JIVE – Joint Initiative for hydrogen Vehicles across Europe

Deliverable 3.1

MEHRLIN – Models for Economic Hydrogen RefueLling INfrastructure

Activities 2.4, 3.1 and 3.2

Performance Assessment Handbook

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0 Executive Summary

The projects JIVE and MEHRLIN run in parallel and work in close cooperation. The key objective of JIVE is to implement and operate of 139 zero emission fuel cell buses in five EU member states at unprecedented scale, thereby advancing their commercialisation. The main objective of MEHRLIN is to promote, deploy and commercialise hydrogen as an alternative fuel, contributing to the European alternative fuel implementation strategy. This includes operating real-pilot hydrogen refuelling stations at seven locations along four Core Network Corridors of the trans-European Transport Network (TEN-T).

Most of the buses co-funded under JIVE will refuel at stations co-funded under MEHRLIN. Both projects involve analysis tasks based on data collected during the demonstration phase. In this respect, JIVE concentrates on the technical performance of the stations and buses, while MEHRLIN focuses on the financial aspects of refuelling station ownership and operation, in particular achieving bankability.

To be able to monitor and assess to which degree targets are achieved, operating data need to be collected, compiled, and evaluated on a steady and coherent basis. This Performance Assessment Handbook is the basis of all monitoring and analysis activities of Task 3.1 in JIVE and Activities 2.4, 3.1 and 3.2 in MEHRLIN. It thus:

- Defines the performance indicators for assessing hydrogen infrastructure and fuel cell bus performance, also in comparison to reference technology (buses with internal combustion engines) as well as to those of other novel drivetrains (notably long range electric buses).
- Defines the descriptive parameters and data points required to calculate indicator figures.
- Explains the frequency of data collection and related details.
- Determines the necessary data structures and formats.
- Defines roles and responsibilities for data collection and performance evaluation.

Figure 0-1 gives an overview of the flow and processing of information:

- The descriptive parameters characterise the deployed hardware, such as the nominal pressure and efficiency of an electrolyser etc. They are usually collected once.
- The data points are the items to be monitored during demonstration. The operating data are collected at the data points. They are recorded regularly, typically daily (e.g. the distance travelled by a bus) or per event (the amount of hydrogen refuelled to a bus).
- The performance indicator values are calculated using the operating data and selected descriptive parameters.

Key Performance Indicators are subsets from the complete lists of bus and infrastructure performance indicators. For the Key Performance Indicators, the work programmes of the two projects state target figures, such as a minimum efficiency of on-site hydrogen generation and a maximum hydrogen consumption of the buses per 100 km travelled.

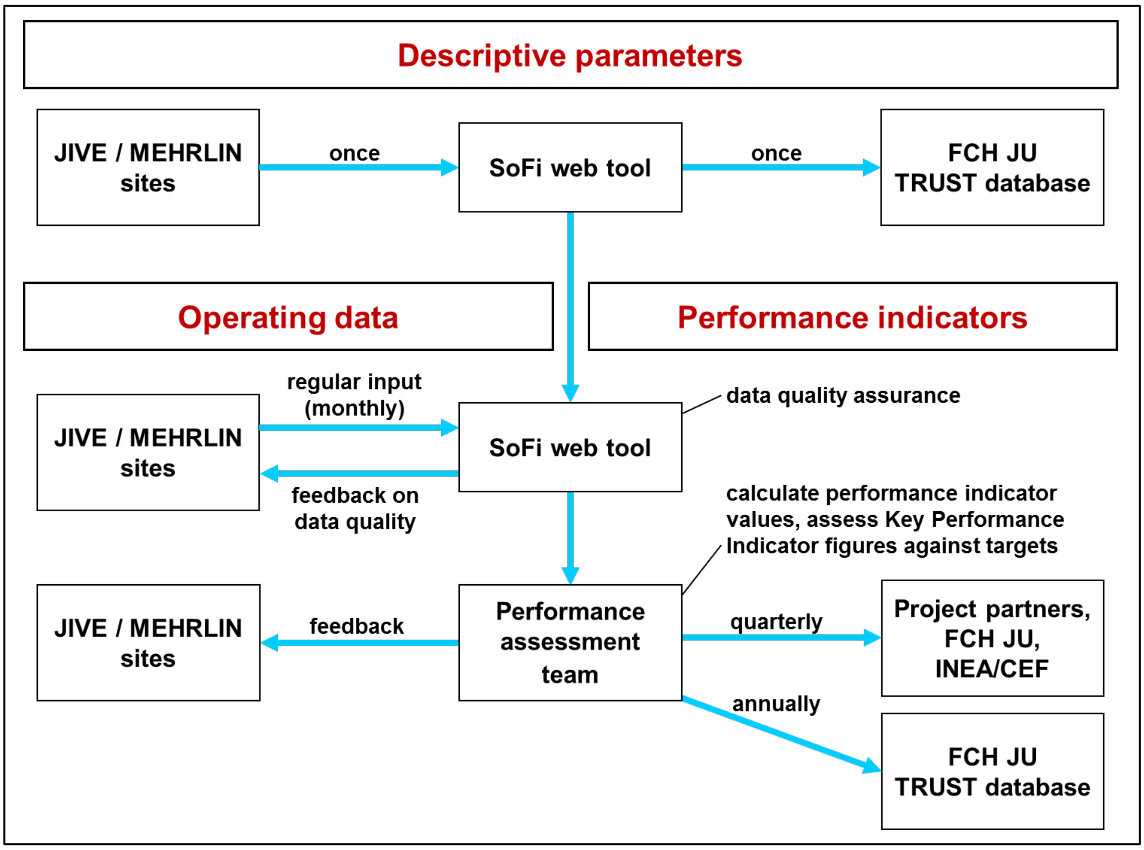

Figure 0-1: Overview of the flow and processing of information for the performance assessment.

Table of Contents

Index of Figures

Index of Tables

List of Abbreviations and Terms

RB	Reference Bus
CAPEX	CAPital EXpenditure
CEF	Connecting Europe Facility
CHIC	Clean Hydrogen in European Cities, project co-funded by the FCH JU under the 7th Framework Programme
CUTE	Clean Urban Transport for Europe, project co-funded by the EU under the 5th Framework Programme
DoA	Description of the Action (formerly Description of Work / DoW)
EU	European Union
FC	Fuel Cell
FCB	Fuel Cell Bus
FCH JU	Fuel Cells and Hydrogen Joint Undertaking, first phase of the FCH JU under the EU 6th and 7th Framework Programme; abbreviation also commonly used for the FCH 2 JU
FCH 2 JU	Fuel Cells and Hydrogen 2 Joint Undertaking, second phase of the FCH JU under the EU Horizon 2020 Framework Programme
FP	Framework Programme
H_2	Hydrogen
HIAD	Hydrogen Incidents and Accidents Database
High V.LO City	Cities Speeding up the Integration of Hydrogen Buses in Public Fleets, project co-funded by the FCH JU under the 7th FP
HPU	Hydrogen Production Unit
HRU	Hydrogen Refuelling Unit
HRS	Hydrogen Refuelling Station (also referred to as Hydrogen Refuelling Infrastructure or Hydrogen Infrastructure)
HyFleet:CUTE	Hydrogen for Clean Urban Transport in Europe, project co-funded by the EU under the 6th Framework Programme

HyTransit	European Hydrogen Transit Buses in Scotland, project co-funded by the FCH JU under the 7th FP
INEA	Innovation and Networks Executive Agency
JRC	Joint Research Centre of the European Commission
kWh	kilowatt-hour
LHV	Lower Heating Value (for hydrogen: 33.33 kWh/kg)
Nm^3	Normal cubic metre (1 m^3 of dry gas at 1,013 bar absolute and 0°C)
OPEX	OPerational EXpenditure
TEN-T	Trans-European Transport Network
ULCF	Ultra-Low Cold Fill
WP	Work Package

1 Introduction

The projects JIVE and MEHRLIN run in parallel and work in close cooperation. JIVE focuses on the demonstration of fuel cell buses while under MEHRLIN most of the corresponding hydrogen refuelling facilities are implemented and operated. Both projects involve analysis tasks based on data collected during the demonstration phase. In this respect, JIVE concentrates on the technical performance of the stations and buses, while MEHRLIN focuses on the financial aspects of hydrogen refuelling station (HRS) ownership and operation (regarding the JIVE buses but also other vehicles), in particular achieving bankability.

