

Hydrogen for Sustainable Mobility: Ongoing Experiences from the Italian LIFE3H Project

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Abstract

This paper outlines the objectives, implementation methods, and ongoing activities of the Italian LIFE3H (Hydrogen demonstration in city, port, and mountain area to develop integrated hydrogen valleys) project co-funded by the European Union LIFE program and participated by local authorities, universities, and industries from three regions in central Italy.

The LIFE3H project aims to develop three Hydrogen Valleys (an integrated system for green hydrogen production, storage, and distribution) in three different areas, involving the use of excess hydrogen from local industrial production to fuel emissions-free buses for passenger transport.

The strategic lines and development policies of Hydrogen Valleys for the production of hydrogen as a green energy carrier are reported at international, European, and national levels.

KEYWORDS: *hydrogen fuel cells vehicle, hydrogen technologies, hydrogen valley, hydrogen refueling station*

1. Introduction

The European Green Deal sets a new and more ambitious target for reducing CO₂ emissions and climate-altering gases, by at least 55% by 2030 (compared to the 1990 level), and confirms the goal of climate neutrality by 2050. Achieving climate neutrality by 2050 requires substantial investment and a wide range of enabling reforms [1].

In Italy, greenhouse gas emissions fell by 17% between 1990 and 2018, from 516 million to 428 million tons equivalent. Adding the net removals due to the absorption of emissions by the agricultural and forestry sector, the amount of emissions in 2018 was 390 Mton CO₂ equivalent. The scenario that would lead Italy to climate neutrality by 2050 thus highlights an emissive gap to be closed mainly through three types of action:

- a substantial reduction in energy demand (particularly in the residential and commercial sectors and in transport);
- a further change in the energy mix in favor of renewable sources, along with extensive electrification for end-use consumption purposes and hydrogen production;
- an increase in CO₂ removals from forest surfaces and soils.

Today, transport emissions represent around 25% of the EU's total greenhouse gas emissions, and these emissions have increased over recent years [2].

Concerning the transport sector, to achieve the above-mentioned emission reduction targets, it is needed to i) make all transport modes more sustainable, ii) make sustainable alternatives widely available in a multimodal transport system and iii) put in place the right incentives to drive the transition.

Hydrogen is universally regarded as a strategic energy carrier countering climate change, as it can contribute to the decarbonization of several difficult sectors, including transportation. Hydrogen, particularly from renewable sources, has the potential to significantly reduce greenhouse gas emissions (GHG) in the transportation sector, with a focus on public transport buses [3, 4, 5], trains [6, 7], garbage trucks, cars, long-distance buses, and delivery vans, and to play a key role in the European Green Deal. In particular, the new technologies behind hydrogen fuel cell electric vehicles (HFCVs) are particularly strong performers in reducing emissions.

Local institutions such as regions and cities have operational tools to intervene directly in the transportation sector, such as replacing obsolete and polluting vehicles in public fleets with less impactful vehicles, investing in local

networks of hydrogen refueling stations (HRS), and establishing different types of incentives for the use of zero-emission vehicles.

The EU Hydrogen Strategy (COM/2020/301), adopted in 2020, identifies the following five policy action points: i) investment support, ii) production and demand support, iii) creation of hydrogen markets and infrastructure, iv) research and international cooperation.

In addition, the Fit-for-55 package [8] (July 2021) includes several legislative proposals that translate the EU hydrogen strategy into a concrete policy framework. These include proposals to set targets for renewable hydrogen deployment in industry and transport by 2030.

COM/2021/803 (Common rules for the internal markets in renewable and natural gases and in hydrogen) and COM/2021/804 [9] on the hydrogen market and decarbonized gas also include proposals to support the creation of optimal, dedicated hydrogen infrastructure with the intention of developing the hydrogen market. With the REPowerEU plan in May 2022, the European Commission completes the implementation of the EU strategy on hydrogen as an important energy carrier to move away from fossil fuel imports from Russia. [10].

Hydrogen and its associated technology supply chain assume a strategic role within the European strategy.

With reference to the hydrogen supply chain development framework, described above, this article reports and describes the activities and objectives of the LIFE3H project co-funded by the LIFE program of the European Union, currently being implemented in three regions of central Italy.

