

Development, implementation and use of a generic nutrient recovery model (NRM) library

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Céline VANEECKHAUTE,
Peter VANROLLEGHEM, Evangelina BELIA
Filip TACK, Erik MEERS



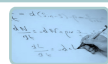
Presentation outline



Problem statement



Objectives



Model development methodology



Model simulation & validation results



Recommendations for research



Conclusions & perspectives



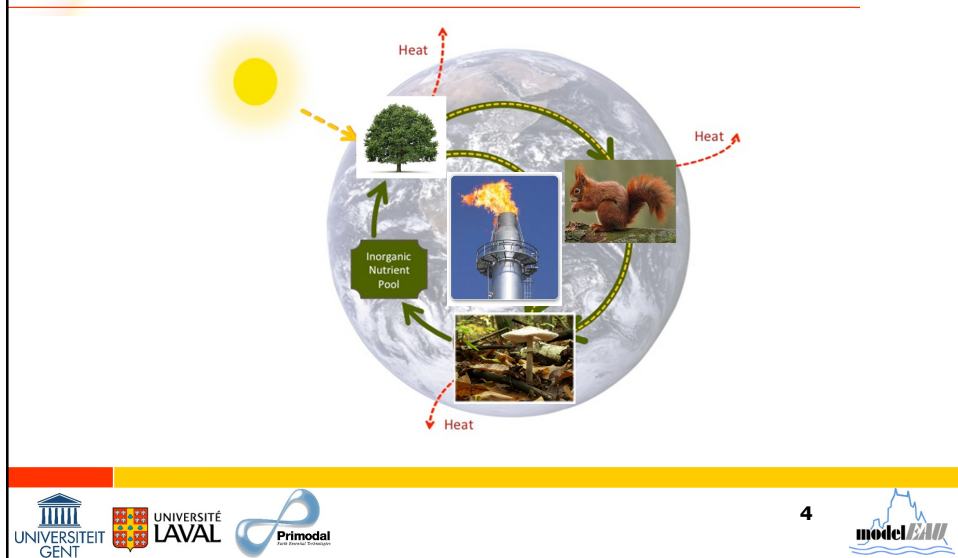
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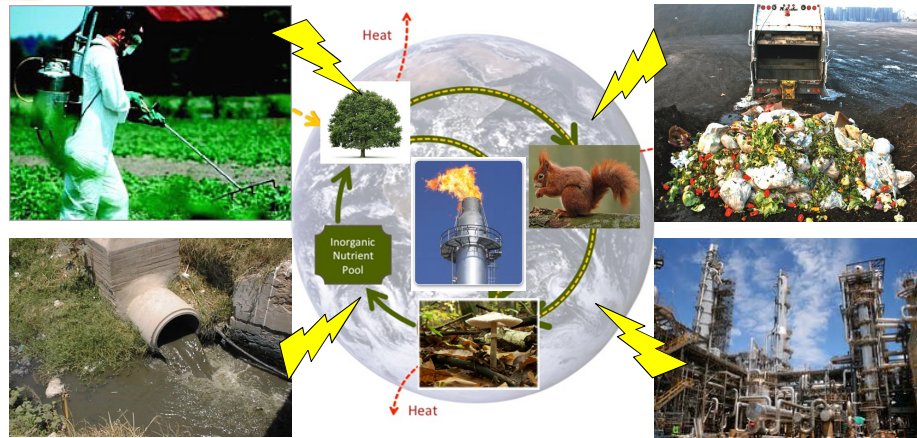
PROBLEM STATEMENT



