Study on use of fuel cell hydrogen in railway environment

Study overview

Shift2Rail Joint Undertaking
FCH 2 Joint Undertaking

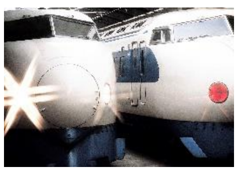
Brussels, 20 November 2019

Hydrogen for rail applications is becoming more and more visible publicly – First trains demonstrated in Germany, more projects planned

Recent developments …

News

"Germany launches world's first hydrogen-powered train"
The Guardian, 17 September 2018



"Hydrogen fuel cell trains herald new steam age"
The Times, 13 May 2018

"French train giant Alstom set to make UK's first hydrogen fleet at British site"
The Telegraph, 14 May 2018

Benefits of FCH rail applications

> Zero emission
> Route flexibility
> Reduced noise
> Higher range compared to battery solutions
> Avoidance of electrification cost

Project example:

FCH trains in North-West Germany

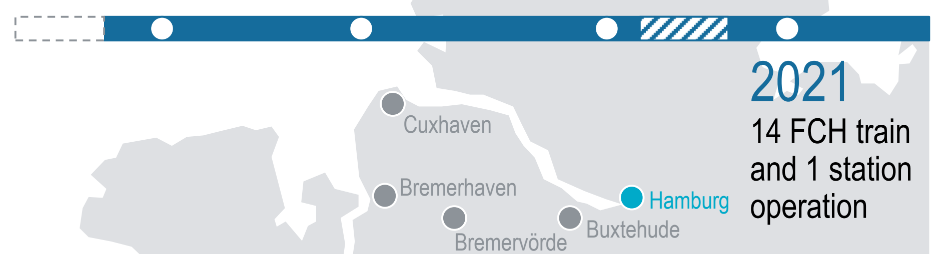
Develop-ment

2016 Alstoms presents first FCH train

2017 LNVG contracts Alstom for 14 FCH trains

2018 First FCH train in operation

2021 14 FCH train and 1 station operation



> FCH train "Coradia iLint" development by Alstom (with support from German government)
> Northern German regional rail operator LNVG commissioned Alstom for 14 FCH trains incl. a 30 year maintenance contract
> Hydrogen is provided by a refuelling station built and operated by Linde (30 year contract)
> State government of Lower-Saxony is supporting the project

Source: Alstom; Roland Berger

The study analysed the potential of FCH technology in the rail industry to lay the groundwork for future R&I projects

Study objectives

Main objectives

1 Provide a **business case and market potential analysis** per rail application and geographical area for the use of FCH technologies in the railway sector and give an overview about the state of the art as well as existing initiatives

2 Provide **case studies by rail application** expressing **potential opportunities** and carry out a **concept design** for each case study compared with other alternative solutions, in a multimodal perspective

3 Identify **technical and non-technical barriers** for the implementation of FCH technologies in the rail sector and show needs in terms of research and innovation, regulation and standards

4 Produce **recommendations on future activities** with particular focus on short term R&I

As a result we have:

- Assessed the potential and applicability of fuel cells & hydrogen in rail and performed the **analytical work as basis for future Research & Innovation funding** from EU sources such as S2R and FCH 2 JU

Source: Roland Berger

We worked with an Advisory Board consisting of FCH and rail industry stakeholders from four – A big thank you for your support!

Advisory Board composition

System integrators / OEMs

- ALSTOM
- SIEMENS
- CAF
- BOMBARDIER

Infrastructure/H_2 suppliers

- THE LINDE GROUP
- TRACTEBEL ENGIE
- HEXAGON
- PITPOINT CLEAN FUELS
- AIR LIQUIDE
- ENGIE
- nel

Operators

- ALPHA TRAINS
- SBB CFF FFS
- ProRail
- DB BAHN
- ÖBB
- ZILLERTALBAHN zug · bus · dampf
- renfe
- SNCF
- Stagecoach

FCH technology providers

- HYDROGENICS SHIFT POWER | ENERGIZE YOUR WORLD
- BALLARD
- POWERCELL
- Nedstack PEM FUEL CELLS
- PROTON MOTOR Fuel Cells · Power Systems
- FUEL CELL POWERTRAIN
- Intelligent Energy

Source: Roland Berger

FCH technology can become a viable alternative to replace diesel engines – First products for passenger service enter market

Shift2Rail and FCH JU study focus applications

- We analysed the potential of fuel cell and hydrogen technology for rail transport for three application areas
- Most activity visible in multiple unit application area (products already being launched
- First insights suggest attractive use cases and good market potential

	Application	Maturity of technology	Range	Speed	Lifetime
Multiple units	Passenger operation in regional transport	First FCH trains in operations since September	up to 1,000 km[1)]	up to 140 km/h	30 years
Shunters	Shunting and short distance operation	?	200-1,000 km[1)]	up to 50 km/h	35 years
Mainline Loco-motives	Med. + long distance freight + passenger service	?	500-1,100 km[1)]	up to 120 km/h	30 years

1) Depending e.g. on # cargo/passengers, stops and topography

Legend: Application; Maturity of technology; Range; Speed; Lifetime; Market entry (shaded: Multiple units)

