



Green hydrogen application in the energy-intensive industry: a feasibility study

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Goal & Outline

The Italian «**Hydrogen Strategy Guidelines**» (2020) define six targets for the national green (renewable*) hydrogen economy in 2030. The study aims to evaluate the techno-economic feasibility and the barriers to substituting natural gas with green hydrogen in an existing hard-to-abate industrial plant.

(* the EU definition of “renewable hydrogen” was adopted after the Italian hydrogen strategy guidelines publication)



5 GW of electrolysis capacity installed



-8 Mton/year CO_2 eq. emissions



10 billion euros of investment



2% of the final energy consumption



GDP ↑ (27 billion €)

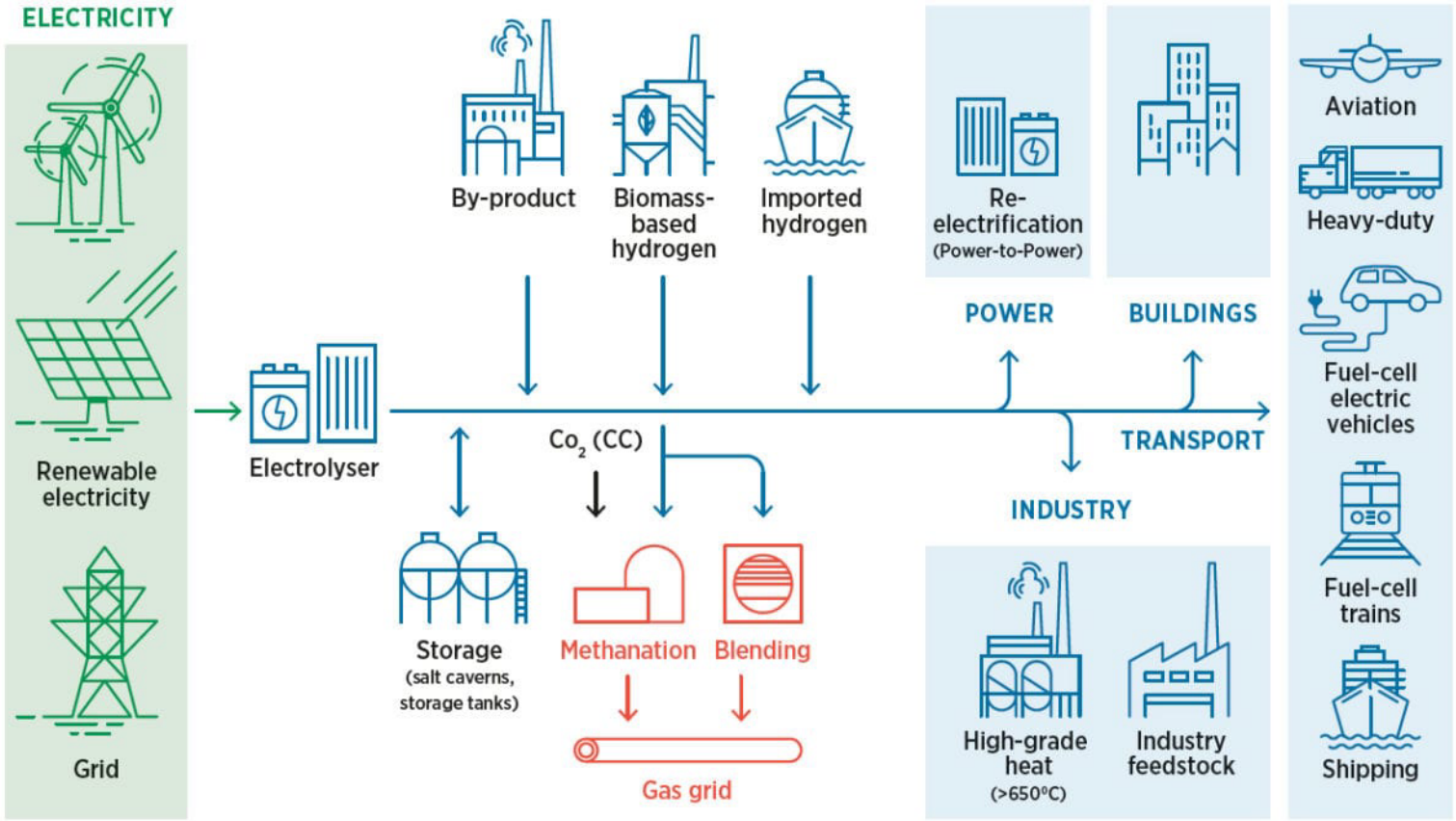


200k & 10k new temporary and fixed jobs

1. **Introduction to Power-to-Hydrogen (P2H)**
2. **Scenario assessment**
3. **Preliminary results and discussion**
4. **Feasibility study**
5. **Conclusions and Future Research**

