Dark fermentation biohydrogen from olive tree pruning: mitigation of inhibitors and perspectives for LCA-TEA in the Mediterranean

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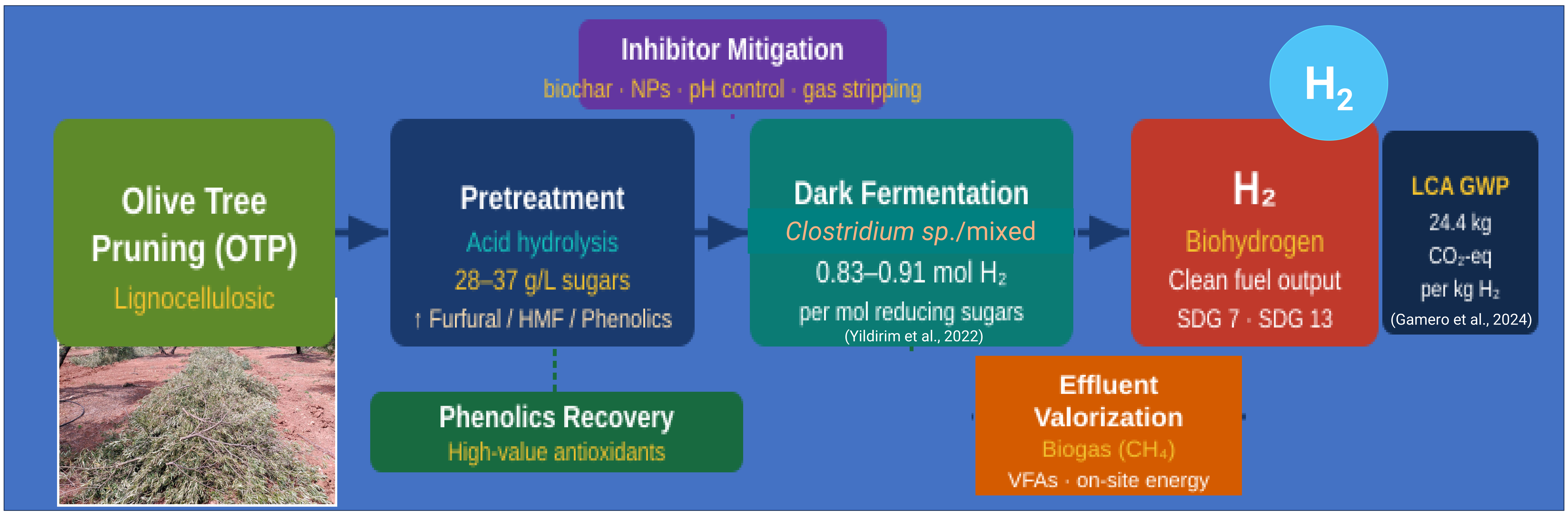
CONTEXT & NOVELTY

Olive tree pruning (OTP) is an abundant lignocellulosic residue across Mediterranean regions - underutilized despite its potential as a renewable feedstock.
Dark fermentation converts hydrolysable carbohydrates into **biohydrogen (H_2)** without light, enabling a circular waste-to-energy route aligned with SDG 7, 12, and 13.
Key novelty challenge: engineering robustness for scale-up - OTP hydrolysates contain inhibitor mixtures that sharply depress H_2 yields. In a biorefinery cascading Process to also obtain antioxidants, volatile fatty acids (VFA), and on-site energy.

- SDG 7 Clean Energy
- SDG 12 Responsible Production
- SDG 13 Climate Action

OTP BIOREFINERY CASCADE: PROCESS OVERVIEW



INHIBITOR MITIGATION LEVERS & INNOVATION OPTIONS

Severity Tuning
Optimize pretreatment to minimize furfural and HMF generation while maximizing sugar release.

Adsorption (Biochar / AC)
Biochar and activated carbon adsorb furans and residual phenolics, reducing inhibitor load prior to fermentation.

Inoculum Adaptation
Gradual exposure of *Clostridium* or mixed consortia to OTP hydrolysates builds tolerance to inhibitor mixtures.

Gas Stripping
Lowering H_2 partial pressure via gas stripping or headspace management shifts metabolism toward the acetate pathway.

Ferrite Nanoparticles (NPs)
$NiFe_2O_4$ / $CoFe_2O_4$ at 200 mg/L → ~0.27–0.29 m³ H_2/kg sugars. Magnetically recoverable (Morán-Alarcón et al., 2026).

LCA–TEA: MEDITERRANEAN ECONOMICS & SCALE-UP OUTLOOK

LCA Gate-to-Gate GWP (Gamero et al., 2024)
24.4 kg CO_2-eq / kg H_2

Feedstock cost contribution
7.5 €/kg H_2 (30 €/t OTP ÷ 4 kg H_2/t dry OTP)

Viable model
Multiproduct Biorefinery

Natural antioxidant
First-stage recovery of high-value phenolic compounds from OTP hydrolysate.

Biogas (CH_4)
Anaerobic digestion of fermentation effluent for on-site heat and power generation.

Volatile Fatty Acids
VFA recovery from effluent as additional value-added chemicals stream.

CO_2 Avoided Burning
Avoided open-burning of OTP as measurable SDG co-benefit in LCA boundary.

Mediterranean scale-up: clustered modular plants (5–50 t/d) near olive groves — minimizing transport, stabilizing feedstock supply, and capturing avoided open-burning impacts as part of the SDG narrative.

CONCLUSIONS

1
H_2 yields from OTP dark fermentation reach only 20–25% of the Thauer Limit due to inhibitor mixtures (furfural, HMF, phenolics) and back-pressure effects.

2
Inhibitor mitigation is the critical engineering challenge for scale-up. A measurable mitigation package — severity tuning, adsorption, inoculum adaptation, gas stripping — must be validated before industrialization.

3
Ferrite NPs paired with carbonaceous adsorbents represent a promising deployable strategy to boost yield and buffer inhibitors simultaneously in OTP fermentation matrices.

4
H_2-only economics are not viable at current performance levels. A multiproduct biorefinery cascade — phenolics → H_2 → biogas / VFAs — is required for techno-economic feasibility in the Mediterranean context.

5
Clustered modular Mediterranean plants near olive groves, capturing avoided open-burning SDG co-benefits, represent the most defensible and economically viable OTP biohydrogen scale-up pathway.

REFERENCES

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