1.1 Objectives of the JIVE project

The main objectives of the JIVE project are:

- Deployment of 139 zero emission fuel cell (FC) buses in 5 EU member states at unprecedented scale (Germany, UK: 3 regions/cities each; Italy, Latvia, Denmark: 1 city each)
- Advance commercialisation of FC buses through large-scale deployment of vehicles and achieve commercial viability for bus operators by end of project (early 2020s) to minimize/ eliminate need for subsidies
- Collaboration of multiple cities and regions in joint procurement processes in 3 regional clusters, allowing large orders to be placed with single bus suppliers. Common specifications for the buses are used to unlock economies of scale.
- Empower local and national governments to regulate for zero emission propulsion for public transport systems

The project comprises five work packages (WP):

1. Bus procurement, deployment and operation
2. Infrastructure deployment and operation
3. Monitoring and analysis
4. Dissemination
5. Project management

1.2 Outline of JIVE work package 3 "Monitoring and analysis"

The WP comprises five tasks:

- Task 3.1 – Data collection and analysis
- Task 3.2 – Analysis of quality of service and stakeholders' acceptance
- Task 3.3 – Impacts on public health and urban living
- Task 3.4 – Best practice and commercialisation planning
- Task 3.5 – Inputs from the industry panel

Objectives of the performance assessment carried out in WP 3 are:

- Develop and implement a data collection strategy and analysis methodology for the evaluation of the technical, economic and operational performance of FC buses and the deployed hydrogen refuelling infrastructure including a comparison of FC buses with diesel reference buses (Task 3.1)
- Assess the environmental benefits and social impacts of the deployed technology e.g. by evaluating the impact of FC bus fleets on public health and urban living
- Capture the lessons learned from implementing and operating large hydrogen bus fleets for follower and observer cities
- Support the operators with the introduction of FC buses and identify the remaining key barriers to their future deployment
- Elaborate pathways for the deployment of larger stations and expanding FC bus fleets.

This document focusses on the data collection and analysis under JIVE Task 3.1.

1.3 Objectives of the MEHRLIN project

The main objective of the MEHRLIN project is to promote, deploy and commercialise hydrogen as an alternative fuel, hence contributing to the European alternative fuel implementation strategy. This includes studies with real-pilot deployments at seven locations in Italy, Germany, the Netherlands and United Kingdom along four Core Network Corridors of the trans-European Transport Network (TEN-T):

- North-Sea Mediterranean,
- North Sea Baltic,
- Rhine-Alpine and
- Scandinavian-Mediterranean.

To achieve the overall objective, the specific objectives will be met by implementing five activities:

1. Deployment of stations
2. Operation of stations
3. Demonstrating the bankability of the stations
4. Dissemination to encourage future deployment
5. Project management

1.4 Outline of the data management in MEHRLIN

Operational and economic data will be collected and examined with the final objective to demonstrate the bankability of the HRSs. The performance of the stations will be assessed from a technical, practical and economic perspective. Monitored data from Activity 2.4 (Data collection) will be summarised into concise reports, setting out the performance of the stations under this project (Activity 3.1 – Analysis of economic data; Activity 3.2 – Analysis of technical and practical performance), and extrapolating the key requirements for the deployment of profitable stations in the future. In addition, the partners will work with financiers to assess these projects in terms of accessing conventional infrastructure debt funding and provide a report on the options for configuring future projects to maximise the debt funding available (Activity 3.3 – Understanding the bankability of the stations).

The assessment of the technical and economic performance of the stations will fulfil the contractual requirements and follow the joint way with the JIVE monitoring and analysis work. Thus, synergies between MEHRLIN and JIVE are created, resulting in comparable and harmonized datasets, and enlarging both projects' data basis for generating project results and drawing conclusions, for example regarding the bankability and commercialisation perspective of hydrogen infrastructure and fuel cell buses.

1.5 Objective and scope of this document

The Performance Assessment Handbook is the basis of all monitoring and analysis activities of Task 3.1 in JIVE and Activities 2.4, 3.1 and 3.2 in MEHRLIN. It relies on the proven assessment frameworks developed in projects such as CUTE/ HyFLEET:CUTE (2001–2009), CHIC (2010–2016) and HyTransit (2013–2018). Thus, progress can be evaluated using the same or, based on learnings from these projects, amended parameters. This is an important element, as it also facilitates assessment of technology development progress across the prior projects.

To be able to monitor and assess to which degree target figures are achieved, operating data need to be collected, compiled, and evaluated on a steady and coherent basis. The Handbook thus:

- Defines the performance indicators for assessing hydrogen infrastructure and fuel cell bus performance, also in comparison to reference (ICE) technology, as well as those of other novel drivetrains (notably long range electric buses).
- Defines the data points required to calculate indicator figures.
- Explains the frequency of data collection and related details.
- Determines the necessary data structures and formats.
- Defines roles and responsibilities for data collection and performance evaluation.

When reference is made to the energy content of hydrogen, its lower heating value (LHV, 33.33 kWh/kg) is referred to throughout in this document, unless otherwise specified. The reason is that only this share in the hydrogen’s energy content can be re-converted to mechanical energy for vehicle propulsion.

2 Performance Assessment Process

Section 2.1 outlines the overall performance assessment approach and introduces key terms. Section 2.2 describes the processes of collecting and evaluating operating data in more detail.

2.1 Descriptive parameters, data points and performance indicators

Figure 2-1 gives an overview of the flow and processing of information.

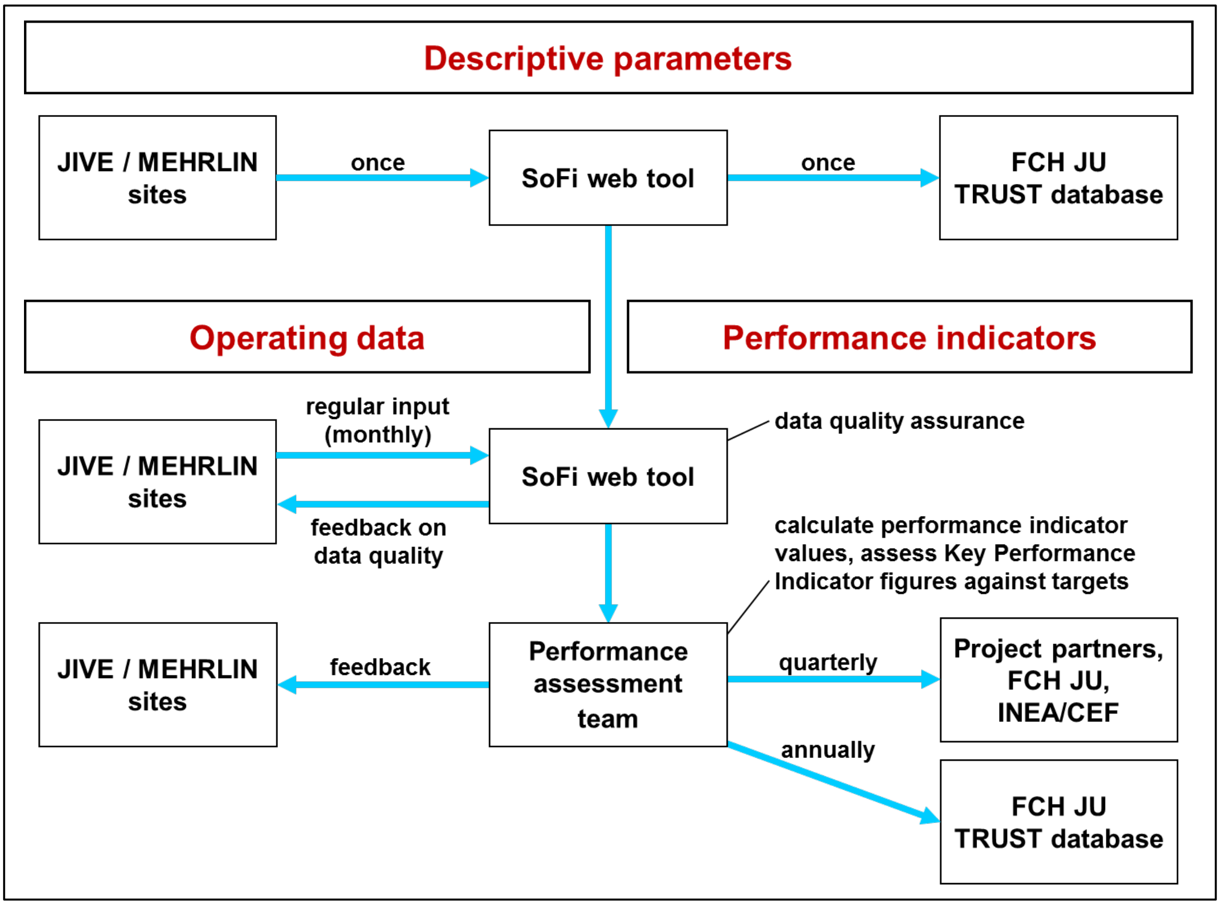

Figure 2-1: Overview of the flow and processing of information for the performance assessment.

2.1.1 Descriptive parameters

Descriptive parameters characterise the deployed hardware (e.g., HRS components and the FC bus), in particular regarding its technical and economic characteristics, such as the nominal daily range of a FC bus as specified by the manufacturer, or the nominal pressure and efficiency of an electrolyser etc. The descriptive parameters are collected usually once for each type of deployed vehicle (FC and diesel reference bus) and for the HRS before or at the beginning of the demonstration activities (and possibly again after any modifications have been made).