The rest of this paper is organized as follows. In Section 2 the Hydrogen Valley policy is described. In Section 3, LIFE3H project is illustrated. Section 4 describes the main project activities and results referred to the mountain environment application.

2. Hydrogen Valley Policy

Over the years, the synergy between public and private companies, and institutional actors at various territorial levels have enabled the creation of locally integrated hydrogen ecosystems (Hydrogen valleys) aimed, as a whole, at climate change mitigation and regional economic development.

A “Hydrogen Valley” is a geographical area – a city, a region, an island, or an industrial cluster - where several hydrogen applications are combined together into an integrated hydrogen ecosystem that consumes a significant amount of hydrogen, improving the economics behind the project. It should ideally cover the entire hydrogen value chain: production, storage, distribution, and final use [11].

Hydrogen valleys require an economic investment, which is necessary to cover a substantial part of the value chain from the production, storage, and transportation of hydrogen to its final use in various sectors (industry, mobility, energy).

Hydrogen Valleys aim to stimulate the local development of the new hydrogen economy as a whole through a bottom-up process.

As a clear sign of a growing and maturing hydrogen market, Hydrogen Valleys have begun to emerge around the world, as illustrated in Fig. 1 [12]. Globally, there are currently 83 Hydrogen actions implemented in 33 countries with a total investment of €125.078 M

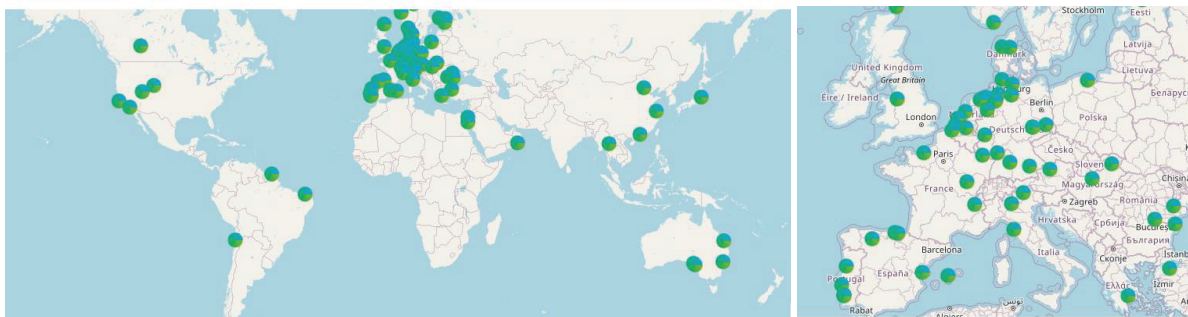


Fig. 1 Spatial distribution of Hydrogen Valleys at the International and European levels [10]

In the European context, several research projects on the hydrogen supply chain have been surveyed, broken down as follows [13]:

- 160 projects funded by the Horizon 2020 and Horizon Europe program, calls 2014-2020 and 2022-1
- 154 projects funded by the Seventh Framework Program (FP7), calls 2008-2013

Only two of the above 314 projects are on the Hydrogen Valley theme.

As for Italy, at present, there are three experiences of Hydrogen Valley (Table). The Italian National Recovery and Resilience Plan, (NRP), recognizes the need to increase the number of Hydrogen Valley and the development of sustainable mobility through the implementation of a hydrogen distribution network.

In Italy, 3.19 billion € has been earmarked for hydrogen production in disused sites (the 'Hydrogen Valleys', 500 million €), the use of hydrogen in hard-to-fill sectors (EUR 2 billion), hydrogen testing for the road (230 million €) and rail (30 million €) transport, and for hydrogen research and development (160 million €) [14].

Hydrogen can be produced through different processes that, depending on the technology and energy sources used, involve different values of emissions to the environment.

Hydrogen is associated with colors that identify its process (Fig. 2); the most common are:

- Green Hydrogen - Obtained from electrolysis, a technology that breaks down water molecules into oxygen (O_2) and hydrogen (H_2) through electricity. To date, this is the most expensive form but also the most environmentally sustainable and totally zero-emission.
- Blue Hydrogen - Produced through steam reforming - a process that uses steam to separate H_2 molecules from natural gas - with subsequent capture of the carbon emissions generated. However, this process involves average emissions of about 5 kg CO_2/kgH_2
- Grey Hydrogen - Produced by steam reforming methane in the same way as blue hydrogen. In this case, however, all emissions generated by the process are released into the atmosphere (approx. of about 9 kg CO_2/kgH_2).