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Introduction: Power-to-Hydrogen (P2H)



PV: photovoltaic
AEC: alkaline electrolysis cell
PEM: proton exchange membrane
SOEC: solid oxide electrolysis cell
AEM: anion exchange membrane

Energy from:
- Wind turbines
- Solar PV
- Other local power sources
- Grid

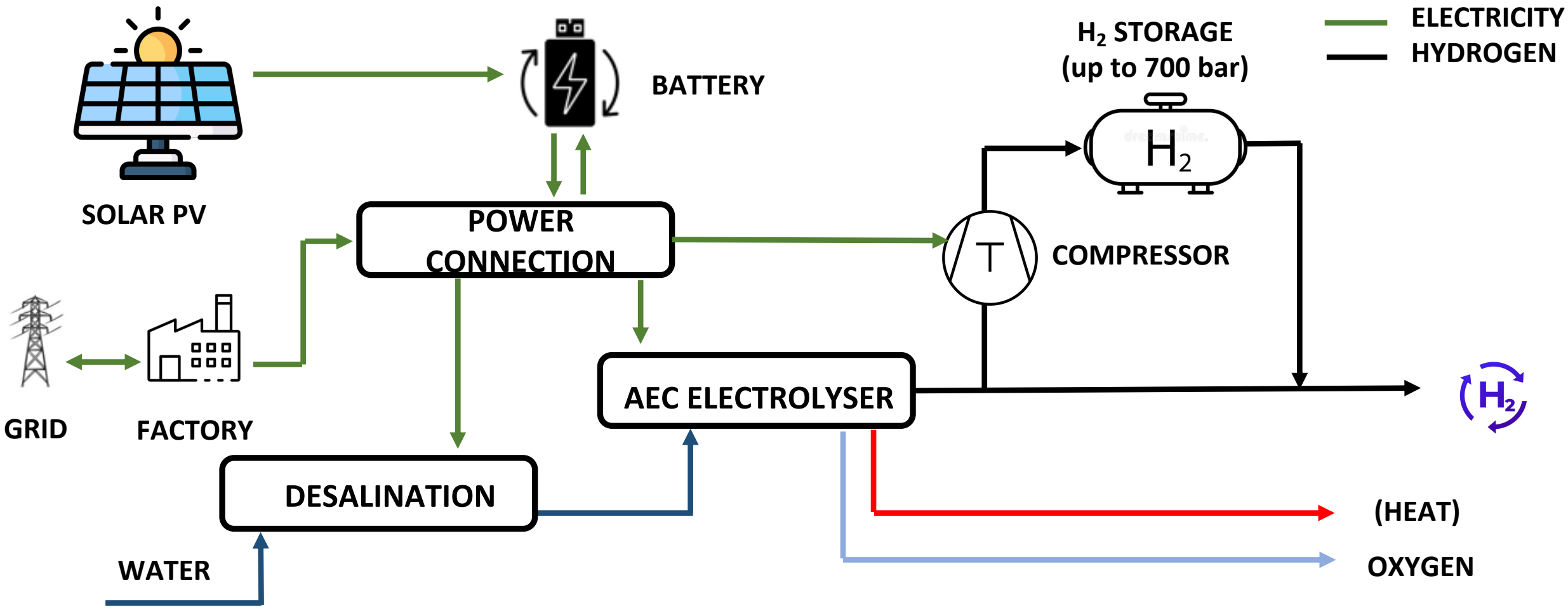
Hydrogen production:
- Electrolysis process (AEC, PEM, SOEC, AEM electrolyser)

Hydrogen storage:
- Tanks
- Salt caverns

Hydrogen use:
- Fuel
- Feedstock
- Blending
- Transport

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Scenario assessment: a local energy-hub for hydrogen production