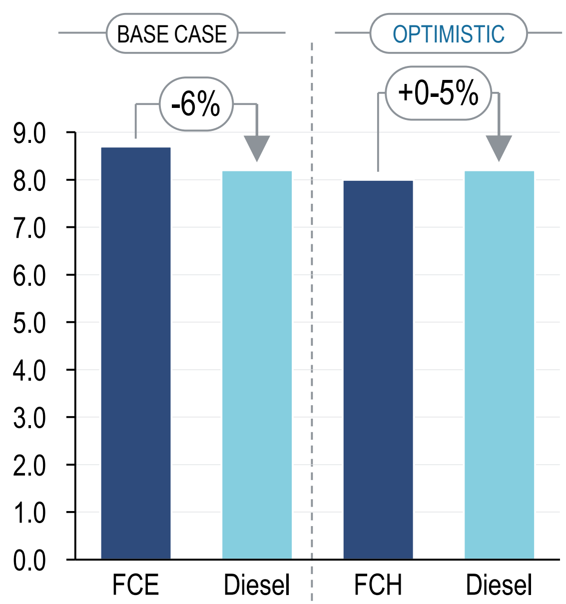
Source: Alstom, ÖBB, Roland Berger

FCH technology has promise in rail sector - Can be competitive with existing technology under certain conditions

Summary results

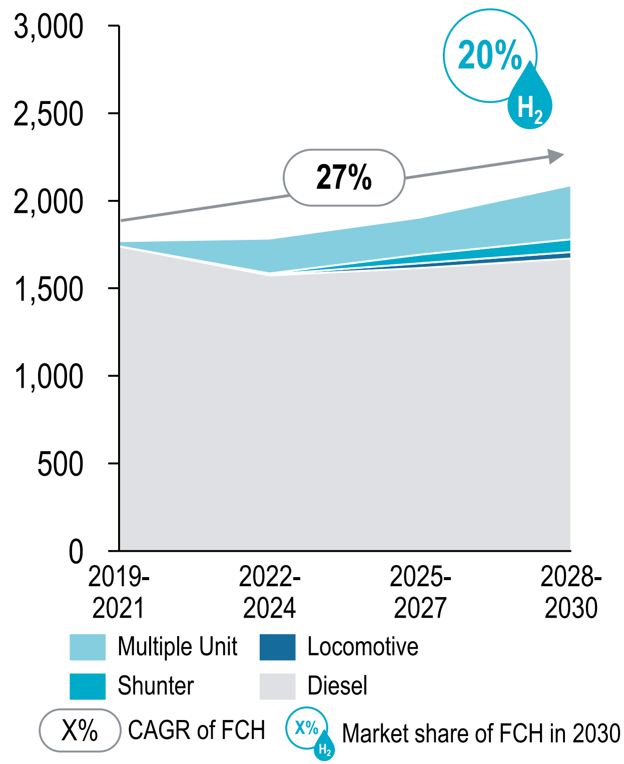
Economic

Estimated Multiple Unit Total Cost of Ownership (TCO) [EUR/km], 2022 prices



Market potential

EU Market potential FCH trains – Base scenario [standard units]



