Biogas-Assisted Solid Oxide Electrolysis for Efficient Renewable Hydrogen Production: The pHyBios Project

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H_2 Summit 2026, Cork 18.19 Nov 2026

Co-funded by the European Union

With funding from the: Federal Ministry of Research, Technology and Space

Context and Motivations



- **Industry:** steel, ammonia, refining, chemicals
- **Energy storage:** long-duration storage, back-up, seasonal balancing
- **Mobility:** heavy-duty, maritime, aviation derivatives
- **Sector coupling:** electricity ↔ hydrogen ↔ fuels ↔ chemicals

<u>Decarbonisation of systems that are challenging electrify</u>

Challenges

- High electricity demands and intermittent renewable energy supply
- Capital costs of electrolyzer and BoP
- Electricity costs
- Infrastructure and system integration constraints

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pHyBios

pure **H**ydrogen from **Bio**gas-Assisted Electrolysi**s**

German partners

IZES gGmbH

moehwald (Bosch Group)

Project ambition

Develop and validate biogas-assisted solid oxide electrolysis technology.

Greek partners

CERTH

DELVEC

- Project period: 01.01.2026–31.12.2028 (36 months)
- Technology readiness target: TRL2 -> TRL4

Link to the project call

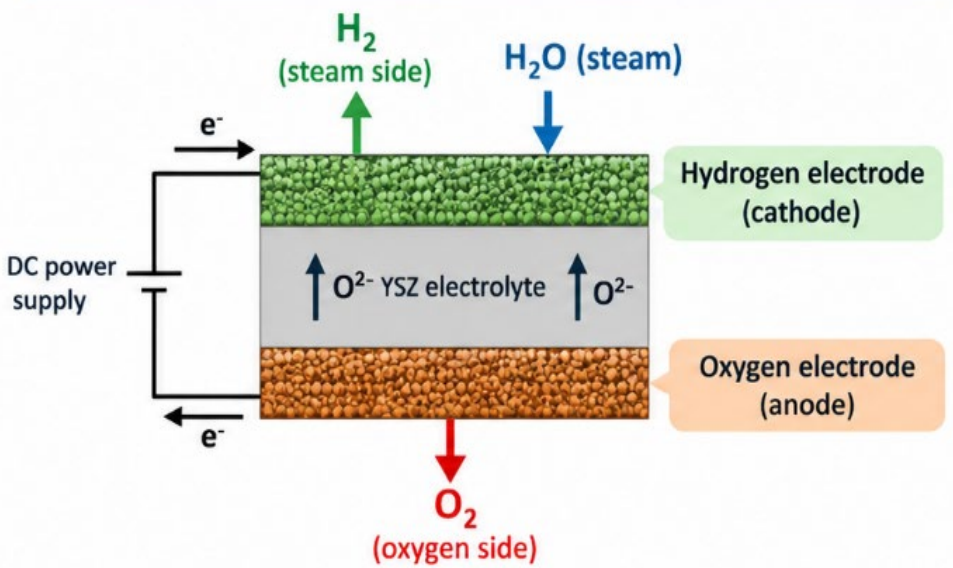
Gefördert durch:
Bundesministerium für Forschung, Technologie und Raumfahrt

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Project Introduction

Conventional SOEC
(steam electrolysis)