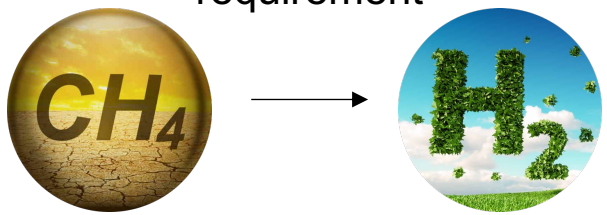


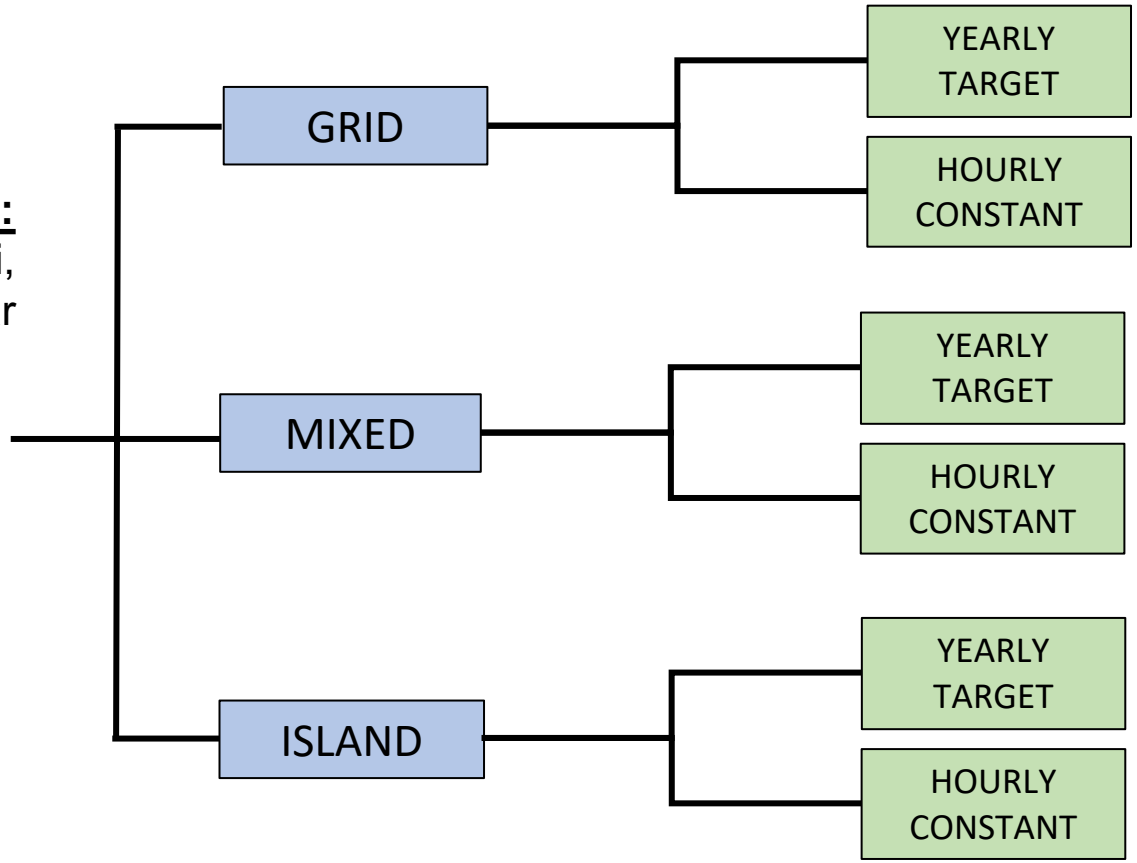
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Scenario assessment: description and preliminary P2H assessment

Case study from energy-intensive industry:
An Italian chemical industry located in Cagliari, southern Italy (1,300 equivalent hours per year of sunlight)

Preliminary P2H feasibility assessment:
Replacement of 10% of the plant energy requirement





Scenarios

- GRID: 100% energy from the grid
- ISLAND: 100% energy from solar PV
- MIXED: hybrid system

Demand type

Yearly target: 42 tons/year
Hourly constant: 4.7 kg/h

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Scenario assessment: the model for P2H plant optimization



INPUT DATA

- Yearly or hourly demand
- Hourly CO_2 emissions and electricity price
- Technical specifications of plant components and costs
- Power profile of the renewable energy plant/s

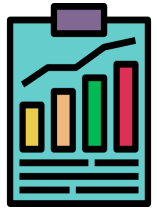


MODEL

Investment and operations linear optimization model

Optiplant model
(ref. *Campion et al., Renewable and Sustainable Energy Reviews, 2023*).

