27th World Mining Congress
LIMA PERU
JUNE, 24th - 26th, 2026

INSTITUTO DE INGENIEROS DE MINAS DEL PERÚ

REPURPOSING A FORMER COAL MINE: GREEN HYDROGEN FOR THE TRANSPORT SECTOR USING THE CIRCULAR ECONOMY COUPLED WITH THE HEATING SECTOR

*A. Krzemień[1], P. Riesgo Fernández[2], G. Fidalgo Valverde[2], A.L. Marqués Sierra[2], F.J. Iglesias Rodríguez[2]

[1]Department of Extraction Technologies, Rockburst and Risk Assessment, Central Mining Institute – National Research Institute, Katowice, Poland,
(*Presenting author: akrzemien@gig.eu)

[2]Department of Business Administration, University of Oviedo, Asturias, Spain

ABSTRACT

This paper presents the design and early implementation progress of the European Union (EU) Research Fund for Coal and Steel (RFCS) MINE-TO-H2 project (Grant Agreement nº 101140154). This demonstrator converts a former underground coal mine (Pozo Fondón, Langreo, Asturias, Spain) into an integrated renewable hydrogen hub coupled with district heating. The demonstrator comprises a 2.5 MW polymer electrolyte membrane electrolysis system (scalable to 5 MW) producing green hydrogen for passenger road transport. Two post-mining resources are valorised: (i) mine water (La Nalona mine) used as the raw water feedstock, treated via reverse osmosis and electro-deionisation, and (ii) open pit reclaimed mining land used for photovoltaic generation complemented by renewable electricity purchased through a power purchase agreement. Hydrogen is stored and distributed at 500 bar via tube trailers ('virtual hydroduct') to a 350 bar refuelling station for intercity buses. Sector coupling is achieved through (a) blending of a fraction of hydrogen into the existing natural gas grid (target up to 2.5% per year) and (b) recovery of electrolyser waste heat to hybridise an existing geothermal district heating installation, with estimated electricity savings of approximately 3.9 GWh per year in the cooling and heat-pump systems. Key project performance indicators include a minimum production of 40 kg H_2 per hour, mine-water consumption of 13 m^3 per 1,000 kg H_2, and demonstrator operation for at least 2 buses currently being developed using fuel cell and H_2 internal combustion technologies. The paper discusses how the project addresses typical mine-closure challenges and proposes a transferable 'mine-to-hydrogen' redevelopment model.

KEYWORDS

Business models for post-mining, revitalisation, mine water, green hydrogen, circular economy

1. INTRODUCTION

The closure of coal mines creates both legacy burdens and, simultaneously, a portfolio of assets that can be repurposed for regional revitalisation (Frejowski, Bondaruk, & Duda, 2021; Siksnelyte-Butkiene et al., 2020). In coal regions in transition, redevelopment options are expected to deliver more than environmental remediation: they must also create new economic activity, retain skills, and support decarbonisation trajectories that are credible to local stakeholders (Bairrão et al., 2023).

The MINE-TO-H2 project in Asturias (Spain), conceptually presented in Figure 1, is positioned within this post-mining context by converting land adjacent to a coal mine into a 2.5 MW (scalable to 5 MW) green hydrogen plant that targets the decarbonisation of transport and other hard-to-abate uses, while integrating circular economy practices and the revitalisation of mining areas.