Fig. 3 shows the trend of global hydrogen production diversified by color [15].

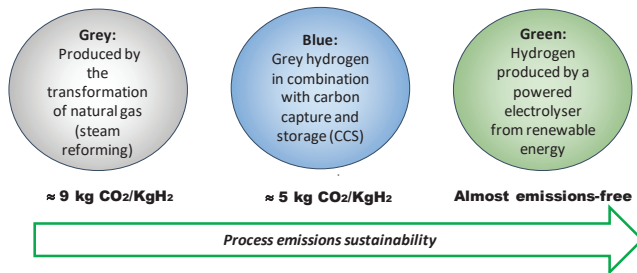


Fig. 2 Hydrogen production processes scheme with associated emissions

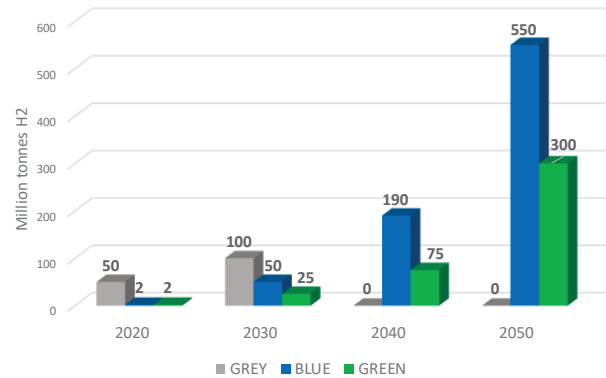


Fig. 3 Global hydrogen production trends [15]

Of course, the cost in the hydrogen market varies depending on the color and thus the production process. Fig. 4 illustrates the current average cost, internationally, of green, gray, and blue hydrogen [17].

Green hydrogen, of course, represents the most attractive for emissions reduction, although currently, the cost is high and not competitive with fossil-based energy carriers.

The cost of green hydrogen production is mainly determined by the cost of electricity (accounting for about 70% of the total cost) and electrolyzers (about 30%). These production factors are affected by a downward trend: the cost of renewable energy has decreased significantly compared to the past, reducing operating expenses; in addition, electrolyzers are becoming cheaper every day, reducing the investment expenses required by green hydrogen. It is estimated that the capital cost of electrolyzers could be reduced by about 70% by 2030 [16].

In contrast, as is expected, the trend in the cost of green hydrogen is expected to decrease significantly over the years, as shown in Fig. 5 [17].

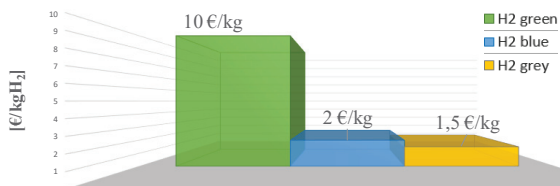


Fig. 4 Current cost of blue, grey and green hydrogen [17]

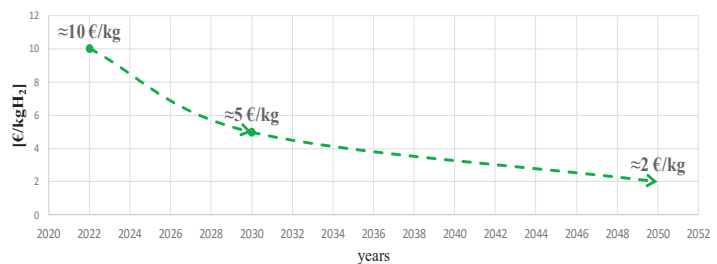


Fig. 5 Green hydrogen cost trend [17]

Therefore, the extensive use of green hydrogen and the associated technology chain in the various application sectors will depend on achieving the above cost targets.