The sites forward the list of parameters to the performance assessment team (see Figure 2-1). Most of the parameters then have to be fed into the TRUST database of the FCH JU for mandatory documentation purposes. That includes the location of the HRS, the type of access to the station (public, restricted or private) etc.

Some of the descriptive parameters are also used in the performance assessment, e.g. to determine the rate of utilisation of a station relative to its design capacity.

The list of descriptive parameters related to the HRS can be found in chapter 3.3 and those concerning the buses in chapter 4.3.

2.1.2 Operating data and data points

The operating data originate from the demonstration activities. They are recorded regularly, typically daily (e.g., the distance travelled by a bus) or per event (the amount of hydrogen refuelled to a bus, periods of downtime and the reasons for downtime etc.).

The individual data points, i.e. the items to be monitored and recorded, are defined in chapters 3.4 and 4.4.

The sites submit data sets to the performance assessment team on a monthly basis, using the web based SoFi tool (see section 2.2).

2.1.3 Performance indicators

The performance indicator values are calculated using the operating data and selected descriptive parameters. In the following, operating data and descriptive parameters are sometimes referred to as “data” as collective term.

Based on the evaluation, the sites receive feedback, e.g. regarding apparent unexpected changes in performance (Figure 2-1). Reports are compiled and distributed quarterly. Annual figures (per calendar year) are fed into the TRUST database.

2.1.4 Key Performance Indicators

The Key Performance Indicators (KPIs) are subsets from the complete lists of bus and infrastructure performance indicators. For the KPIs, the work programmes of the two projects state target figures, such as a minimum efficiency of on-site hydrogen generation and a maximum fuel consumption of the buses per 100 km travelled.

2.2 Data collection and analysis process

This section further explains how the operating data, generated at the data points, are handled and analysed. This is also visualised in Figure 2-2.

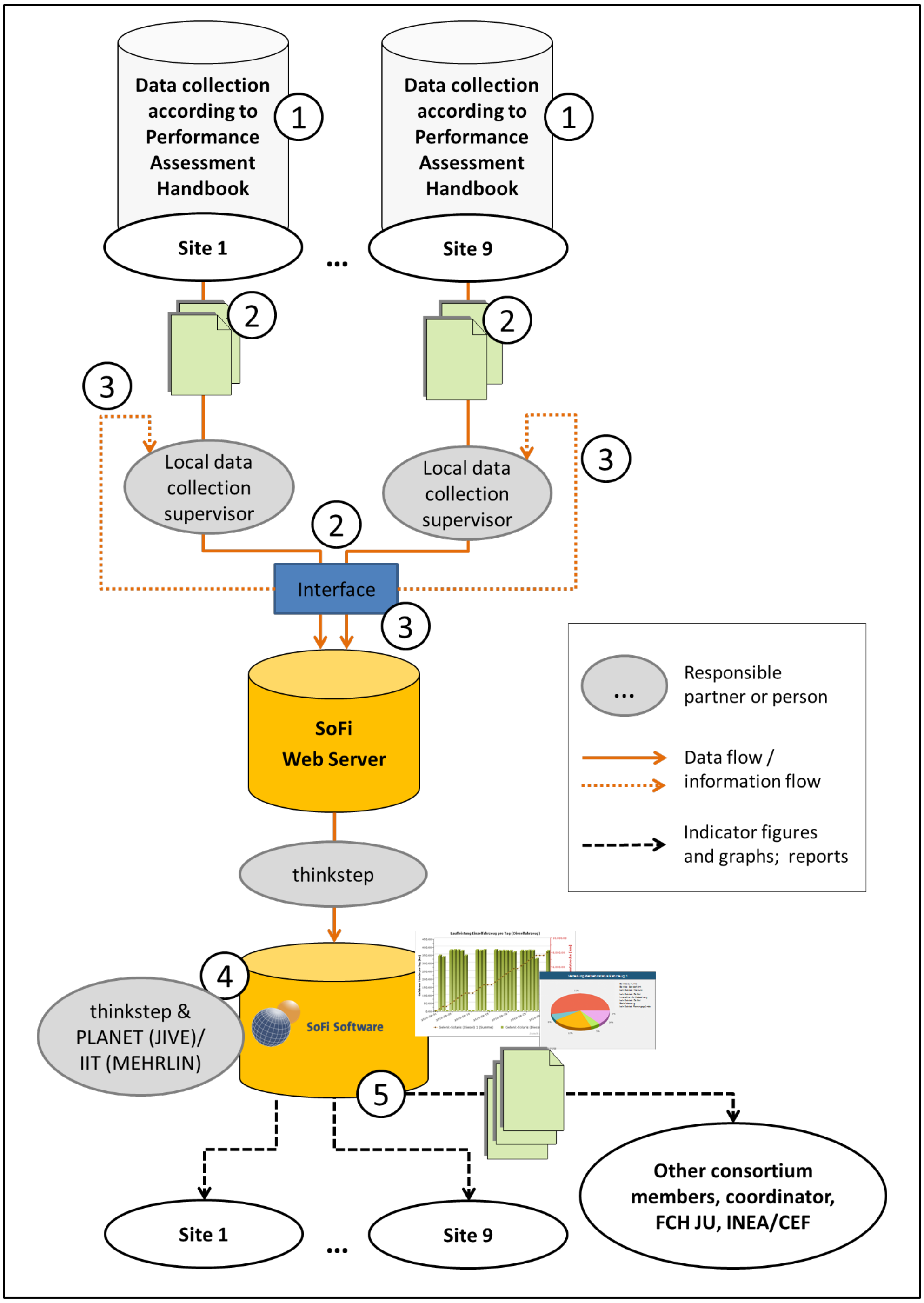

Figure 2-2: The data collection and analysis process in JIVE and MEHRLIN.
Steps 1 to 5 correspond with the structure of section 2.2.

2.2.1 Data collection at the sites

Operational data are collected at each site according to the specifications described within this document, both for refuelling infrastructure and bus operation, during the local operating period. It is recommended to establish an automated data collection system in the HRS and buses that cover the data points described in section 3.4 and 4.4 to the extent possible.

For a consistent data logging, a data collection template will be provided for HRS and FC bus operational data monitoring, respectively, listing the individual data points to be recorded, based on the data points listed in this document.

2.2.2 Compilation of monthly datasets and data upload

Datasets have to be compiled on a monthly basis and submitted by the 15th of the following month in the SoFi tool. Templates will be provided for HRS and FC bus data uploading to support the operators in providing their data in the agreed format (MS-Excel readable). They will be customized to account for local needs and the data collection process (e.g., by the operator or automatically by the manufacturer). The local data collection supervisors are responsible for meeting the timeline and for data completeness.

Separate from the monthly data reporting routine, incidents with respect to quality and safety have to be reported whenever they occur. The purpose of incident reporting is to communicate critical information in a rapid, concise and standardised manner (see Annex B for the incident reporting templates used in previous projects). The need for this was a key learning in the first multi-site fuel cell bus demonstration project. Incident reports also have to be forwarded to the Institute for Energy and Transport of the Joint Research Centre (JRC) as the administrator of the Hydrogen Incidents and Accidents Database (HIAD)[1] for the European Commission.

2.2.3 Plausibility check and feedback on data quality

When a dataset has been uploaded, a first check is carried out. It comprises completeness, format, consistency and plausibility, based on specifications implemented in SoFi by the assessment team together with the project partners.

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[1] https://odin.jrc.ec.europa.eu/giada/Main.jsp

If the datasets are complete and all figures are within the expected ranges, an acknowledgement of receipt is sent out and no further activity is required. Otherwise, the local data collection supervisor receives an automated feedback in the format of an e-mail message specifying the encountered out of spec values, missing data etc.

Once a dataset is complete and checked successfully, the data will be imported into the SoFi database.

2.2.4 Data analysis

By the end of the following month, the performance assessment partners analyse the datasets, calculate the performance indicators and compile the results in tables and graphs.

The analysis can involve queries to the site in terms of peculiarities in the data that were not detected in the automated plausibility check under step 3. That may apply to changes in efficiency, which are striking but still fall within the expected range, for example.

The analysis is typically carried out per month, per calendar year (required for the TRUST database in particular), and for the entire operating period up to the latest completed month, collectively referred to as “evaluation period”.

Some performance indicators are more meaningful on a longer-term basis, so that monthly figures are not generated. An example is the operational expenditure (OPEX) per kilogram of hydrogen dispensed that may change from month to month due to expenditures for annual maintenance or stocking spare parts, as already touched upon in section 2.1.2.

Any emerging issues with respect to data availability, data quality and the level of performance will be addressed with the appointed responsible(s) at the affected site in a conference call or in the next in-person meeting, depending on urgency and severity.