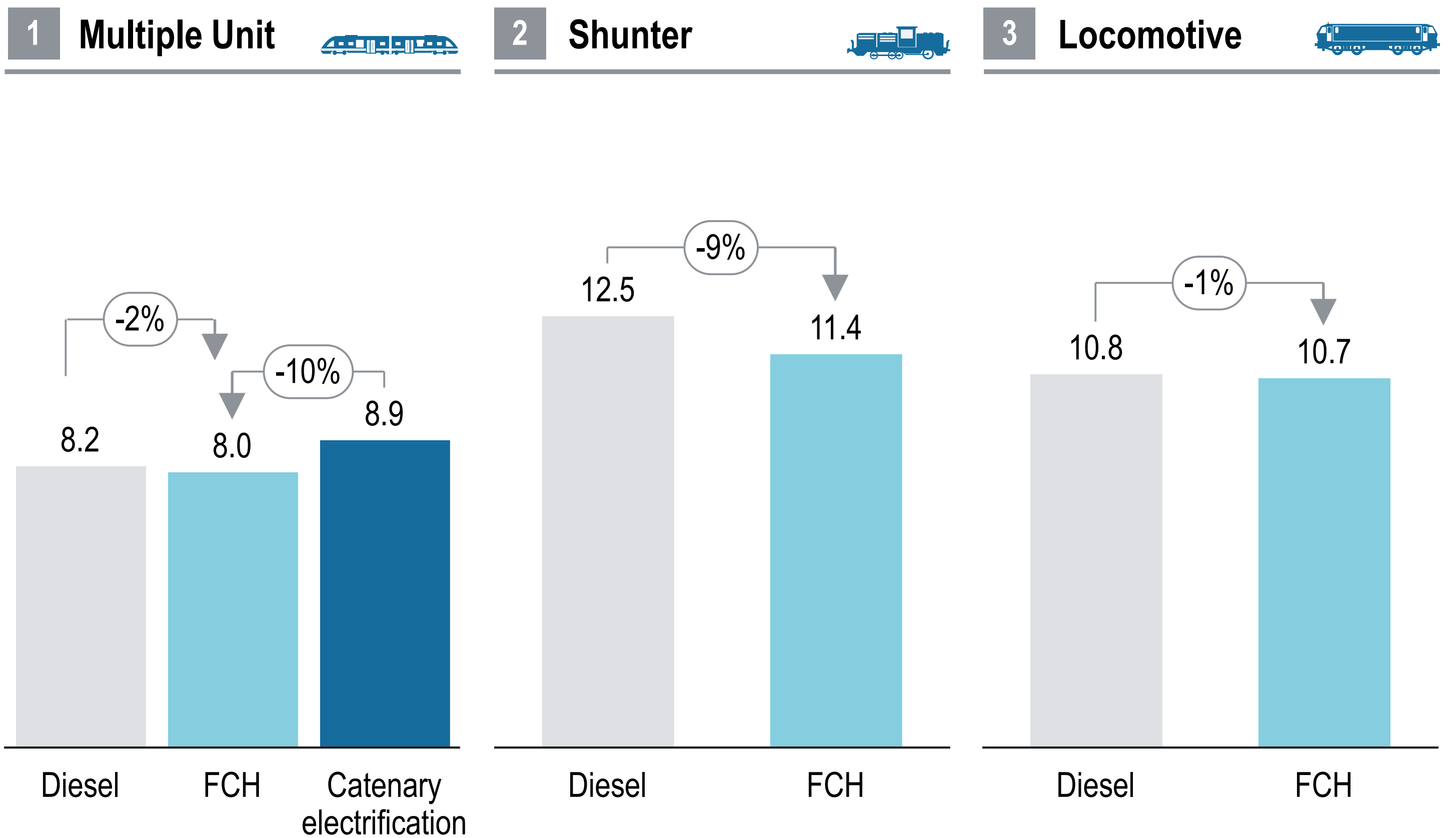
Case and barrier analysis

- 10 case studies demonstrated that FCH technology can be competitive highly dependent on specific case conditions
  - FCH technology competitive on non-electrified routes ~100 km
  - FCH attractive for routes with low utilisation
  - Low energy prices driver of competitiveness (e.g. by-product hydrogen)
- No show-stopping barriers for FCH in rail exists but still optimization potential
- Three research and innovation topics have been identified to tackle these barriers

Source: Roland Berger

Optimistic assumptions suggest competitiveness of the FCH train in all three applications with a TCO advantage up to 10%

High-level TCO assessment – Optimistic case in 2022 [EUR/km]



+X% FCH TCO difference versus alternatives

Comments

> A TCO assessment in a optimistic case is based on a potential for:
  – Electricity price reduction
  – Diesel price increase
  – H_2 consumption decrease
  – FCH train CAPEX reduction

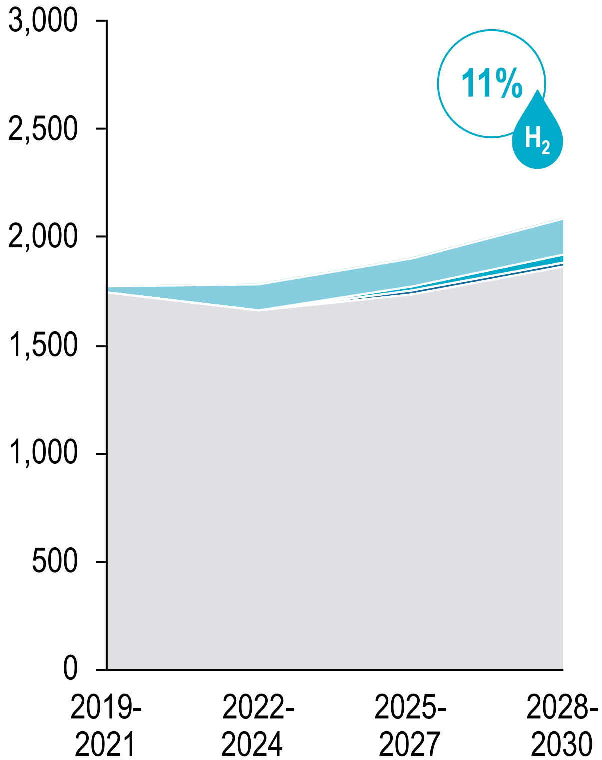
> TCO modelling suggests that FCH trains can be competitive given **high annual utilisation** and **low energy sourcing cost**

