Sustainable Production of Astaxanthin using Robust Control
Production Durable d'Astaxanthine en utilisant le contrôle commande

Microalgae are photosynthetic organisms which convert carbon dioxide and light into high-value compounds (antioxidants, proteins, ...) with applications in pharmaceutics, cosmetics, food, contributing to the global bioeconomy (Acién Fernandez et al., 2021). They are mostly cultivated as suspended cells in conventional outdoor systems (closed photobioreactors - PBR and raceways) but recently, a new and promising approach has emerged to simplify biomass harvesting and improve productivity: **the biofilm-based cultivation** (Zhuang et al., 2018) in which cells adhere and grow on a support (Fanesi et al., 2022*; Li et al, 2024*). Biofilms were shown to be more productive with a reduced environmental footprint (Penaranda et al., 2023). This new approach can therefore significantly improve the sustainability and cost effectiveness of microalgae production, broadening their field of application.

Besides, tools for efficient on-line monitoring and control of microalgae cultures are poorly developed and implemented though their interest for the optimization of microalgae farming. Regarding process control, its main goal is to ensure that the culture operates at the maximum productivity regardless environmental perturbations (e.g. varying light and temperature in outdoor conditions). Robust control strategies have been developed to maximize the productivity of microalgae but only few have been validated on real experimental datasets (Bernard 2011, Tebbani et al. 2014*, Otalora et al. 2024) and almost none have been applied to photosynthetic biofilm-based technologies (Lamare et al. 2019). **For the first time, astaxanthin** (high-value antioxidant compound, pigment) **production using *H. pluvialis* cultivated in a rotating biofilm reactor has been demonstrated at LGPM** (Morgado et al., 2023*, European project ITN DigitalAlgaesation). A monitoring tool was also developed and validated to measure in a non-destructive way biomass areal density and astaxanthin content (Morgado et al., 2024*). Furthermore, an original dynamic model predicting astaxanthin production was established (Morgado et al., submitted).

The goal of this PhD thesis is to design and validate optimization and control strategies to maximize, online, the astaxanthin productivity in a biofilm rotating system. At the end, an automatically controlled system is expected. Experimental, monitoring and modelling approaches developed in the framework of D. Morgado thesis will be applied and extended in this thesis. **This will be achieved in several steps**: first, experiments will be carried out to provide additional data to upgrade the existent model. The impact of operational process on biomass and astaxanthin productivity will be monitored. Optimal operating conditions will be then identified. Finally, robust control laws will be designed to maintain the bioprocess at its maximal astaxanthin productivity (Tebbani et al., 2014, 2015*). **Outcomes from this thesis** will contribute to increase the scientific knowledge on the formation of photosynthetic biofilms which are still poorly studied and have a great industrial potential. From an engineering point of view, an automatically controlled biofilm-rotating set-up will be proposed.

The project will be carried out in the Laboratory of Chemical Engineering and Materials Science (LGPM) which brings expertise in microalgae bioprocess development and monitoring and the Laboratory of Signals and Systems (L2S) which has extensive experience in bioprocess modelling, optimization and control.

Required skills: Microbial culture, experience in modelling of dynamic systems and computer programming.
PhD: starting by September 2025.

Contact: Please contact Filipa Lopes (filipa.lopes@centralesupelec.fr) for further information.
How to apply? Please send a CV and a cover letter to Filipa Lopes using the above-mentioned contact information.

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Annexe

Figure 1 – Astaxanthin production (in red) in open-ponds (Figure on the left). Rotating biofilm-based systems at pilot scale (Figure on the right), (Bernstein et al., 2014)

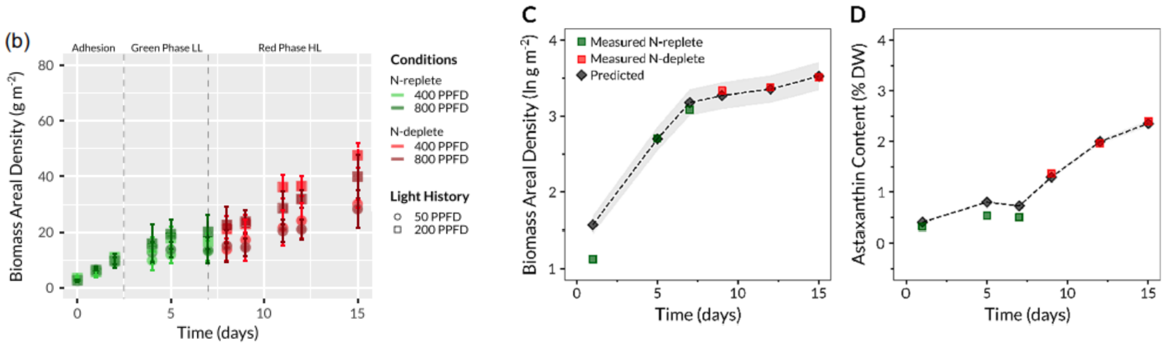

Figure 2 - Dynamics of biomass areal density of *H. pluvialis* biofilms (Morgado et al., 2023) over 15 days of cultivation in different light intensity (PPFD of 400 and 800 µmol.m^{-2}.s^{-1}) and nitrogen conditions (nitrogen, N-replete and N-deplete) (on the left). Biomass and astaxanthin content predicted by models obtained by spectroscopic analysis (Morgado et al., 2024).