Our nutrient world



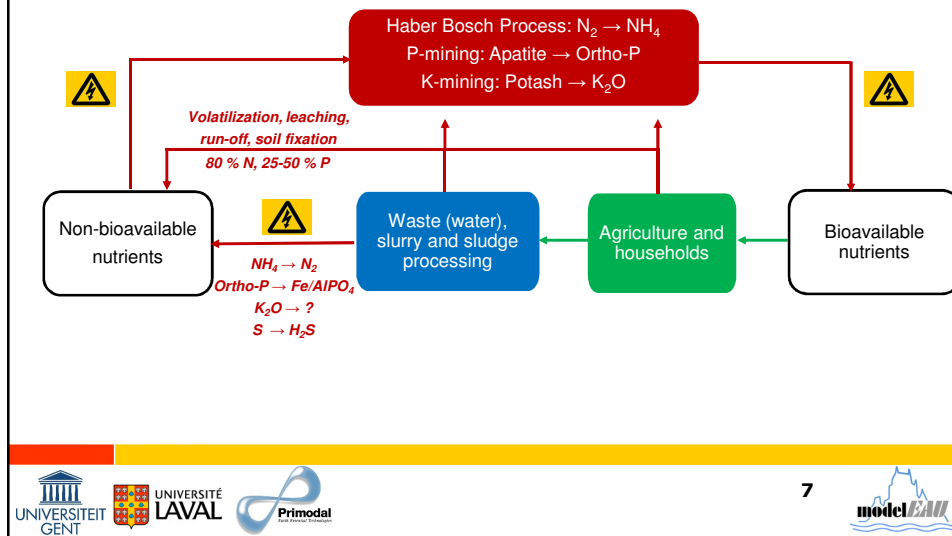
Our nutrient world



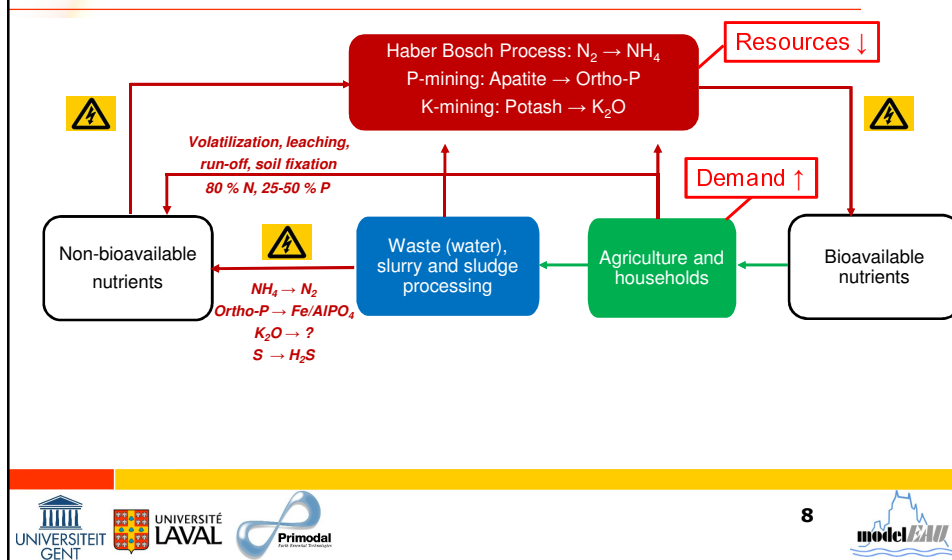
Our nutrient world



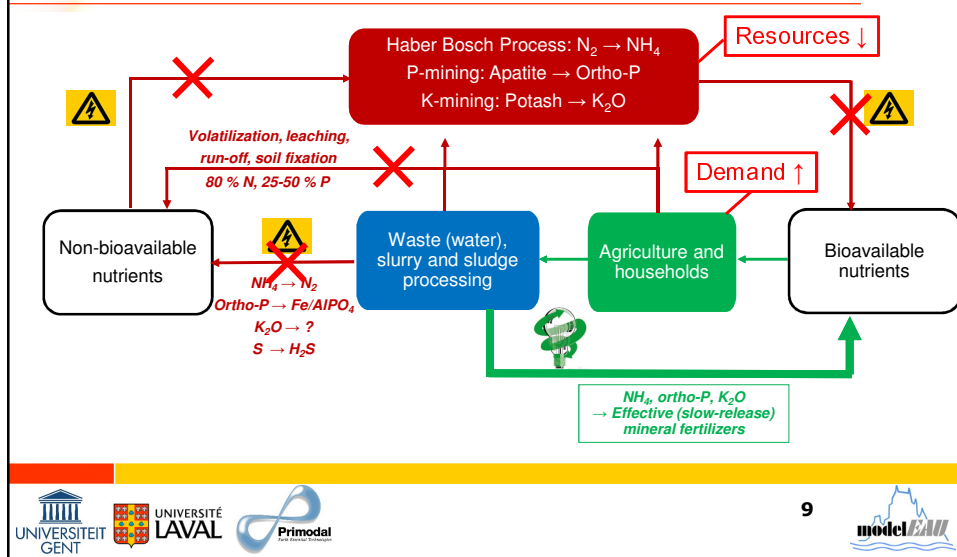
Need for sustainable resource management



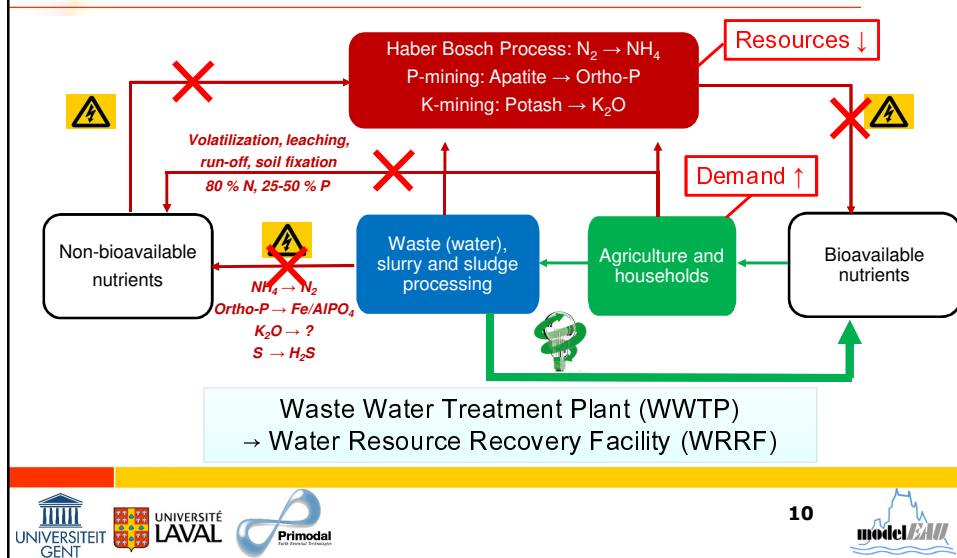
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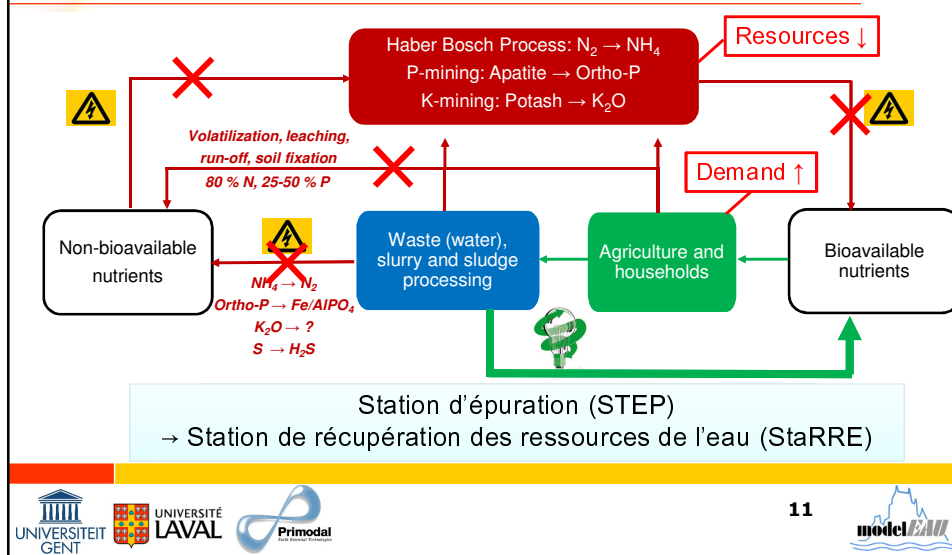
Need for sustainable resource management



Need for sustainable resource management



Need for sustainable resource management



Nutrient recovery processes

- Precipitation $\rightarrow$ struvite, calciumphosphates



Nutrient recovery processes

- Precipitation → struvite, calciumphosphates
- Ammonia stripping → NH_3



Nutrient recovery processes

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- Membrane filtration → H_2O , N-K concentrates



Nutrient recovery processes

- Precipitation → struvite, calciumphosphates
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- Membrane filtration → H_2O , N-K concentrates
- Biomass production and harvest → biomass