Source: Expert interviews, Roland Berger

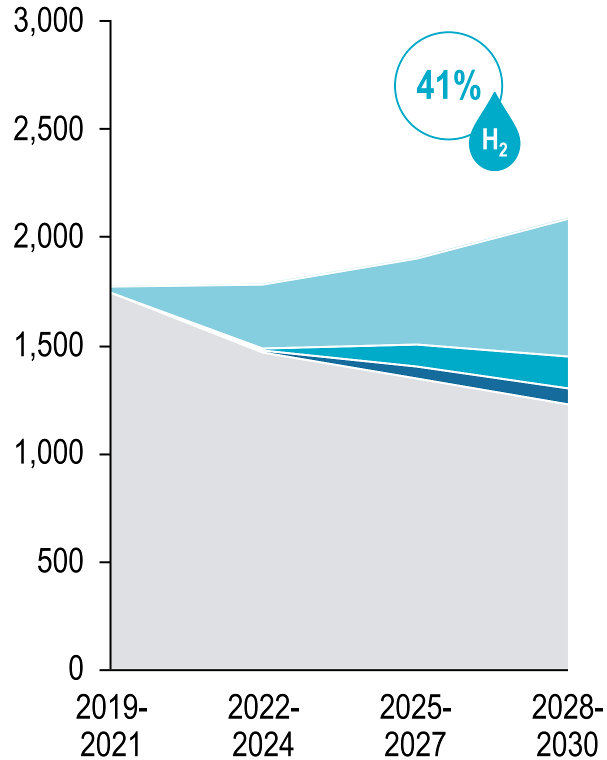
Even at this early stage of market development, market feedback suggests significant potential for FCH trains in Europe

Market potential for FCH trains in Europe [standard units[1)]]

Low scenario



High scenario



Additional market potential exists

Market potential for FCH trains could further increase by addressing, e.g.:

> Existing green image of the rail segment and lack of awareness for the business case of FCH trains

> Long lifetime of diesel trains and short-term purchasing decisions

> Uncertainty about alternatives to FCH technology

> Market potential from export opportunities to other geographies

Multiple Units | Shunter | Mainline Locomotive | Diesel | X% CAGR of FCH share | X% Market share of FCH in 2030

1) According to definition of UNIFE World Rail Market Report

Source: Market research, Expert interviews, Roland Berger

A Market potential in the base scenario is driven by FCH Multiple Units in the Frountrunner markets; by Shunters – in other markets

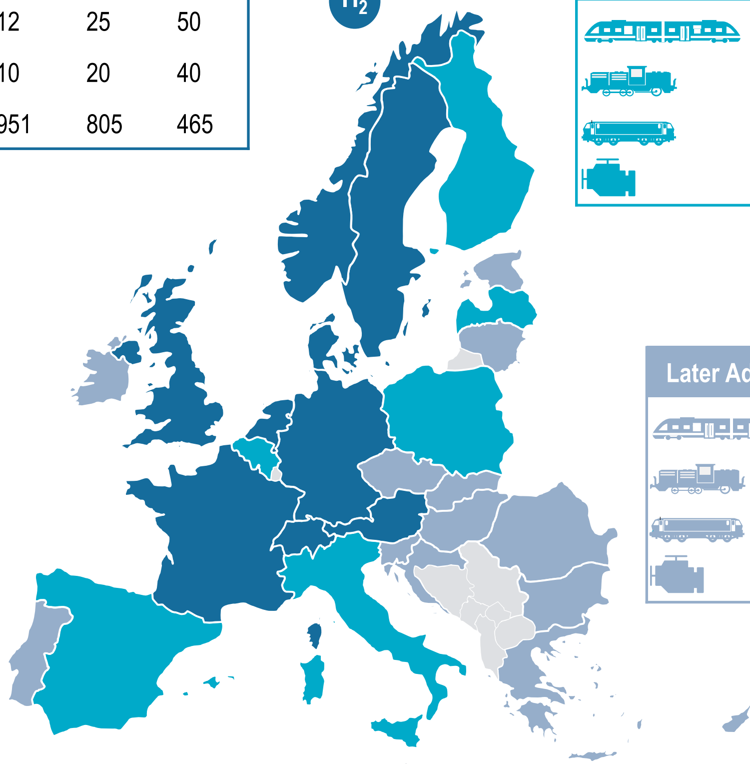
Overview of FCH train markets outlook for 2030 [standard units[1)]]