2.2.5 Results and reports

Reports will be available for consortium partners[2], the coordinator, the FCH JU and INEA/CEF project officers, and the public, with varying level of aggregation and anonymization as needed.

Evaluations will be retrievable online via the SoFi tool for each appointed user at each site, with access of operators being restricted to own data by individual access rights. Operators may grant access to further users at their discretion.

Additionally, aggregated results will be made available in the SoFi tool in form of averages, data ranges or benchmarks as appropriate. Potential data sensitivities indicated by a project partner will be addressed with the coordinator/consortium and the project officer and considered in the reporting as agreed between the partners and the project officer.

Quarterly Performance Assessment Summaries are foreseen from June 2018 (month 18) onwards (D3.2). Comprehensive Interim and Final Performance Assessment Reports will be compiled (D3.3 in month 42 and D3.4 in month 70).

The quarterly summaries will include projections up to the end of operation, in order to verify that the KPI targets with respect to hydrogen dispensed, kilometres travelled etc. can be reached if operation continues as before (see Table 3-2 and Table 4-2 for these targets).

Findings from the performance monitoring activities will be presented and discussed in the biannual consortium meetings.

The outcomes of the assessment activities will also serve as input for

- the analysis work in the other tasks of WP 3 in JIVE
- progressive performance improvement activities of the operators as part of Tasks 1.4 (Operation and maintenance of the buses) and 2.2 (Operation and maintenance of the stations) in JIVE
- Activities 2 and 3 in MEHRLIN and
- dissemination in both projects.

[2] Regarding the HRS, this includes the partners from the MEHRLIN project.

3 Hydrogen Refuelling Infrastructure

3.1 Introduction

In terms of the performance assessment, the hydrogen refuelling infrastructure consists of four areas:

- On-site hydrogen production in the HPU (Hydrogen Production Unit),
- Hydrogen compression, storage, and dispensing in the HRU (Hydrogen Refuelling Unit),
- External hydrogen delivery, and
- Aspects related to operation of the entire HRS (Hydrogen Refuelling Station).

Figure 3-1 shows a generalised schematic of a hydrogen infrastructure facility.

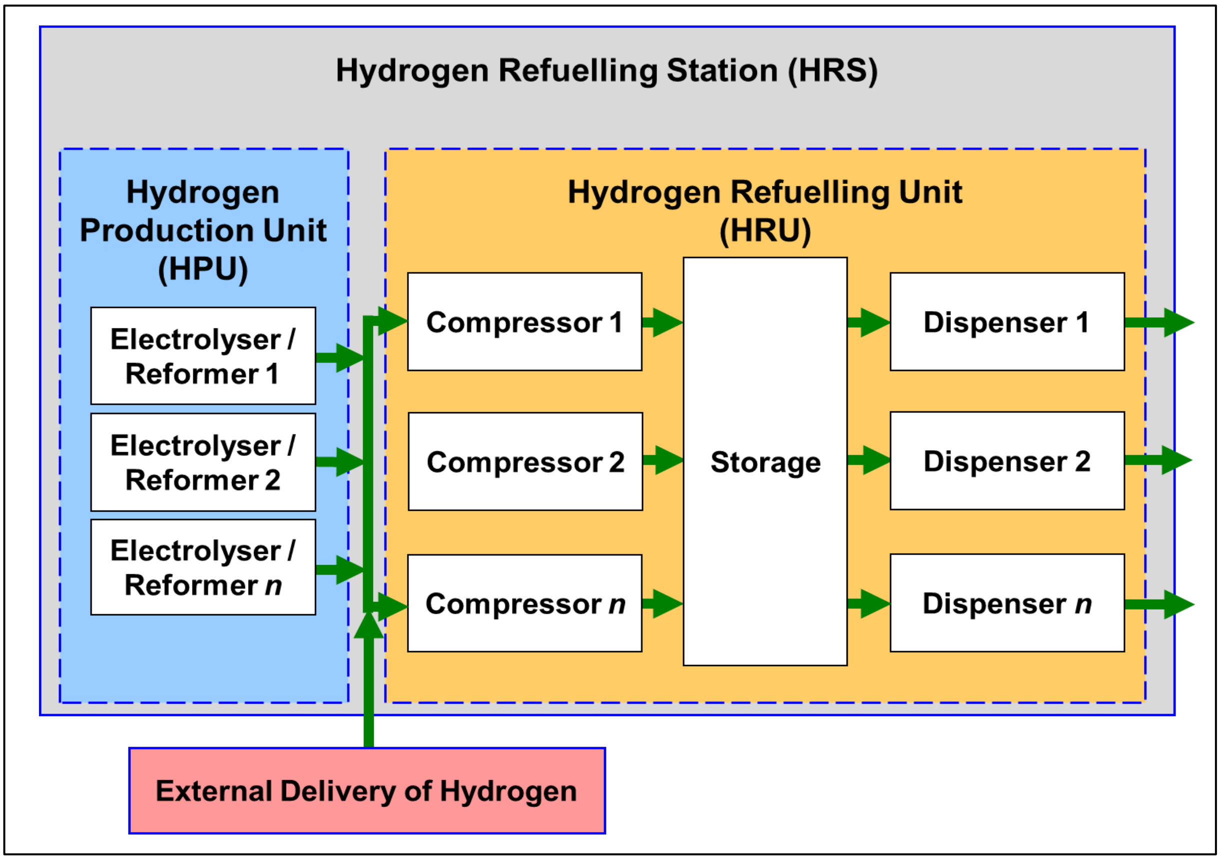

Figure 3-1: Areas covered by the JIVE and MEHRLIN hydrogen refuelling infrastructure performance assessment.
Generalised schema. There may be separate storage banks, e.g. for 350 and 700 bar refuelling, and extra dispensers for refuelling cars. Additional battery charging/ conditioning that may be implemented at individual sites is not included here.

Hydrogen is generated on site from electricity or natural gas and water in the HPU, or supplied from external sources. It is compressed, stored and dispensed on demand to the buses by the HRU. Dispensing requires a pressure differential between the on-site storage and the vehicle tanks (decanting). Depending on the design of the station, filling may have to be completed with a booster compressor (not included in Figure 3-1). The compressor charging the station storage and the one for completing the filling can be the same physical unit that is able to operate in different modes.

All sites in JIVE and MEHRLIN have a Station Unit, but not all have implemented a Production Unit for on-site generation of hydrogen. Hence, a separate consideration of the Station and Production Unit is of key significance for the purpose of performance assessment. Also in day-to-day operation, it is important that they can run independent of each other so that, in the event of Production Unit failure, refuelling of the buses can be ensured by backup external hydrogen delivery.

Table 3-1 provides an overview of this chapter in terms of tables that it contains.

It starts with the descriptive parameters related to the four areas of refuelling infrastructure analysis (Table 3-4 to Table 3-8). A further distinction is made between electrolysis-based and non-electrolysis-based production technologies. The parameter identifiers are defined accordingly:

- HPU-PE stands for "Hydrogen Production Unit, Parameter Electrolysis",
- HPU-PO for "Hydrogen Production Unit, Parameter Other Production technologies",
- EXT-P for "External Hydrogen Delivery, Parameter", and
- HRS-P for the entire HRS.

The data point identifiers are kept in line with the "Infrastructure Data Points Specification" document that was circulated among the JIVE and MEHRLIN partners in February 2017 (Table 3-9 to Table 3-12). Only the financial data points have been removed from these tables and compiled into new Table 3-13, together with a number of new items to account for the requirements of the economic analysis in MEHRLIN.

The performance indicators labelling follows an approach similar to that for the descriptive parameters (Table 3-14 to Table 3-16):

- HPU-I for indicators related to the HPU,
- HRU-I for indicators related to the HRU, and
- HRS-I for indicators related to the entire HRS.

Table 3-1 ends with the KPIs. They are a subset of the performance indicators, as explained in the preceding chapter.[3]

Due to their importance, the KPIs are detailed first, in the following sub-section 3.2. Next are the descriptive parameters (section 3.3), the data points (section 3.4) and the complete list of performance indicators (section 3.5).

Battery charging and/or conditioning, which may be implemented at individual sites, is included in the tables of descriptive parameters, data points and performance indicators in terms of costs induced, power consumption and revenue generated.

Table 3-1: Overview of tables with the descriptive parameters, data points and (key) performance indicators related to hydrogen refuelling infrastructure.