SUPER P2G https://superp2g.eu/



RESULTS

- Hydrogen production cost [€/kg]
- CO_2 emissions
- Sizing of system components

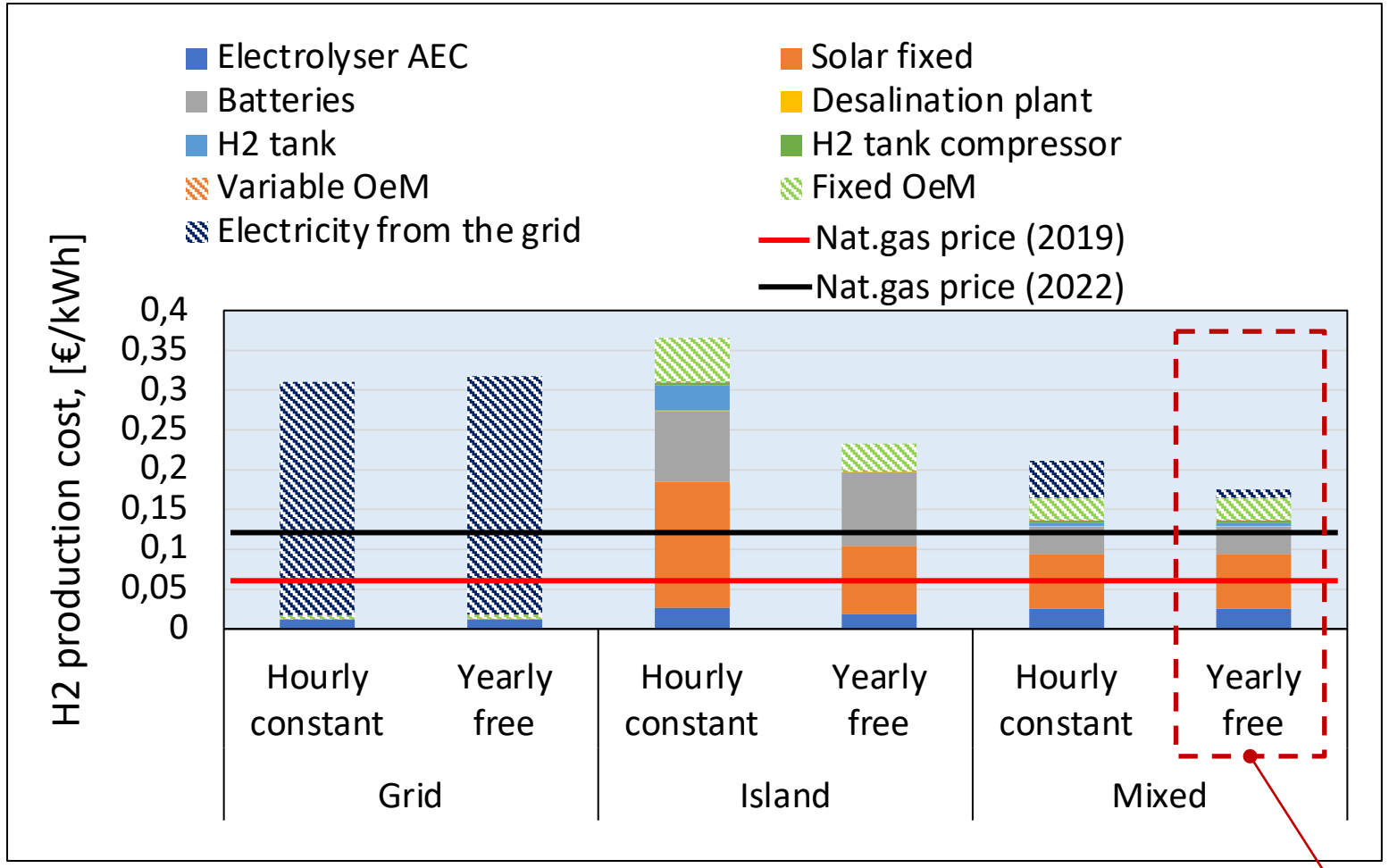
$$Obj = min \sum_{u,t} P_{u,t} \times X_{u,t} + \sum_{u} (I_u \times A_u + F_u) \times C_u + \sum_{u,t} V_u \times X_{u,t}$$

$$A_u = \frac{d(1+d)^n}{(1+d)^n - 1} \quad \text{(Annuity factor)}$$

$P_{u,t}$	Price of output from u at time t
$X_{u,t}$	Flow of mass/energy from u
I_u	Investment costs of unit u
F_u	Fixed cost
C_u	Installed capacity of unit u
V_u	Variable cost of unit u
d	Discount rate
n	Plant lifetime

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Preliminary results and discussion: hydrogen production cost



Component	Unit	CAPEX [€/unit]	OPEX [€/unit/year]
Desalination	kg/h	26.2	-
Electrolyser	kW	750	220
Compressor	kg/h	11000	220
Tank	kg	900	18
PV plant	kW	870	10.6
Battery	kWh	320	5.1

Technical parameters	Value
Electricity from the grid	0.19 €/kWh
Electrolyser efficiency	51.2 kWh/g H_2
Compressor efficiency @700 bar	2.53 kWh/kg H_2
Battery charging/discharging efficiency	98%/97%

(Data from scientific literature – see *Guzzini et al., 2023 Summer School F.Turco Proceedings*, for reference).

Investment costs are depicted in full colour and operating costs are dashed.