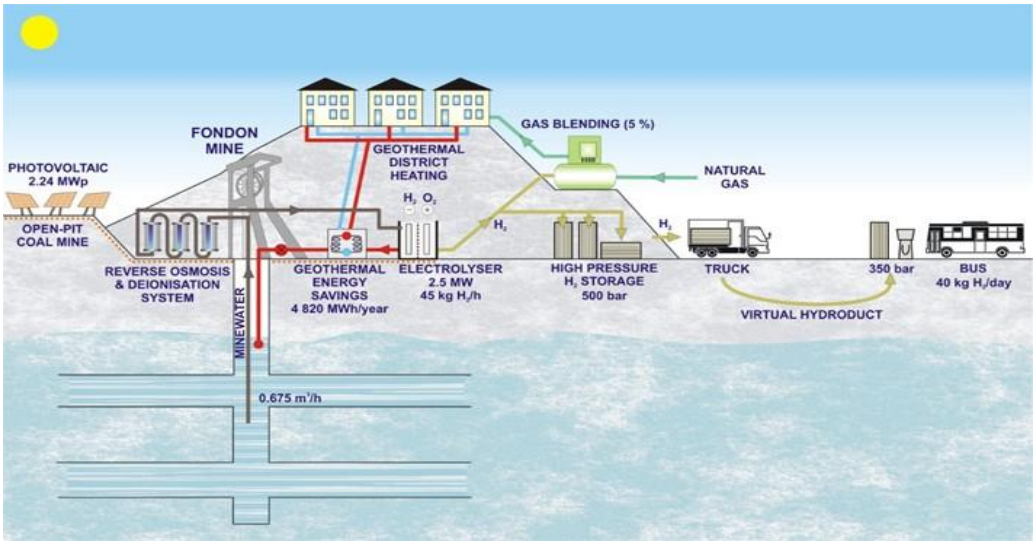


Figure 1 – Scheme of the MINE-TO-H2 project

The paper aims to contribute to post-mining areas revitalisation by presenting (i) the integrated technical concept (mine water → electrolysis → 500 bar distribution → mobility, with heat recovery to district heating and blending into the gas grid), (ii) an initial implementation status based on engineering and permitting progress, and (iii) a business-oriented discussion of replicability and enabling conditions in mine-closure settings in Poland.

2. POST-MINING ASSET VALORISATION AND CIRCULAR-ECONOMY LOGIC

MINE-TO-H2 is designed around a circular-economy logic that treats mine-closure "problems" as inputs for new energy services (Krzemień et al., 2023). The project explicitly leverages the competitive advantages of underground and open-pit mining environments, proposing that mine water and reclaimed land can serve as resources for hydrogen and photovoltaic energy generation, respectively.

Beyond H_2 production, the project emphasises sector coupling as a pathway to maximising local value creation, as noted by Ramsebner et al. (2021). Two coupling routes are embedded in the design: (i) hybridisation with an existing geothermal district heating system through electrolyser heat recovery, and (ii) partial blending of hydrogen into existing natural gas infrastructure, enabling a gradual and modular transition with reduced need for new pipelines, following the synergies pointed out by Brown et al. (2018). The concept is complemented by supporting measures intended to strengthen regional capabilities and facilitate replication: benchmarking other coal mines, developing business cases, and training and re-skilling programmes for former miners and coal-region stakeholders.

3. CASE STUDY: MINE-TO-H2 DEMONSTRATOR AT POZO FONDÓN

3.1 Site and strategic location

The demonstrator is located at the Pozo Fondón mine site in Sama (Langreo, Asturias, Spain), a central position where a high share of the regional population and industrial activity are concentrated within a radius of approximately 60 km. This site supports the intended mobility application and reduces distribution distances for early hydrogen uptake.

3.2 Process configuration and design bases

The plant is designed as an integrated process chain consisting of: raw mine-water extraction and intermediate storage; water treatment; PEM electrolysis; hydrogen purification; multi-stage compression; and storage/distribution in 500 bar tube trailers. The electrolysis package is specified at 2.5 MW and designed to deliver approximately 500 Nm^3/h of high-purity hydrogen (99.998%, UNE-EN 17124:2022) at an outlet pressure of around 30 bar.

A process simulation has been used to validate the design's internal consistency. The model represents a 2.5 MW PEM system operating at 550 V with 289 cells in series, assuming an overall efficiency of 90%. Hydrogen production is estimated at approximately 49.5 kg/h at 30 °C and 30 bar after purification, while a substantial fraction of input power is dissipated as heat, requiring cooling.

3.3 Mine water as feedstock and treatment requirements

Mine water is extracted from the La Nalona mine drainage. The project reports that sufficient flows have been available for decades, and an intermediate storage tank is included to stabilise the water supply.

Indicative raw-water characteristics include pH 7.8–8, conductivity above 1,000 µS/cm, iron concentrations up to 7 mg/L, and notable dissolved ions (e.g., sulphates around 350 mg/L and magnesium around 55 mg/L), indicating the need for dedicated pre-treatment and purification before electrolysis.