Groups of Items (and Identifier)	**Hydrogen Production Unit**		**Hydrogen Refuelling Unit**	**External Hydrogen Delivery**	**Entire Hydrogen Refuelling Station**
	Electrolysis	**Other Technologies**			
Descriptive Parameters	**Table 3-4** (HPU-PE.xx)	**Table 3-5** (HPU-PO.xx)	**Table 3-6** (HRU-P.xx)	**Table 3-7** (EXT-P.xx)	**Table 3-8** (HRS-P.xx)
Technical Data Points	**Table 3-9** (1.xx)		**Table 3-10** (2.xx)	**Table 3-11** (3.xx)	**Table 3-12** (4.xx)
Financial Data Points	**Table 3-13** (5.xx)				
Performance Indicators including KPIs	**Table 3-14** (HPU-I.xx)		**Table 3-15** (HRU-I.xx)	None	**Table 3-16** (HRS-I.xx)
KPIs	**Table 3-2 (JIVE) and Table 3-3 (MEHRLIN)** (HRI-x and MEHR-y)				

[3] Therefore, a regular performance that is also a KPI in both projects gets three identifiers: One for being a regular performance indicator (HPU-I.xx, HRU-I.xx or HPS-I.xx), one for being a KPI in JIVE (HRI-x) and one for being a KPI in MEHRLIN (MEHR-y).

3.2 Key Performance Indicators

Table 3-2 and Table 3-3 list the KPIs in JIVE and MEHRLIN respectively. Table 3-2 also includes the targets from the FCH JU's 2016 Annual Work Plan that some of the JIVE targets are based on.

Comparison of the tables reveals that while the KPIs of the two projects overlap, the related target levels usually do not coincide. For example, the availability of the station (meaning the HRU) is a KPI in both JIVE and MEHRLIN. The JIVE target is to reach 98% availability with aspirations to achieve more than 99%. More than 99% is also the target in MEHRLIN, however only to be reached towards the completion of the project, while the JIVE target applies for the complete demonstration phase after a teething period of up to six months.

MEHR-1 is a KPI not related to performance in operation but requires a minimum nominal dispensing capacity.

The KPIs related to infrastructure operation are explained in the following.

Table 3-2: Key Performance Indicators and performance targets for the hydrogen refuelling infrastructure in JIVE.

KPI no.	Parameter	FCH JU 2016 AWP target	JIVE targets (KPIs)
HRI-1	Efficiency of on-site hydrogen production (at capacity factors > 20%)	No target	> 56% (LHV basis)
HRI-2	Efficiency of complete supply chain (production unit and station unit)	No target	> 51% (LHV basis)
HRI-3	Availability of station (after teething period of max. six months)	98% (excluding scheduled preventive maintenance)	98% (excluding scheduled preventive maintenance) with aspiration to achieve > 99%
HRI-4	Amount of hydrogen dispensed to project buses	No target	> 4,500 kg per bus per year
HRI-5	Speed of dispensing	No target	> 3 kg/min
HRI-6	Cost of hydrogen dispensed	9 €/kg excl. taxes	≤ 9.0 € / kg dispensed (excl. taxes) at end of project
HRI-7	Hydrogen purity	> 99.999%	> 99.999%

Table 3-3: Key Performance Indicators and performance targets for the hydrogen refuelling infrastructure in MEHRLIN.

KPI no.	Parameter	MEHRLIN target per station	Comments
MEHR-1	Dispensing capacity	> 300 kg/day	
MEHR-2	Total amount of hydrogen dispensed over the first 18 months of operation	> 72.000 kg	
MEHR-3	Rate of utilisation (capacity factor)	> 60%	relative to daily dispensing capacity
MEHR-4	Availability of the station by end of the Action	> 99%	
MEHR-5	Cost of hydrogen dispensed	< 10 €/kg excl. VAT	< 8 €/kg planned
MEHR-6	Hydrogen purity	≥ 99.999%	or equivalent standard
MEHR-7	Total captive fleet refuelling window	< 4 h	
MEHR-8	Time to fill	< 10 min per bus	complete fill from empty

3.2.1 Efficiency of on-site hydrogen production (HRI-1)

This KPI is determined by dividing the energy content of the amount of hydrogen produced by the energy consumption of the HPU over the same period. It will be calculated for the HPU overall, and for each electrolyser and reformer.

When hydrogen is produced by water electrolysis, the target efficiency of 56% correspond to a consumption of 59.5 kWh electrical energy for generating 1 kg hydrogen. In case of steam methane reforming, most of the energy required for producing hydrogen comes from natural gas, but in addition power is consumed for operating the plant. Both streams of energy are taken into account for calculating the production efficiency.

Electrolysers with a nominal efficiency of more than 56% have been on the market for a long time. However, in previous demonstration projects, much lower HPU efficiencies were sometimes observed. One reason for this can be that the HPU is overdimensioned. In this case, the electrolyser(s) remain in stand-by over long periods while still consuming some electricity. During periods with capacity factors[4] lower than 10% to 15%, stand-by losses strongly affect performance, potentially resulting in monthly efficiency values less than 50%, as observed at some sites in the CHIC project [Stolzenburg/Graham 2016][5]. Therefore, the JIVE target is defined for periods with capacity factors higher than 20%.

As also observed in CHIC, the electrolysers integrated into buildings seemed to perform some 2% to 4% better on average than those installed in containers. This can be explained by the fact that containerised units usually receive all energy via one single power plug, including e.g. for lighting and heating, which are not genuinely part of the production process and result in reduced efficiency values. This needs to be considered when comparing and assessing numbers from various sites.

A good metering concept is required in any case. It must ensure that the efficiency of hydrogen production can be determined per electrolyser and reformer, respectively. To this end, power and natural gas consumption need to be metered individually as well as the amount of hydrogen produced should be recorded per unit. Equally important, consumption for lighting and heating should *not* captured by these meters, as mentioned.

A sample metering concept for the overall refuelling facility can be found in Figure 3-2. It includes power, natural gas and hydrogen, and shows data point identifiers according to Table 3-9 to Table 3-12 in section 3.4 (same numbering as in the data points document of February).

[4] The capacity factor is a measure of the rate of utilisation of a system. If a unit were to be operated 24 hours per day at rated capacity during its lifetime, its capacity factor would be 100%.

[5] The reason for this under-utilisation in the CHIC project was the building in of over-capacities to allow for redundancy in the case of equipment failure or to consider a future enlargement of fleet size. Moreover, the fuel economy of the buses improved greatly, which reduced the daily hydrogen demand. It was not clear at the beginning of the project that the specific fuel consumption per kilometre travelled would be more than halved compared with previous trials.

