# Control Structure Design and Real-Time Optimization for Continuous Bio-Based Aniline Production

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## MOTIVATION

### Why bio-based aniline?

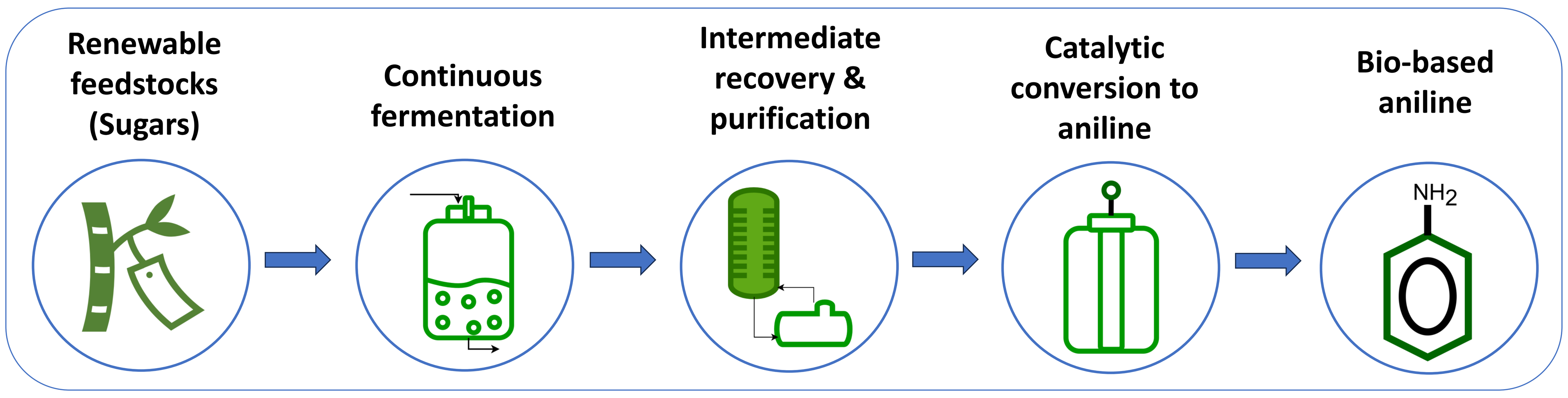
- Aniline is a key building block for polyurethanes [1] and is currently produced mainly from fossil-based feedstocks.
- Bio4PURConti [2] aims to develop the first continuous production route to bio-based aniline from renewable feedstocks.

### Why process control and optimization?

- Continuous operation [3] enables higher productivity, better resource efficiency and lower footprint [2].
- This requires advanced control and real-time optimization methods capable of handling <u>model uncertainty</u>, <u>limited online measurements</u>, and <u>multiple operational constraints</u>.

## PROCESS OVERVIEW

### Bio-based aniline production from renewable feedstock using continuous fermentation




<u>Objective</u>: To maintain high cell concentrations while continuously supplying fresh nutrients and removing the product, improving sustainability, process efficiency, and scalability.

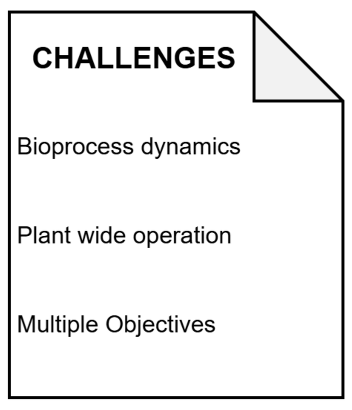
## CHALLENGES

### Bioprocess dynamics

- Model uncertainty and process variations
  - Time-varying biological behavior
- Limited online measurements
  - Key variables are difficult or expensive to measure in real time

### Plant wide operation

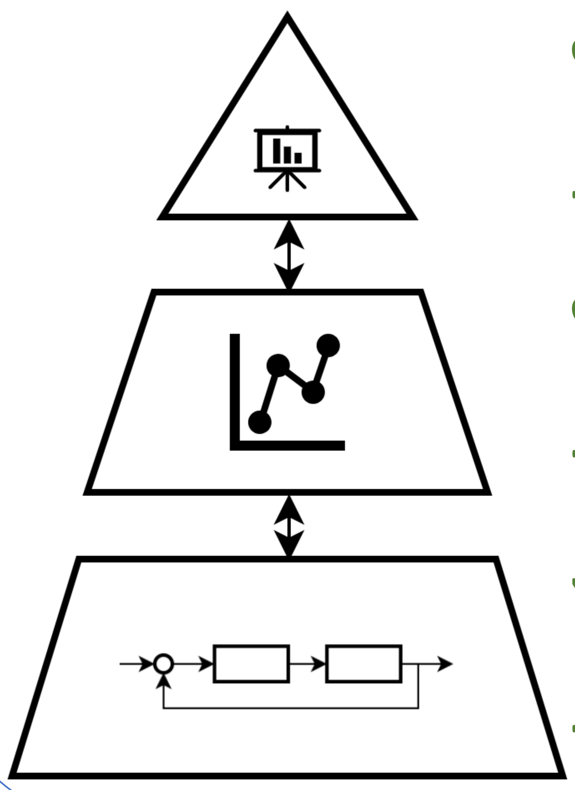
- Strong process interactions
  - Coupled unit operations
- Multiple operational constraints
  - Quality and operating limits




