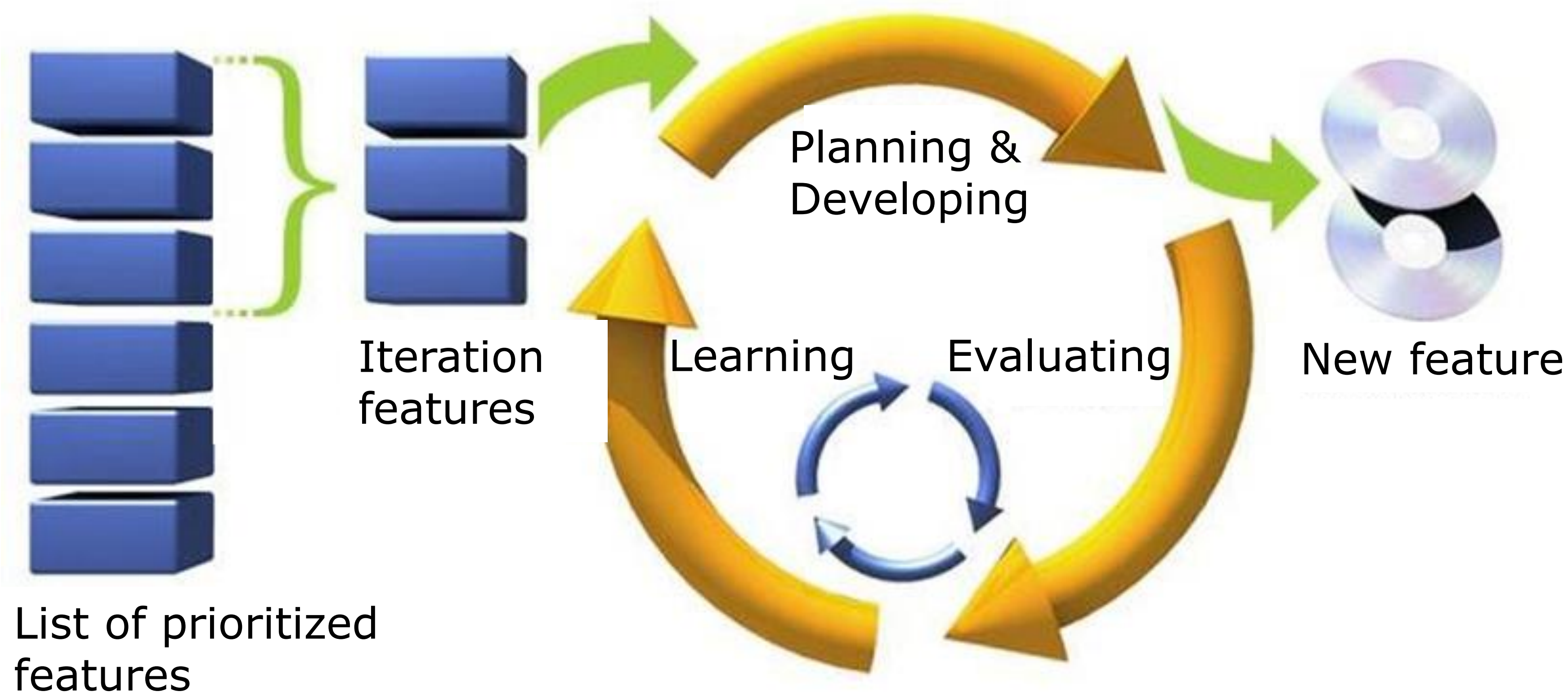
End-product distribution

Multi-dimensional decision-support systems (DSS) for holistic optimization



optim-
Decision support tool for organics valorization