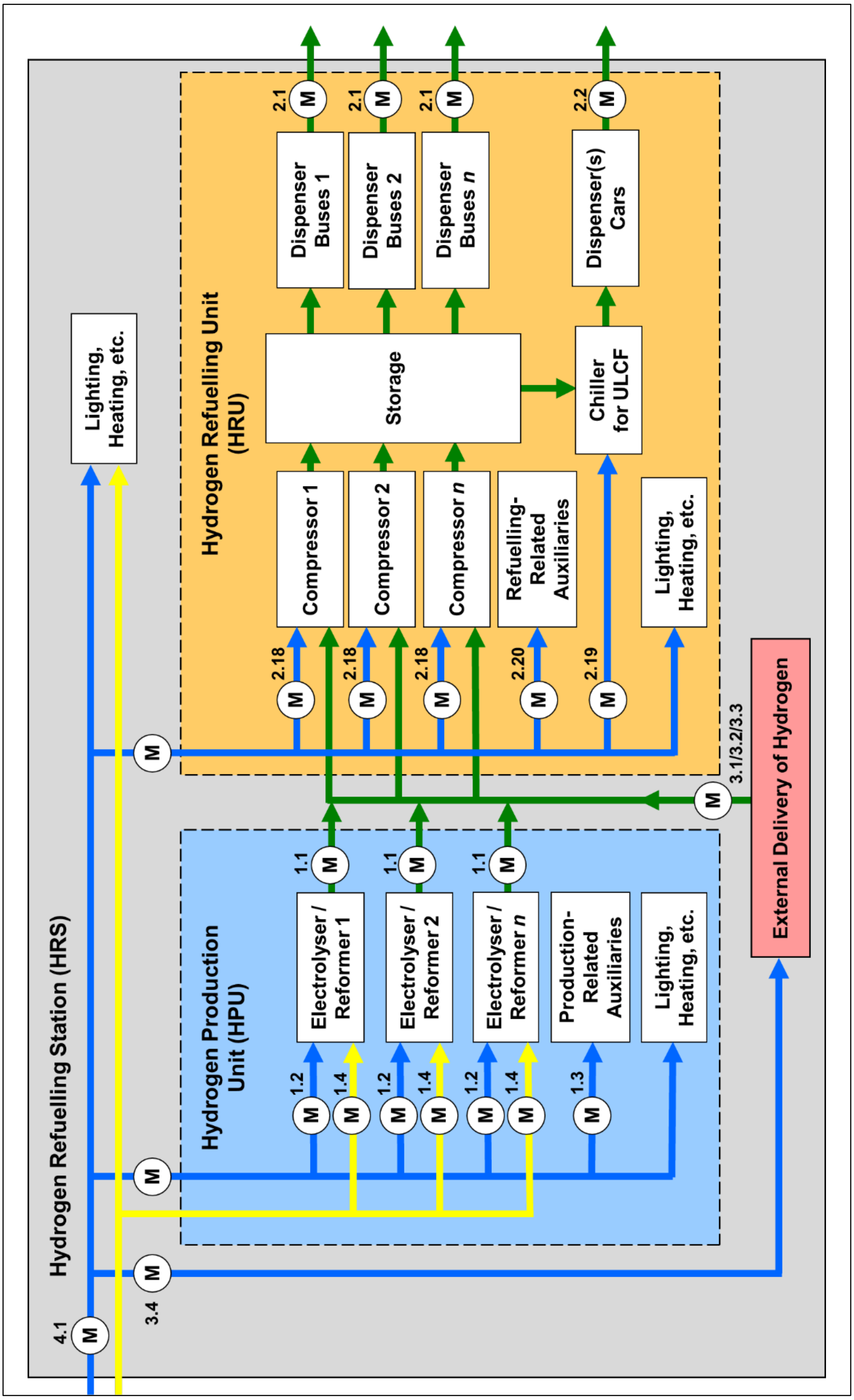

Figure 3-2: Sample metering concept for power, natural gas and hydrogen.
Blue arrows: power, yellow arrows: natural gas, green arrows: hydrogen, M = Meter. Numbers next to meters are data point identifiers according to Table 3-9 to Table 3-12. Metering of power consumption for battery charging/conditioning, which may be implemented at individual sites, is not included here.

The individual local metering concept may differ from what is shown in Figure 3-2:

- There may just one hydrogen purifier for several or for all electrolysers or reformers, to reduce the investment. In that case, there may be just one meter per purifier. This, however, will not facilitate determining the amounts of hydrogen generated per electrolyser/reformer.
- The hydrogen produced by electrolysers often is not actually metered but calculated by the PLC of the electrolyser from current and voltage readings using a proprietary algorithm that also takes into account hydrogen losses in the purifier. In this case (assuming that these figures can be considered sufficiently accurate), separate mass flow meters may not be required.
- When the electrolysers, reformers and/or compressors are not building-integrated but containerised, they are likely to have just one power plug, so that electricity consumption for lighting and space heating cannot be separated that for the genuinely hydrogen-related processes, as mentioned.
- Determining the amount of hydrogen supplied from external sources can also be based on delivery notes. However, if “normal” or “standard” cubic meters are stated there, the assumed ambient temperature needs to be taken into account carefully.

For water, only one meter is required. It should be placed upstream the water purifier to capture not just the water split it the electrolyser or reformer but also the amount lost due to purification.

3.2.2 Efficiency of the complete on-site hydrogen supply chain (HRI-2)

This KPI accounts for the energy consumption of the HRU in addition to that of the HPU, in order to determine the efficiency of the complete on-site supply chain from power and natural gas arriving at the facility to hydrogen dispensed. It is only meaningful for sites with exclusive on-site generation. (Periods of occasional external backup delivery of hydrogen can be excluded, but a regular “mixed” supply of on-site and external hydrogen supply will make it impossible to determine this KPI).

Again, a good metering concept is key to arrive at meaningful indicator figures that do not include e.g. energy consumption for heating and lighting. At sites with refuelling of cars in addition to buses, the power consumption for ultra-low cold fill devices

(ULCF, see Figure 3-2) that facilitate their fast refuelling needs to be excluded, too, or rather be captured by a separate meter, because ULCF units are energy intensive.

In CHIC, the efficiency figures for complete on-site hydrogen supply chains were approximately 3% lower than those for hydrogen generation only. Therefore, meeting the target of more than 51% efficiency along the complete chain should be no problem as long as the 56% target for the HPU is met.

3.2.3 Availability of station (HRI-3 and MEHR-4)

The availability of the stations is calculated on a 24/7 basis. This means that per year, up to 175.2 *DH* (Downtime Hours) may occur to still reach the 98% availability target and less than about 87.6 *DH* to achieve more than 99% availability:

$$Annual\ avaibility = \frac{8760 - DH}{8760} * 100\% \qquad (Equation\ 1)$$

Downtime happens when the HRU is not available for refuelling a bus, typically visualised by a red light at the dispenser and logged by the PLC. If several dispensers or nozzles are in place, downtime occurs when *none* of them is available for refuelling. An outage of one of several nozzles/dispenser for bus refuelling merely results in a *reduced dispensing capacity* if the HRU is designed to operate them in parallel, i.e. there are not just there for contingency.

Periods during which the HRU is not in service due to scheduled preventive maintenance (*SPMH*) do not count as downtime but they need to be recorded because they affect the basis for determining availability:

$$Annual\ avaibility = \frac{8760 - DH - SPMH}{8760 - SPMH} * 100\% \qquad (Equation\ 2)$$

Again, the HRU is only considered being out of service due to scheduled preventive maintenance when *all* dispensers/nozzles are not ready for refuelling. As long as one of them remains active (ready for refuelling a bus), this means a reduction in dispensing capacity, as above.

Component outage, particularly outage of one or all compressors, does not immediately result in HRU downtime. Even if all compressors are down, downtime of the HRU will only occur when the station storage has run too empty (low pressure) to refuel a bus (resulting in a “red light” at the dispenser(s)).

Availability of the HPU is monitored following the same methodology but this performance indicator is not a KPI (i.e. no target figures exists). From the HRU's perspective, the HPU is a component just like a compressor. Therefore, downtime of the HPU will not immediately result in downtime of the HRU (only if the storage runs empty because the HPU remains down for some time and backup external delivery cannot be activated quick enough).

In CHIC and the ongoing HyTransit project, the target for HRU availability is 98%. The majority of the CHIC sites surpassed it or was very close to meeting it. All CHIC sites scored more than 94%. The average availability of the station in HyTransit was 99.4% by end of 2017.

Scheduled preventive maintenance *did* constitute downtime in CHIC. Even so, downtime for this cause was negligible at most sites, thanks to good maintenance concepts, in line with a fully modular design of a station that allows maintenance of dispensers, compressors largely on a one-by-one basis instead of having to switch off the entire facility. Elsewhere, up to 1.5% availability were lost for a week of annual maintenance or for regular monthly maintenance.

As in previous trials, the most prominent reason for downtime in CHIC were failures of hydrogen compressors. This happened even though most sites had built-in redundancy with two units installed in parallel, while the capacity of one unit would have been sufficient to supply the daily fuel demand. If there had been no downtime caused by hydrogen compressors, all sites would have achieved 97.7% average availability at least.

Difficulties with compressors were avoided at one of the sites by external hydrogen delivery at high pressure, above the rated tank pressure of the buses, so that filling of the buses could be achieved without compression at the station being required.

3.2.4 Amount of hydrogen dispensed to project buses (HRI-4 and MEHR-2) and Rate of utilisation (MEHR-3)

This KPI is straightforwardly calculated by summing up all bus fills over the evaluation period, such as a month, a year or the entire demonstration period. In JIVE (KPI HRI-4), the target is to dispense more than 4,500 kg to each bus per year. In MEHRLIN (KPI MEHR-2), more than 72,000 kg shall be dispensed per site over the first 1.5 years of operation. Moreover, in MEHRLIN the daily rate of utilisation is targeted to surpass 60% (KPI MEHR-3). Therefore, a station with a nominal capacity of 350 kg/d is expected to dispense more than 210 kg/d.

3.2.5 Speed of dispensing (HRI-5), Time to fill (MEHR-8) and Total captive fleet refuelling window (MEHR-7)

The speed of dispensing is determined by dividing the amount of hydrogen refuelled by the time that it took to refuel this amount ("time to fill") for each refuelling event. The JIVE target is to dispense faster than 3 kg/min on average across all fills during the evaluation period (KPI HRI-5) while MEHRLIN requires a time to fill from empty to completely full in less than 10 minutes (MEHR-8). At a speed of 3 kg/min, 30 kg hydrogen can be dispensed during 10 min. In addition, KPI MEHR-7 sets the window for refuelling the complete bus fleet to a maximum of 4 hours, thereby capping waiting times between two fills.

There are two ways of looking at the time to fill:

- A. Time to fill can be the entire refuelling procedure, from swiping an RFID card (or similar) at the dispenser after arriving at the station up to the moment when the station terminates the filling process and signals this. This is the perspective of a bus operator.
- B. Time to fill can be the filling process only. Before the refuelling process starts, the PLC of the station will first explore the status of the bus tank via communication with the vehicle (infrared interface between nozzle and receptacle or data cable) and/or via sending a hydrogen pulse into the tank and evaluating pressure response. After the, it will start the filling process as such. This is the technical perspective, e.g. for determining the actual gas flow rate (g/sec or kg/min).