3. LIFE3H Project

The LIFE3H (Hydrogen demonstration in city, port, and mountain area to develop integrated hydrogen valleys) project, co-funded by the LIFE program of the European Union, has the overall objective to set up, demonstrate and exploit three Hydrogen Valleys starting from the implementation of clean H_2 transit buses fuelled with surplus H_2 coming from local industrial productions thus closing the economical circle locally [18]. The project will demonstrate new transport solutions to increase air quality by reducing emissions and facilitating mobility, economic growth & environmental sustainability in urban and natural areas.

The sites for setting up the Hydrogen Valleys are located in three regions of central Italy: i) Abruzzo: Altopiano delle Rocche, a mountain area with ski resorts and part of the Regional Park Sirente Velino ii) Umbria: the historical city of Terni and iii) Lazio: port of Civitavecchia.

LIFE3H project specific objectives are:

- build up the first 3 Italian HVs laying the basis of one transregional HV;
- develop common & sustainable road Local Public Transport mobility; implement integrated local policies & regulatory approaches for widespread deployment of Hydrogen Refuelling Stations and Fuel Cell vehicles;
- increase circular economy by storing and using H₂ waste from local industries like steel mills and chlorine-soda plants; create a standard smart sustainable mobility management system;
- develop a Hydrogen Valley implementation strategy allowing future expansion in the project sites and replication in other sites;
- raise citizens' awareness & improving policy commitment to spread sustainable hydrogen-based mobility and improve air quality at sites of high historical, environmental, and archaeological value.

LIFE3H project is coordinated by Abruzzo Region with a partnership composed of a balanced mix of Public Bodies, Research Institutions, Industrial Partners, and Consultancies. The project has a total cost of 6,339,853 € of which 2,978,671 € co-funded by EU program LIFE 2020. LIFE3H started in September 2021 and will last 4 years.

The main key performance indicators (KPI) of the project are listed in Table.

Table

Main LIFE3H project KPI

H ₂ bus fleet	H ₂ cost	Global bus Total Cost of Ownership	Environmental impact
Total number of buses deployed in the project: # 2 bus 12 meters H-city #2 bus 8 meters H-mountain #2 bus 8 meters H-port	Hydrogen selling price target between 5-8 €/kg	Bus total cost of ownership 1 €/km diesel equivalent	Amount of saved CO ₂ emissions by the demonstration program → 1 ton/year saved

The project involves the development of a series of activities divided into homogeneous topics and working groups established by the different partners.

4. The LIFE3H Project in Abruzzo Region

This section presents the main ongoing activities and results referring to the part of the LIFE3H project related to the Abruzzo region (Fig. 6). The project implies the use of two transit buses as a shuttle connection inside of the Sirente-Velino Nature Park environment (Abruzzo Region) between the two ski resorts of Ovindoli (Magnola) and Rocca di Cambio (Campo Felice), running all year round with trips from Friday to Sunday, including public holidays. The estimated weekly mileage of the two buses amount to 1,460 km.

The transit buses will be run by T.U.A. Spa, the regional public transport company, and will be fueled by hydrogen made available by Società Chimica Bussi S.p.A., a local chemical company based in Bussi in Tirino (Pescara) already produces green hydrogen through electrolytic processes powered by hydroelectric energy. Therefore, it is available to be captured, purified, and compressed for use as fuel. This is key to implementing activities with reduced impact in terms of CO₂ emissions and from a circular economy perspective. The HRS will be realized by Greenture, the former Snam 4 mobility, meanwhile, the monitoring of the project actions will be performed by the Interdepartmental Research Center for Transport and Sustainable Mobility (CITraMS) of the University of L'Aquila and all activities will be coordinated and supported by Abruzzo Region.

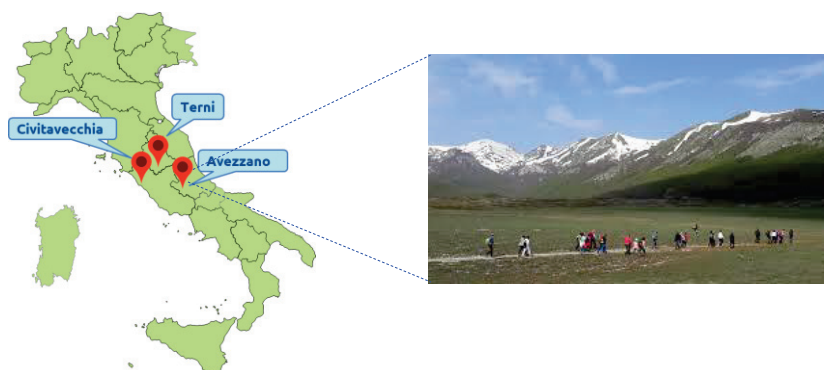


Fig. 6 LIFE3H project: location of the three Hydrogen Valleys and view of the Sirente-Velino Nature Park environment (Abruzzo Region)

4.1. Methodological Approach and Preliminary Results

Regarding the project activities concerning the application in mountainous areas of the Abruzzo Region, the following are some of the main activities and results obtained so far.