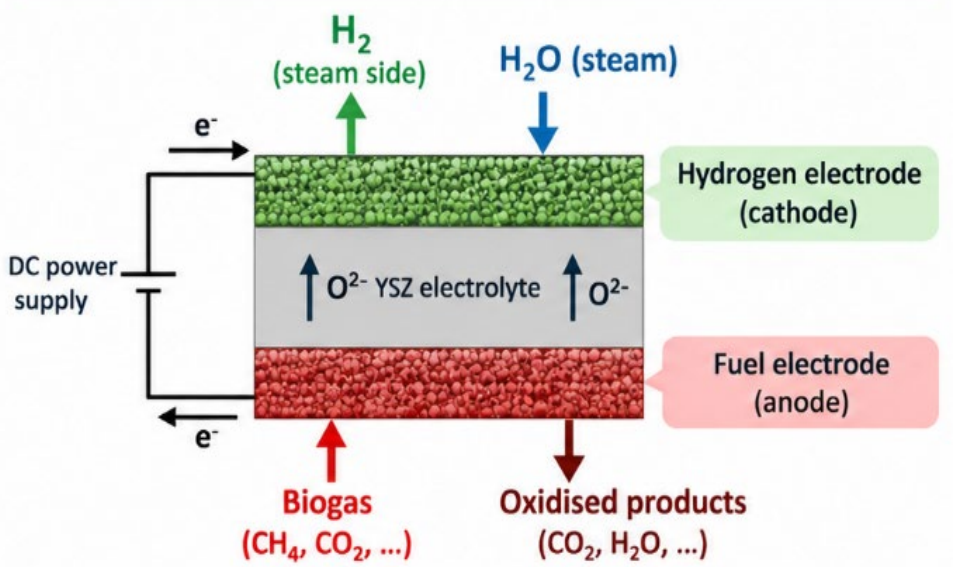


Cathode (steam reduction): $H_2O + 2\ e^- \rightarrow H_2 + O^{2-}$

Anode (oxygen evolution): $O^{2-} \rightarrow \frac{1}{2}\ O_2 + 2\ e^-$

Overall reaction: $H_2O \rightarrow H_2 + \frac{1}{2}\ O_2$

Biogas-assisted SOFEC
(steam electrolysis with fuel oxidation)



Cathode (steam reduction): $H_2O + 2\ e^- \rightarrow H_2 + O^{2-}$

Anode (fuel oxidation): $Fuel + O^{2-} \rightarrow oxidised\ products + 2\ e^-$

Overall reaction: $H_2O + Fuel \rightarrow H_2 + oxidised\ products$

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pHyBios Concept and Operation Modes

Inputs

Biogas (CH_4 / CO_2)

Steam (H_2O)

Electrical input, depending on regime

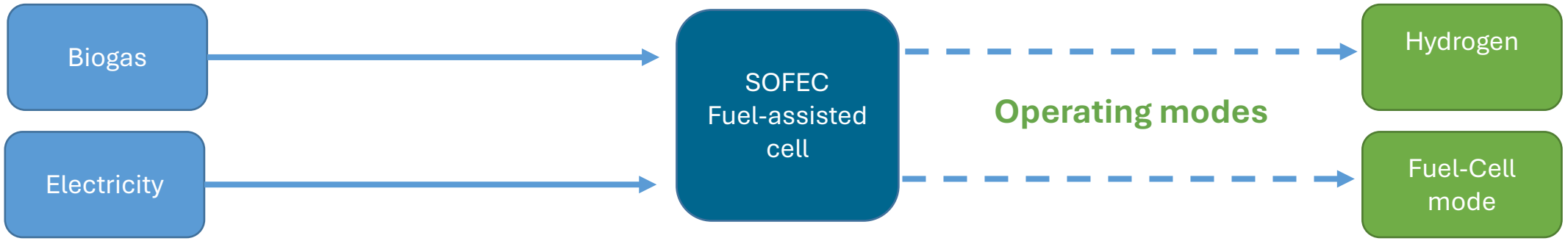
SOFEC

Steam reduction at H_2 electrode + fuel oxidation at opposite electrode

Outputs / modes

Hydrogen production

Separate fuel-cell operating branch in model



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pHyBios Concept and Work Flow

WP1 — **Coordination & Dissemination**

Project management, communication and German–Greek cooperation

WP2 — **Advanced Materials**

Electrodes and components tailored to biogas-assisted operation

WP3 — **Short-Stack & Testing**

Stack development and experimental testing on the moehwald bench

WP4 — **Modelling & Integration**

Electrochemical modelling, biogas-plant integration and digital-twin development

WP5 — **Holistic Assessment**

Life-cycle, economic and social analyses; business and replication pathways

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State of the Art: methodology



01 Materials and cell architecture

02 Biogas chemistry and degradation

03 System boundaries & comparisons

04 Modelling & electrochemical equations

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State of the Art

Materials and cell architecture

Electrolyte

Yttria-stabilised zirconia (YSZ): oxide-ion transport.