Frontrunner	Low	Base	High
	150	273	569
	12	25	50
	10	20	40
	951	805	465

Base 2030 28% H_2

Newcomer	Low	Base	High
	10	21	41
	15	29	58
	4	8	17
	497	467	409

Base 2030 11% H_2



Later Adopter	Low	Base	High
	7	15	30
	9	19	37
	4	8	15
	419	398	357

Base 2030 9% H_2

X% H_2 Market share of FCH in 2030

Comments

> The Market potential will depend on the projected diesel purchasing volumes

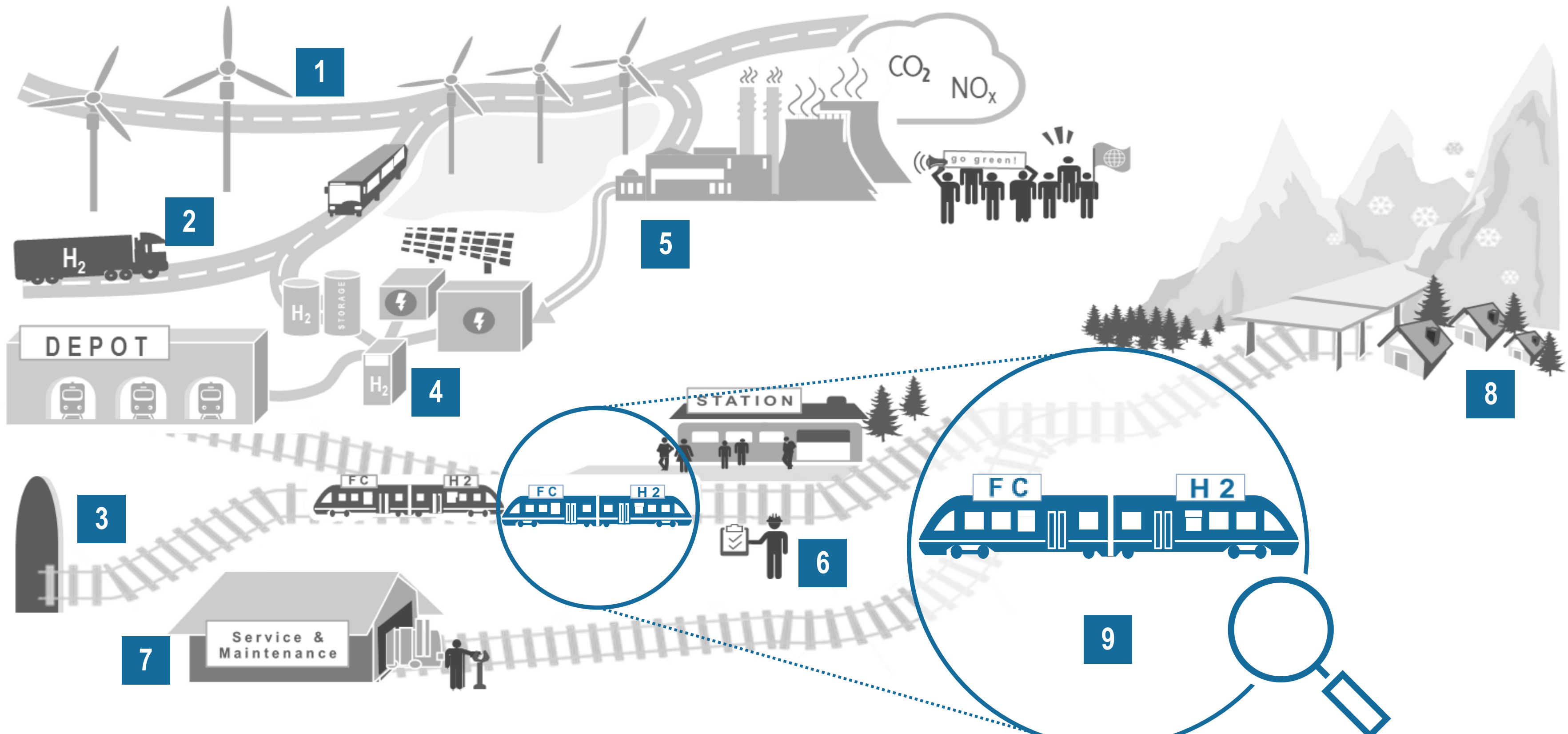
> Substitution of diesel trains is driven by the Multiple Units in the Frontrunner markets

> On the other hand, Shunters drive the substitution in the Newcomer and Later Adopter markets

1) According to definition of UNIFE World Rail Market Report

Source: Market research, Expert interviews, Roland Berger

Analysis of the FCH train eco-system included several selected focus topics – One focus topic was developed in each case study



1 Renewable H_2 generation via electrolysis
2 Multimodal approach with buses/trucks/etc.
3 Interoperability with other infrastructure
4 H_2 refuelling station
5 Industrial H_2 supply
6 Regulations and permitting
7 Service and maintenance requirements
8 Safety/public acceptance of H_2 technology
9 Technical requirements

Source: Roland Berger

No barriers are show-stoppers for FCH rail technology, but R&I projects are required to realise a broader commercial potential

Perspectives on barriers and R&I

Barriers for FCH trains

> **No** principle **show-stoppers** to the deployment of FCH technology in the rail environment exist
> **High priority barriers** are related to **financing** FCH train deployment, **lack of standard scalable design** and **H_2 storage optimisation**

Suggested Research and Innovation (R&I)

> **R&I projects** can bring FCH technology significantly closer to commercialisation by **addressing high priority barriers**
> Three key project topics
  – **Large-scale demonstration** of Multiple Units fleets
  – **Prototype devel.** and testing of Shunters or Mainline Locomotives
  – Research and **tech. dev.** of **optimised H_2 storage** system
> **Medium**, **low** priority **barriers can integrated** in the same R&I project

Source: Expert interviews, Roland Berger

FCH technology is a promising pathway to further improve the environmental friendliness of rail transportation

Conclusion

Numerous exciting developments have taken place during the project ...