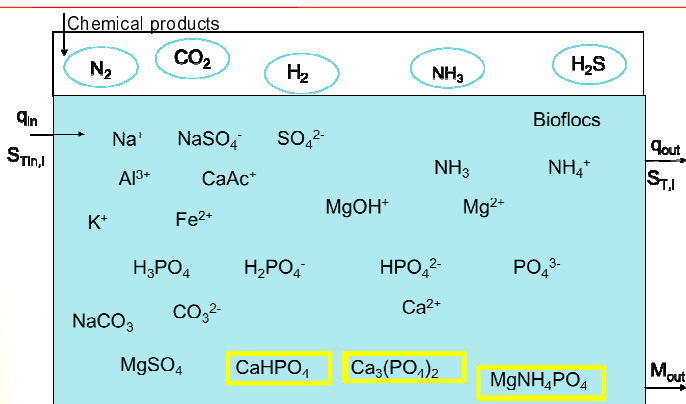


Nutrient recovery processes

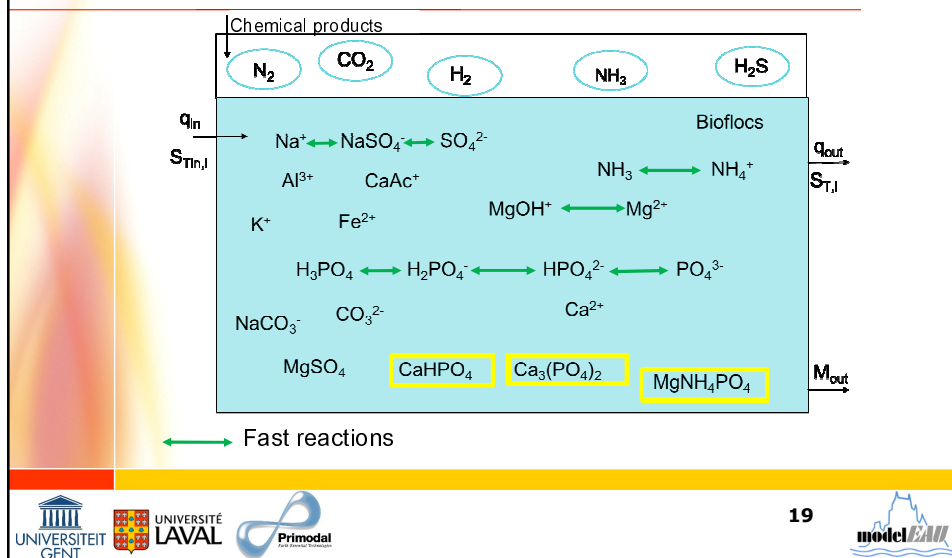
- Precipitation → struvite, calcium phosphates
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- ...

⇒ Mainly physicochemical unit processes !

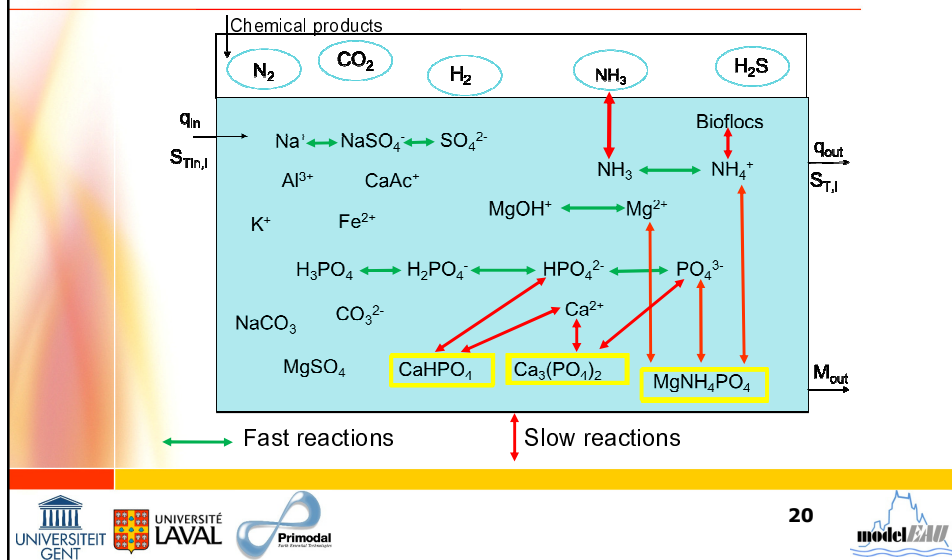
Prerequisite = marketable fertilizers



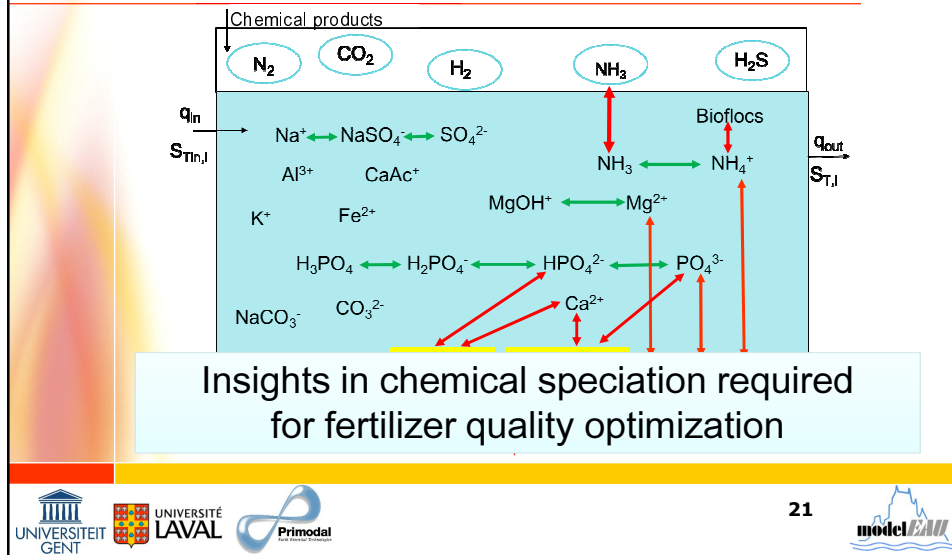
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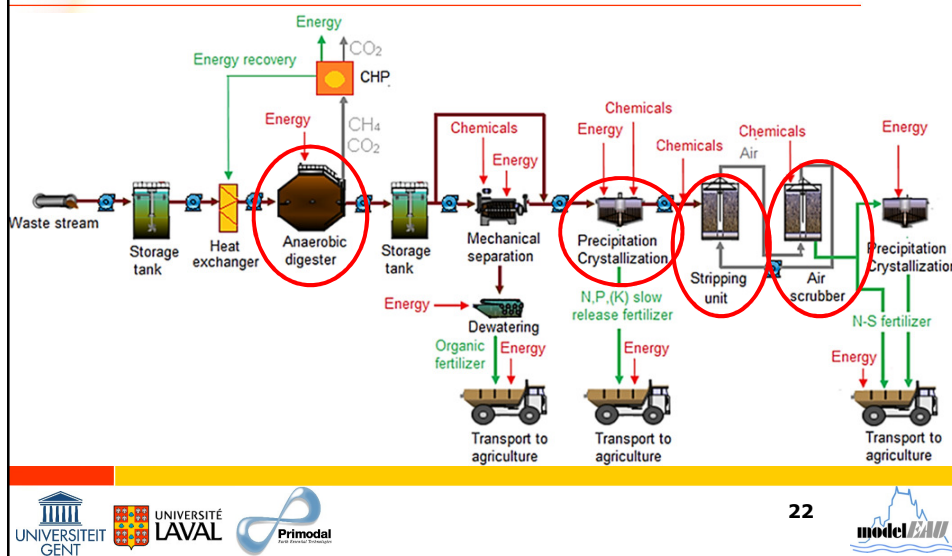
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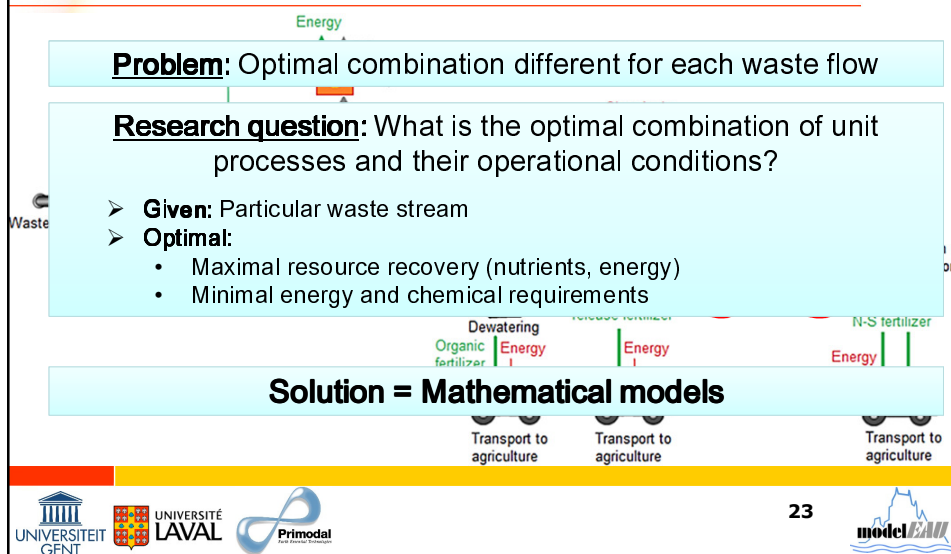
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Potential flow diagram of a WRRF