Hydrogen electrode

Ni–YSZ composite: widely used in conventional SOEC configurations.

Opposite electrode

LSM / LSCF: conventional oxygen-electrode materials; fuel-side suitability requires evaluation.

Key scientific issue

Catalytic activity, chemical compatibility and durability must be evaluated under actual biogas-assisted conditions.

Sources: Laguna-Bercero (2012); Hauch et al. (2008); Drosakis et al. (2024).

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State of the Art

Biogas chemistry and degradation

Steam methane reforming

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2$$

Dry methane reforming

$$CH_4 + CO_2 \rightleftharpoons 2CO + 2H_2$$

Carbon formation

$$2CO \rightleftharpoons CO_2 + C$$

Carbon deposition may reduce electrode activity.

Contaminant exposure

H_2S and other impurities can contribute to electrode degradation; gas conditioning matters.

Sources: Drosakis et al. (2024); Lanzini et al. (2017); Hagen and Winiwarter (2017).

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State of the Art

Modelling & electrochemical equations

Operating cell voltage

$$V_{cell} = E_{OCV,assisted} + \eta_{act} + \eta_{ohm} + \eta_{conc}$$

Faraday-law hydrogen production

$$\dot{n}H_2 = N_{cell} \cdot j \cdot A_{cell} \cdot \eta_F / (2F)$$

EOCV, assisted is semi-empirical, not yet a thermodynamically validated equilibrium potential.

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State of the Art

What has the literature demonstrated?

Conventional SOEC

Established electrochemical framework and commonly used materials.

Fuel-assisted electrolysis

Experimental and modelling evidence of reduced applied electrical demand.

Biogas-assisted operation

Direct experimental studies exist, but evidence is comparatively limited and heterogeneous.

Sources: Laguna-Bercero (2012); Luo et al. (2014); Drosakis et al. (2024).

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Research Gaps and Opportunities

1. Thermodynamically consistent assisted equilibrium potential
2. Coupled methane conversion, fuel utilisation and gas composition
3. Cell and short-stack experimental calibration and validation
4. Thermal management, steam generation and BoP integration
5. Techno-economic and life-cycle assessment

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Conclusion

Scientific potential

Fuel-assisted SOEC may reduce external electrical demand through coupling with fuel oxidation.

Assessment requirement

Advantages depend on fuel conversion, electrode stability, heat integration and consistent system boundaries.

pHyBios contribution

The project combines materials, experimental characterisation, short-stack testing and modelling to address these gaps.

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Perspectives

1st Year | 2nd Year | 3rd Year

WHERE WE ARE NOW

Project

Consortium established; activities underway since January 2026

WP2–WP3

Materials and experimental work in progress; validation results to be consolidated

WP4

Preliminary MATLAB cell-level electrochemical framework developed

Model scope

Semi-empirical assisted OCV; voltage losses; theoretical H_2 rate; operating regimes

NEXT STEPS & DEVELOPMENT

1. Thermodynamics

Replace assisted OCV approximation with chemical-potential-based formulation

2. Fuel chemistry

Couple methane conversion, gas composition and fuel utilisation

3. Experimental validation

Calibrate polarisation and H_2-production predictions using WP2/WP3 data

4. System integration

Add thermal management, steam generation, gas conditioning and BoP

5. Holistic evaluation

Extend to system energy balance, TEA, LCA and replication analysis

Current MATLAB outputs are preliminary and are not yet experimentally validated or representative of complete-plant efficiency.

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Thank you!

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