D1.3 – Report on generic requirements for bi-mode fuel cell hybrid trains

WP 1 – Generic FC train requirement specifications and concept

Task 1.2 – Use cases and derivation of related requirements for generic train development

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Date	05/08/2021	
Document ID	FCH2RAIL-1042268182-876	
Document status	X	Draft prepared for final review within task / WP
	X	Finalised draft document at task / WP level
	X	Document after quality check
	X	Document approved by SC
	X	Document approved by TMT
	X	Document submitted to FCH-JU

Dissemination level	
PU: Public	**X**
CO: Confidential, for members of the consortium only (including the Commission Services):	

Document status history

Status description	Date	Partner	Status code in file name
Draft prepared for final review within task	15/07/2021	Abraham Fernández Del Rey, RENFE	Draft_final_review_task
Draft prepared for final review within WP	15/07/2021	Abraham Fernández Del Rey, RENFE	Draft_final_review_WP
Finalised draft document at WP level	30/08/2021	Abraham Fernández Del Rey, RENFE	WP_final_draft
Document after quality check	07/09/2021	Maider Varela, CAF	QC
Document approved by SC	27/09/2021		
Document approved by TMT	27/09/2021		
Document submitted to FCH-JU	27/09/2021	Holger Dittus, DLR	Submitted

Contributions table

Partner	Contribution
ADIF	Shunting locomotives specifications, working hours, consumption and infrastructure compatibility
CAF	Bi-mode trains performance references Support and review. Quality check
DLR	Specifications of shunting locomotive Alstom Prima H3 and DMU Stadler series 650. Support and review
CNH2	Support and review
TME	Support and review
IP	Support and review

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under Grant Agreement No. 101006633. This Joint Undertaking receives support from the European Union’s Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe research.

Executive summary

The project ‘Fuel Cell Hybrid Power Pack for Rail Applications’ was an innovation action in Horizon 2020, the most significant research programme in the European Union. Aimed at reducing the production costs of fuel cell systems in transport applications while increasing their lifetime to levels that can compete with conventional technologies, the programme has awarded the project entitled FCH2Rail, under Grant Agreement No. 101006633 ([1]).

FCH2Rail is a project focussed on developing, building, testing, demonstrating and homologating a scalable, modular and multi-purpose Fuel Cell Hybrid PowerPack (FCHPP) applicable for different rail applications (multiple units, mainline locomotives and shunting locomotives). It is also suitable for retrofitting existing electric and diesel trains, to reach TRL7.

The purpose of deliverable D1.3 is to ascertain general high-level requirements for various types of vehicles.

The first part of the document (section 3) describes the characteristics of the services operated with the main categories of vehicle: XMU’s multiple units, mainline locomotives and shunting locomotives.

The second part (section 4) develops vehicle specifications to meet the demands derived from various use cases. All partners contribute to the information in order to depict the different scenarios. This section establishes the requirements for state-of-the-art hydrogen vehicles.

New trains must meet future needs while contributing to greener performance and maintaining profitability. Even though the deliverable focusses on the FCHPP requirements, the vehicle should also comply with the general requirements of a hydrogen bi-mode train operating in the Spanish network.

Sections 5, 6 and 7 deal with operational aspects and safe interactions between the hydrogen vehicles and the infrastructure. They are developed to maintain the high standards of safety currently reached by infrastructure administrators.

Glossary of terms

Abbreviations	Description
FCH	Fuel Cell Hybrid
FCHPP	Fuel Cell Hybrid Power Pack
DMU	Diesel Multiple Unit
EMC	Electromagnetic Compatibility
MD	Middle range services (“Media Distancia”)
XMU	Multiple Units with an undetermined power source. (H hydrogen, D diesel, E electric)
HVAC	Heating, Ventilation and Air Conditioning
RFIG	Red Ferroviaria de Interés General (approx. translates as general interest rail network)
LCC	Life-Cycle Cost

Acronyms	Description
CA	Consortium Agreement
GA	Grant Agreement
FCH2Rail	Fuel Cell Hybrid Power Pack for Rail Applications

Contents

1. Background

Figure 1: S334 (left) and CIVIA (right), waiting in Chamartín Station (source: photo stock ADIF)

This deliverable contains the general requirements for bi-mode fuel cell hybrid trains. It is a step towards adopting the strategic regulations of the European Union: The European Green Deal and the European Hydrogen Strategy.

As a part of this European strategy, the Fuel Cells and Hydrogen Joint Undertaking (FCHJU) (https://www.fch.europa.eu/) approved the consortium formed by several key partners under the project FCH2Rail (https://verkehrsforschung.dlr.de/en/projects/fch2rail).

FCHJU is a unique public-private partnership that supports activities in fuel cell and hydrogen energy technologies in Europe. It aims to accelerate the market introduction of these technologies and realise their potential as an instrument in achieving a carbon-clean energy system.

As a token of the effect of this strategy, Figure 2 shows the renewed interest in hydrogen technology and its application to the railways as a replacement for diesel traction, not only in Europe but worldwide.

In 2019, projects related to hydrogen technology were scarce. In 2021, projects of different types can be found not only in Europe but also worldwide. Some for the acquirement of new vehicles, others for conversion to hydrogen systems or for research programmes to gain a deeper understanding of hydrogen applied to railways systems.

Hence, this deliverable states the requirements for the future of rail transport partially based on the performance of existing diesel trains (usually with many years of service) and the commercial services currently carried out by these existing trains.

To date, European rail operators have established well-known and robust expertise in railway operations. The development of hydrogen vehicles means revolutionary changes in the way railways operate. As a result, the procedures currently deployed require some analysis and improvement to integrate hydrogen vehicles into current railway networks.

Consequently, operators expect the resulting bi-mode hydrogen vehicles to maintain the services currently provided by diesel trains. Services that retain the benefits of an electric vehicle in the catenary section and preserve the versatility of current operations in non-catenary sections.

On top of this, Spanish and Portuguese networks have developed new high-performance infrastructures that co-exist with old, traditional sections. Most of the vehicles under consideration here will have to be suitable for both types of service. Accordingly, bi-mode trains will play a unique role in answering these requirements.

This document is contained in Work Package 1. It is the result of the work carried out in Task 1.2, focussing on the general requirements of the next generation of H2 trains.

In Work Package 1, several tasks are developed in parallel starting at the same time as the project, 1st January 2021 (Month 0). Thus, it is essential to have a global vision of the whole work package in order to understand the progress of the work and the interaction between the project activities.

On the whole, Task 1.1 is a cross-sectoral task for the duration of the work package and comprises the analysis of use cases and requirements. Intermediate outputs are required to develop work on the other tasks. These outputs mainly relate to the scalability of the fuel cell powerpack (FCHPP). The first transfer of information from Task 1.1 to Task 1.2 took place in month 2, achieving the milestone MS1 when all infrastructure and operational data was released by the infrastructure administrators and rail operators in Task 1.2 in developing the requirements for the demonstrator vehicle. After two months of work by all partners, confidential deliverable 1.2 was released in month 4. It contained all the requirements to be considered by the demonstrator for a selected range of services. In addition to this, deliverable 1.1 will continue until month 15 and provide more results.

As other use cases are under study, Task 1.2 will continue after the end of deliverable 1.2 and the work will expand the analysis to multiple units at a higher level. Analyses will then take place in Task 1.1 regarding the use cases of mainline locomotives and shunting locomotives. The outputs generated in the previous task (1.1) regarding 'use cases' are turned into two deliverables in Task 1.2: one related to the demonstrator requirements (D1.2) and a second deliverable related to generic requirements for bi-mode fuel cell hybrid trains (D1.3).

Deliverable 1.3 includes primary and authorised public information gained from Tasks 1.1, 1.2 and 1.4. This information is mainly related to the operational requirements of autonomy and refuelling in a broad sense. Analyses will be carried out in greater detail in Task 1.3 in order to translate the requirements into a vehicle proposal through the definition of the FCHPP.

The correlation between Tasks 1.1, 1.2 and 1.3 does not end here, however. Task 1.2 sets out the general requirements for the next generation of hydrogen train. These requirements include the experience of CAF as a manufacturer for the Spanish market (XMUs). Where no recent expertise is available for other vehicles, all the partners assess mainline and shunting locomotives.

Task 1.3 is closely related to the previous tasks because it receives inputs from both of them.

Tasks 1.4 and Task 1.5 take place at the same time as Task 1.2. Task 1.4 develops essential information and understanding of refuelling processes and storage analysis, which have a direct impact on autonomy. Besides that, innovative HVAC systems are under research in Task 1.5 to shed light on the auxiliary power demand.