To properly carry out the project activities concerning the sizing of the vehicles and the hydrogen storage and HRS, the following methodological approach was identified.

The methodological approach consists of the following steps: i) vehicle parametric model construction and identification of vehicle type; ii) identification of the route and typology of transit bus; iii) acquisition of the topographical characteristics of the route and of the kinematic profile in real traffic conditions; iv) simulation of the bus on the chosen path; v) definition of powertrain characteristics and vi) hydrogen consumption analysis [19]

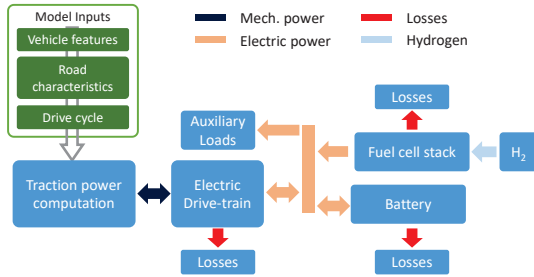


Fig. 7 Scheme of system simulator [19]

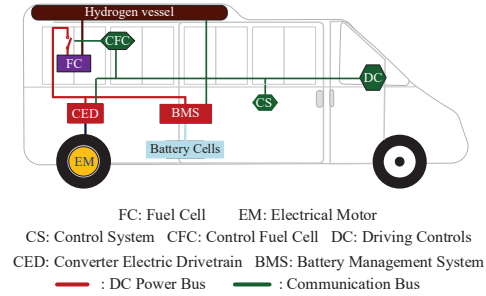


Fig. 8 Scheme of hydrogen-fueled transit bus [19]

Fig. 7 illustrates the scheme of the numerical parametric system simulator developed to design a complex vehicle architecture and calculate fuel consumption.

Fig. 8 shows the proposed vehicle architecture whose power plant uses an electric traction motor (EM) fed by a hybrid power unit consisting of a hydrogen Fuel Cell (FC) and a battery pack system. The traction motor, the FC, and the battery pack system are connected to the DC power bus (continuous red line) by means of converters: a Converter Electric Drivetrain (CED) and a Battery Management System (BMS). To manage the power flows required, a master control system (CS) communicates with the FC control system (CFC) and the driving control (DC) via a communication bus (green line).

The running of the vehicle, with the architecture described above and a carrying capacity of 25 passengers, was simulated on the selected route using real data acquired on the driving cycle and route characteristics. This simulation enabled the design of the vehicle's power train components and energy consumption.

The results show the feasibility of adopting hydrogen hybrid passenger buses even in mountainous areas on high-gradient routes. For the considered round trip path, a 150 kW peak power traction motor, an ESS peak power of 200 kW, and an FC power of 40 kW are able to manage both power and energy requirements with an H₂ consumption of 6.4 kg. Net of all the uncertainty parameters that can influence the simulation results, it is however more appropriate to consider a range of values for the average consumption which, in this study, is between 20/25 km/kg_{H₂} [19].

The project involves the construction of the refueling station (HRS) at the Avezzano interport area (Fig. 9 and Fig. 10) near the A24 highway exit, with the intent also to refuel additional possible hydrogen vehicle fleets in the future.



Fig. 9 Aerial view of the fueling station location site



Fig. 10 Hydrogen refueling Station preliminary design

HRS sizing is designed by Snam S.p.A partner considering conditions of an average ambient temperature of about 15°C and vehicles with i) initial residual cylinder pressure of 90 barg equal to 10 kg H₂ ii) final vehicle cylinder filling pressure of 350 barg equal to 35 kg.