Both are of interest. The difference between the two periods can be more than one minute. Option A, the more challenging one, used to be requested by the FCH JU for its TEMONAS database. This will also be the prime focus of the assessment in JIVE, in order to facilitate an easy comparison with the findings in CHIC and HyTransit.

The dispensing equipment allowed a maximum gas flow rate of 120 g H_2 per second. This corresponds to 7.2 kg H_2/min. However, the actual momentary and average flow rate depends on the constantly changing pressure differential between station storage and bus tank. It is also influenced by the refuelling protocol that the manufacturer applies, by the capacity of the station storage (including the size and number of banks it has) and of the bus tank, by temperature, and by whether or not the station receives information on the status of the bus tank. While the maximum flow rate of 7.2 kg H_2/min may be reached at some point during a fill, the average across a complete filling event will be much smaller than this figure.

Based on the results from CHIC and HyTransit, it seems to be certain that the JIVE target of dispensing faster than 3 kg/min can hardly be reached without data communication between station and bus. The average speed of dispensing in the two projects ranges from 2.1 kg/min to 2.8 kg/min.

3.2.6 Cost of hydrogen dispensed (HRI-6 and MEHR-5)

The JIVE target is to keep the specific costs per unit of hydrogen dispensed below 9 €/kg (excl. taxes) by end of project. The MEHRLIN target is to achieve less than 10 €/kg with aspirations to undercut 8 €/kg.

Contributions to overall costs come from the depreciation of the facility (resulting from capital expenditure; CAPEX), and from fixed and variable operational expenditure (OPEX). The former two can be kept low by intensely utilising the plant, spreading the expenditure across many unit of hydrogen dispensed. Variable OPEX are dominated by the energy feedstock, namely power in case of (on-site) electrolysis. Assuming an efficiency of the on-site hydrogen supply chain of 51% (target for KPI HRI-2) and a price of 0.10 €/kWh, 6.54 €/kg hydrogen result, which is more than two-thirds of the 9 €/kg maximum. Lower variable cost may be achieved via methane steam reforming or buying by-product hydrogen.

In CHIC, there was a target for the specific OPEX only: Less than 10 €/kg hydrogen dispensed at the start of the demonstration phase and less than 5 €/kg during or towards the end of the project. However, this could not be achieved by any of the sites and, in fact, OPEX of up to 20 €/kg were encountered. The reasons include high prices for power (up to 0.17 €/kWh) and low capacity factors (smaller than 25% on average).

HyTransit has the same 10 €/kg OPEX target. In 2017, the station in this project was rather close to meeting it at an average capacity factor of about 50%.

3.2.7 Hydrogen purity (HRI-7 and MEHR-6)

Hydrogen will be dispensed in compliance with SAE J2719 “Hydrogen Fuel Quality for Fuel Cell Vehicles”, thereby securing a hydrogen purity of 99.999%, which is the target level in both projects, and avoiding any critical contaminants. Assurance will be made the responsibility of suppliers via contract. All stations need to be designed with sufficient filtration to avoid the risk of contamination from working fluids or other contaminants that could arise within the station. On-site electrolysers and reformers need to be compliant by design as well. Hydrogen from external sources has to come with a quality certificate for each delivery.

Since analysis is complex and costly, hydrogen samples will only be taken and analysed if a quality problem is suspected despite the technical and organisational precautions. Any such event will be recorded and assessed via the incident reporting system (see section 2.1.2 and Annex B).

The purity of hydrogen has not been an issue in CHIC and HyTransit, except for a very small number of incidents in CHIC.

3.3 Descriptive parameters

The parameters characterising the hydrogen refuelling infrastructure can be found in the following set of tables.

- On-site hydrogen production using electrolysis (Table 3-4),
- On-site hydrogen production using other production technologies (Table 3-5),
- Hydrogen compression, storage, and dispensing in the HRU (Table 3-6), and
- External delivery of hydrogen (Table 3-7).

The descriptive parameters only have to be supplied once, by the start of operation, or again after modifications to the plant. Most of them are requested for the TRUST database of the FCH JU. Some will also be used for the performance assessment in JIVE and/or MEHRLIN. For example, the nominal dispensing capacity (descriptive parameter HRU-P.28 in Table 3-6) is required for determining the capacity factor of the HRU, which is a performance indicator (Table 3-15 in section 3.5).

Table 3-4: Descriptive parameters of the HPU (electrolysis)
HPU-PE = Hydrogen Production Unit, Parameter Electrolysis.

Parameter number	Parameter (electrolysis)	Unit	Comments
General information			
HPU-PE.1	Country		
HPU-PE.2	Town		
HPU-PE.3	Postcode		
HPU-PE.4	Deployment date	dd/mm/yyyy	Date at which the production unit was first put in operation
HPU-PE.5	Electrolyser manufacturer		

Parameter number	Parameter (electrolysis)	Unit	Comments
HPU-PE.6	Stack manufacturer		
HPU-PE.7	Technology		Alkaline, PEM, SOEC, PCEC, AME, or Other (specify "Other")
HPU-PE.8	TRL @ start of operations		see Annex A for the Technology Readiness Levels (TRL)
HPU-PE.9	Rated system lifetime	hours	
HPU-PE.10	Rated stack lifetime	hours	
HPU-PE.11	Hydrogen purity before purification		Please specify the nature and concentration of the impurities, if known
HPU-PE.12	Hydrogen purification method		
HPU-PE.13	Hydrogen purity after purification	%	Purity of the hydrogen produced (after drying, oxygen removal and/or other purification steps, if applicable), please specify the nature and concentration of the impurities, if known
HPU-PE.14	Operating pressure	bar	
HPU-PE.15	Operating temperature	°C	
HPU-PE.16	Number of electrolysers in the HPU		
HPU-PE.17	Number of stacks per electrolyser		
Capacity, Efficiency and Dimensions (*in the following, figures are required per electrolyser if not stated otherwise*)			
HPU-PE.18	Nominal hydrogen weight capacity	kg/d	
HPU-PE.19	Nominal hydrogen volume capacity	Nm^3/h	
HPU-PE.20	Minimum hydrogen volume capacity	Nm^3/h	
HPU-PE.21	Nominal power	kW	
HPU-PE.22	Maximum overload capacity	%	
HPU-PE.23	System minimum power	%	
HPU-PE.24	Stack nominal power	kW	At DC power level
HPU-PE.25	Renewable [power] feed		No renewable feed, Solar electricity, Wind electricity, Hydro electricity, Grid elec-

Parameter number	Parameter (electrolysis)	Unit	Comments
			tricity accompanied by green certificates, Biomass/biogas, and/or Other (specify "Other)
HPU-PE.26	Fraction of renewable [power] feed	%	
HPU-PE.27	Power converter		AC/DC, DC/DC, No converter, or Other (specify "Other")
HPU-PE.28	Input voltage	V	
HPU-PE.29	Power usage of auxiliary equipment in standby	kW	
HPU-PE.30	Power usage of auxiliary equipment at nominal capacity	kW	
HPU-PE.31	Rated stack electrical efficiency (HHV, DC current)	%	
HPU-PE.32	Rated system electrical efficiency (HHV, AC current)	%	
HPU-PE.33	Transient response time	seconds	Average time to ramp up from 30% to 100% load at nominal power and operating temperature
HPU-PE.34	Time from standby to nominal capacity	seconds	Time required to reach the nominal hydrogen output rate operating capacity (HPU-PE.19) when starting the electrolyser from stand-by mode (system already at operating temperature)
HPU-PE.35	Time from standby to nominal power	seconds	Time required to reach the nominal power (HPU-PE.21) when starting the electrolyser from stand-by mode (system already at operating temperature)
HPU-PE.36	Time from cold start to nominal capacity	seconds	Time required to reach the nominal hydrogen output rate operating capacity (HPU-PE.19) when starting the electrolyser from shutdown mode
HPU-PE.37	Time from cold start to nominal power	seconds	Time required to reach the nominal power (HPU-PE.21) when starting the electrolyser from shutdown mode
HPU-PE.38	Electrolyser footprint	m^2	
HPU-PE.39	Electrolyser volume	m^3	
HPU-PE.40	Nominal water consumption by the stack	litres/Nm^3	

Parameter number	Parameter (electrolysis)	Unit	Comments
HPU-PE.41	Nominal water consumption overall	litres/Nm^3	Including losses resulting from water purification
Financial			
HPU-PE.42	Specific manufacturing costs	€/kW	Actual cost of system manufacturing per kW of nominal power (labour, materi-als, utilities), or purchase price, excluding land costs, overheads, VAT and other taxes
HPU-PE.43	Electrolyser price	€	Price of the transaction between the electrolyser manufacturer and the electro-lyser buyer. Any grant amount should not be accounted for here (price before any rebates, grants etc.). Exclude HRU. Exclude VAT. Regarding procurement cost, cost of land and civil works, depreciation period and cost of capital see Table 3-8.

Table 3-5: Descriptive parameters of the HPU (other production technologies).
HPU-PO = Hydrogen Production Unit, Parameter Other production technologies.