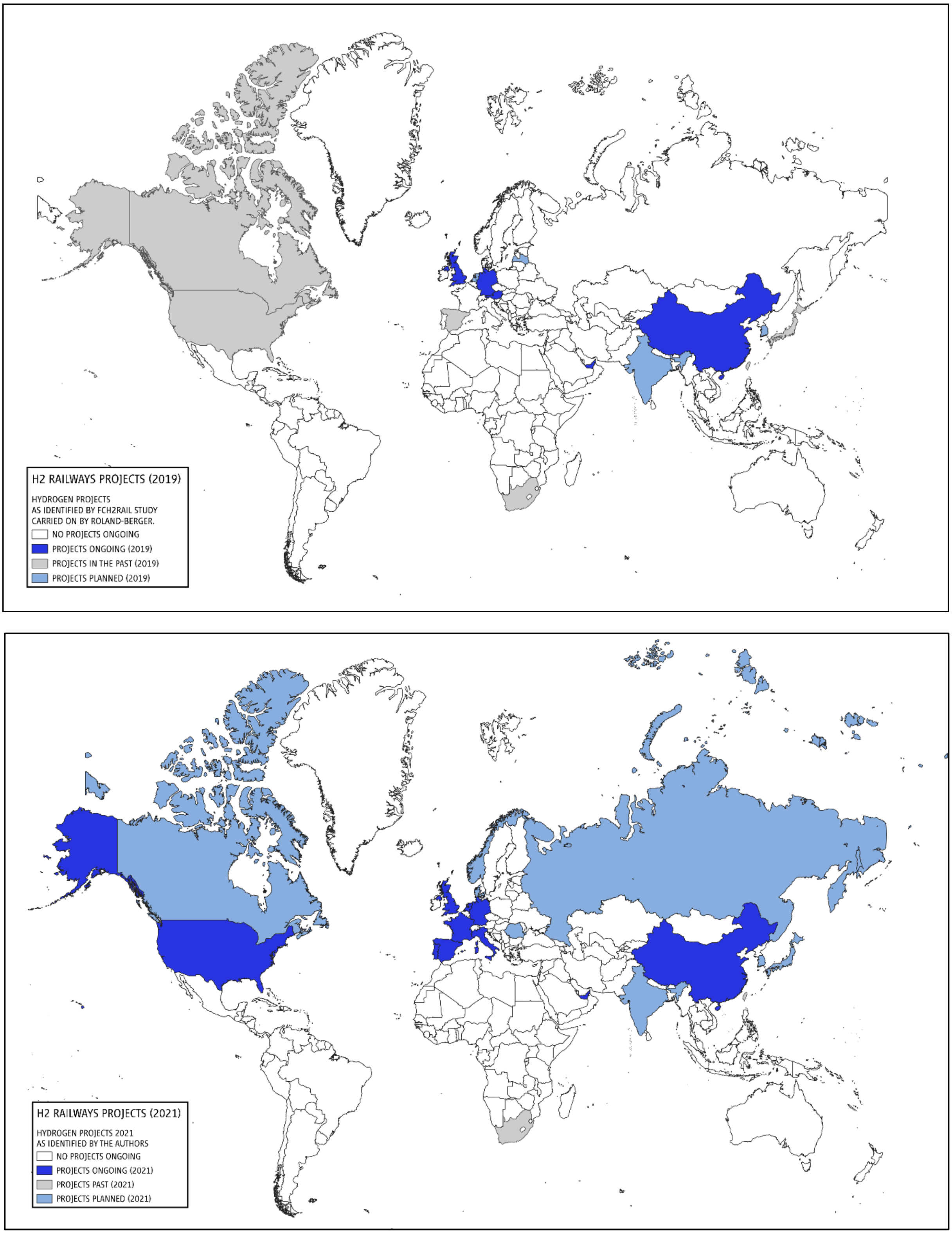

Figure 2: Evolution of the projects based on hydrogen fuel cells in railways (own depiction)

2. Objective and methodology

The main objective of this deliverable is to bring together the high-level requirements in addressing the needs of services currently provided by diesel vehicles while leaving enough room for generic FC trains that provide the same services with at least the same performance.

The methodology is to recover the services already analysed in more depth in Task 1.1, which will yield Deliverable 1.1.

Once all the services for the different types of vehicle have been determined, the general requirements will be defined at a high level, bearing in mind the need for scalability in the architecture of the power pack.

The deliverable also defines the requirements expected regarding compatibility with the infrastructure and additional requirements needed for operation.

3. Characteristics of the services intended for operation with hydrogen (existing diesel services or potential new ones)

One of the most challenging aspects of the project is to answer the needs of the Iberian network. Unlike other regions in the Spanish network, there are two key aspects that make these services difficult to fulfil with the average vehicle design. Firstly, the operator needs these vehicles to operate on any network line (operative generality requirement). Secondly, the vehicles need to run over the whole of the Spanish orography (power requirement).

Trying to fulfil these two basic requirements is proving to be a challenge. Therefore, in the following sections, the partners have compiled the most important requirements for replacing diesel services with hydrogen bi-mode vehicles. Finally, a hydrogen vehicle will show that it is possible to cover most of the services identified with existing H2 technology or by extending the FCHPP.

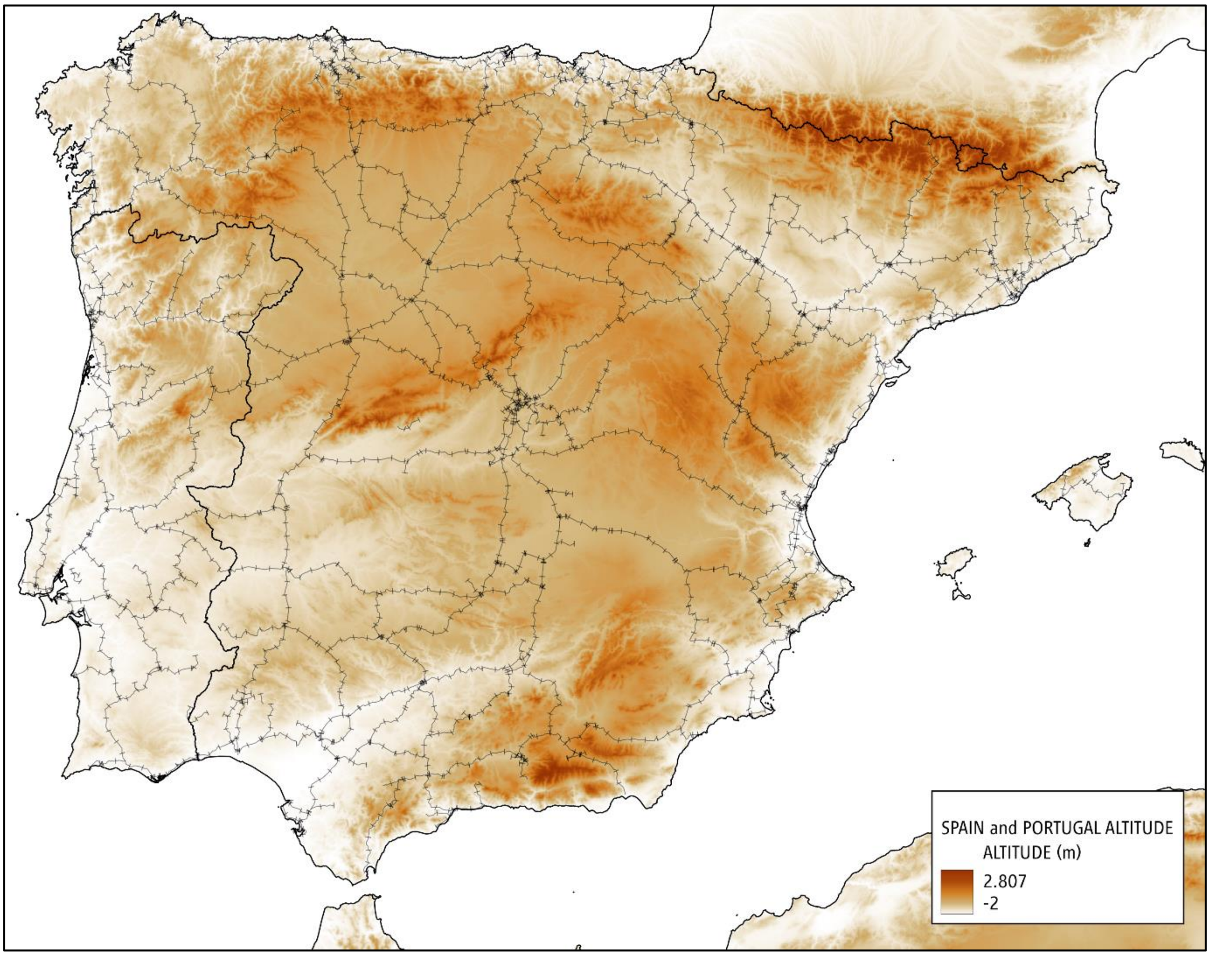

Figure 3: Iberian peninsula rail network (own depiction)

3.1 XMUs (monomode, bi-mode vehicles)

In Task 1.1, the partners described the requirements for the services currently fulfilled by diesel multiple units for analysis. Analysis of the most representative services was then covered in Task 1.1 to Task 1.2. Task 1.1 to Task 1.2 clarified the desirable performance requirements from the operator that is to provide those services. Finally, the partners adapted those requirements to the characteristics met by the current state-of-the-art technology, showing that these vehicles can fulfil current services while adhering to timetables.

Tasks 1.1 and 1.2 explained that one of the critical aims of the project is to acquire an in-depth understanding of the services identified and how a railway operator can develop services in hydrogen mode on a scalable architecture.

Other tasks in Work Packages 1, 2 and 3 need the requirements in order to dimension the system for developing the scalable architecture. In this section, the operator compiles the requirements for multiple units based on several aspects. Some conditions are based on experience while others are based on future needs.

The document presents separate considerations for services using the Iberian gauge and metric gauge networks.

3.1.1 Iberian gauge

Figure 4: Renfe S594 diesel multiple unit

Iberian gauge is used in both Spain and Portugal. Most diesel vehicles use Iberian gauge, but the Spanish network has developed using both gauges. The implication is that a train must be able to run across the whole network. This means that it must be easy to switch new vehicles to standard gauge with a minimum of changes (such as bogie replacement) or they must have gauge-changing bogies.

When considering diesel vehicles, one aspect that does not affect the specification process is electrification of the line. Sometimes, it is an operational decision to offer a partially electrified service simply with a diesel vehicle. If the same service is to be covered by a hydrogen bi-mode vehicle, however, electrification is of great importance because it directly impacts performance indicators such as autonomy.

Hence, the key point is as follows. To assure that the new multiple units are compatible with the entire network, they must run safely over Iberian gauge and standard gauge where some portions are electrified with 3 kV DC or 25 kV AC or even non-electrified. Figure 5 reflects the complexity of the services.

Commuter services

The services have been divided into three groups: commuter services, middle-range services and long-range services. Sometimes they are referred to as ‘Use Cases’ during the project.

Commuter services in Spain are urban rail services that connect towns surrounding the main city with each other and the main city itself. Although most networks in the vicinity of big cities are electrified, some are still non-electrified. Currently, those services are provided by diesel units.

Table 1 shows diesel commuter services with no electrification of the line. The operation of hydrogen bi-mode trains could provide more sustainable and greener transportation for those services.