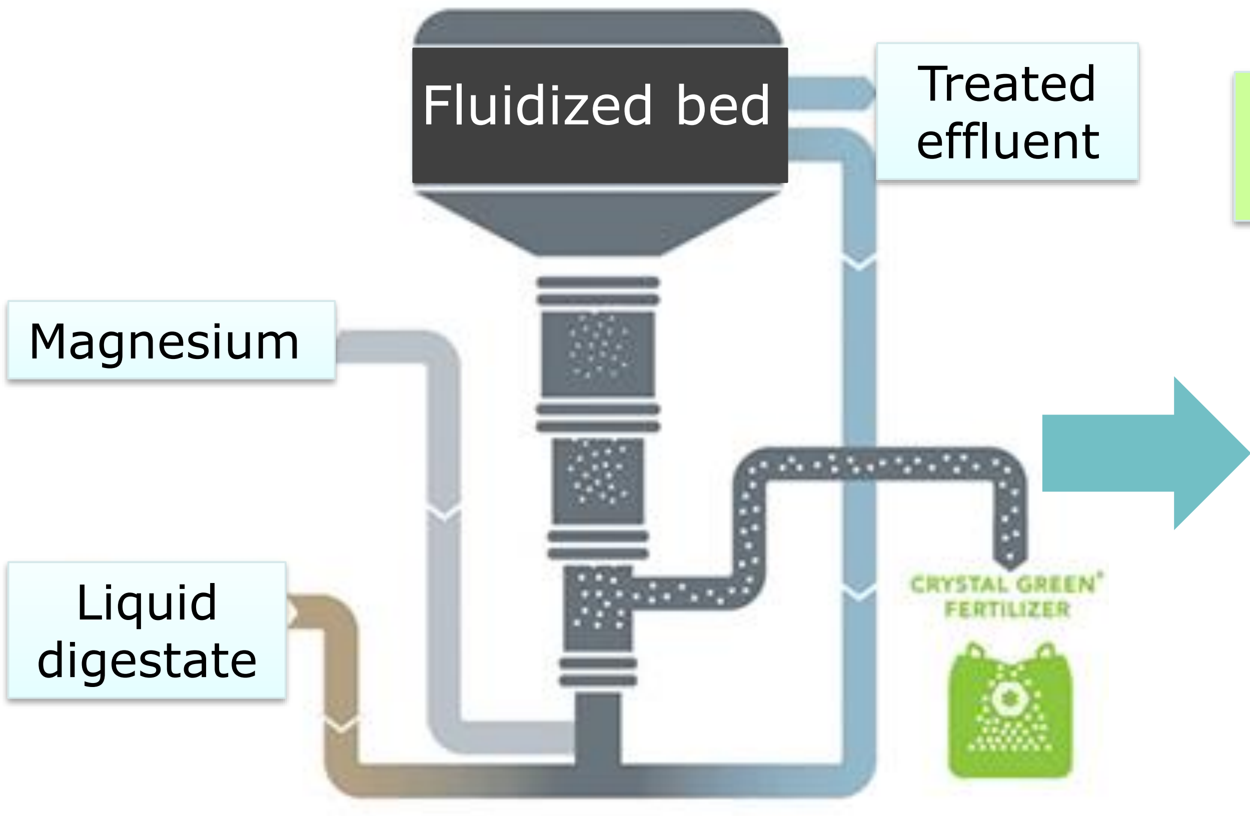
Agile software development for fast DSS implementation



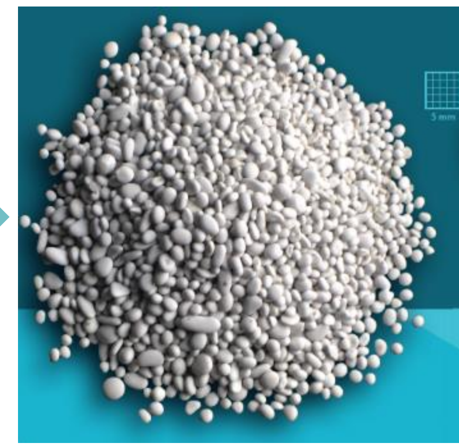
Fast end-user focused and communication-based approach
=> <u>Nutrient stakeholder platforms</u>