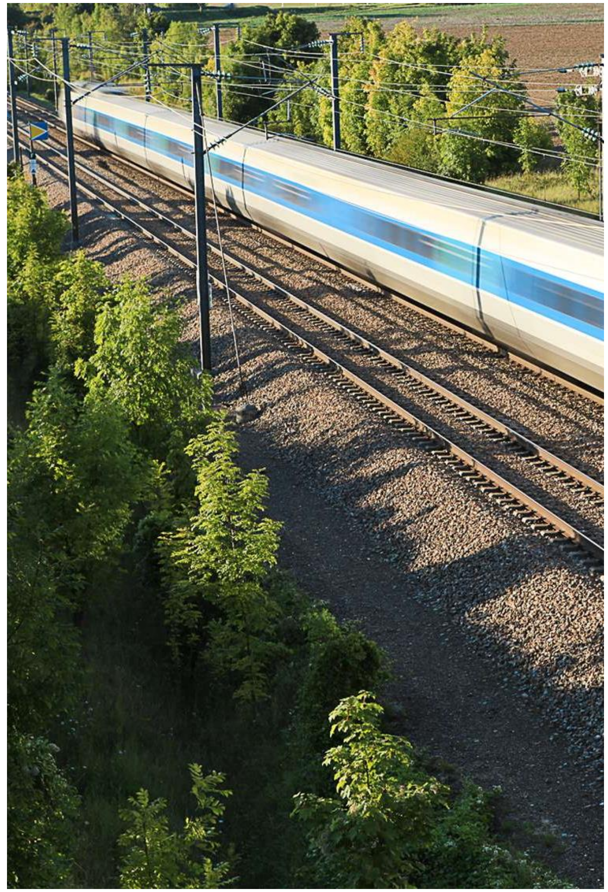
"Germany launches world's first hydrogen-powered train" The Guardian, 17 September 2018

"SNCF to run fuel cell trains in 2022" Railway Gazette, 10 December 2018

... and the future could hold more potential

"First European hydrogen Shunters go to work in new trial" Breaking News, 2020

"1,000th FCH train enters service, as Europe targets diesel rail emissions" Breaking News, 2030



Source: The Guardian, Railway Gazette, Roland Berger

We have dedicated hydrogen and fuel cell experts at your disposal in all major global markets – Our expert today is...

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- > Project financing and PPP
- > Energy/ renewable energy
- > Zero emission transport
- > Institution building
- > Strategic communication
- > Technology commercialization
- > Financing of innovative technologies

Roland Berger

THINK:ACT

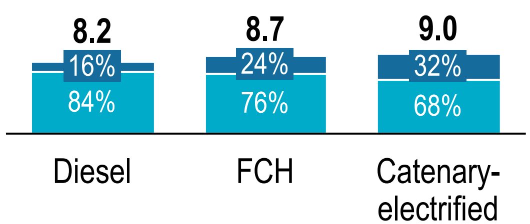
The TCO is mainly driven by high OPEX costs, economies of scale on the infrastructure side and asset utilisation rate

Key TCO drivers

CAPEX and OPEX costs

> TCO is mainly driven by energy OPEX, i.e. the electricity price for on-site production or the external purchasing cost of trucked-in hydrogen

> CAPEX for the train is decisive for a competitive TCO

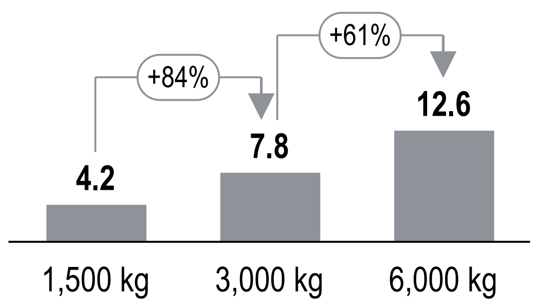


Economics of scale

> Larger and high performing HRS and H_2 production facilities have a positive impact on the TCO

> Power purchasing cost on the FCH train side can be expected with a larger batch purchase orders

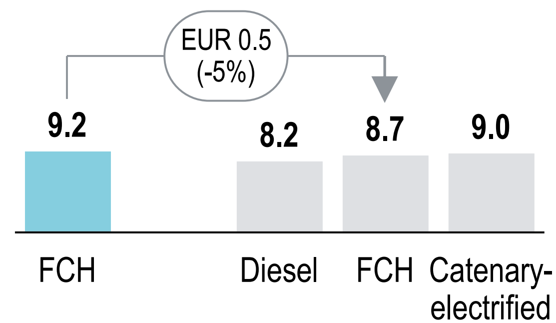
> Specific train components (e.g. FC stacks) show a significant cost reduction potential



Asset utilisation

> A heavier utilisation of fuel cell system will decrease the service and maintenance intervals leading to higher costs

> A hydrogen refuelling and production infrastructure is another option for an optimised utilisation rate due to no significant hourly, daily and seasonal peaks



CAPEX[1] in the base case [EUR/km]
OPEX[1] in the base case [EUR/km]
Daily kg capacity of HRS and its CAPEX [EUR m]
TCO[1] given 50% utilisation of HRS and H2 production facility[2] [EUR/km]
TCO[1] given 100% utilisation of HRS and H2 production facility[2] [EUR/km]

1) For a Multiple Unit 2) Based on a 6,000 kilogram per day station capacity

Source: Expert interviews, Roland Berger

Detailed analysis was conducted on ten case studies selected based on balanced technological and geographical perspectives