Service type	Service	Rolling stock	Traffic volume (trains/day)
COMMUTER	C-3 Sevilla S.J. - Cazalla-Constantina	S598	6
COMMUTER	C-1 Murcia del Carmen - Alacant-Terminal	S592	45
COMMUTER	C-2 Murcia del Carmen - Aguilas	S592	6
COMMUTER	C-3 Alacant-Terminal - Sant Vicent Centre	S592	32
COMMUTER	C-3 Valencia Nord - Utiel	S592	11
COMMUTER	C-5 Valencia Nord - Caudiel	S592	6

**By the time of reading this deliverable, some of the services may be electrified as there are some ongoing studies of projected electrification*

Table 1: Commuter services with diesel multiple units

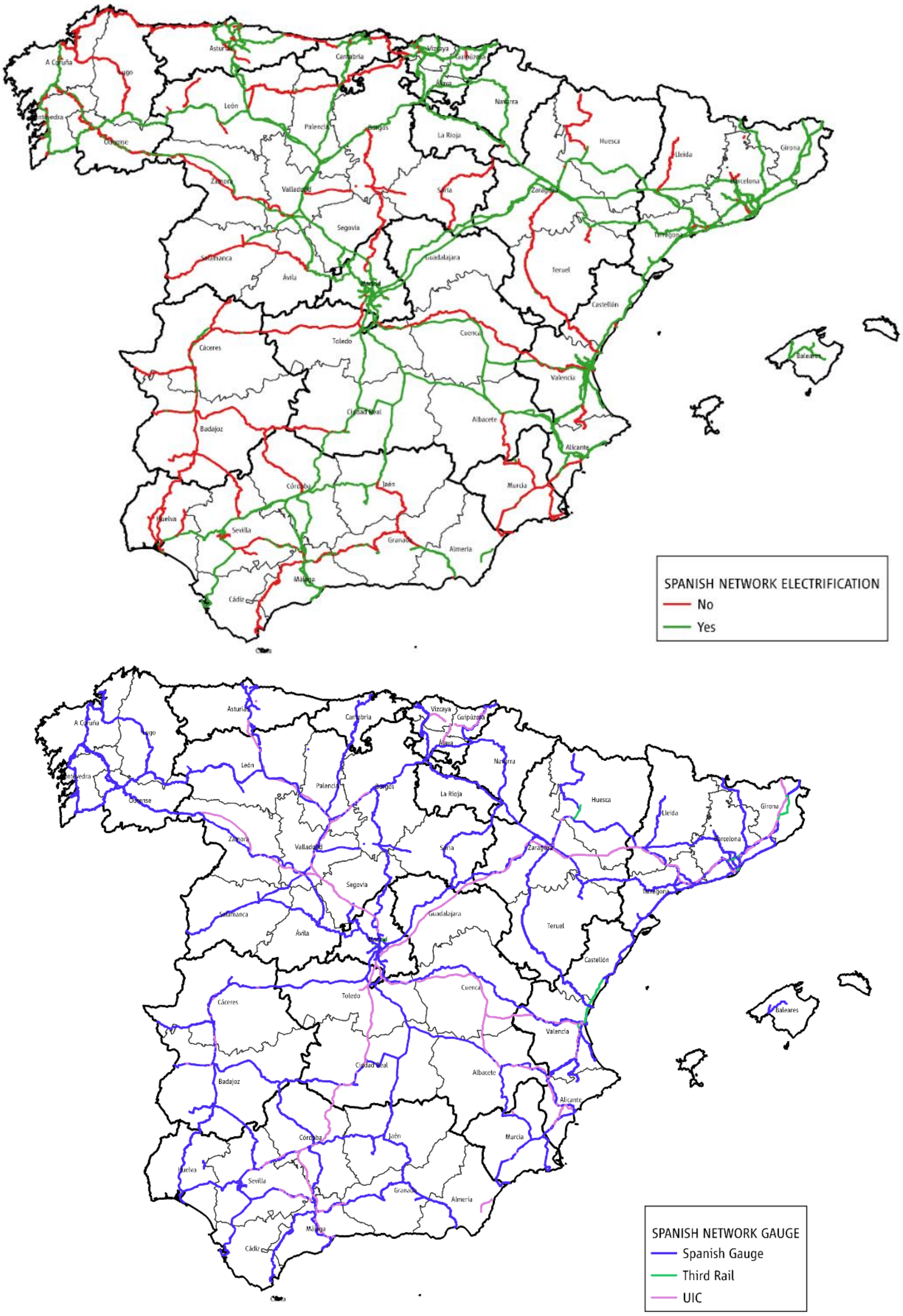

Figure 5: Map of the Spanish rail network (above: electrification; below: network gauge) (own depiction)

Middle range services (MD)

Middle range services (MD) are possibly where hydrogen could reveal its highest potential. MD services connect larger cities with surrounding towns and less populated cities. These services are less frequent than commuter services. Some of them connect different regions called 'Comunidades Autónomas', i.e. the equivalent of 'régions' in France, 'Bundesländer' in Germany or 'Distritos' in Portugal.

The MD model in Renfe is complex and comprises a wide range of services:

- **Avant:** Middle range services that cover services on standard high-speed gauge and Iberian gauge lines. The vehicles in current use are the Alstom S104, S114 and CAF/Alstom 121. A key requirement for some of the former vehicles is the ability to change gauge (max. speed: 250 km/h).
- **Regional:** Services stopping at (almost) all the stations on the line. Their operation is complex as they co-exist with commuter services. On electrified lines, the vehicles used include the CAF/MACOSA S440R, CAF/ALSTOM 446, 447 and double-deckers such as the S450). If the service does not co-exist with commuter services, the vehicles used are the S470 on electrified lines and the MACOSA S592 and Renfe TCR S596 on non-electrified lines.
- **Regional Exprés:** This is a kind of service with fewer stops than regional services. This means that the commercial speed is higher. Comfort is also greater compared to regional services. If the line is electrified, the vehicles used are the CAF/MACOSA S440R, S470 or the CAF/MACOSA S448. If the line is not electrified, the MACOSA S592 and S592.200 are used.
- **MD:** (Media Distancia) Regional services that are offered using the CAF S449, S594, S598 and S599. These services run on electrified and non-electrified lines.
- **Intercity:** Originally, these were long-distance services. Currently, they are long-distance services but with MD fares. The multiple units used in these services are the CAF/Alstom S120, S120.5, S121, CAF S449 and the S599.

This indicates that the number and variety of services are vast with a large proportion using diesel vehicles (see Table 2).

	Line	Rolling stock series	Traffic volume (trains/day)
MIDDLE RANGE	Granada - Algeciras	S598	2
MIDDLE RANGE	Huelva - Jabugo	S598	2
MIDDLE RANGE	Sevilla - Almería	S599	2
MIDDLE RANGE	Sevilla - Málaga	S598	4
MIDDLE RANGE	Sevilla - Málaga	S599	
MIDDLE RANGE	Salamanca - Madrid	S599	12
MIDDLE RANGE	Salamanca - Valladolid - Palencia	S594	5
MIDDLE RANGE	Valladolid - Palencia - León	S594	6
MIDDLE RANGE	Valladolid - Puebla Sanabria	S594	2

	Line	Rolling stock series	Traffic volume (trains/day)
MIDDLE RANGE	Murcia - Cartagena	S599	10
MIDDLE RANGE	Teruel - Zaragoza	S594	7
MIDDLE RANGE	Valencia - Alicante - Murcia - Cartagena	S599	4
MIDDLE RANGE	Valencia - Teruel - Zaragoza	S599	5
MIDDLE RANGE	Valencia - Xativa - Alcoi	S592	8
MIDDLE RANGE	Zaragoza - Canfranc	S596	4
MIDDLE RANGE	Zaragoza - Canfranc	S599	
MIDDLE RANGE	Madrid - Puertollano - Badajoz	S599	8
MIDDLE RANGE	Madrid - Soria	S598	5
MIDDLE RANGE	Madrid - Soria	S599	
MIDDLE RANGE	Madrid - Talavera	S599	11
MIDDLE RANGE	A Coruña - Ferrol	S594	6
MIDDLE RANGE	A Coruña - Lugo - Monforte	S594	4
MIDDLE RANGE	A Coruña - Vigo	S599	29
MIDDLE RANGE	Santiago - Carballiño - Ourense	S594	3
MIDDLE RANGE	Vigo - Ourense - Ponferrada	S594	4
MIDDLE RANGE	Madrid - Siguenza	S599	9
MIDDLE RANGE	Vigo - Oporto	S592	N/A

Table 2: Middle range services with diesel multiple units

Long-range services

Long-range services are essential services connecting major cities with other large cities at long distances. Most of them are provided on high-speed lines but also on Iberian gauge lines. Diesel services in this category are long-distance services with a long trip time and a high number of stops but not as high as MD services. Without them, direct connection between large cities would leave the smaller cities and towns in-between without any rail service.

Because the distance is high and the number of stops considerable, it is impossible to offer more trains per day.

In addition, the number of passengers per day is relatively low, so a combination of locomotives and coaches suits the service variability perfectly.