To meet the electrolyser manufacturer's requirements, the selected treatment train comprises preliminary solid filtration followed by reverse osmosis and electrodialysis (EDI). Annual mine-water consumption is estimated at 3,780 m^3/year (approximately 630 l/h), with a nominal water requirement of about 1 m^3/h to support electrolysis and associated operations.

3.4 Hydrogen storage, distribution and refuelling concept

Hydrogen is compressed and stored at 500 bar to enable high-capacity distribution by tube trailers (a ‘virtual hydroduct’ approach). The project positions 500 bar distribution as an innovation in the Spanish context, enabling materially higher transported hydrogen volumes per trip compared with the prevalent 200 bar logistics chain.

The engineering design includes fixed and mobile storage units at 500 bar, with two mobile and two fixed units, each sized at approximately 1,073 kg H_2. A 350-bar hydrogen refuelling station (HRS) is designed for heavy vehicles, with a minimum sizing for the consecutive filling of three buses per day. Hydrogen is supplied directly from 500 bar tube trailers; due to the pressure difference, neither on-site compression nor pre-cooling is considered necessary.

3.5 Sector coupling: district heating integration and gas-grid blending

Heat recovery is implemented via a closed electrolyser cooling circuit. The cooling water demand is continuous, with a peak flow of approximately 75 m^3/h and a maximum delta-temperature of 10 °C, enabling a thermal jump suitable for integration with the existing district heating chillers. A project study estimates total annual energy benefits of 3.9 MWh/year from the combined effect of recoverable heat, improved chiller performance and avoided electrolyser refrigeration.

.

In parallel, the concept includes blending a portion of the produced hydrogen into the existing natural gas grid, addressing both technical and regulatory learning needs in a context where harmonised European injection conditions have not yet been fully consolidated.

3.6 Renewable electricity supply and land-use constraints

Renewable electricity supply is foreseen through a combination of direct photovoltaic generation and a power purchase agreement (PPA) for additional renewable electricity, as illustrated by Nicita et al. (2020).

The original plan to locate photovoltaics within a former open-pit mine required reserve plots for contingencies and attention to geotechnical and geomorphological constraints.

During implementation, the planned photovoltaic location in the 'El Cantil' open pit was found to be incompatible with environmental and heritage restrictions, prompting relocation to Plot 6 of the Modesta Industrial Park. The updated preliminary design reports a DC capacity of 1.184 MWp and an expected annual production of 1,593.2 MWh/year for this plot, with additional locations planned to complete the supply.

4. IMPLEMENTATION STATUS AND SUPPORTING MEASURES

Engineering and permitting have progressed alongside the conceptual design. A key milestone was the granting, in October 2024, of a water concession to use water from the La Nalona mine for green hydrogen production at the Fondón mining well, published in the Official State Gazette, accompanied by authorisation for the electrical connections required for plant supply.

In July 2025, the Langreo City Council provided initial approval for a Special Plan that modifies the land uses of the Fondón site to enable construction of the green hydrogen plant. In September 2025, the Principality of Asturias authorised the Strategic Environmental Assessment, thereby exempting a full environmental impact assessment from being required, subject to compliance with specified parameters. Figure 2 presents an infography of the plant layout.



Figure 2 – Infography of the hydrogen plant layout at Pozo Fondón mine

Supporting measures being developed include a process risk assessment, replication benchmarking, business case development and training and re-skilling programmes. A preliminary hazard identification (HAZID) study has already been conducted to assess the acceptability of major hazards and define actions for subsequent design stages.

The primary purpose of the coal mining benchmarking (CMB) will be to develop and test a mechanism to investigate the feasibility of multiplying the solution by repurposing former coal mines into green hydrogen plants, where green hydrogen may be produced by other mining companies (including in other locations, e.g., Poland).

Implementation of activities will include:

(i) identification and description of the technological and operational parameters of the solution based on the work carried out ;
(ii) identification of the economic conditions for the implementation and operation of the investment; and
(iii) testing the tool for selected locations and formulating recommendations for the business model.