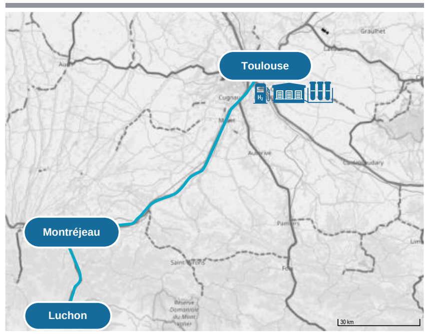
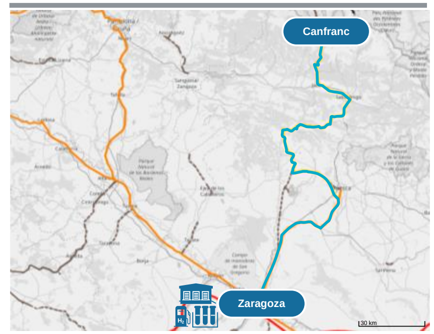
Overview of selected case studies

	Location	Application	Country
1	Groningen & Friesland		NL
2	Aragon region		ES
3	Montréjeau – Luchon		FR
4	Brasov – Sibiu (Theoretical)		RO
5	Riga node		LV
6	Gdansk		PL
7	Hamburg-Billwerder		DE
8	Frankfurt (Oder) – Hamburg		DE
9	Kalmar – Linköping		SE
10	Tallinn – Narva		EE

Source: Roland Berger

FCH MUs present a clean, economically sensible alternative to existing technology in dense networks with many unelectrified lines

Multiple Unit case study results [EUR/km$_{train}$]

		Montréjeau – Luchon, France	Aragon, Spain	Groningen & Friesland, Netherlands
Overview				
Track length		140 km	165 km	300 km
Rolling stock		3x 4 car trains (bi-mode)	2x 4 car trains (bi-mode)	70x 3 car trains
H_2 consumption		0.36 kg/km	0.31 kg/km	0.22 kg/km
Characteristics		Partly electrified route with a low utilisation on 36 km	Cross border connectivity and long rout without electrification	Fast trains for intercity connections
Diesel		18.5	9.3	4.8
FCH	H_2	**21.2**	**12.4**	**4.9**
Catenary		27.5	22.5	4.4
Battery		19.9	13.7	5.2
CO_2 saving potential in one year		**1,334 t**	**767 t**	**56,389 t**

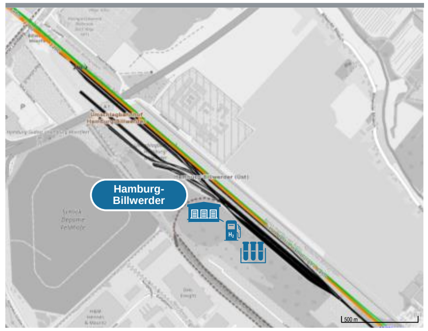
Source: Expert interviews, Roland Berger

FCH technology is more competitive in use cases where Shunters have larger loads, idle less and travel longer distances

Shunter case study results [EUR/km_{train}]

Overview

Hamburg-Billwerder, Germany



Riga Node, Latvia

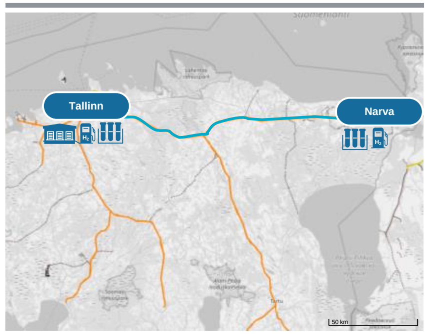
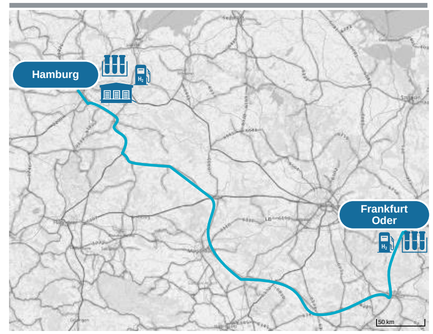
Gdansk, Poland

	Hamburg-Billwerder, Germany	Riga Node, Latvia	Gdansk, Poland
Track length	10 km	100 km	35 km
Rolling stock	15 Shunters	15 Shunters	10 Shunters
H_2 consumption	0.39 kg/km	0.49 kg/km	0.72 kg/km
Characteristics	Shunting yard in a large urban area and next to Hamburg port	Shunting operation between several port terminals	Marshalling yard in collocation of the refinery supplying hydrogen
Diesel	10.1	20.9	32.1
FCH	**12.7**	**20.4**	**36.7**
Catenary			
Battery	11.6	21.8	36.9
CO_2 saving potential in one year	**1,969 t**	**3,350 t**	**339 t**

Source: Expert interviews, Roland Berger

FCH Mainline Locomotives could be competitive in cases where route interoperability is limited, but still face barriers to market entry