Currently, just two of the lines identified are offered with diesel multiple units (there is a section for mainline locomotives with additional services later):

	Line	Rolling stock series	Traffic volume (trains/day)
LONG RANGE	Madrid - Cuenca - Valencia	Aut. 592	4
LONG RANGE	Madrid - Zafra - Sevilla	Aut. 598	4
LONG RANGE	Madrid - Zafra - Sevilla	Aut. 599	

Table 3: Long-range services with diesel multiple units

To obtain a comparative idea of the vehicles suitable for providing the three categories of services listed above, CAF collected the following references of bi-mode vehicles that could be used as an initial approach:

Vehicle	Load cond. (Tn)	Max. speed (km/h)	Max. power at wheel (kW)	Specific power (kW/t)	Installed power (kW)	Starting accel. (m/s²)	Average accel. 0-40 km/h (m/s²)	Average accel. 0-100 km/h (m/s²)	Average accel. 0-160 km/h (m/s²)
Reference 1: Bimode (3 cars + technical car)	177	160	1,450	8.19	1,970	0.86	0.81	0.48	0.28
Reference 2: Bimode (3 cars + technical car)	185	140	1,400	7.56	1,920	0.87	0.79	0.45	0.31
Reference 3: Bimode (4 cars + technical car)	221	140	1,400	6.34	1,920	0.74	0.67	0.37	0.25
Reference 4: Bimode (3 cars. + technical car metric gauge)	108	80	615	5.67	960	0.81	0.7	0.41	
Reference 5: Bimode (regional – 6 cars)	357	160	1,950	5.46	2,800	0.77	0.68	0.33	0.17
Reference 6: Bimode (Intercity – 3 cars)	193	160	970	5.03	1,400	0.78	0.7	0.31	0.14
Reference 7: Bimode (regional – 2 cars)	183	160	960	5.24	1,400	0.77	0.67	0.32	0.15
Reference 8: Bimode – 2 cars	78	140	1,000		2,800 – 1,700		1.10	0.31	

Table 4: Different CAF models for providing diesel services (CAF article)

The following tasks present further analyses and conclusions.

3.1.2 Metric gauge

Figure 6: Trip from Vega de Anzo. Santa María de Grado (Asturias) (source: photo stock ADIF)

Spain has the most extensive metric network in Europe. This network provides services to most of the cities and small villages in the north of Spain. Some of the services are commuter services while others cover middle-range services.

Metric gauge networks are globally managed by several local operators, mainly: FGC, FGV, Euskotren but also national operators such as Renfe FEVE among others. Each of the operators mentioned above operates its networks and services differently. In a case in point, Renfe FEVE offers the same services for EMU and DMU as on the Iberian gauge.

- Different parts of the network are located in opposite corners of the country such as the main network crossing the north of Spain from the Basque Country to Galicia and a small line in the south from Cartagena to Los Nietos.
- There are two different types of service with multiple units. One of them is commuter services and the other is MD services. Commuter services are similar to those on Iberian gauge – a large number of stations separated by small distances. Medium-range services (MD) are, however, longer when compared to the Iberian gauge with considerably longer distances between stations and long trip times. Task 1.1 also includes the possibility of extending the use of

hydrogen to this type of vehicle. It identifies, therefore, metric gauge services as a use case of diesel vehicles suitable for an FCHPP.

The Renfe FEVE network uses diesel units for the services listed in Table 5, and Figure 7 shows the metric network in Spain.

Management area	Line	Rolling stock series	Trains/ day	Passengers (mean/day)
AM CERCANIAS PAÍS VASCO	Bilbao - Concordia - La Calzada	S2700	31	2,906 (*)
AM CERCANIAS MURCIA	Cartagena Plaza Bastarreche - Los Nietos	S2900	21	1,072
AM CERCANIAS ASTURIAS	Collanzo - Baiña	S2400	12	7,408 (*)
		S2600		
AM CERCANIAS GALICIA	El Ferrol - Ortigueira	S2400	5	279 (*)
		S2700		
		S2900		
AM CERCANIAS CASTILLA Y LEÓN	León - Cistierna - Guardo	S2600	5	635
		S2900		
AM CERCANIAS ASTURIAS	Oviedo - Infiesto (APD)	S2400	24	7,408 (*)
		S2700		
ANCHO METRICO MEDIA DISTANCIA	El Ferrol - Oviedo	S2400	2	No data available
		S2700		
		S2900		
ANCHO METRICO MEDIA DISTANCIA	La Asunción universidad - Bilbao La Concordia	S2700	2	No data available
		S2400		
ANCHO METRICO MEDIA DISTANCIA	Oviedo - Santander	S2400	2	No data available
		S2700		
ANCHO METRICO MEDIA DISTANCIA	Santander - Bilbao La Concordia	S2400	0	No data available
		S2700		

Table 5: Metric gauge services in the Renfe FEVE network

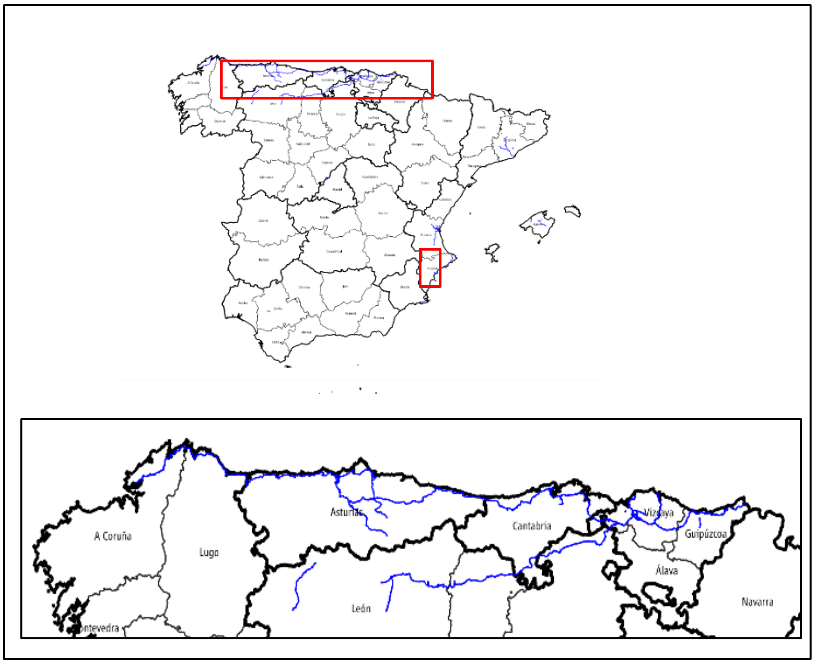

Figure 7: Metric gauge network

3.1.3 Standard gauge

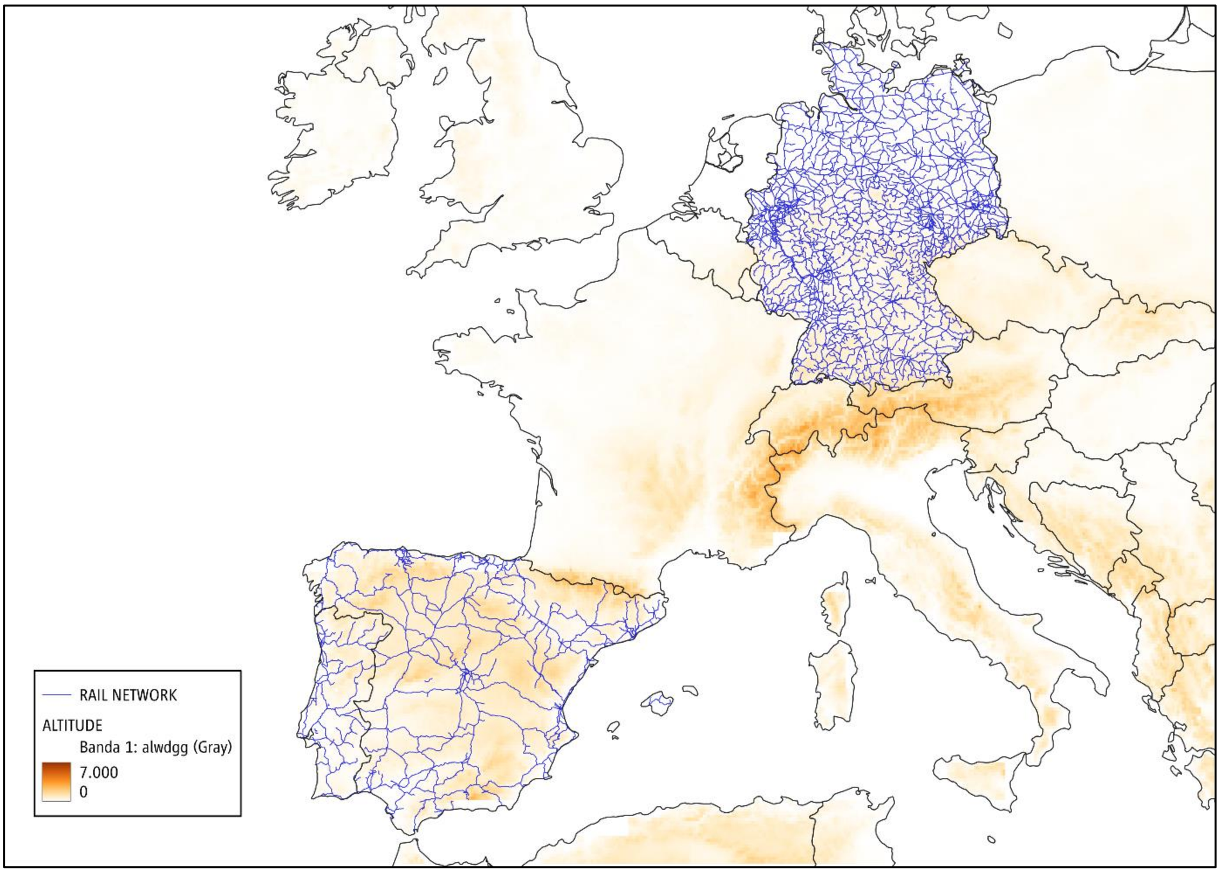

Figure 8: Differences between the Iberian and German rail networks (own depiction using data from IGN)

Apart from Spain and Portugal, Germany is another country where additional information should be gathered for the FCHPP and its scalability. The map above shows that the network is extensive, less dense in Spain and denser in Germany.