Potential flow diagram of a WRRF



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Modelling challenges

Existing WWTP models

- Good description of biological principles for N & COD removal
- Lack of physicochemical reactions and speciation
- No models for nutrient recovery systems

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Modelling challenges

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- Good description of biological principles for N & COD removal
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WRRF models

- Physicochemical principles essential to describe nutrient recovery
 - pH ? Ion-pairing ? Precipitation ? Redox ? ...
- Some progress made for an. digestion (CEIT, UCT, etc.)
- No models for selective nutrient recovery based on detailed speciation and reaction dynamics

Modelling challenges

Existing WWTP models

WRRF models

⇒ Lack of models to adequately put together optimal treatment trains and their operating conditions

OBJECTIVES

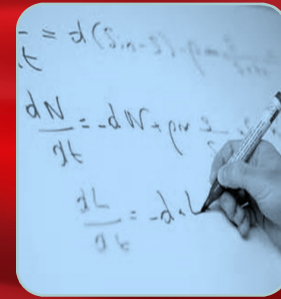


Specific research objectives

1. To **develop generic models** for the best available resource recovery systems including:
 - detailed chemical speciation
 - biological and physicochemical reaction kinetics
 - interactions between three phases (liquid-solid-gas)
2. To apply the models as a **tool for optimization** of single processes and treatment trains in order to:
 - maximize resource recovery (nutrients, energy)
 - minimize energy and chemical requirements



MODEL DEVELOPMENT METHODOLOGY



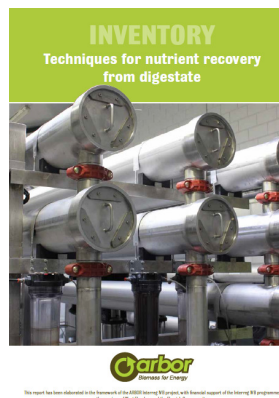
$$\frac{dN}{dt} = -dN + \mu N$$

$$\frac{dL}{dt} = -dL$$



I. Selection of unit processes and input streams

- Selection of unit processes (Vaneekhaute et al., submitted):

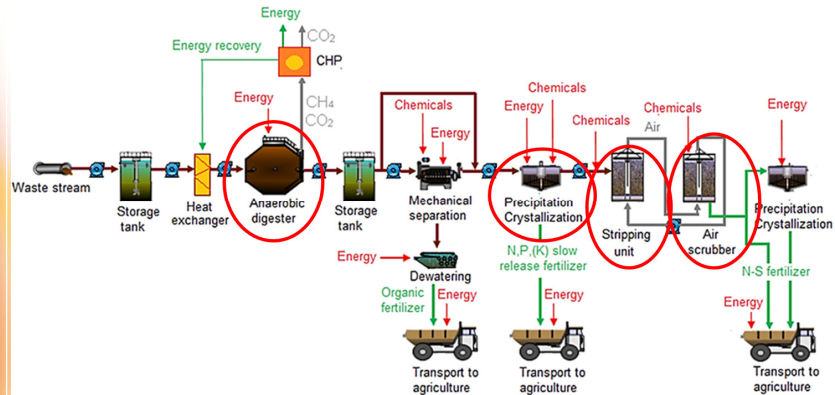


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I. Selection of unit processes and input streams

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I. Selection of unit processes and input streams

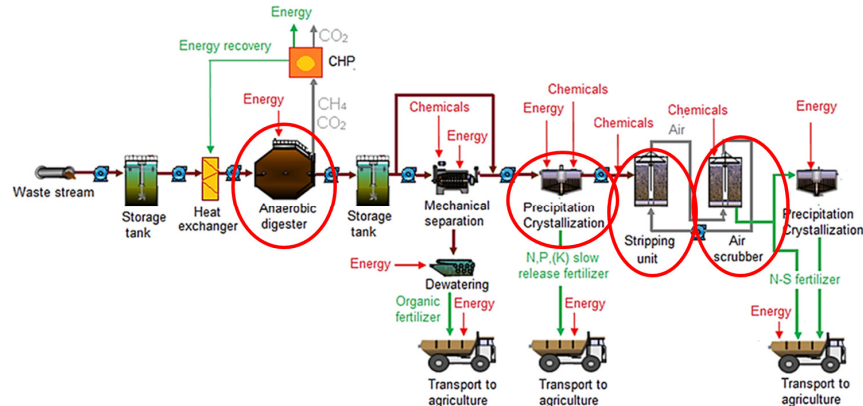
- Selection of unit processes (Vaneekhaute et al., submitted):

Type	Unit	Model name
Key units	1. Anaerobic digester	NRM-AD
	2. Precipitation/crystallization unit	NRM-Prec
	3. Stripping unit	NRM-Strip
	4. Air scrubber	NRM-Scrub
<i>- Full-scale application</i> <i>- Economic feasibility</i>		
Ancillary units	1. Separation unit	NRM-Settle
	2. Storage tank	NRM-Store
	3. Chemical dosing unit	NRM-Chem
	4. Heat exchanger	NRM-Heat