The overarching aim of the CMB process is to structure the assessment process, assess the solution's feasibility in selected locations, and raise awareness among decision-makers responsible for investment and development strategies. Critical paths to implementing alternative activities on former mine sites will be identified.

Communication, dissemination and exploitation are designed as continuous activities to accelerate stakeholder learning and uptake. Planned measures include an updated project website (https://minetoh2project.uniovi.es/) with a consultation area, annual newsletters, and a promotional video.

The communication plan proposes a multi-channel approach that combines a web presence, professional networks, social media, and targeted events to reach authorities, industry, civil society, and international platforms.

5. PRELIMINARY FINANCIAL ANALYSIS

A preliminary economic assessment of the green hydrogen plant, without considering the blending operation and PV installation, was developed to assess the project's likely feasibility.

According to the detailed budget presented in the proposal, the capital expense (CAPEX) required, including demonstration operating costs, is shown in Table 1, excluding value-added tax (VAT).

Table 1 – MINE-TO-H2 project CAPEX

Description	Estimated cost (EUR)
2.24 MWp Photovoltaic plant	2,020,000
Electrolyser system	3,200,000
Mine water feeding and treatment systems	220,000
Hydrogen storage and refuelling systems	4,323,220
Electrical system connection	324,000
Mechanical & electrical balance of plants	1,870,000
Digital Twin and Artificial Intelligence software	110,000
Rental of equipment	187,850
Personnel costs	400,000
TOTAL CAPEX	12,655,070

The technical and economic parameters required for cash flow calculation are presented in Table 2. Financial outcomes will be calculated over 20 years, with depreciation periods also of 20 years for the green hydrogen plant and the photovoltaic installation.

Table 2 – Technical and economic parameters for cash flow calculations

Description	Value
Functioning hours of the installation for one year	6,000 h
Hourly production of hydrogen	45 kg/h
Annual hydrogen production	270,000 kg/year
Annual photovoltaic functioning hours	1,200 h/year
Photovoltaic energy production	3,600 MWh/year
Tolls and charges for electricity supply	15 €/MWh
Operating expenses (personnel, maintenance, repairs)	250,000 €
Electrical consumption of the plant	3 MWh
Hydrogen sale price	7 €/kg
Power purchasing agreement (PPA) price	55 €/MWh
Green hydrogen plant depreciation period	20 years
Photovoltaic installation depreciation period	20 years
Nominal weighted average cost of capital (WACC)	8%
Working Capital proportion over CAPEX	4%
Benefit tax rate	20%

Table 3 presents the project's cash flows. A real after-tax WACC of 6% calculated using the Fisher equation will be applied as the discount rate. Consequently, all projected cash flows are expressed in real euros (being 2025 the benchmark), i.e., excluding inflation effects. This ensures internal consistency between the discount rate and the monetary streams being discounted. It also reduces reliance on long-term inflation assumptions for individual cost and revenue items, which are inherently uncertain and can introduce avoidable variability into the results over a multi-decade project horizon.

Table 3 – MINE-TO-H2 project cash flows (EUR

Item	Year 0 (EUR)	Years 1-20 (EUR)
Capital expenditure (CAPEX)	(12,655,070)	
Working capital	(506,203)	
Revenue forecast		1,890,000
Operating expenses		(1,258,000)
Depreciation		(632,754)
EBITDA		(754)
Taxes		0
Net income		(754)
CASH FLOW	13,161,273	632,000

The Net Present Value (NPV) will be:

$$NPV = -12.66 + \frac{0.75}{(1+0{,}06)} + \ldots + \frac{0.75}{(1+0{,}06)^{20}} = -5{,}62\ million\ EUR \quad (1)$$

and the Internal Rate of Return (IRR):

$$IRR = -0.92\%, \quad (2)$$

These figures show that, to achieve economic viability in future replication projects, at least 30% of the CAPEX should be funded by local, regional, or national sources.

Finally, it will be interesting to conduct a sensitivity analysis to identify which variables most affect the results. The sensitivity analysis was developed with TopRank 7.5 from Palisade Corporation (2016), and its results are presented in Figure 3.