### Multiple objectives

- Productivity, yield, product quality
- Robust and sustainable operation

## PROPOSED FRAMEWORK

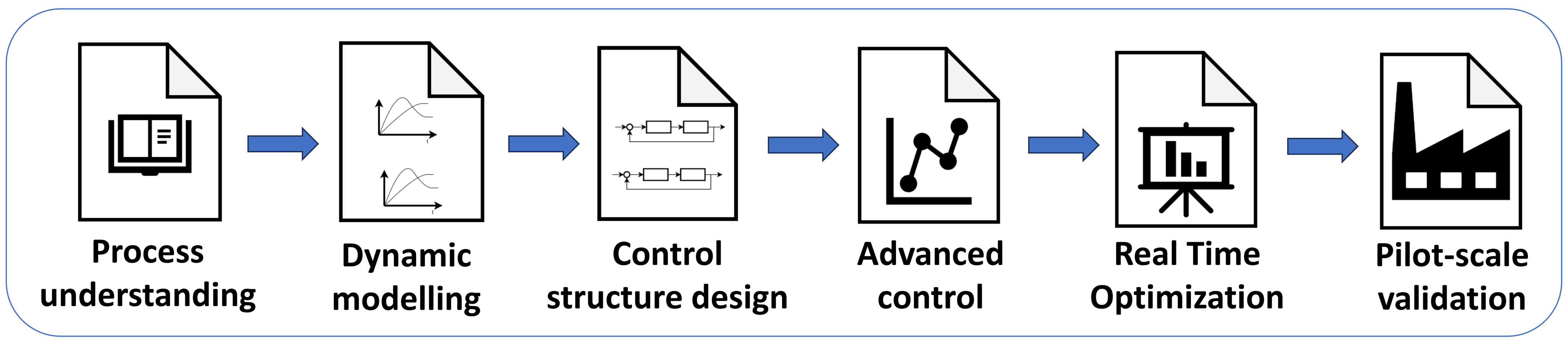


**Layer 3 — Real-Time Optimization**
- Modifier adaptation
- Model uncertainty

**Layer 2 — Advanced Control**
- State estimation
- Model Predictive Control
- Constraint handling

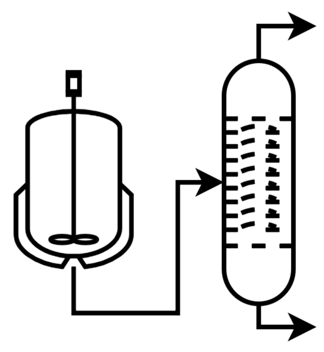
**Layer 1 — Regulatory Control**
- Feed flow rates
- pH
- Levels
- Temperature

## RESEARCH METHODOLOGY



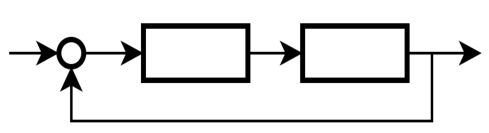

### Control-oriented process understanding

- Identify key manipulated, controlled variables and disturbances
- Understand dominant couplings and time scales
- Basis for control structure and optimization



### Control structure design

- Plant-wide control structure design
- Switching control structures [4] for changing operating conditions

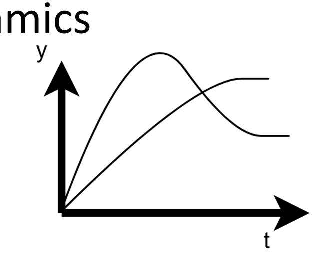


### Real-time optimization

- Optimization under model uncertainty
- Plant-model mismatch compensation
- Modifier adaptation [5] to approach the plant optimum

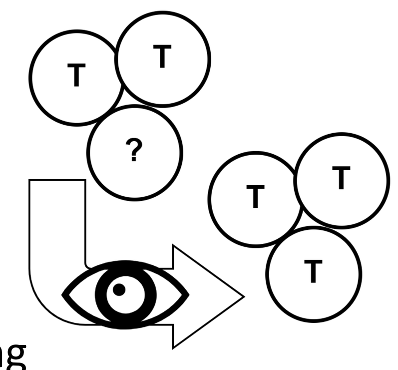
### Dynamic models for control

- Capture dominant process dynamics
- Quantify model uncertainty
- Support state estimation and controller design



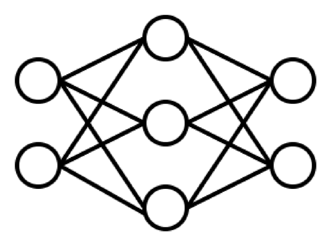

### Advanced Control

- State estimation (Moving Horizon Estimation) for unmeasured variables
- Model Predictive Control
- Robust operation under uncertainty
- Multiple constraints handling




### Surrogate models for optimization

- Use surrogate models [6] for fast optimization
- Approximate steady-state relationships



### Pilot-scale validation

- Validation at the 150 L pilot scale
- Semi-industrial demonstration at 1.5 $m^3$ Bio Base Europe Pilot Plant facility [2]

## EXPECTED OUTCOMES & IMPACT

### Scientific & methodological outcomes

- Control-oriented understanding of the process
- Plant-wide control structure
- State estimation for unmeasured variables
- MPC and real-time optimization framework
- Methods to handle model mismatch
- Surrogate models for fast optimization

### Process & application impact

- Robust and stable continuous operation
- Improved productivity and resource efficiency
- Better coordination of upstream and downstream units
- Support for pilot-scale implementation
- Contribution to sustainable production of bio-based aniline

The research aims to develop a control structure and real-time optimization framework, incorporating modifier adaptation and surrogate models, to enable robust, efficient, and economically attractive operation of a novel continuous bio-based aniline process.

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