The main technical features of the HRS (with an estimated cost of about € 976,800) are:

- 370 kg trailer @ 200 barg or cylinder packs @200-300 bar.
- 5 barg pressure reduction system.

- Priority system for a direct initial charge from the trailer, depending on trailer pressure and vehicle cylinder pressure.
- Two coupled "fuelmaker" H₂ compressor systems, about 6-8kW, total capacity from 2.2 kg/h @ 5barg.
- Integrated charging system without flow management according to vehicle cylinder pressure and temperature.

5. Conclusions

This paper has described, in the international context, the strategic lines, development policies, and implementation of hydrogen valleys.

In this framework, were referred the objectives, implementation methods, and ongoing activities of the Italian LIFE3H project participated by local authorities, universities, and industries from three regions in central Italy.

The LIFE3H project aims to develop three Hydrogen Valleys demonstration in three different areas (city, port, and mountain), involving the use of excess hydrogen from local industrial production to fuel emissions-free buses for passenger transport.

Regarding the application of the project in the protected mountain environment of the Abruzzo region, the results of the activities carried out so far, have made it possible to i) identify the architecture of the hydrogen-powered transit bus, ii) design the components of the vehicular powertrain, iii) calculate the fuel consumption, and iv) size the refueling station.

Acknowledgement

This study was developed under the project LIFE3H (Hydrogen demonstration in city, port, and mountain area to develop integrated hydrogen valleys) which was co-funded by the European Union LIFE Program Grant Number LIFE20 ENV/IT/000575

References

1. European Commission. 2019. Communication from the commission, The European Green Deal.
2. MIMS, Ministero delle Infrastrutture e della Mobilità Sostenibile. 2021. (In Italian) Cambiamenti climatici, infrastrutture e mobilità.
3. **Ciancetta, F.; Ometto, A.; Rotondale, A.; D'Ovidio, G.; Masciovecchio, C.** 2016. Analysis of flywheel-fuel cell system for mini electrical bus during an urban route, 2016 International Symposium on Power Electronics, Electrical Drives, Automation and Motion, SPEEDAM 2016, 1093-1098.
4. **D'Ovidio, G.; Masciovecchio, C.; Totani, G.** 2014. Sizing of hydrogen hybrid power unit for city bus, Proceedings of 18th International Conference Transport Means, 50-53.
5. **D'Ovidio, G.** 2007. Design of a hybrid power plant for city buses, World Electric Vehicle Journal, 68-72.
6. **D'Ovidio, G.; Carpenito, A.; Masciovecchio, C.; Ometto, A.** 2017. Preliminary analysis on advanced technologies for hydrogen light-rail trains application in sub-urban non electrified routes, Ingegneria Ferroviaria 72(11): 865-878.
7. **D'Ovidio, G.; Ometto, A.; Valentini, O.** 2020. A novel predictive power flow control strategy for hydrogen city rail train, International Journal of Hydrogen Energy 45(7): 4922-4931.
8. European Commission. 2019. Fit for 55.
9. EU Directive. 2021. Common rules for the internal markets in renewable and natural gases and in hydrogen.
10. European Commission. 2022. REPowerEU Plan.
11. Clean hydrogen Partnership. Available from: www.life3h.eu
12. Mission Innovation Hydrogen Valley Platform. Available from: <https://h2v.eu/>
13. Clean Hydrogen Partnership. Available from: https://www.clean-hydrogen.europa.eu/projects-repository_en
14. Community Idrogeno. Available from: <https://www.ambrosetti.eu/community-innotech/community-idrogeno/>
15. Longden et al. (2021) and Hydrogen Council (2011)
16. Come procede lo sviluppo dell'idrogeno verde. Available from: <https://www.startmag.it/energia/idrogeno-verde-prezzo-domanda/>
17. IEA (International Energy Agency). 2019. The future of hydrogen
18. LIFE20 ENV/IT/000575 LIFE3H (Hydrogen demonstration in city, port, and mountain area to develop integrated hydrogen valleys) project. Available from www.life3h.eu
19. **Ciancetta, F.; Di Pasquale, M.; D'Ovidio, G.; Ranieri, S.; Villante, C.** 2023. Performance simulation of hydrogen-electric transit bus running in a mountain environment, European Transport – Trasporti Europei 90: 9.