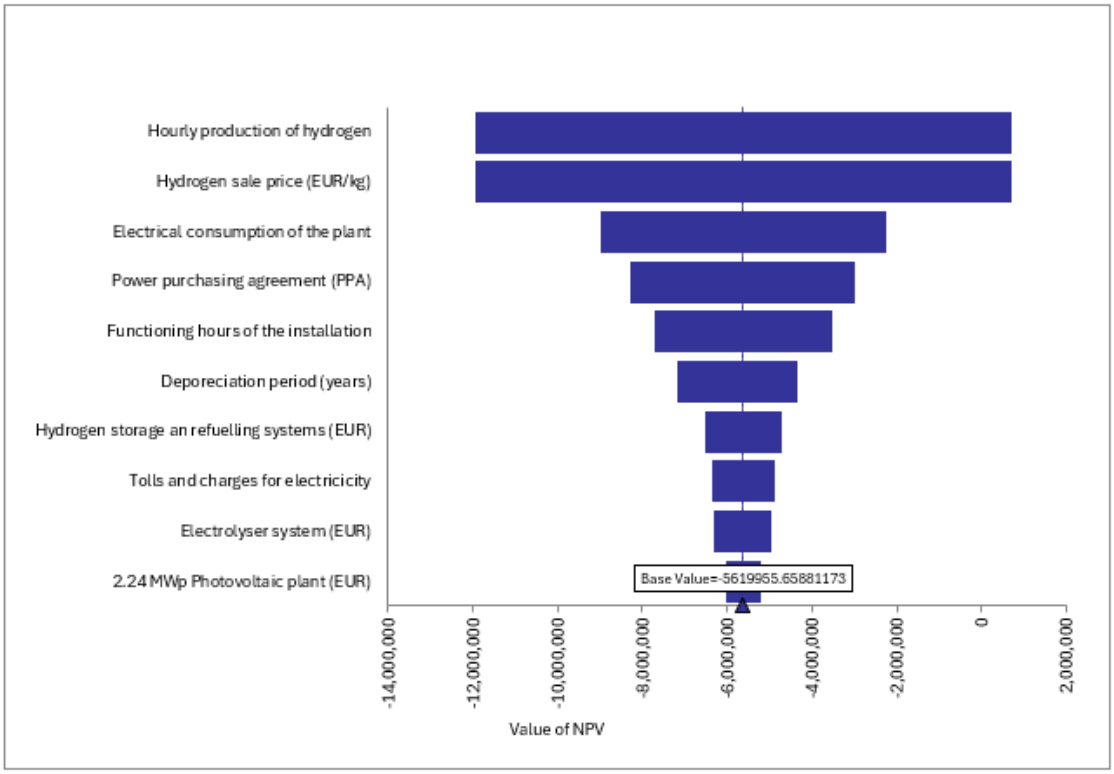


Figure 3 – Tornado graph of the Net present value (NPV)

The sensitivity analysis reveals that the variables with the greatest impact on the project's financial performance are the hourly hydrogen production rate and the hydrogen sale price, as these parameters directly determine revenue streams and cash flow.

A second tier of influence is observed for the plant's specific electricity consumption, the conditions of the power purchase agreement (PPA), and the facility's annual operating hours, followed by the depreciation period. In contrast, the remaining input parameters exhibit a comparatively marginal effect on the Net Present Value (NPV), indicating limited sensitivity of the economic results to variations in those variables.

6. DISCUSSION: IMPLICATIONS FOR POST-MINING RECLAMATION AND REVITALISATION

From a reclamation and revitalisation perspective, the MINE-TO-H2 configuration demonstrates how post-mining assets can be recombined into an energy hub that produces multiple local value streams: decarbonised mobility, improved district heating efficiency, and knowledge creation for replication. The use of mine water as a raw material for electrolysis addresses ongoing pumping requirements in flooded mines by adding a productive outlet, potentially reducing dependence on alternative freshwater supplies.

Land-use constraints, including environmental and heritage restrictions, are shown to be material implementation risks for mine-site renewables. The relocation of the photovoltaic plant from a planned open-pit mine plot to an industrial park plot illustrates the need for flexible redevelopment portfolios and reserve plots, as well as early screening of planning constraints.