One of the vehicles used in Germany is the Stadler series 650 (Regio-Shuttle RS 1) with the following specifications:
- One-piece, low-floor railcar (65% low-floor)
- Two independent diesel engines (MAN D2865 LUH 07) of 228 kW each
- Top speed of 120 km/h
- Air-spring suspension bogies
- Passenger area with 77 seats (including 6 folding seats) and approx. 78 standing places
- One multi-purpose compartment for wheelchairs, pushchairs or bicycles at both entry areas
- A toilet in the passenger compartment
- Calm, friendly passenger areas
- Modern passenger information system with TFT monitors
- Wide, double-leaf, swing-out sliding doors

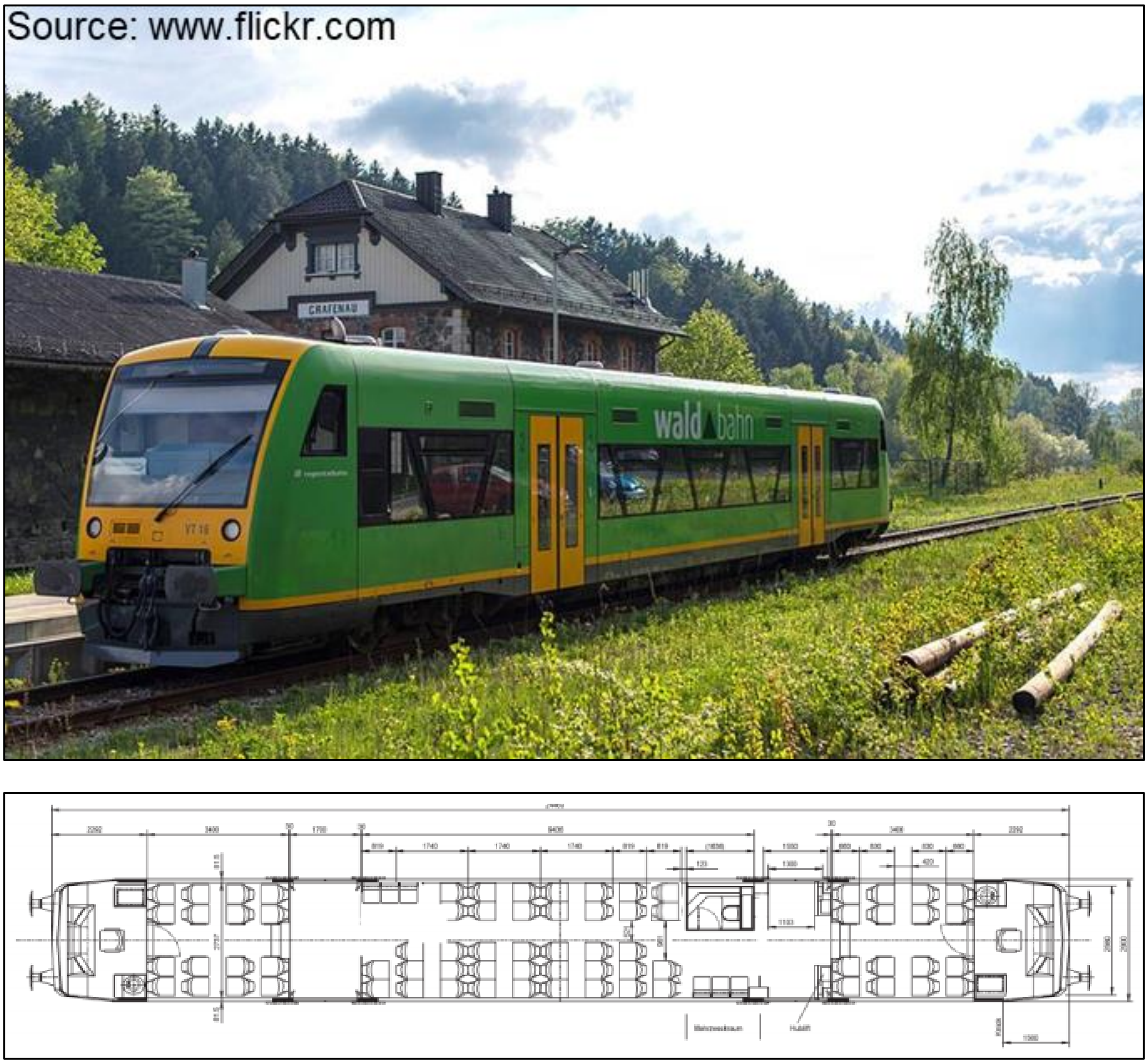
Source: www.flickr.com

Figure 9: Stadler series 650 (Regio-Shuttle RS 1).

3.2 Mainline locomotives

Locomotives coupled with Talgo coaches currently operate over non-electrified lines. They provide most of the long-distance services (Figs. 10, 11, 12).

Figure 10: Locomotive S334 pulling a Talgo coach combination (Author: F. Javier Rodriguez Olmos)

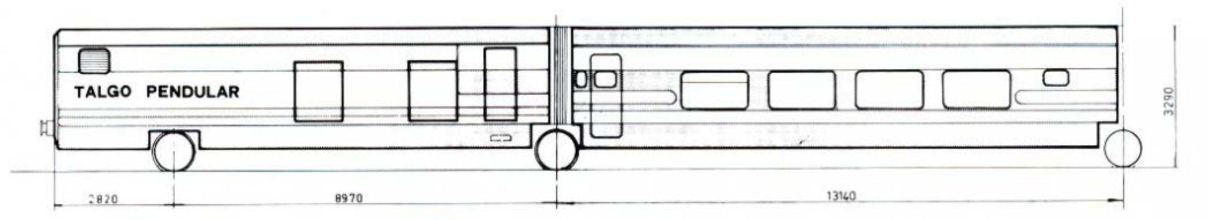

Figure 11: FFE / Renfe archives (Source: www.listadotrenes.com)

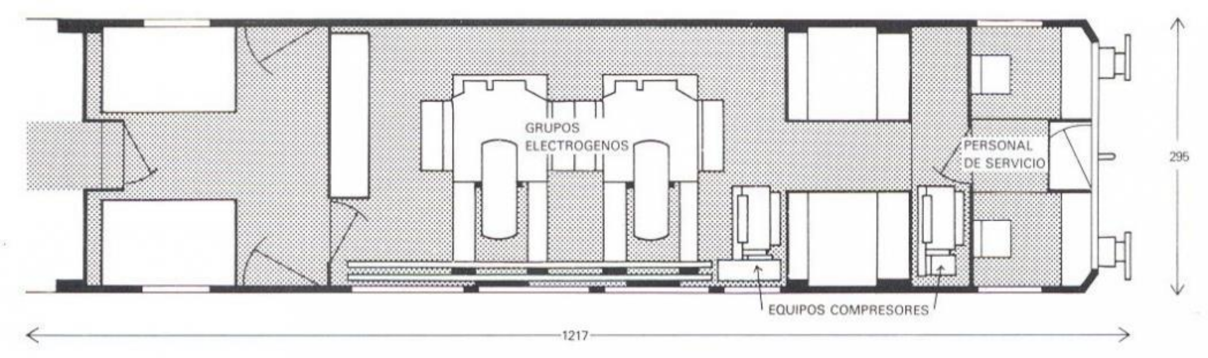

Figure 12: FFE / Renfe archives (Source: www.listadotrenes.com)

In the past, Renfe generally used coaches for most of the services. In Spain, even high-speed started with electric locomotives. Subsequently, later vehicle bids moved to electrical (EMU) or diesel multiple units (DMU).

Table 6 shows a list of services currently implemented with locomotives and coaches:

SERVICE	LOCOMOTIVE	TRAINS/DAY	KM	CAPACITY (PASSENGERS)	NO. COACHES
CHAMARTIN - CARTAGENA	S334	4I – 4V	534.2	220 – 500	9-10
CHAMARTIN - MURCIA DEL CARMEN - AGUILAS	S334	1I – 1V	452	220 – 250	9-15
ALACANT TERMINAL - CARTAGENA	S334	1I – 1V	142	320 – 356	12-14
ALACANT TERMINAL - LORCA SUTULLENA	S334	1I – 1V	141	320 – 356	12-14
SAN SEBASTIÁN - LISBOA STA. APOLONIA	S333	1I – 1V	1047	412	28
A CORUÑA - FERROL	S333 & S334	1I – 1V	69	250	16-18
CHAMARTIN - A CORUÑA	S252 & S333	1I – 1V	849	226-250	16-18
MONFORTE DE LEMOS - PONTEVEDRA	S333	1I – 1V	205.1	218	13
SAN SEBASTIÁN - A CORUÑA	S334	1I – 1V	895	258	10-11
CHAMARTIN - HUERCAL-VIATOR	S334	2I – 2V	556	88-280	5-11
CHAMARTIN - ALMERÍA	S334	2I – 2V	556	88-280	5-11
CHAMARTIN - BADAJOZ	S334	1I – 1V	472.5	134-170-278	5-7-10
CHAMARTIN - GRANADA	S334	1I – 1V	496	220-246	9-11
MADRID P.ATOCHA - CAMB.ANTEQUERA - ALGECIRAS	S252 & S334	2I – 2V	634	134-280	5-11
A CORUÑA - MONFORTE DE LEMOS	S333	2I – 2V	189.6	110-120	14-15

Table 6: Services operated with locomotives and Talgo coaches

Task 1.1 further develops the analysis of these services, including simulations of services with locomotives and coaches.

3.3 Shunting locomotives

Figure 13: S310 shunting locomotive (Source: photo stock ADIF)

Shunting locomotives (also known as shunters or switchers) are a particular use case. A shunting locomotive is rolling stock that provides the motive power necessary to sort wagons or coaches when forming a train.

Examples of currently operated locomotives are present for all European operators: DB V60, SNCF Y8400, ADIF S310, etc.

Services related to these locomotives involve mainly low-speed manoeuvres, such as taking wagons or empty coaches from the marshalling yard to the train. For this, the characteristics of shunting locomotives are quite similar in terms of power and performance.

The mission profile is similar and independent of the country: a relatively low number of hours of accumulated service, sometimes waiting in idle mode while switched off the rest of the day [3].