APPLICATION EXAMPLE

Process 1: Struvite precipitation

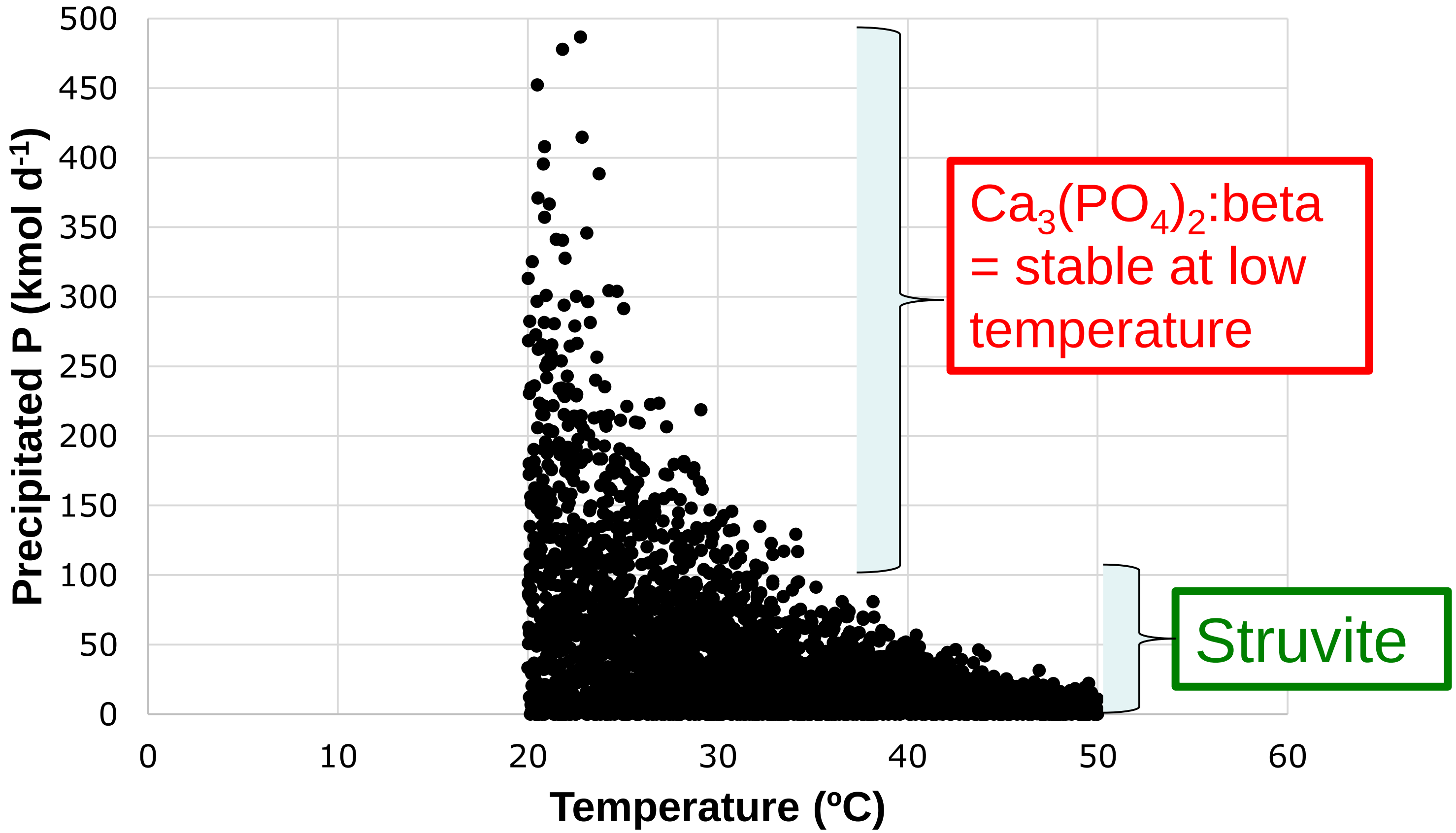