Sector coupling through heat recovery can strengthen the economic and environmental case for post-mining hydrogen hubs by creating an additional local 'off-take' for otherwise wasted thermal energy.

Project calculations indicate total annual savings of approximately 3.9 GWh/year when integrating electrolyser cooling with district heating operations under specified conditions.

However, business viability and replicability remain sensitive to market and policy conditions. The preliminary financial analysis reports a negative net present value and a negative internal rate of return under the assumed parameters, concluding that replication projects would likely require at least 30% of CAPEX to be covered by public funding to become viable.

This points to the importance of aligning mine redevelopment programmes with regional and national just transition instruments, as well as of designing off-take agreements and regulatory pathways (e.g., for grid blending) that lower investment risk.

Finally, the project's emphasis on training, re-skilling and stakeholder engagement is particularly relevant for post-mining revitalisation. The project framework includes explicit targets for training former miners and coal-mine managers, and for advising other coal mining companies on feasibility, embedding human-capital transition within the technical demonstrator.

7. CONCLUSIONS

This paper presented the design logic and early implementation progress of a post-mining hydrogen demonstrator that combines: mine-water-based electrolysis; 500 bar storage and tube-trailer distribution; a 350 bar refuelling station for intercity buses; blending into the natural gas grid; and waste-heat recovery to hybridise geothermal district heating.

The concept illustrates a practical pathway for turning mine-closure legacies into assets for renewable energy services.

The MINE-TO-H2 approach is technically grounded in detailed engineering and process simulation, and it is complemented by governance and supporting measures (risk assessment, business cases, benchmarking and training) that are essential for wider adoption in coal regions in transition. It provides a transparent performance framework for evaluating circular-economy impacts, climate-mitigation outcomes, and just-transition benefits.

Future work within the project will provide operational performance data from commissioning and hot testing, allowing refinement of the business case and the replication 'mould' for other mine contexts. For practitioners, the findings suggest that early integration of land-use planning, mine-water management, and local heat networks can improve the feasibility of post-mining energy redevelopment projects.

ACKNOWLEDGEMENTS

This work is based on the MINE-TO-H2 project funded by the Research Fund for Coal and Steel (RFCS) of the European Commission, with Grant Agreement nº 101140154. The authors acknowledge the contributions of the project consortium and the host-site stakeholders.

REFERENCES

Bairrão, D.; Soares, J.; Almeida, J.; Franco, J.F.; Vale, Z. (2023). Green Hydrogen and Energy Transition: Current State and Prospects in Portugal. *Energies, 16*, 1–23.

Brown, T.; Schlachtberger, D.; Kies, A.; Schramm, S.; Greiner, M. (2018). Synergies of Sector Coupling and Transmission Reinforcement in a Cost-Optimised, Highly Renewable European Energy System. *Energy, 160*, 720–739.

Palisade Corporation (2016). TopRank, Version 7.5. Palisade Corporation: Ithaca, NY, USA.

Frejowski, A.; Bondaruk, J.; Duda, A. (2021). Challenges and Opportunities for End-of-Life Coal Mine Sites: Black-to-Green Energy Approach. *Energies, 14(5)*, 1385.

Krzemień, A.; Frejowski, A.; Fidalgo Valverde, G.; Riesgo Fernández, P.; García-Cortés, S. (2023). Repurposing End-of-Life Coal Mines with Business Models Based on Renewable Energy and Circular Economy Technologies. Energies, 16, 7617.

Nicita, A.; Maggio, G.; Andaloro, A.P.F.; Squadrito, G. (2020). Green Hydrogen as Feedstock: Financial Analysis of a Photovoltaic-Powered Electrolysis Plant. Int. J. Hydrogen Energy, 45, 11395–11408.

Ramsebner, J.; Haas, R.; Ajanovic, A.; Wietschel, M. (2021). The Sector Coupling Concept: A Critical Review. Energy Environ., 10, 1–27.

Siksnelyte-Butkiene, I.; Zavadskas, E.K.; Dalia, S.; Streimikiene, D. (2020). The Assessment of Renewable Energy Technologies in a Household : A Review. Energies, 13, 1164.