Another common characteristic of these vehicles is their long life. Most of them are more than 30 years old (reaching 50 in some cases). Shunt locomotive builders have included advances regarding implementation of the latest hydraulic transmissions and hybridisation technologies:

Alstom Prima H3 shunting locomotive	
Builder:	Alstom Stendal
Year:	2013
Configuration:	A’AA’
Power	600 – 1000 kW (hybrid)
Gauge:	1435 mm
Length:	12800 mm
Height:	4245 mm
Width:	3130 mm
Weight:	67.5 t
Axle load:	22.5 t
Max. speed:	100 km/h
Tractive effort	219.18 kN
Tank:	2200 l

Class Y8400 (France)		CP Class 1200 (Portugal)		Details DB Class V 90 (Germany)	
Type and origin					
Power type	Diesel	Power type	Diesel-electric	Power type	
Builder	Arbel Fauvet Rail	Builder	Brissonneau & Lotz, Sorefame	Builder	MaK, Jung-Jungenthal, Henschel, Krupp, Klöckner-Humboldt-Deutz (KHD), Rheinstahl
Build date	1990–1995	Build date	1961–1964	Build date	1966-1974
Total produced	150	Total produced	25	Total produced	408
Specifications					
Configuration					
Whyte	0-4-0	UIC	Bo'Bo'	UIC	B'B'
UIC	B				
Gauge	1,435 mm (4 ft 8+1⁄2 in) standard gauge	Gauge	1,668 mm (5 ft 5+21⁄32 in) Iberian gauge	Gauge	1435 mm
Length	10.14 m (33 ft 3 in)	Length	14,680 mm (48 ft 2 in)	Length	14,000 – 14,320 mm
Loc. weight	36 tonnes (35 long tons; 40 short tons)	Loco weight	61 t	Loco weight	80 t
Fuel type	Diesel	Prime mover	MGO-V-12AHSR	Prime mover	MTU V8 4000 R41 (remotorised)
Prime mover	Poyaud V12	Traction motors	x4	Traction motors	-
Engine type	V12 diesel	Cylinders	V12	Cylinders	V8
Transmission	Hydraulic	Transmission	-	Transmission	Hydraulic
Performance figures					
Maximum speed	60 km/h (37 mph)	Maximum speed	80 km/h (50 mph)	Maximum speed	70 – 80 km/h (high speed) 40 km/h (low speed)
Power output	205 kW (275 hp)	Power output	615 kW (825 hp)	Power output	800 kW
		Tractive effort	157 kN	Tractive effort	188 kN (high speed) / 236 kN (low speed)
Career					
Operators	SNCF	Operators	Comboios de Portugal	Operators	DB Cargo
Class	Y8400	Class	Série 1200	Class	Class V 90

Table 7: Comparison between different shunting locomotives used in different countries (Source: wikipedia)

4. Rolling stock type related requirements on FCHPP and hydrogen trains

This section aims to define the performances according to what is affordable using state-of-the-art hydrogen technology. The consortium partners obtained some early results regarding diesel vehicles currently providing the services mentioned above. Also, previous stages have achieved some results that show no direct translation of diesel to hydrogen requirements.

It is also important not to forget the average age of the diesel fleet (more than ten years). For this reason, this section does not aim to state a closed list of requirements for a new train, as they could evolve with the state of the art.

Tasks 1.1 and 1.2 identified the requirements. They improve the understanding of the possibilities of hydrogen vehicles as well as listing the difficulties found. Further work will develop a high-level description of general requirements from the ‘use cases’ aspect.

As the project advances, a clearer understanding of the advantages and limitations of a hydrogen vehicle will be achieved. Mainly, the project will obtain this understanding from experience in the field with the demonstrator train.

Considering the different stakeholders affected by this new technology, the partners have collected the general global requirements or needs for an FCH train from several perspectives, classifying the vehicles currently in use at different levels of suitability for a scalable architecture.

The characteristic of the vehicle itself should be connected with the services described above because one of the final objectives of the project is to homologate an FCHPP suitable for refurbishing existing vehicles.

This means that a range of characteristics is needed to develop a scalable FCHPP. This form of expressing the needs or requirements as a range is derived from the understanding that some leeway is needed for new vehicles when specifying the characteristics accounting for the design of the FCHPP. Some of these needs affect the salient features of the base vehicle, others have to be understood progressively alongside the rest of the partners as well as their input and advice.

Although bi-mode, this type of train still has to accomplish all the general requirements for other vehicles. A brief description is given here but does not pretend to cover all the needs and does not affect the definition of FCHPP.

The vehicle has to be able to run on rails with a nominal rail gauge of 1,668 mm as well as all RFIG lines with Iberian gauge.

Since the train can be removed from Iberian gauge lines onto standard gauge, the train gauge must be easy to change in an intervention in a workshop or run with variable gauge systems.

Earlier requirements came from the idea that the train must be fit for use on all Spanish lines of the gauges listed above and without any change in infrastructure. The train gauge must fulfil the reference contour ADIF – GHE16 (Iberian gauge) / G1 (UIC gauge) and IP PTb +(Cpb+) gauge as defined in standard EN-15273.

When fed from the catenary line, trains shall be bi-tension, i.e. work with nominal voltages of 3 kV DC and 25 kV AC at a nominal frequency of 50 Hz.

Figure 14: CIVIA EMU

The train definition observed several standards: EN-50163 and EN-50388, as the catenary voltage could fluctuate in service. The standards state that the vehicle will work with a permanent 3.9 kV DC as well as other additional requirements.

In contrast to purely electric trains, dual-mode trains must also be able to run on non-electrified lines, fed from a generator system or on-board batteries.

For running under catenary, geometrical and other information is included in the Infrastructure Administrator Network Declaration under the standard EN-50367.

From the operator's point of view, some parameters are fundamental for operating the trains and providing services to the different points of the line.

The builder's responsibility is to make sure that the vehicle is fully compatible with the requirements of the lines where it provides services. In addition, some of the requirements are based on the current state of the art. Nevertheless, the maximum specifications currently available will be provided.

Before beginning construction, a simulation must be carried out in order to understand the capabilities of the vehicle under conditions that are more or less similar to actual conditions:

- Maximum cant deficiency of 180 mm must be considered.
- At some singular points, there is a maximum gradient in the line of 45‰. These vehicles provide services at some points that reach this value, e.g. La Tour de Carol. The vehicle must be able to start running on a gradient with these characteristics.
- Radius requirements are 250 m for common tracks. In any case, it must follow UIC 527.1, considering those values as informative and not as a limit.

Regarding maximum speeds, the requirements analysis must take two considerations into account:

- speed under the overhead line (200 km/h)
- non-electrified (160 km/h, ideally 200 km/h).

This means that this speed is the one for commercial service in normal conditions with any wheel radius, at continuous and unlimited time regimes, normal load, on a horizontal straight track and acceleration of at least 5 cm/s^2 (except for shunting locomotives).

Regarding rail dynamics validation, the train must comply with the standard EN-14363 regarding tests and simulations of the dynamic behaviour to be accepted, including ride quality and comfort according to the standard EN-12299.

In terms of noise, the noise TSI requirements for bi-mode vehicles must be achieved as usual, although there are no specific limits in the current regulations for hydrogen trains developed.

Train length is an important parameter that limits the space available for FCHPP and has been defined for several configurations. In a hydrogen bi-mode vehicle, the length could be approximately 50 – 90 m, including the technical car (if any).

4.1 XMUs (monomode, bi-mode vehicles)

4.1.1 Terms of performance and efficiency

The following tables provide a summary of some of the interrelationships of high-level requirements that are imposed independently of the technology:

AMBIENT CONDITIONS

Exterior temperature (°C) *Note: This can vary depending on the location of each route*	
Average	T3 EN-50125 – [-25°C – +45°C]
Maximum and minimum values	
Humidity	According to the psychrometric diagram for T3 in EN-50125
Altitude (m)	1400 m referred to Spanish sea level (A1 acc. to EN-50125)
Regulation curve for HVAC	EN-14750 Category A; Zone I in winter (-10°C); zone I in summer (+40°C). For trips of more than 1 h, EN-13219-1 must also be considered.

Table 8: XMU ambient conditions

When it comes to environmental conditions, trains must withstand all the environmental conditions that occur on RFIG lines. No reduction in performance is permitted even under severe weather conditions. Also, all the equipment and systems must start up under the temperatures considered in standard EN-50155 for a class of OT3.

PERFORMANCES – IBERIAN GAUGE

	Catenary section	**Non-catenary section**
Max. adhesion coefficient braking	0.15 emergency braking (ETI loc&pass brake 4.2.4.6.1) 0.20 dynamic brake (acc. to EN-16185)	
Max. adhesion coefficient traction	0.24	

Traction performance		
Starting acceleration	0.70 – 0.85 m/s^2	0.70 – 0.85 m/s^2
Average acceleration or maximum time from 0 to 100 km/h*	0.40 – 0.50 m/s^2	0.30 – 0.50 m/s^2
Reference load for traction performance (MD) (EN-15663)	Mass in working order + 1 passenger/seat	Mass in working order + 1 passenger/seat
Reference load for traction performance (Commuter) (EN-15663)	Mass in working order + 1 passenger/seat + 4 passengers/m^2	Mass in working order + 1 passenger/seat + 4 passengers/m^2

** If the maximum speed is ≥ 120 km/h, average acceleration from 0 to maximum speed will be > 0.25 m/s^2*

Braking performance	
Service deceleration	1.1 m/s^2
Reference load for braking performance	Braking performance independent of load conditions

Power performance		
Power at wheel	1,400 – 1,600 kW (for 3 cars)	Min. 1,000 – 1,200 kW (for 3 cars)

Table 9: XMU performances on Iberian gauge

The train must be modular with the FCHPP. It must be possible to easily modify and reconfigure the combination of hydrogen fuel cells and batteries in order to adapt the train to meet operational needs.