Struvite = $MgNH_4PO_4{:}6H_2O$



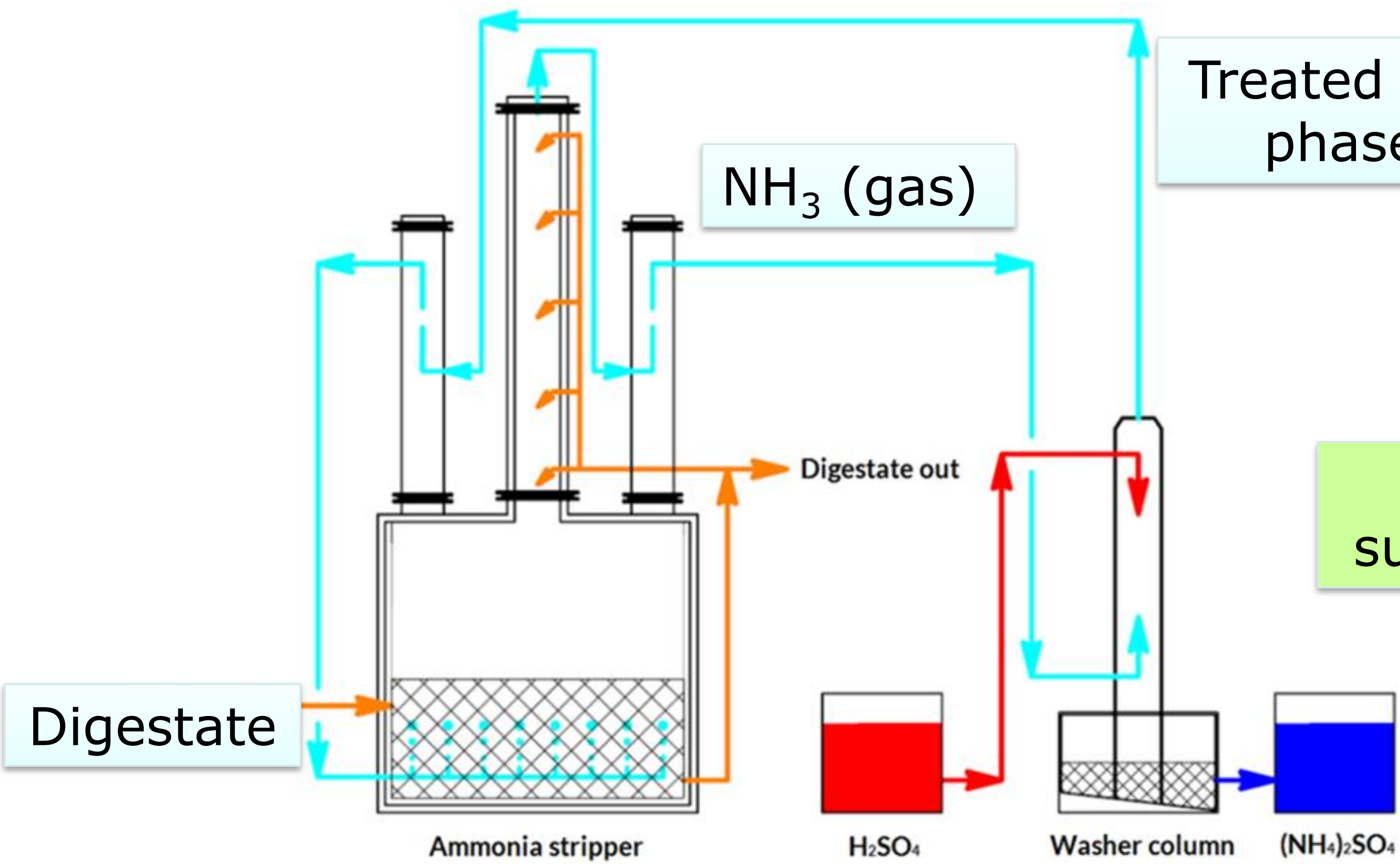
Source: adapted from Ostara (2015)