0.6 MW AEC electrolyser
1.4 MW PV plant
1.9 MWh batteries

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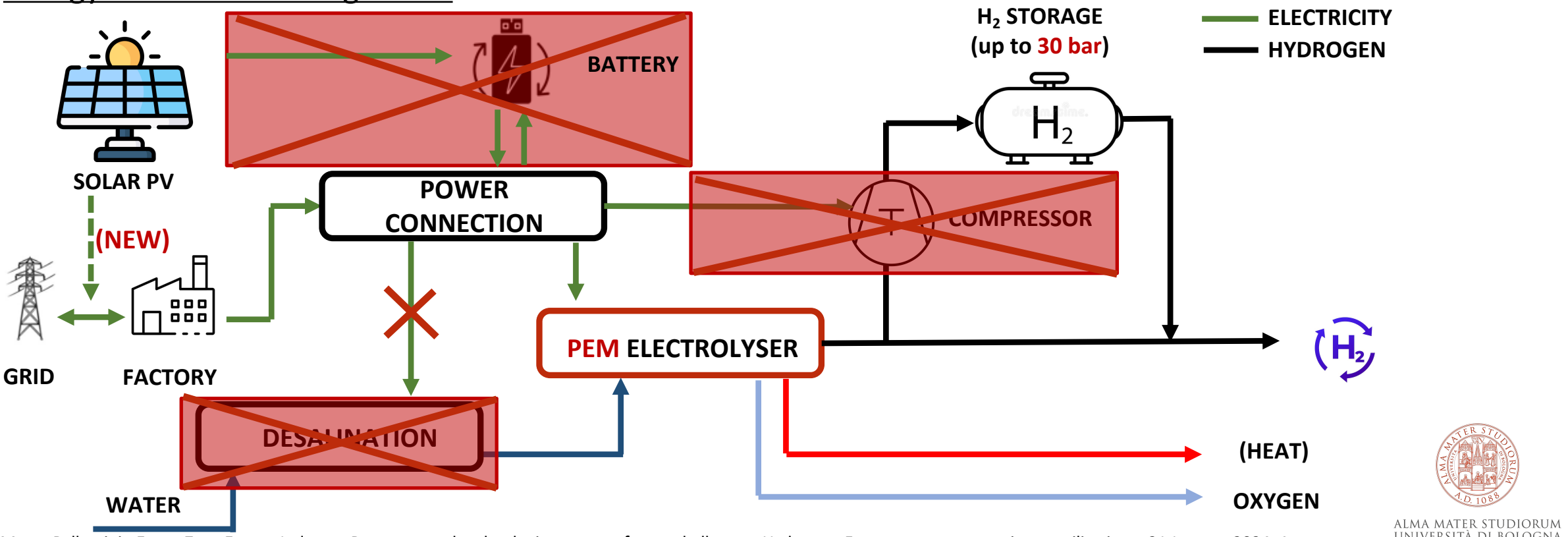
Preliminary results and discussion: scenario assessment key findings

- In the case of annual demand, production costs are always lower than in the other case because hydrogen storage (in tanks) is not required, and oversizing of renewable plants is avoided.
- The scenario that yields the lowest hydrogen production cost is MIXED, with a production cost of about 0.21 €/kWh with hourly demand and 0.17 €/kWh with annual demand.
- In the ISLAND scenario, the production cost is significantly lower with the annual demand type. This can be attractive for processes where it is possible to work in discontinuous mode (*batch operation*).
- Replacing methane use with hydrogen in energy-intensive sectors requires external supporting funding.
- Even considering a decrease in investment costs in future years, the cost of producing hydrogen is unlikely to be comparable to the cost of buying methane unless there are economic incentives.

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Feasibility study: a “modified” local energy-hub for hydrogen production

Based on the findings of the scenario analysis, a feasibility study has been completed to carefully estimate the costs and evaluate with a higher degree of detail the technical solutions to be adopted for hydrogen integration into the industrial processes in the case of yearly demand and mixed scenario. Some modifications were introduced in the hydrogen-hub concept to minimize energy storage and simplify PV energy and water management.