PERFORMANCES – METRIC GAUGE

	Catenary section	Non-catenary section
Max. adhesion coefficient braking	0.15 emergency braking (ETI loc&pass brake 4.2.4.6.1) 0.20 dynamic brake (acc. to EN-16185)	
Max. adhesion coefficient traction	0.24	

Traction performance		
Starting acceleration	0.85 – 1.1 m/s^2	0.6 – 0.9 m/s^2
Average acceleration or max. time from 0 to 100 km/h	0.5 – 0.6 m/s^2	0.4 – 0.5 m/s^2
Reference load for traction performance (MD) (EN-15663)	Mass in working order + 1 passenger/seat	Mass in working order + 1 passenger/seat
Reference load for traction performance (Commuter) (EN-15663)	Mass in working order + 1 passenger/seat + 4 passengers/m^2	Mass in working order + 1 passenger/seat + 4 passengers/m^2

Braking performance	
Service deceleration	1.1 m/s^2
Reference load for braking performance	Braking performance independent of load conditions

Power performance		
Power at wheel	750 – 950 kW (for 3 cars)	Min. 600 kW – 800 kW (for 3 cars)

Table 10: XMU performances for metric gauge

4.1.2 Autonomy

TARGET AUTONOMY – IBERIAN GAUGE		
Route/Service	**Minimum**	**Target**
Long and medium distance	650 – 750 km	1,000 km
Commuter	250 – 350 km	800 km

TARGET AUTONOMY – METRIC GAUGE		
Route/Service	**Minimum**	**Target**
Medium distance	450 – 600 km	1,000 km
Commuter	300 – 400 km	800 km

Table 11: XMU autonomies

4.1.3 Operational and LCC parameters

Metric and Iberian gauges share operational and LCC parameters:

TARGET END OF LIFE		
	Minimum	**Target**
Fuel cells	25,000 h (5 years)	40,000 h (8 years)
Batteries	25,000 h (5 years)	40,000 h (8 years)

TARGET REQUIREMENTS	
Available refuelling downtime	15 mins – 30 mins per train depending on infrastructure

Table 12: XMU operational and LCC parameters

4.1.4 Degraded modes, reliability, availability

DEGRADED MODES, RELIABILITY AND AVAILABILITY	
Type of failure	**Action: Maintain regular operation, retire vehicle…**
Simple failure that causes the most harmful reduction of power	Maintain normal operation. Required to continue trip without impact on operation
-50% traction power at wheel	Reduced operation until end of trip and remove vehicle from service
-75% traction power at wheel	Remove vehicle from service
*No simple failure must leave the vehicle with less than 50% of traction performance	
Mean time between failures (MTBF)	11,000 hours MTBF globally for vehicle (considering a failure as 5-min delay)

Table 13: XMU degraded modes

4.2 Mainline locomotives

With the aim of developing an FCHPP, Task 3.1 takes additional types of vehicle into consideration in order to study their different needs in terms of performance. Multiple units are taken as the reference to start designing the FCHPP components. The consortium will carry out further analyses to adapt the system to requirements.

The locomotives approach is different because of the varying needs to respond to the power and autonomy of the services. The analysis carried out in Task 1.1 concludes that the operator uses two different kinds of locomotive to answer operational needs. These locomotives are representative as most of their specifications are proven to work. They have a range of suitable characteristics that should also be retained if they were to be hydrogen powered. Hence, they represent a relevant platform for designing a scalable FCHPP, and furthermore broaden the database for the general FCHPP design evaluation by bearing their well-known ranges in mind.

Finally, as the locomotive has to be modified to install the FCHPP, the possibility of a simple conversion to a hydrogen bi-mode locomotive could also be evaluated because a traction converter has to be installed. As a newly built locomotive, a bi-mode locomotive would be preferred.

4.2.1 Terms of performance and efficiency

AMBIENT CONDITIONS	
Exterior temperature (°C) *Note: This can vary depending on the location of each route*	
Average	T3 EN-50125 – [-25°C – +45°C]
Maximum and minimum values	
Humidity	According to the psychrometric diagram for T3 in EN-50125
Altitude (m)	1,400 m referred to Spanish sea level (A1 acc. to EN-50125)
Regulation curve for HVAC	EN-14750 Category A; Zone I in winter (-10 ºC); zone I in summer (+40°C) For trips > 1 h, EN-13219-1 must also be considered

Table 14: Mainline locomotives' ambient conditions

GENERAL REQUIREMENTS (ranges)	
Wheel diameter	965 – 1,067 mm
Gauge	1,668 mm
Width	3,060 mm – 3,160 mm
Height (from upper point of rail)	4,280 mm – 4,307 mm
Length between bumpers	20,700 mm – 22,330 mm
Max. speed	140 km/h – 200 km/h
Electric drives	4-6
Weight	90 t – 120 t
Dynamic braking	Rheostatics with energy recovery system
Pneumatic braking	Yes
Multiple unit	Yes
Power at wheel	1,800 – 2,200 kW
Load by axle	20 – 22.5 t
Configuration	Bo'Bo' – Co'Co'
Tractive effort (kN)	178 kN – 281kN@23km/h

Table 15: Mainline general requirements

PERFORMANCES

	Mainline locomotive
Max. adhesion coefficient braking	0.13 emergency braking (ETI loc&pass brake 4.2.4.6.1) 0.20 dynamic brake (acc. to EN-14198)
Max. adhesion coefficient traction	0.24
Tractive performance	
Starting acceleration	0.6 – 0.80 m/s²
Average acceleration or maximum time from 0 to 100 km/h	0.3 – 0.45 m/s²
Reference load for traction performance	14 Talgo coaches at max. speed
Braking performance	
Service deceleration	1.1 m/s²

** If maximum speed is ≥ 120 km/h, average acceleration from 0 to maximum speed > than 0.25 m/s²*

Table 16: Mainline performances

4.2.2 Autonomy

TARGET AUTONOMY – SPANISH GAUGE

Route/Service	Kilometres
Long-distance services	800 – 1,000 km

Table 17: Mainline target autonomy

4.2.3 Operational and LCC parameters

Operational and LCC parameters are the same as for XMUs:

TARGET END OF LIFE

	Minimum	Target
Fuel cells	25,000 h (5 years)	40,000 h (8 years)
Batteries	25,000 h (5 years)	40,000 h (8 years)

Table 18: Mainline locomotives end of life

whereas the refuelling target has been eased owing to the expected higher mass of hydrogen carried by locomotives.

TARGET REQUIREMENTS

Available refuelling downtime	15 mins – 45 mins per train depending on infrastructure

Table 19: Mainline locomotives' refuelling time

4.2.4 Degraded modes, reliability, availability

Operational parameters for mainline locomotives are the same as for bi-mode hydrogen units:

DEGRADED MODES, RELIABILITY AND AVAILABILITY

Type of failure	Action: Maintain regular operation, retire vehicle…
Simple failures that cause the most harmful reduction of power	Maintain normal operation. Required to continue trip without impact on operation
-50% traction power at wheel	Reduced operation until end of trip and remove vehicle from service
-75% traction power at wheel	Remove vehicle from service

No simple failure is allowed to leave the vehicle with less than 50% of traction performance

Mean Time Between Failures (MTBF)	11,000 hours MTBF globally for the vehicle (considering a failure as 5-min delay)

Table 20: Mainline degraded modes

4.3 Shunting locomotives

Figure 15: Shunting locomotive S310 (Author: Ismael Peinado)

Figure 16: Shunting locomotive S311 (Author: Oriol Paris)

4.3.1 Terms of performance and efficiency

Shunting locomotives are primarily beyond the scope of TSI Loc&Pass; it is, therefore, up to the operator to follow Directive (UE) 2016/797, Art 1, Section 4, Letter b:

“Member States may exclude, from the scope of the measures implementing this Directive on the interoperability of the rail system within the European Union, the infrastructure and vehicles reserved for a strictly local, historical or touristic use.”

There are two sizes of shunting locomotives in marshalling yards of ADIF: One is exclusively for movements inside the wagon yard and the other for short displacements between marshalling yards.

They are intended for manoeuvring coaches and wagons in marshalling yards. Given the specificity of their task, therefore, they are usually low-powered with high starting effort.

One additional characteristic that has always put these vehicles in the crosshair of hydrogen technology is that, since these locomotives usually work in the same marshalling yard, autonomy has a lower effect than for mainline locomotives since these locomotives operate near a refuelling station or a mobile refuelling tank most of the time. In that case, the refuelling frequency can be increased, improving the vehicle's weight and decreasing the number of tanks installed.

This group of locomotives has specific characteristics such as a very long lifecycle (approx. 50 years) and bogies that are designed to work in a small curve radius for long periods as they spend most of their time in marshalling yards or workshop yards.

PERFORMANCES

	Inter-yard shunting locomotive (e.g. S310)	**Local shunting locomotive (e.g. S311)**
Max. adhesion coefficient braking	0.13 emergency braking (ETI loc&Pass brake 4.2.4.6.1) 0.20 dynamic brake (acc. to EN-14198)	
Max. adhesion coefficient traction	0.24	
Traction performance		
Starting acceleration	0.6 – 0.85 m/s^2	0.6 – 0.85 m/s^2
Average acceleration or max. time from 0 to max speed	0.1 – 0.35 m/s^2	0.1 – 0.35 m/s^2
Reference load for traction performance	Depending on no. of carr.	Depending on no. of carr.
Braking performance		
Service deceleration	1.1 m/s^2	

Table 21: Shunting locomotives’ performance

GENERAL REQUIREMENTS		
	Inter-yard shunting locomotive (e.g. S310)	**Local shunting locomotive (e.g. S311)**
Wheel diameter	1,067 mm	1,100 mm
Gauge	1,668 mm	1,668 mm
Width	3,085 mm	3,050 mm
Height (from upper rail point)	4,305 mm	4,250 mm
Length between bumpers	12,550 mm	14,200 mm
Max speed	~110 km/h	~90 km/h
Weight	78 t – 80 t	80 t – 85 t
Dynamic braking	-	-
Pneumatic braking	Yes	Yes
Multiple unit	Yes	Yes
Power at wheel	600 kW	800 kW
Load by axle	20 t	20 t
Configuration	Bo'Bo'	Bo'Bo'
Tractive effort (kN)	Min. 129 kN @ 14 km/h for 1,200 t	Min 254 kN @ 7,5 km/h for 1,200 t

Table 22: Shunting locomotives' general requirements

4.3.2 Autonomy

Due to the operation of this kind of vehicle, shunting locomotive autonomy is expressed in a different way. It is not described in terms of kilometres but in terms of hours of service:

AUTONOMY REQUIREMENTS		
	Inter-yard shunting locomotive (e.g. S310)	**Local shunting locomotive (e.g. S311)**
Working hours	~4 h	~4 h
Idle mode	12 h	12 h
Stand-by	8 h	8 h

Table 23: Shunting locomotives' autonomies

These figures were obtained from field information provided by the Spanish infrastructure administrator (ADIF).