Monte Carlo simulation results: Effect of temperature on P precipitation



⇒ Struvite purity ↑ if temperature ↑

Process 2: NH_3 stripping and absorption

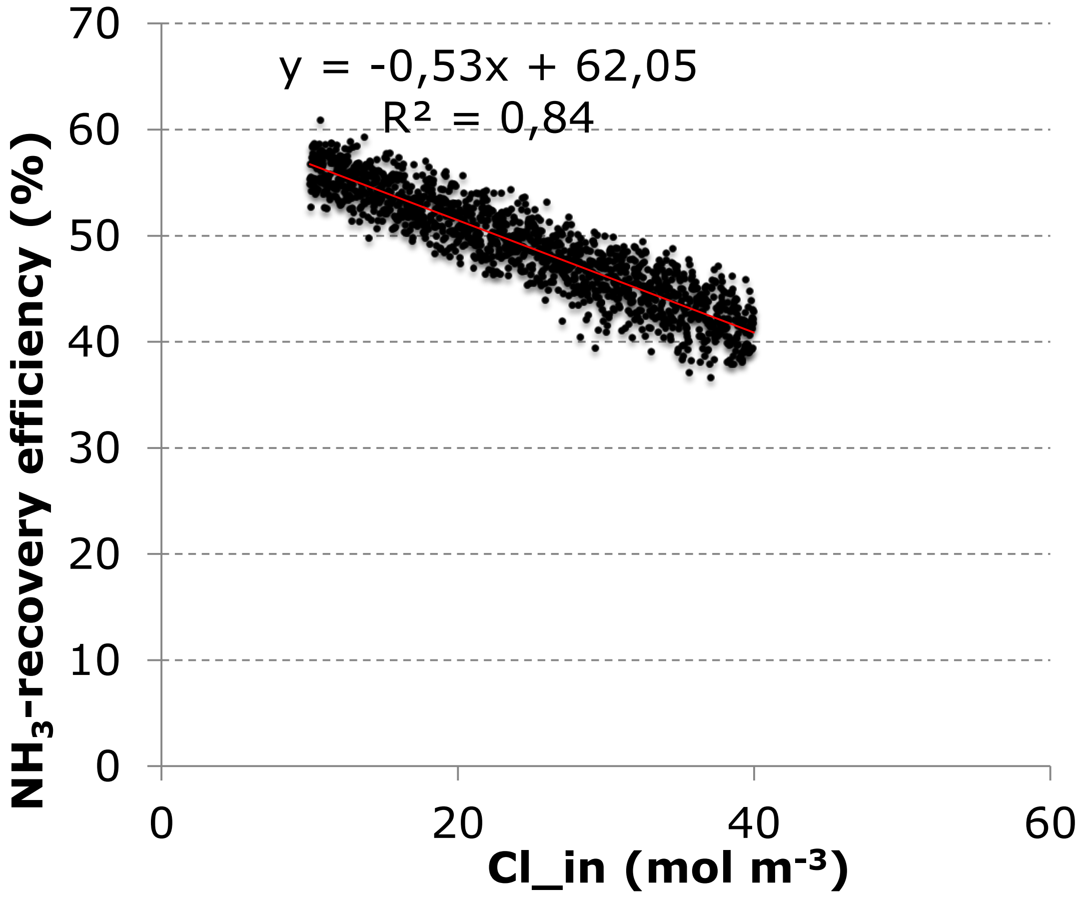


VILLE DE QUÉBEC

Ammonium sulfate fertilizer

Source: adapted from Colsen (2015)