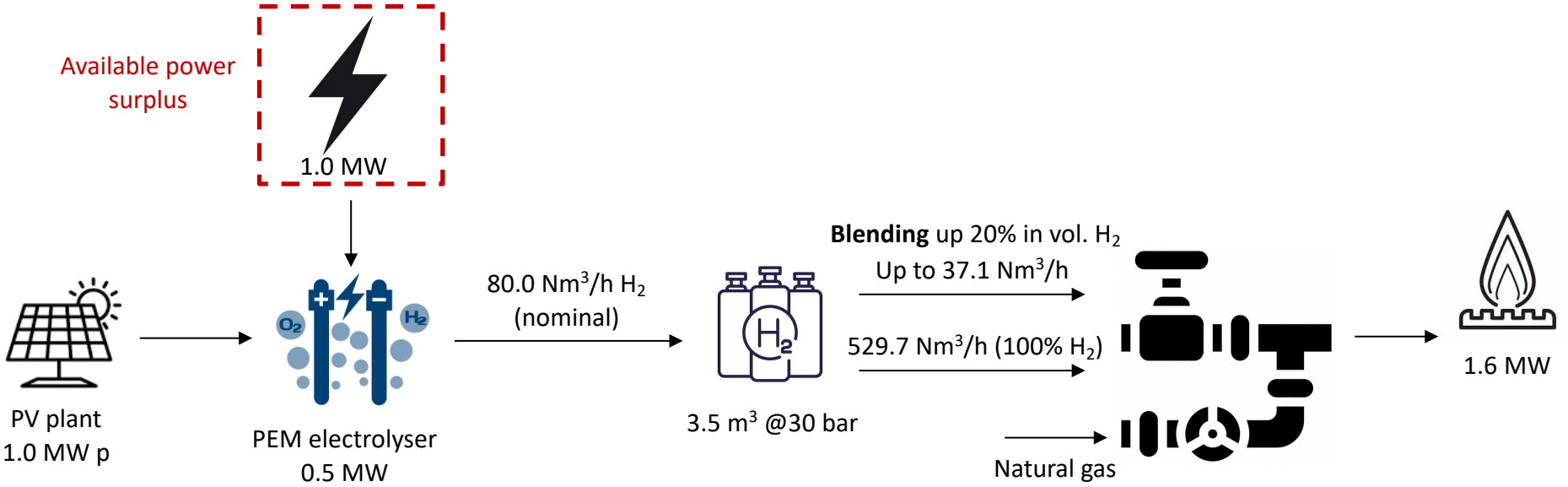
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Feasibility study: technological solutions for an effective P2H integration

Focus on one single burner (lower than 10% of whole site energy demand) → opportunity to test a 100% hydrogen switch

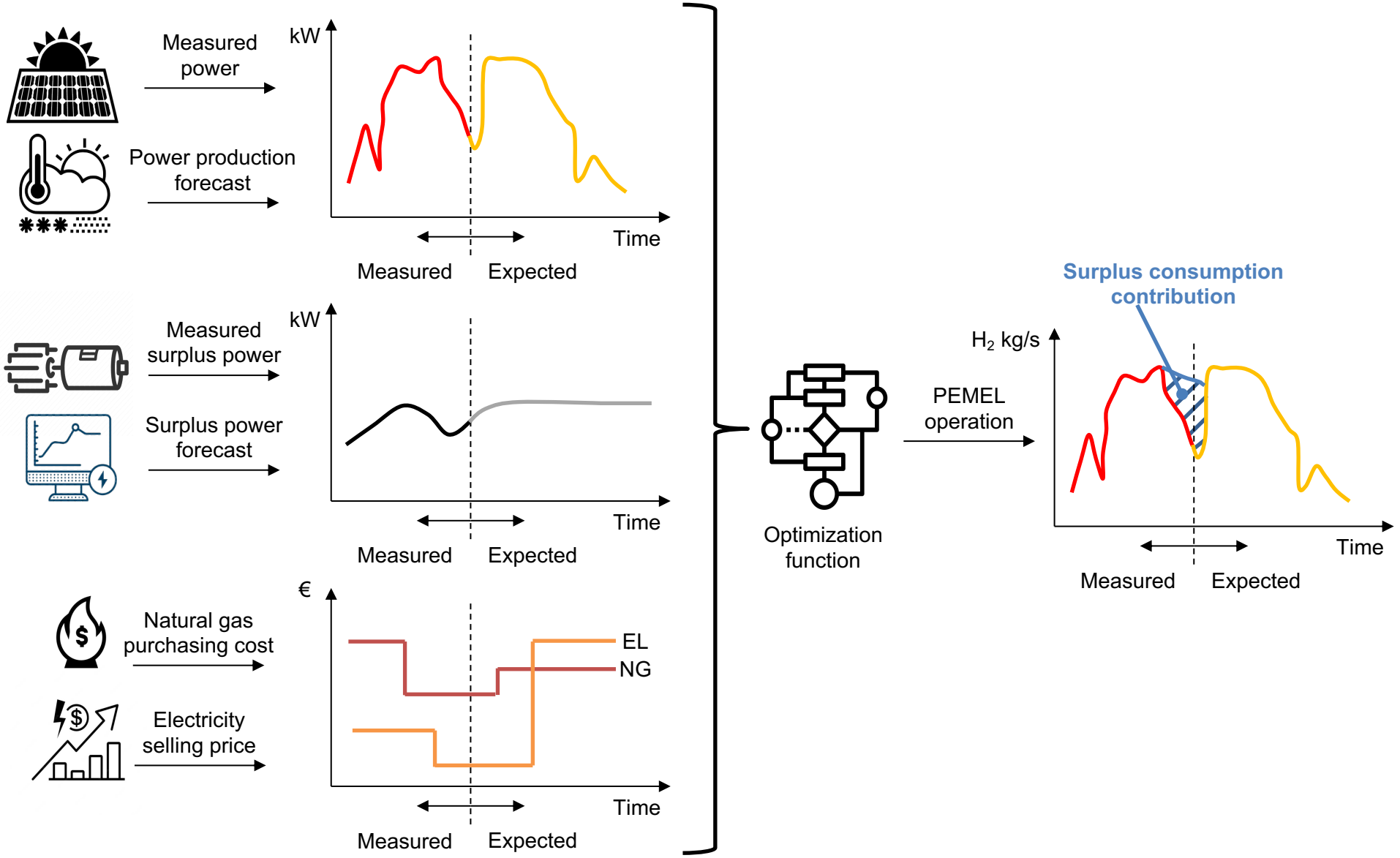
Technological solutions needed:

1. smart management of energy flows (renewable power, existing power surplus, renewable hydrogen production and storage, blending ratio);
2. management of hydrogen blending from 0% to 100%.



