HUMANFORHYDRO: Valorization of ligno-HUMic-like compounds derived from sewAge sludge for the degradatioN oF organic pOllutants and pRoduction of HYDROgen

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Introduction

The management of sewage sludge from wastewater treatment plants (WWTPs) is an increasing environmental and economic challenge worldwide, driven by rising sludge volumes and the high costs of treatment and disposal (García-López *et al.*, 2025; Ferrentino *et al.*, 2023). In Europe, stricter regulations and expanding urban wastewater infrastructure have further intensified these challenges, with sludge handling accounting for up to 65% of total WWTP operating costs (Ferrentino *et al.*, 2023). Increasing restrictions on conventional disposal methods have prompted strategies to recover valuable sludge components such as lipids, proteins, carbohydrates and fibrous materials for conversion into biofuels, platform chemicals, or fertilizers, thereby reducing waste and supporting a circular economy (di Bitonto *et al.*, 2025). Among these fractions, ligno-humic-like compounds (LHLs), which can constitute up to 30% of sludge mass (di Bitonto *et al.*, 2020), remain largely underutilized despite their distinctive chemical properties. Their aromatic structures and redox-active functional groups enable them to act as electron shuttles in bioelectrochemical systems and as support for photoactive metal oxides, enhancing solar-driven photocatalytic degradation of pollutants while simultaneously producing hydrogen (Bravo *et al.*, 2025; Gonzalez-Nava *et al.*, 2023, Saravanan *et al.*, 2021). By integrating LHL-based technologies, WWTPs can move beyond disposal-focused operations to become multifunctional facilities capable of recovering energy and materials, improving water quality, and supporting circular economy objectives.

Project Objectives and Consortium

The HUMANFORHYDRO project (Valorization of ligno-HUMic-like compounds derived from sewAge sludge for the degradation of organic pOllutants and pRoduction of HYDROgen) addresses these challenges by systematically recovering, characterizing and applying LHLs in advanced wastewater treatment processes. The recovered LHLs are integrated into two complementary technological routes: in bioelectrochemical systems, they act as electron shuttles that accelerate organic matter degradation and enhance hydrogen production; in photocatalytic systems, they serve as functional support for metal oxides, improving visible-light absorption and interfacial charge transfer to drive both pollutant degradation and hydrogen generation. By combining these approaches, the project simultaneously addresses resource recovery, wastewater treatment, and clean energy production within a circular economic framework.

Figure 1. Schematic of the HUMANFORHYDRO project showing LHL recovery from sewage sludge and their use in bioelectrochemical and photocatalytic systems for hydrogen production and pollutant removal.

The project is conducted by a multidisciplinary consortium: the CNR Water Research Institute (IRSA, Bari) coordinates the project and leads LHL recovery and catalyst development; the University of Bari (UNIBA) conducts detailed physicochemical characterisation of LHLs and hybrid materials; and the University "La Sapienza" of Rome (UNIROMA) evaluates LHL performance in microbial electrolysis cells, assessing electron transfer efficiency, organic matter degradation, and hydrogen production. This integrated workflow ensures optimised material properties, technological feasibility and scalable processes.

Expected Results and Impact

The HUMANFORHYDRO project develops innovative technologies for reducing sewage sludge and valorising wastewater through hydrogen production in line with the European Green Deal and the Italian PNRR. It aims to WWTPs into integrated biorefineries, addressing challenges such as excessive sludge production and high disposal costs. The project also exploits the energy potential of wastewater to produce green hydrogen via bioelectrochemical systems and photocatalysis, aiming to make WWTPs energy-neutral or net energy producers. HUMANFORHYDRO further enhances pollutant removal through advanced oxidation processes, effectively degrading persistent compounds that conventional treatment cannot eliminate. Overall, the project embodies a circular economy approach, demonstrating sustainable wastewater management that simultaneously reduces sludge, generates clean energy, and improves water quality, providing a scalable model for environmentally friendly resource recovery at national and international levels.

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