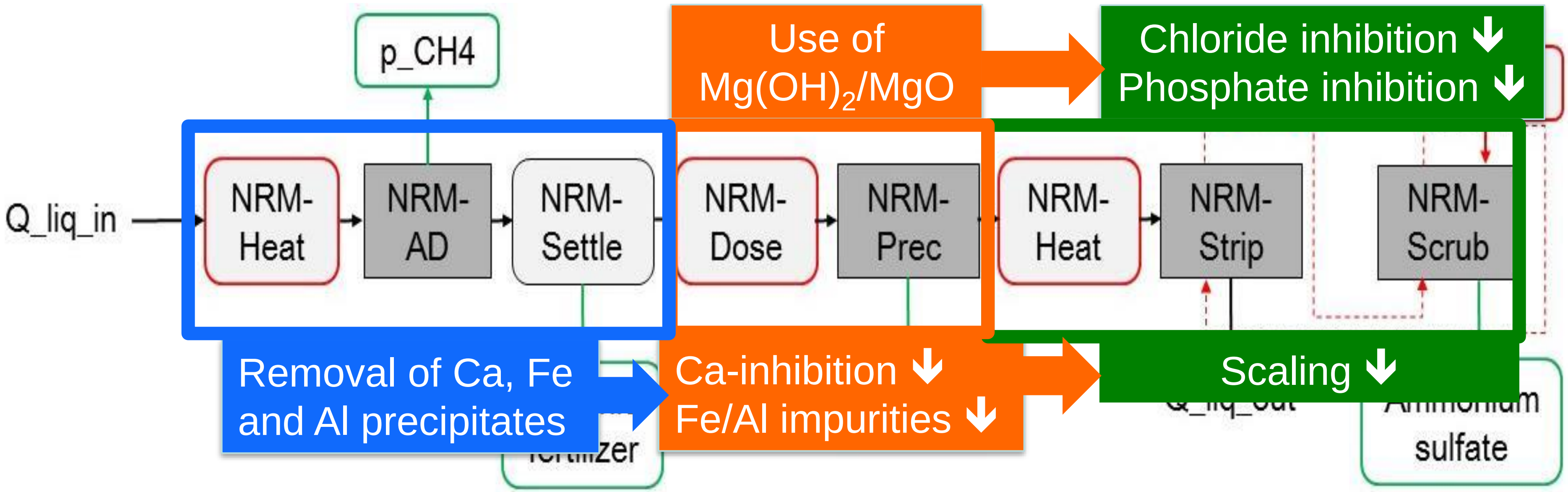
Monte Carlo simulation results: Impact of chlorides on NH_3 recovery efficiency



⇒ Practical implication for treatment train design: If preceding P-precipitation → use $Mg(OH)_2$/MgO instead of $MgCl_2$

Using GSA results for treatment train configuration

C-recovery P-recovery N-recovery



Consumables
→ Costs

Recovered products
→ Revenues

Treatment train optimization: Economic analysis

Optimized Biorefinery

Financial benefits:

~ variable costs:

5 \$ m^{-3} manure y^{-1}

90 \$ ton^{-1} solids y^{-1}

~ variable + capital costs:

2 \$ m^{-3} manure y^{-1}

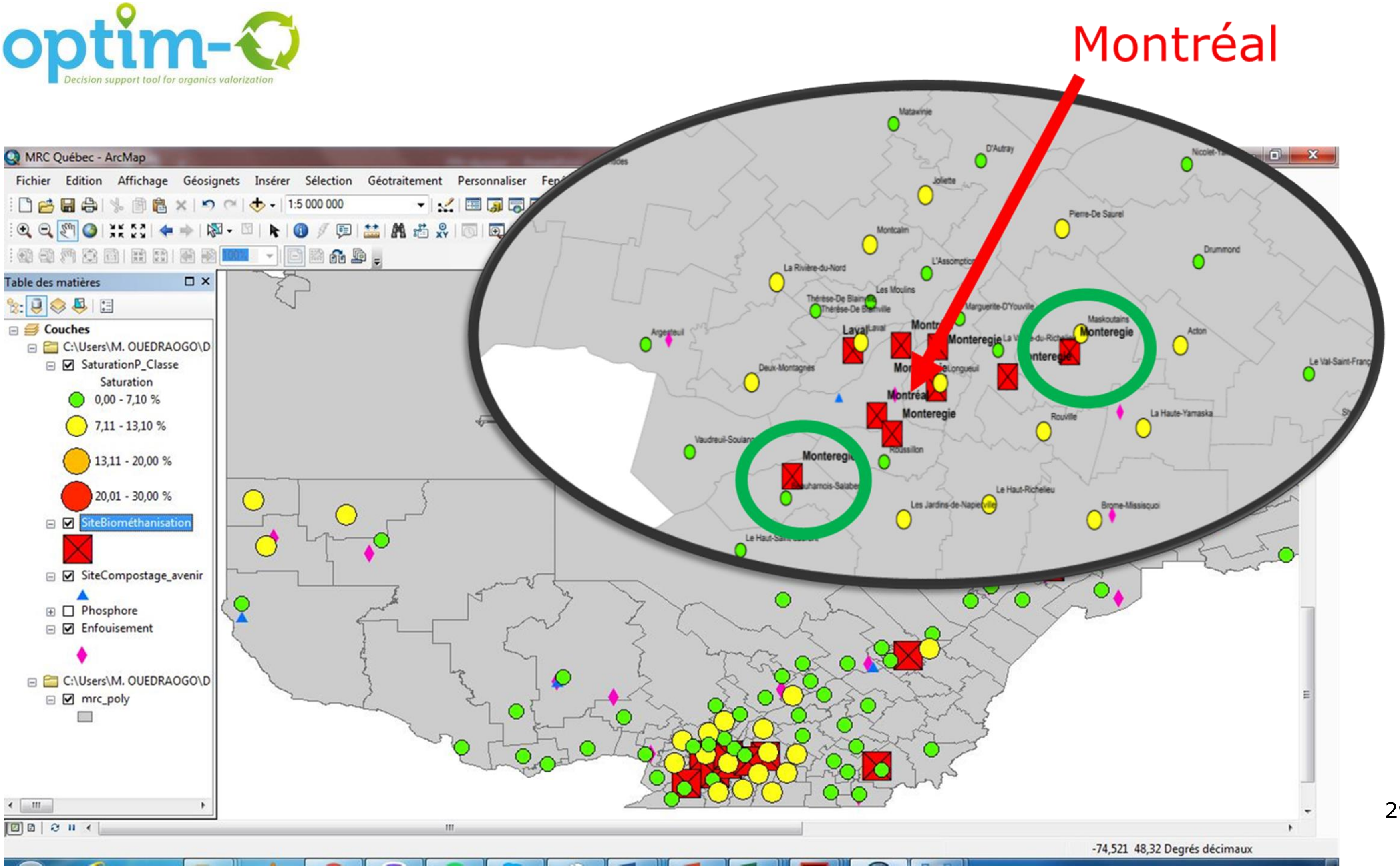
40 \$ ton^{-1} solids y^{-1}

Subsidies

Heat balances

ZeroCost-Biorefinery (pay-back time: 7 years)

Use of DSS to find a market for the recovered end-products



TAKE-HOME MESSAGE

Numerical methods are a must for integrating and optimizing the value chain !

« Nothing is lost, nothing is created, everything is transformed! »

Further reading

- Vaneeckhaute C. (2019). Towards Quality by Design and process analytical technology for enhanced nutrient recovery from wastewaters. Nature - npj Clean Water; 2(1), 14.

- Vaneeckhaute C, Remigi EU, Tack FMG, Meers E, Belia E, Vanrolleghem PA. (2019). Model-based optimization of an integrated nutrient and energy recovery treatment train. Journal of Environmental Engineering and Science (JEES), Special Issue: Nutrient and energy recovery from wastewater resource recovery facilities; 14(1): 2-12.

- Vaneeckhaute C, Remigi E, Tack FMG, Meers E, Belia E, Vanrolleghem PA. (2018). Optimizing the configuration of integrated nutrient and energy recovery treatment trains: A new application of global sensitivity analyses to the generic nutrient recovery model (NRM) library. Bioresource Technology; 269: 375-383.

- Vaneeckhaute C, Claeys FHA, Tack FMG, Meers E, Belia E, Vanrolleghem PA. (2018). Development, implementation and validation of a generic nutrient recovery model (NRM) library. Environmental Modelling and Software; 99: 170-209.

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