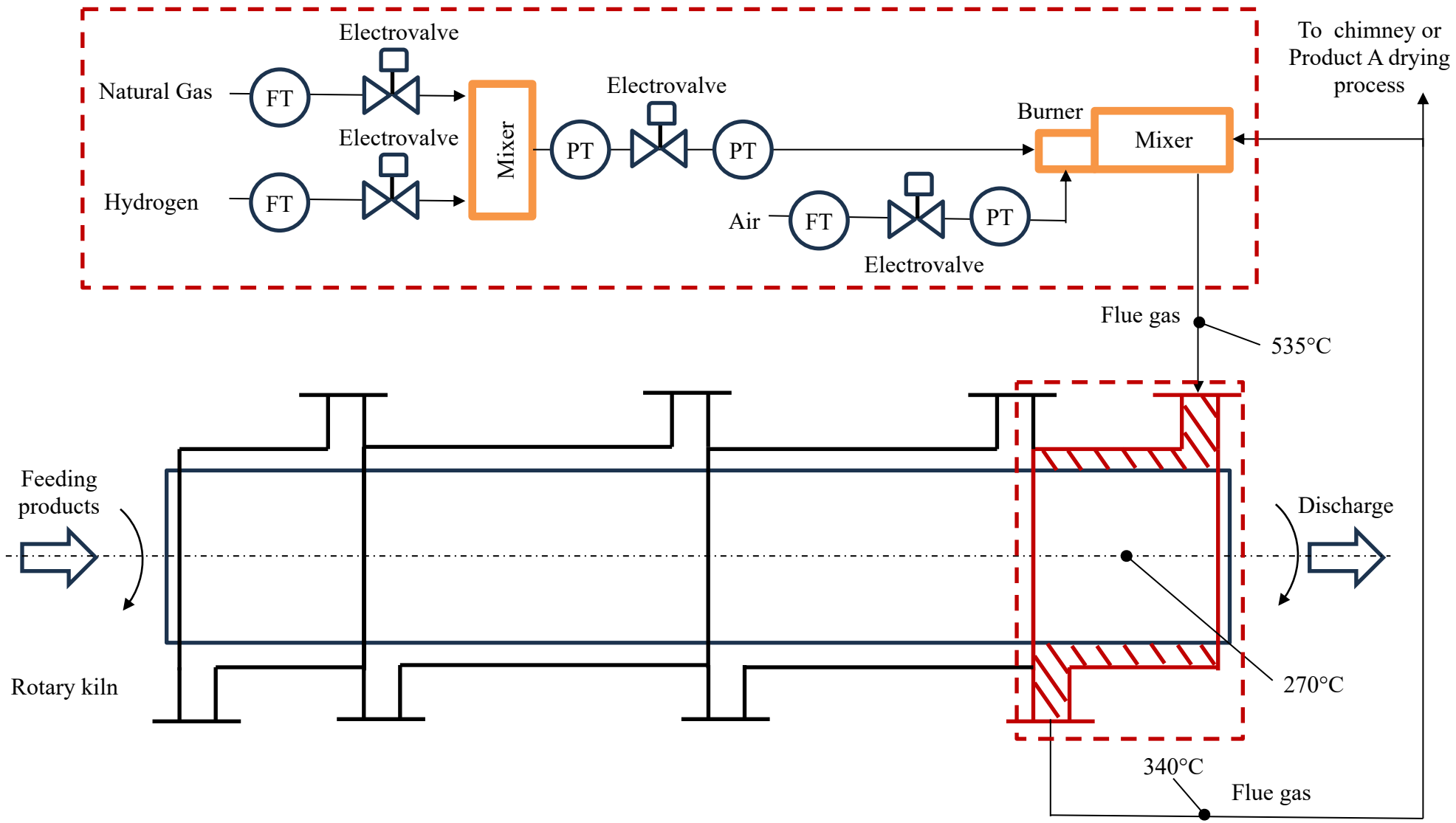
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Feasibility study: smart management of energy flows



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Feasibility study: blending unit