Nutrient recovery model

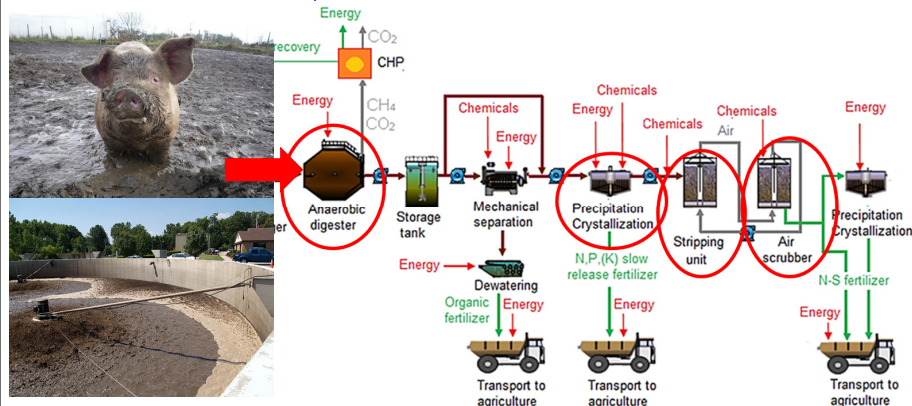
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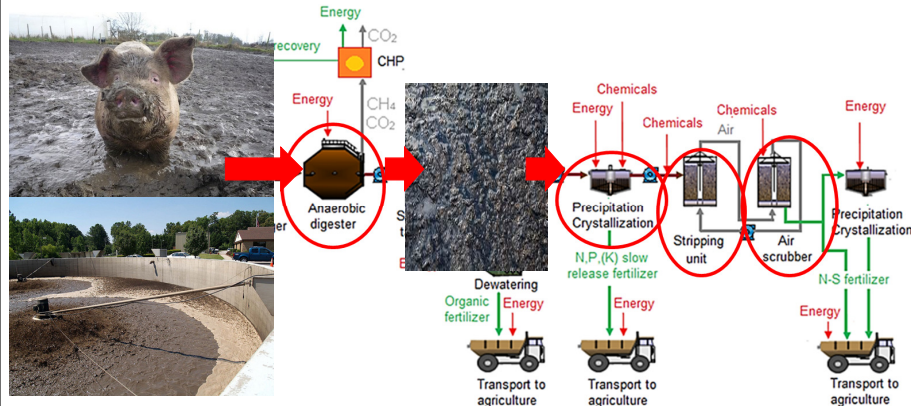
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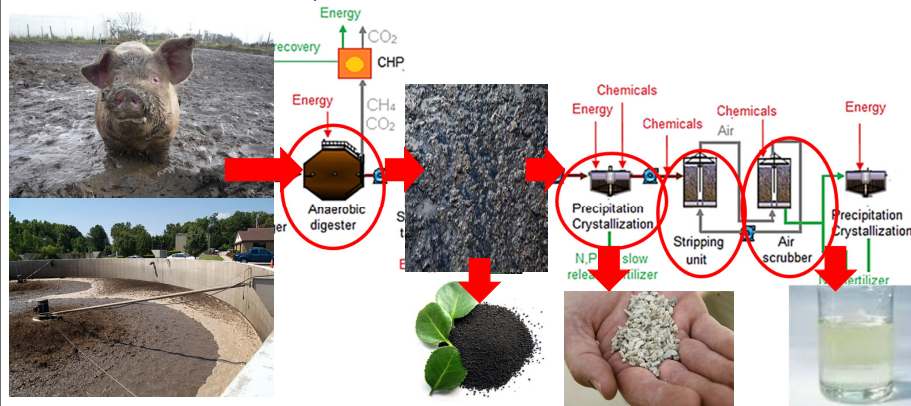
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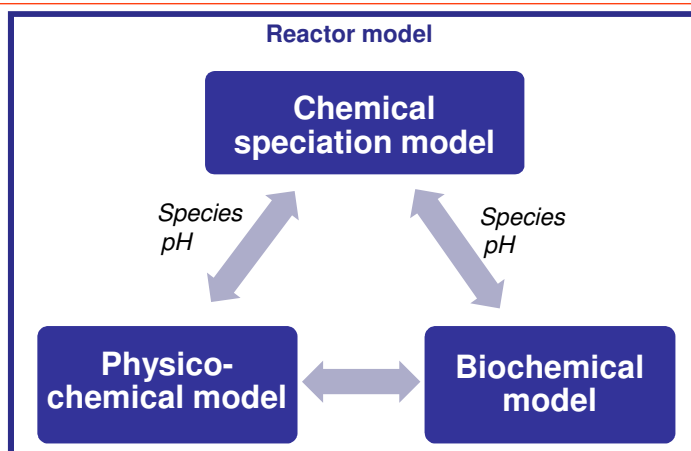
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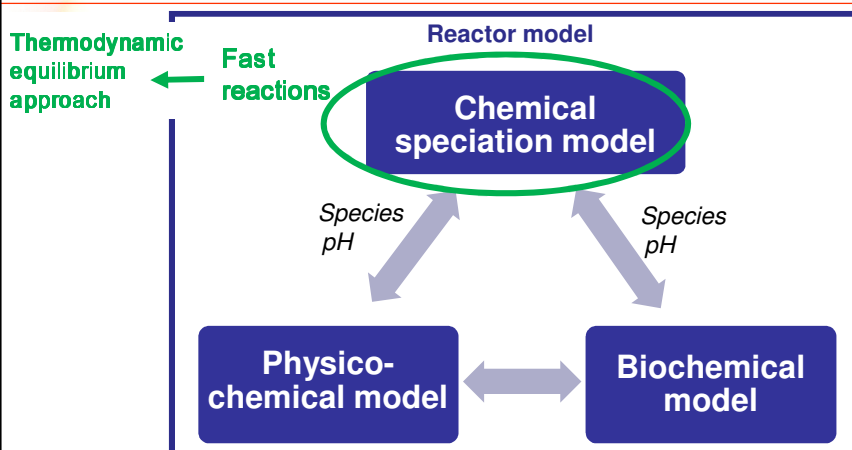
II. Model theory and implementation