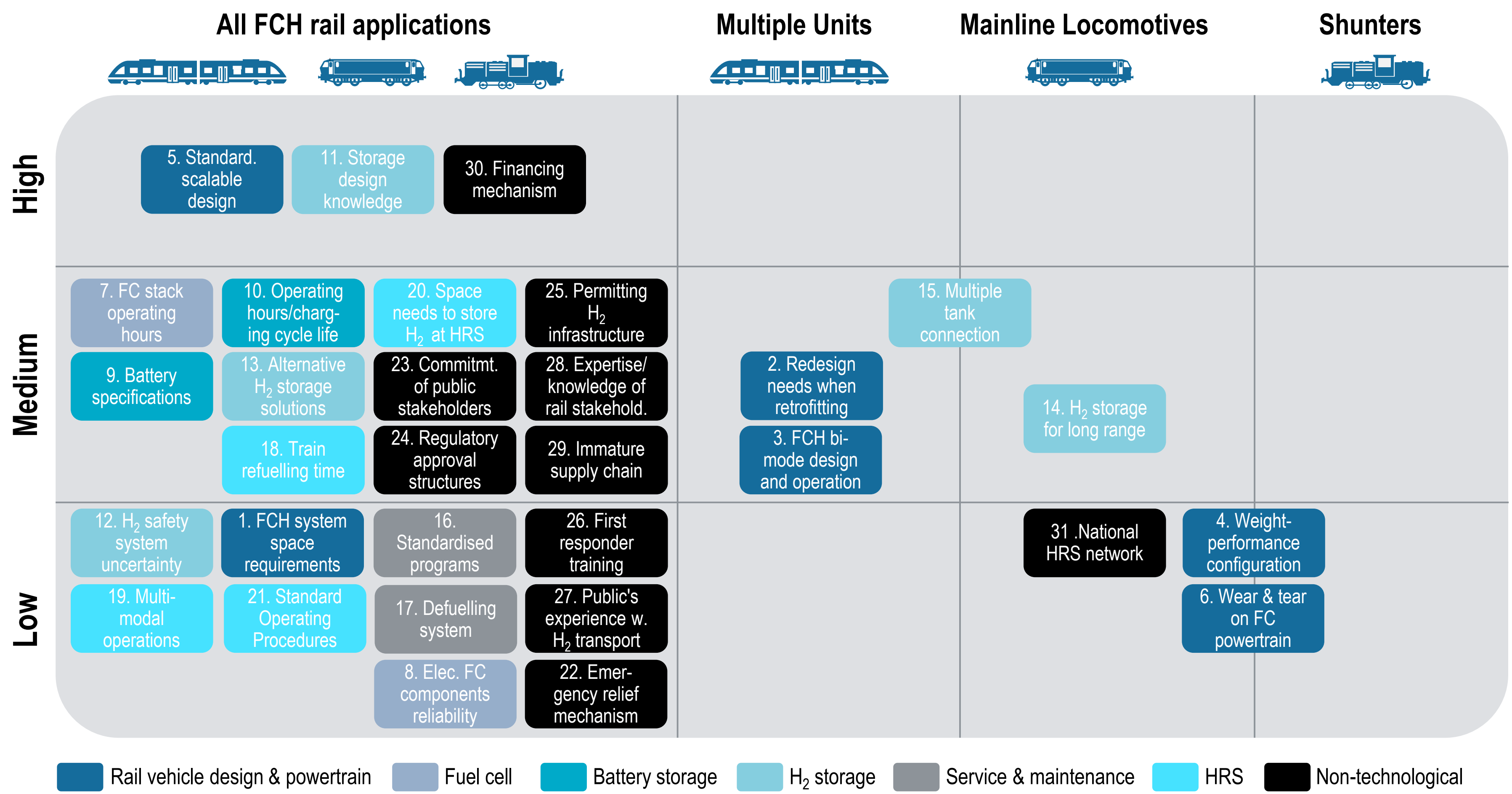
Mainline Locomotive case study results [EUR/km$_{train}$]

	Tallinn – Narva, Estonia	Frankfurt (Oder) – Hamburg, Germany	Kalmar – Linköping, Sweden
Overview			
Track length	210 km	720 km	230 km
Rolling stock	2 Locomotives	5 Locomotives	5 Locomotives
H_2 consumption	0.67 kg/km	0.82 kg/km	0.48 kg/km
Characteristics	Cross-border operation between Russia and Estonia	Shunting operation between several port terminals	Passenger and freight transport between two cities
Diesel	22.6	9.2	5.7
FCH	**22.8**	**11.9**	**6.7**
Catenary	24.4	6.4	22.0
Battery			
CO_2 saving potential in one year	**2,556 t**	**12,874 t**	**4,980 t**

Source: Expert interviews, Roland Berger

Analysis identified 31 barriers in total, with most applying to all FCH train applications and other specific to certain use cases

Overview of barriers for FCH trains



Source: Roland Berger

Three priority R&I topics should be addressed to unlock the full market potential of FCH trains

Overview of recommended R&I projects

	A Large-scale demonstration of Multiple Unit train fleets	B Development, engineering and prototype operation of Shunters or Mainline Locomotives	C Technology development for optimised hydrogen storage system for FCH rail applications
High-level project scope	Trains: 10 - 15 Refuelling stations: 1 – 2	Locomotives: 5 - 10 Refuelling stations: 1 – 2	
Objectives of project	> Large scale demonstration project of 15 or more Multiple Units could enable the first fleet sized FCH train deployment	> Development and implementation of five new FCH Shunters or Mainline Locomotives (or ten retrofits), including concept design, engineering, and prototype	> Integrated technology development project for optimised hydrogen storage including analysing; filling pressure, tank location, cross-car connections, etc
Est. budget before funding	EUR 80 – 100 m	EUR 15 – 20 m	EUR 4 – 7 m

Source: Roland Berger