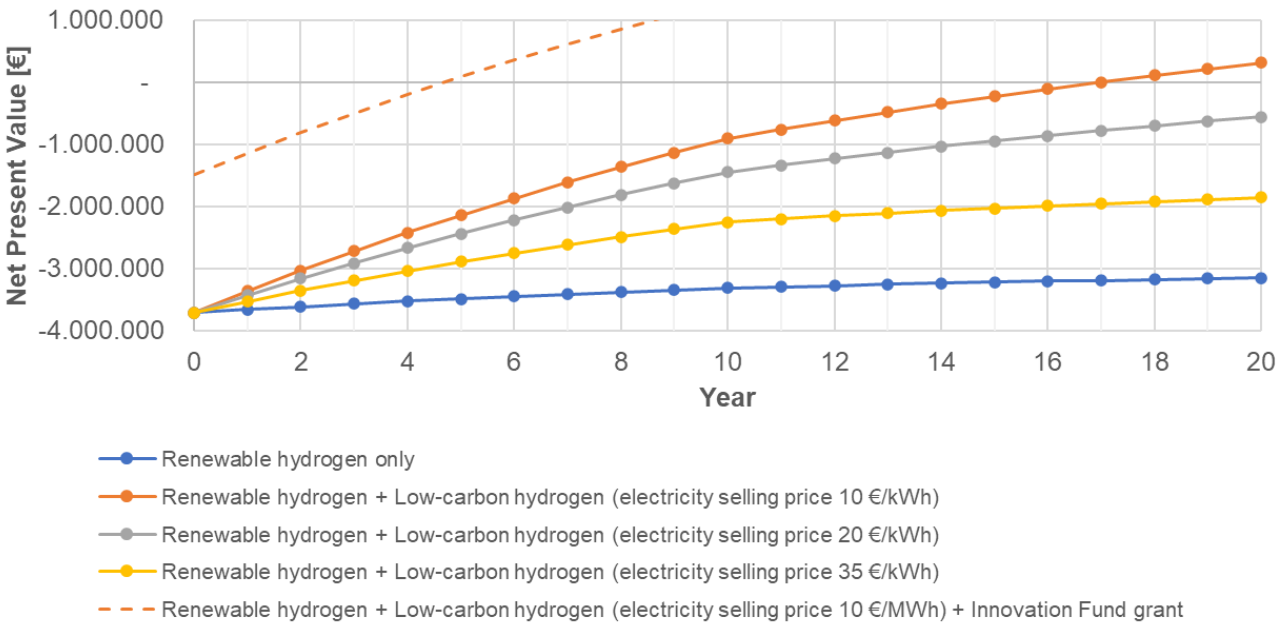


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Feasibility study: techno-economic findings

Item	Value
Evaluation period	20 years
Discount rate	5%
Energy surplus consumed for H_2 generation (a)	6,950 MWh
Hydrogen produced by PV power	761 MWh/year
Hydrogen produced by power surplus (max)	4,170 MWh/year
Natural gas purchasing price (b)	70 €/MWh
Electricity selling price (c)	10-20-35 €/MWh
PV plant cost*	800 €/kW p
PEM electrolyser cost*	1,800 €/kW
Blending unit cost*	100,000 €
Balance of Plant (BOP) cost*	300,000 €
Civil works	190,000 €
Engineering cost	485,000 €
Installation and commissioning cost	930,000 €
Energy efficiency certificates**	260 €/TOE
OPEX costs	0.5% of CAPEX
Natural gas emissions factor	57.632 ton CO_2/TJ

* Installation excluded.
** Guaranteed for ten years, with 2022 as the reference year.
a) Based on the hypothesis of consuming the 1 MW surplus for 6,950 hours per year.
b) Based on estimation for LNG transported to Sardinia and locally regasified.
c) Authors' hypothesis – minimum selling price 50 €/MWh (in 2019).



A combination of (high) CAPEX and (high) OPEX incentives is required to reach economic sustainability.

Otherwise, (very) low price electricity would be needed…

INNOVATION FUND
Driving clean innovative technologies towards the market

Investment submitted to Innovation Fund Small-Scale call for projects for 60% co-fund to CAPEX

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Conclusions and Future Research

- The use of green (renewable) hydrogen in energy-intensive industries is technically feasible and can support the decarbonization pathway of energy intensive processes.

- Local generation and use of green (renewable) hydrogen as a fuel, even if in the best scenario, is not cost-competitive with natural gas due to energy commodity price – relatively high selling/purchasing price of electricity and low purchasing price of natural gas.

- CAPEX and OPEX reduction is fundamental to achieve the economic sustainability of P2H: economy of scale of hydrogen technologies can help, but it is not enough. A combination of CAPEX/OPEX reduction by external (public) support is fundamental.

- Next step of the study: identify the combination of CAPEX/OPEX incentive measures that can maximize the impact for the investors with the minimum public support.

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