Combined three-phase physicochemical-biological models



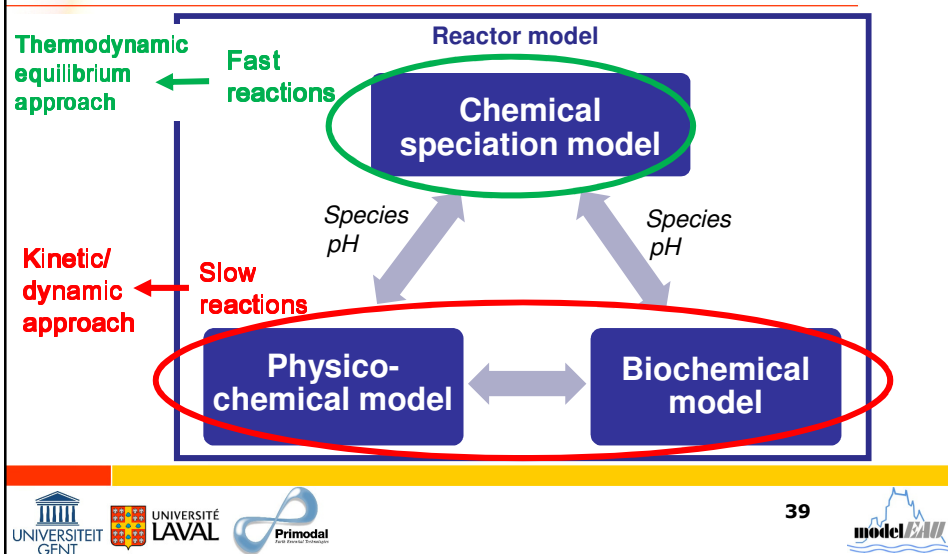
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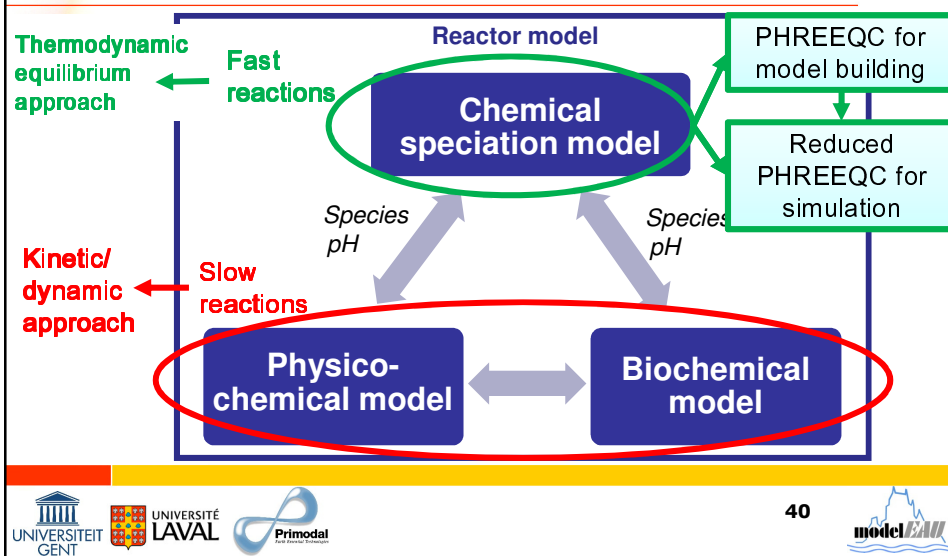
Combined three-phase physicochemical-biological models



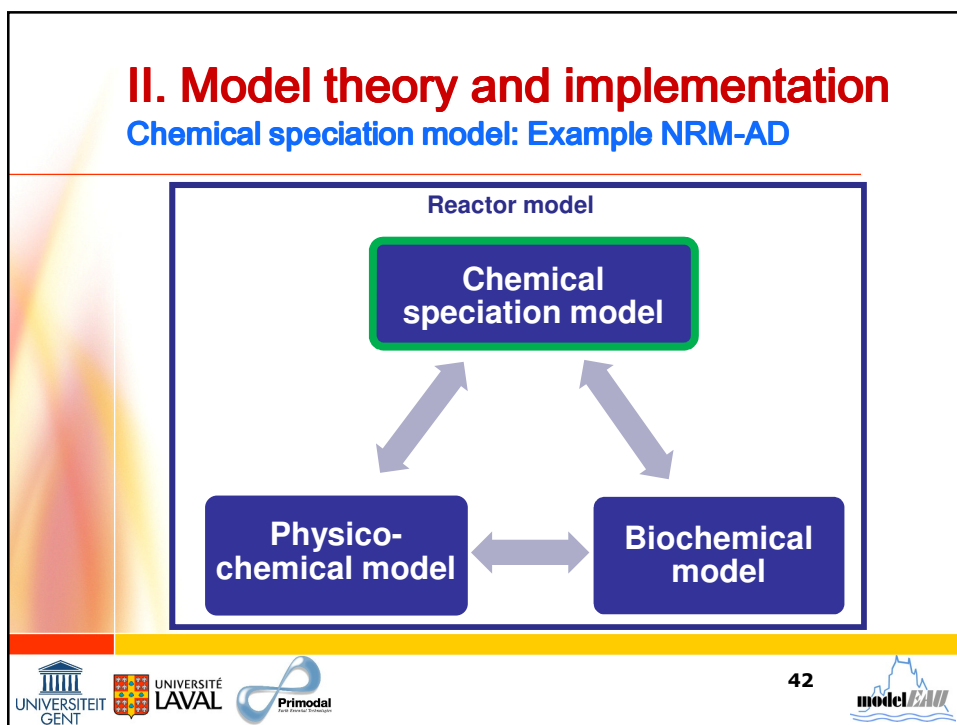
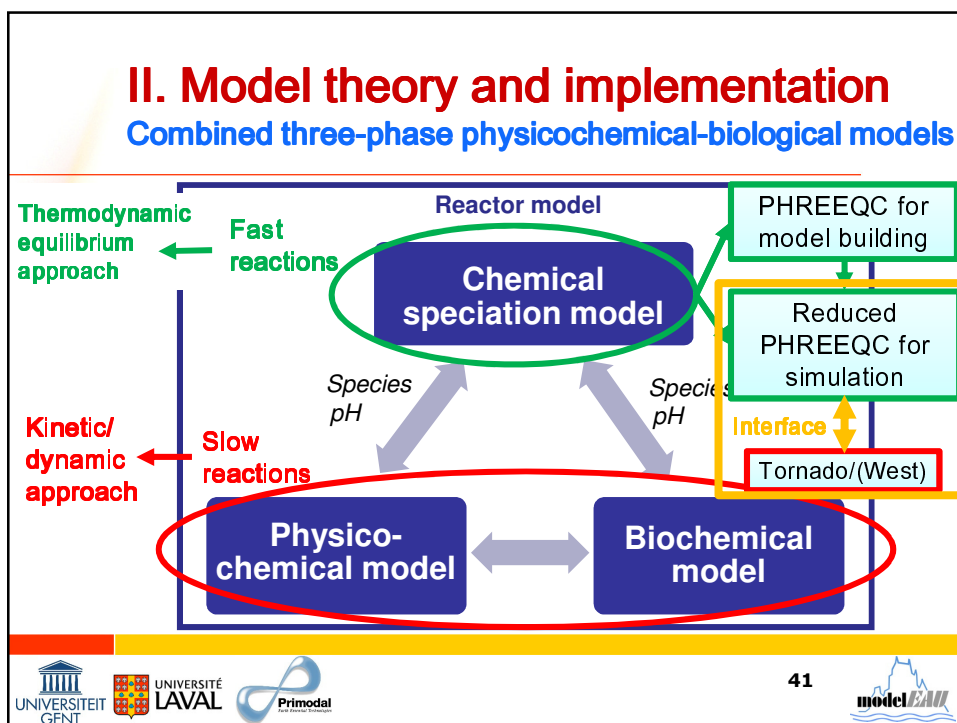
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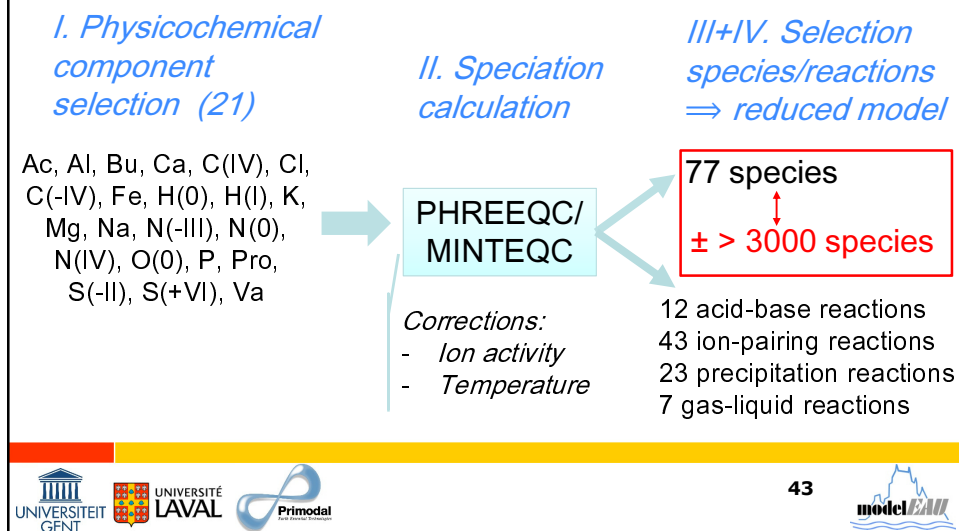