4.3.3 Operational and LCC parameters

	Minimum	**Target**
Fuel cells	25,000 h (5 years)	40,000 h (8 years)
Batteries	25,000 h (5 years)	40,000 h (8 years)

Table 24: Shunting locomotives' operational and LCC parameters

4.3.4 Degraded modes, reliability, availability

DEGRADED MODES, RELIABILITY AND AVAILABILITY

Type of failure	Action: Maintain normal operation, retire vehicle…
Simple failures that cause the most harmful reduction of power	Remove vehicle from service
-50% traction power at wheel	Remove vehicle from service
-75% traction power at wheel	Remove vehicle from service

Mean time between failures (MTBF)	11,000 h

Table 25: Shunting locomotives' degraded modes

5. Vehicle and infrastructure compatibility

When providing services with hydrogen, special needs concerning the infrastructure must be considered. Railway operators will have to decide where to operate the hydrogen vehicles with the following identified requirements mainly based on compatibility and safety considerations.

Although there is no doubt that all current infrastructures are safe for trains to run on, some modifications may be needed to adapt them to the use of hydrogen. From a present perspective, the following non-exhaustive list of requirements must be met for a railway operator to provide a service.

5.1 Hydrogen refuelling station placement and terrain

If the vehicle needs to be refuelled with hydrogen, a specific refuelling operation is required. This operation is entirely different from diesel refuelling operations. Given the technical difficulties associated with the storage and discharge of hydrogen, special efforts have been made to investigate the requirements for this procedure. Task 1.4 covers all the high-level aspects related to hydrogen refuelling. The results of this study can be found in the public deliverable D1.5.

5.2 Enclosed spaces from the point of view of infrastructure

5.2.1 Tunnels

The operator provides services on lines that also frequently run through tunnels. A general requirement for tunnels is that any source of sparks should be avoided and adequate ventilation provided.

In any case, the final safety requirements for the infrastructure and operation are still under analysis in the safety study carried out in Task 9.4.

5.2.2 Stations (above ground/underground)

An underground rail station is a situation that entails considerable risks. This kind of station will need detailed analysis, including the requirement to provide a service to them.

In any case, the final safety requirements for infrastructure and operation are still being analysed in the safety study carried out in Task 9.4.

6. Operational requirements for H2 vehicles

Traditional railway operations will be disrupted by hydrogen trains. Operators should re-evaluate common tasks to include all the safety measures deemed necessary. Additional measures will be proposed during the project as new hazards are identified.

A safety mode for the hydrogen system should be implemented, with the use cases defined in Task 9.4. They could include a safety mode to automatically protect all the systems on the train that involve hydrogen, primarily for essential operations such as parking and long-term stops.

Task 1.5 studies deal with the refuelling procedures, nozzle definition and system requirements. This task also studies the advantages of 350-bar compressed H2 and, if technically possible, the feasibility of hydrogen storage at 700 bar or as liquid hydrogen. It will provide essential information on refuelling and storage.

6.1 Parking requirements (safety)

When using a hydrogen-powered vehicle, the operator should study the standard operating procedures in order to protect the train when the service has finished in the following situations:

- When the vehicle is parked in a siding or yard
- Some kind of ‘end of action’ procedure needs to be developed to secure the train when it is not running

Ideally, the train should be able to send information remotely for a certain period of time in order to continuously monitor the status of the safety-related systems.

Safety-related aspects will be assessed in the scope of Task 9.4. It will identify hazards and define mitigation measures.

7. Maintenance requirements for H2 vehicles

Maintenance operations for base vehicles should not differ from those for the overall vehicle. On the contrary, the maintainer should use a specialised workshop for hydrogen components.

Most of the requirements for all workshops in Renfe are standardised. Therefore, in general and in relation to the train, all workshop features should be the same as for any other vehicle.

A crane moves all the equipment. Its position and characteristics, the characteristics of the hook, tractive capacity, mechanical and electrical connection must match the hydrogen vehicles.

For bogies, vertical movements should be appropriate to their weight. To remove the bogies, two methods are usually used: The bogies are removed using a lifting plate, or the car body is lifted with hydraulic equipment.

The lifting plate must take the following into account:

- Synchronisation of the system
- Minimum clearance height for a low unit
- Position for lifting points
- Dimensions of the lifting plate

A procedure to access roof equipment is required. Typically, a key interlock system is used to allow access when following a sequence where the catenary is switched off. In parallel, personnel should use a key interlock system or other means in the vehicle.

The length and height of gantries will depend on the type of vehicles to be maintained and differ from those for locomotives, especially when the aim is to maintain multiple units. Some gantries use fixed handrails and others use folding handrails.

Workshop pits must allow safe dismantling of the underframe equipment and low-voltage chassis equipment, using appropriate machinery and lifting equipment. Hence, in the worst case, crane clearance is required for the removal of equipment, which means that the loads and dimensions of the equipment must be within a certain range. Low-voltage chassis elements must be protected both mechanically and electrically.

7.1 Workshops

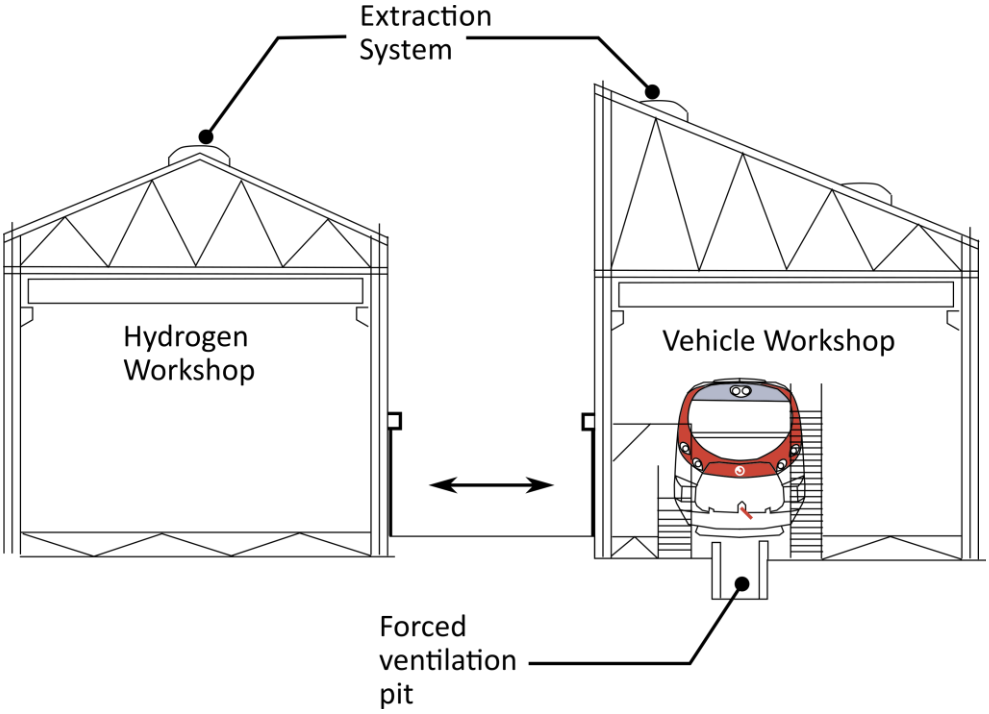

Figure 17: Workshop set-up to maintain hydrogen railways

Given that the train would require electrical power during certain maintenance work, the first type of electrical connection required is a 415-V train connection to supply the train during the maintenance work; secondly, an additional system to supply the traction batteries with energy so they can be recharged in a reasonable time and at least the same number of battery modules to connect the train in the maintenance workshop. If possible, they should be mounted in the rail yard as well.

Adequate ventilation is required to prevent the hydrogen concentration from exceeding the lower explosion limit (LEL) of 4% during the maintenance work.

In any case, the final safety requirements for the maintenance work are still being analysed as part of the safety study carried out in Task 9.4.

8. Conclusion

This deliverable describes all the services currently provided by some form of diesel vehicle. Their requirements are given at a high level for multiple units, mainline locomotives and shunting locomotives.

This work identifies multiple units as the more suitable for the application of FHCPP in a first approach and considering the state of the art. The partners have carried out a more comprehensive analysis of this type of vehicle. They have also taken into account the market expectations for multiple units in Spain and the Spanish government's directive to avoid non-green traction technologies.

The requirements for vehicles and services were analysed in detail for Spain and complemented by the additional analysis carried out for Germany in Task 1.1.

Secondly, the study describes vehicles providing services from a general point of view in terms of requirements. These requirements relate to performance, autonomy, operational aspects, degraded modes and LCC. They constitute a set of characteristics of the vehicles that were used to define the FCHPP in Task 1.3. Tasks 3.2 to 3.4 use them to determine the scalability and modularity of the FCHPP.

The requirements reflected here represent the state of the art for batteries and fuel cells. These components are expected to evolve in the future and exceed current performance.

The requirements for the refuelling protocol and the HRS are considered from an operational point of view, while a more in-depth development is carried out in Task 1.4.

The deliverable also includes the high-level infrastructure requirements to ensure compatibility as well as operational and maintenance aspects. In general, all safety requirements are still subject to further analysis as part of Task 9.4. Partners could add additional requirements as Task 9.4 advances.

9. References

[1] European Comission, 'Grant Agreement Number- 101006633 - FCH2Rail', 2020.

[2] Consortium FCH2Rail Project, 'Consortium Agreement FCH2Rail', 2020.

[3] Study on use of fuel cell hydrogen in railway environment, Roland Berger, 2019.

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

A.1 List of figures

A.2 List of tables