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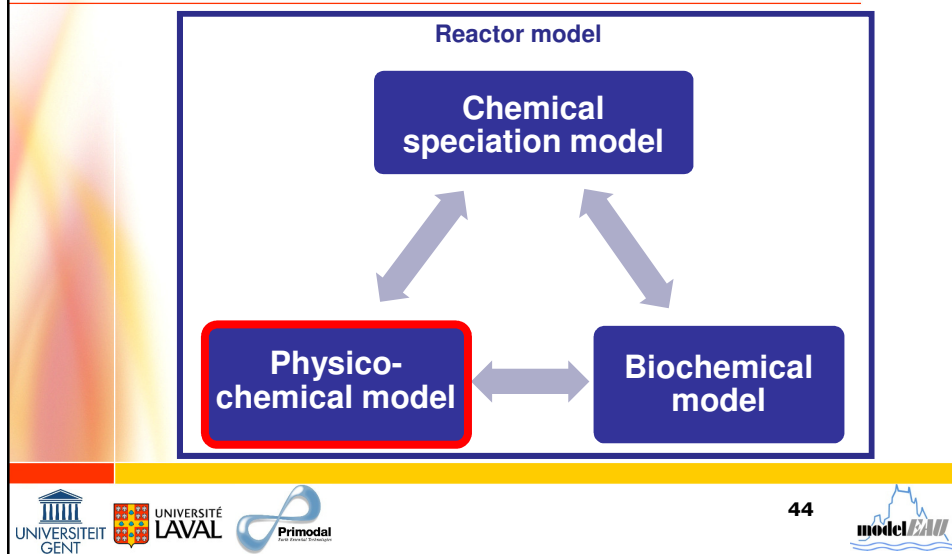
II. Model theory and implementation

Chemical speciation model: Example NRM-AD



II. Model theory and implementation

Physicochemical transformation model



II. Model theory and implementation

Physicochemical transformation model

▪ Liquid-gas transfer:

$$\rho_{CO_2,T} = k_L a_{CO_2} * (S_{CO_2,liq} - H_{CO_2} * p_{CO_2,gas})$$

Calculated by PHREEQC at every time step

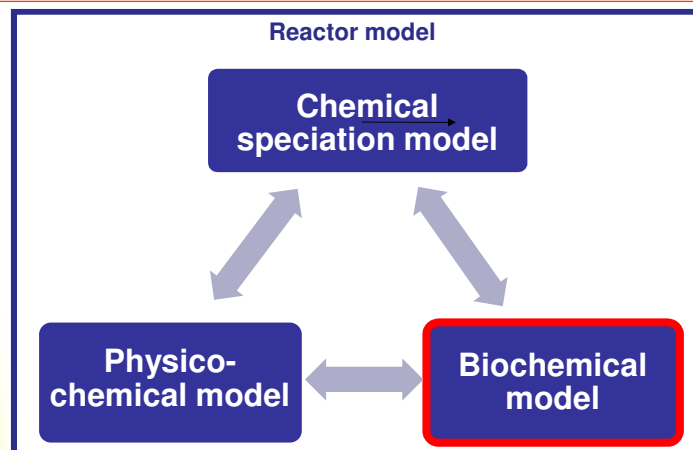
▪ Liquid-solid transfer:

$$\rho_{struv} = k_{r,struv} * [S_{r,struv} - 1]^2$$

Relative supersaturation
Calculated by PHREEQC at every time step

II. Model theory and implementation

Biochemical transformation model (NRM-AD)



II. Model theory and implementation

Biochemical transformation model (NRM-AD)

BIOCHEMICAL

- ADM 1 (19): Disintegration, hydrolysis, acidogenesis, acetogenesis, methanogenesis
Batstone et al. (2002)

→ COD-conversions
N-release/uptake



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II. Model theory and implementation

Biochemical transformation model (NRM-AD)

BIOCHEMICAL

- ADM 1 (19): Disintegration, hydrolysis, acidogenesis, acetogenesis, methanogenesis
Batstone et al. (2002)

PHYSICOCHEMICAL

- Acid-base systems (9)
- Ion-pairing (43)
- Precipitation-dissolution (23)
- Gas-liquid exchange (7)



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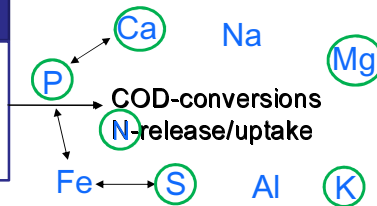


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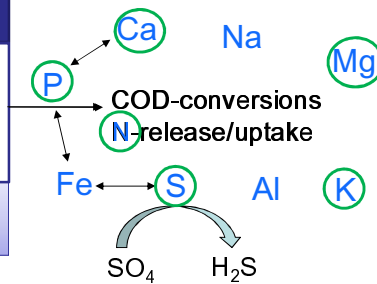


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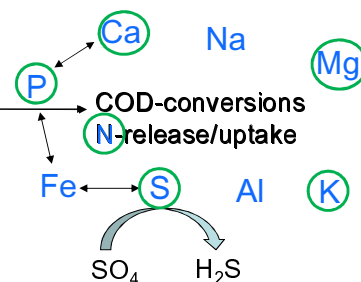
- ADM 1 (19): Disintegration, hydrolysis, acidogenesis, acetogenesis, methanogenesis
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- Extension 1 (8): Sulfurgenesis
Knobel & Lewis (2002)



II. Model theory and implementation

Biochemical transformation model (NRM-AD)

BIOCHEMICAL
• ADM 1 (19): Disintegration, hydrolysis, acidogenesis, acetogenesis, methanogenesis <i>Batstone et al. (2002)</i> • Extension 1 (8): Sulfurgenesis <i>Knobel & Lewis (2002)</i> • Extension 2: Inclusion new components in stoich. matrix ADM 1 (P, K, S) • Optional extension 3 (4): EBPR sludge <i>(Ikumi, 2011)</i>



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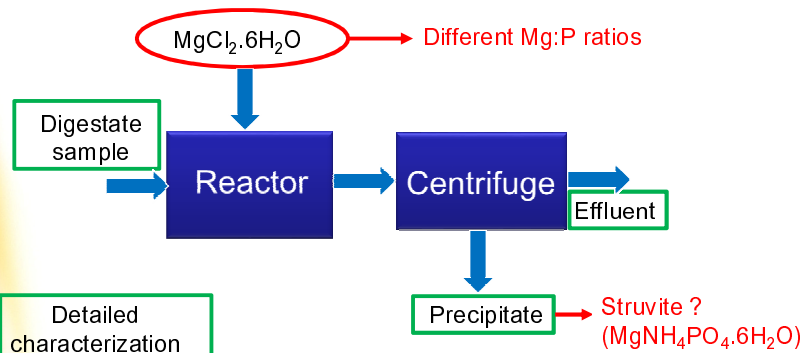


MODEL SIMULATION & VALIDATION RESULTS



NRM-Prec: Validation

- Lab-scale experiments P-precipitation



NRM-Prec: Validation

- Simulation vs. experimental results (after 12h)

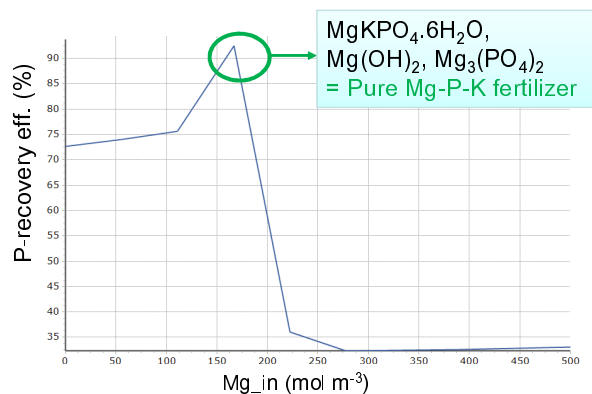
Mg:P	Digestate 1 % P-recovery			Digestate 2 % P-recovery	
	Exp.	Model without NaH ₂ PO ₄	Model with NaH ₂ PO ₄	Exp.	Model with NaH ₂ PO ₄
1:1	41	95.60	41.32	28	27.76
2:1	44	97.91	43.62	29	29.29

⇒ Importance of a detailed solution speciation and input characterization !

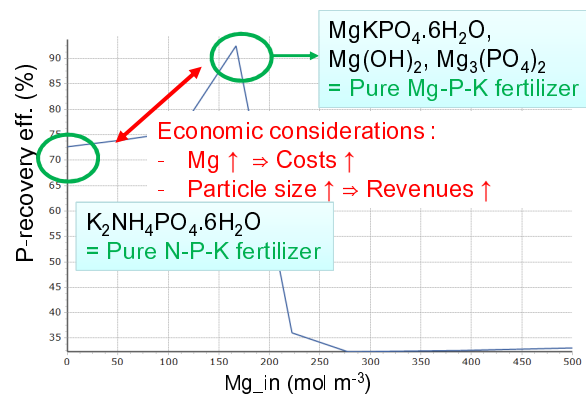
NRM-Prec: Scenario analyses and process optimization

- Main precipitates: struvite, Ca- and Mg-phosphates, Ca- and Mg-carbonates, AlPO_4 , Fe- and Al-carbonates
 ⇒ No pure struvite fertilizer !
- Practical recommendations (if struvite is target):
 - Removal of CaCO_3 prior to precipitation (Huchzermeier et al., 2012)
 - Perform struvite precipitation upstream of Fe/Al dosing

NRM-Prec: Scenario analyses and process optimization



NRM-Prec: Scenario analyses and process optimization



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RECOMMENDATIONS FOR RESEARCH



Recommendations for further experimental research

- Detailed characterisation input composition
→ Essential for process optimization
- Determination kinetic rates in real matrix ↔ pure solutions
→ Better prediction of fertilizer quality in time
- Development generic chemical analysis procedure for
precipitate identification



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CONCLUSIONS & PERSPECTIVES



Conclusions

- Generic **nutrient recovery model (NRM) library** created
- **PHREEQC-Tornado/West interface** developed & verified
- Default parameters + proper input characterization
⇒ **Good agreement** with steady state experimental results (to be confirmed)
- Opportunities for better process **understanding and optimization**

Perspectives

- Further dynamic data collection (on-going):
 - NRM-AD: Full-scale Greenwatt (BE)
 - NRM-Prec: Pilot-scale St. Hyacinthe (QC)
 - NRM-Strip/NRM-Scrub: Pilot-scale Waterleau (BE)



Perspectives

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 - NRM-AD: Full-scale Greenwatt (BE)
 - NRM-Prec: Pilot-scale St. Hyacinthe (QC)
 - NRM-Strip/NRM-Scrub: Pilot-scale Waterleau (BE)
- Selection most important parameters for process optimization: Global sensitivity analysis (on-going)
- Process optimization (on-going):
Single units + treatment train



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Acknowledgements



Fonds de recherche
Nature et
technologies



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**THANK YOU FOR
THE ATTENTION**

QUESTIONS ?

celinevaneekhaute@gmail.com