Parameter number	Parameter (other prod. technologies)	Unit	Comments
General information			
HPU-PO.1	Country		
HPU-PO.2	Town		
HPU-PO.3	Postcode		
HPU-PO.4	Deployment date	dd/mm/yyyy	Date at which the production unit was first put in operation
HPU-PO.5	Manufacturer		
HPU-PO.6	Hydrogen production method		
HPU-PO.7	Description of the production unit		
HPU-PO.8	Target application		

Parameter number	Parameter (other prod. technologies)	Unit	Comments
HPU-PO.9	TRL @ start of operations		see Annex A for the Technology Readiness Levels
HPU-PO.10	Hydrogen feedstock		
HPU-PO.11.1	Main energy source		
HPU-PO.11.2	Specific energy content	kWh/Nm³	Lower heating value under normal conditions
HPU-PO.12	Secondary energy input/parasitic losses		
HPU-PO.13	Catalyst(s)		
HPU-PO.14	Rated system lifetime	hours	
HPU-PO.15	Hydrogen purity before purification	%	Please specify the nature and concentration of the impurities, if known
HPU-PO.16	Hydrogen purification method		
HPU-PO.17	Hydrogen purity after purification	%	Purity of the hydrogen produced (after drying, oxygen removal and/or other purification steps, if applicable), please specify the nature and concentration of the impurities, if known
HPU-PO.18	Operating pressure	bar	
HPU-PO.19	Operating temperature	°C	
HPU-PO.20	Number of production devices (such as stacks or reformers tubes) within the HPU		
Capacity, Efficiency and Dimensions (in the following, figures are required per production device if not stated otherwise.)			
HPU-PO.21	Nominal hydrogen weight capacity	kg/d	
HPU-PO.22	Nominal hydrogen volume capacity	Nm³/h	
HPU-PO.23	Minimum hydrogen volume capacity	Nm³/h	
HPU-PO.24	Nominal power	kW	With respect to “Main energy source” / HPU-PO.11, such as natural gas
HPU-PO.25	Maximum overload capacity	%	With respect to “Main energy source”
HPU-PO.26	Minimum power	%	With respect to “Main energy source”

Parameter number	Parameter (other prod. technologies)	Unit	Comments
HPU-PO.27	Nominal power	kW	With respect to “Secondary energy input” / HPU-PO.12
HPU-PO.28	Nominal electric power	kW	If not covered above (main or second energy source)
HPU-PO.29	Electricity origin		Solar, Wind, Hydro-electric, Grid, and/or Other (specify “Other”)
HPU-PO.30	Nominal conversion thermal efficiency	%	With respect to “Main energy source”
HPU-PO.31	Nominal conversion total efficiency	%	With respect to all energy consumption
HPU-PO.32	Time from standby to nominal capacity	seconds	Time required to reach the nominal hydrogen output rate operating capacity (HPU-PO.22) when starting the electrolyser from stand-by mode (system already at operating temperature)
HPU-PO.33	Time from cold start to nominal capacity	seconds	Time required to reach the nominal hydrogen output rate operating capacity (HPU-PO.22) when starting the electrolyser from shutdown mode
HPU-PO.34	Footprint of hydrogen production unit	m^2	
HPU-PO.35	Volume of hydrogen production unit	m^3	
HPU-PO.36	Nominal water consumption by the stack	litres/Nm^3	
HPU-PO.37	Nominal water consumption overall	litres/Nm^3	Including losses resulting from water purification
Financial			
HPU-PO.38	Specific manufacturing costs today	€	Per tonne of production capacity per day
HPU-PO.39	Specific manufacturing costs – Estimated @ mass production	€	Per tonne of production capacity per day
HPU-PO.40	Price for the hydrogen production unit	€	Price of the transaction between the manufacturer and the buyer. Any grant amount should not be accounted for here (price before any rebates, grants etc.). Exclude HRU. Exclude VAT. Regarding procurement cost, cost of land and civil works, depreciation period and cost of capital see Table 3-8.

Table 3-6: Descriptive parameters of the HRU.
HRU-P = Hydrogen Refuelling Unit, Parameter.

Parameter number	Parameter	Unit	Comments
General information			
HRU-P.1	Country		
HRU-P.2	Town		
HRU-P.3	Postcode		
HRU-P.4	Location type		Inner city, Outer city (motorway), Outer city (non-motorway), Countryside or Other (specify "Other")
HRU-P.5	Station setting		Petrol station forecourt, Stand-alone hydrogen refuelling station, or Other (specify “other”)
HRU-P.6	Type of access		Public: anyone can access with no prior registration, Restricted: pre-registered users only, Private: private facility, or Other (specify "Other")
HRU-P.7	Manufacturer		
HPU-P.8	TRL @ start of operations		see Annex A for the Technology Readiness Levels (TRL)
HRU-P.9	Operator		
HRU-P.10	Deployment date	dd/mm/yyyy	Date at which the hydrogen refuelling station was first put in operation
HRU-P.11	Nominal ambient temperature range for HRU operation, minimum	°C	
HRU-P.12	Nominal ambient temperature range for HRU operation, maximum	°C	
HRU-P.13	Hydrogen supply logistics		On-site production, Delivered, compressed gas H_2 trailer, Delivered, compressed gas H_2 pipeline, Delivered, liquid hydrogen trailer, and/or Other (specify “Other)
HRU-P.14	Renewable [power] feed		No renewable feed, Solar electricity, Wind electricity, Hydro electricity, Grid electricity accompanied by green certificates, Biomass/biogas, and/or Other (specify “Other)

Parameter number	Parameter	Unit	Comments
HRU-P.15	Fraction of renewable [power] feed	%	
HRU-P.16	Footprint of complete HRU	m^2	
Compression			
HRU-P.17	Number of hydrogen compressors		
HRU-P.18	Type of compressor		
HRU-P.19	Number of compression stages		
HRU-P.20	Nominal inlet pressure		Range, if applicable
HRU-P.21	Nominal outlet pressure		
HRU-P.22	Nominal hydrogen compression capacity	kg/h	Hydrogen throughput per compressor
HRU-P.23	Power required at nominal compression capacity	kW	Per compressor
HRU-P.24	Footprint	m^2	Per compressor
Storage			
HRU-P.25	Nominal hydrogen storage pressure	bar	Per bank
HRU-P.26	Nominal hydrogen storage capacity	kg	Total and per bank
HRU-P.27	Temperature at which nominal hydrogen storage capacity applies	°C	
HRU-P.28	Geometric volume of the hydrogen storage vessels		Total and per bank
HRU-P.29	Storage footprint	m^2	
Dispensing / general			
HRU-P.30	Daily capacity	kg/d	
HRU-P.31	Hourly capacity	kg/h	Per dispenser and per nozzle
HRU-P.32	Number of dispensers		

Parameter number	Parameter	Unit	Comments
HRU-P.33	Number of nozzles		
HRU-P.34	Dispensing pressure	bar	For each dispenser and nozzle
HRU-P.35	Type of hydrogen meter at dispenser		Specify
HRU-P.36	Nominal meter accuracy	± %	
HRU-P.37	Hydrogen purity standard		e.g. according to SAE J2719 and/or ISO 14687
Dispensing / 350 bar			
HRU-P.38.1	Refuelling protocol		SAE TIR J2601, SAE J2601 (light duty vehicles), SAE J2601-2 (heavy duty vehicles), SAE J2601-3 (forklifts), or Others (specify “Other”)
HRU-P.38.2	Communication between HRS and FC bus		Specify if infrared interface, cable, other or none
HRU-P.39	Daily capacity	kg/d	Per dispenser and per nozzle
HRU-P.40	Number of buses per day		
HRU-P.41	Hourly capacity	kg/h	Per dispenser and per nozzle
HRU-P.42	Number of buses per hour		
HRU-P.43	Other type of vehicles refuelled at 350 bar?		Specify
HRU-P.44.1	Waiting time after a certain number of vehicles refuelling or a certain amount of hydrogen dispensed?	min	Specify conditions
HRU-P.44.2	Planned length of daily refuelling window	hours	
Dispensing / 700 bar			
HRU-P.45	Refuelling protocol		SAE TIR J2601, SAE J2601 (light duty vehicles), SAE J2601-2 (heavy duty vehicles), SAE J2601-3 (forklifts), or Others (specify “Other”)
HRU-P.46	Number of cars per hour		
HRU-P.47	Number of cars per day		
HRU-P.48	Other type of vehicles refuelled at 700 bar?		Specify

Parameter number	Parameter	Unit	Comments
HRU-P.49	Nominal power of ultra-low cold fill unit	kW	
HRU-P.50	Waiting time after a certain number of vehicles refuelling or a certain amount of hydrogen dispensed?	min	Specify conditions
Financial			
HRU-P.51	CAPEX for the HRU	€	Total costs incurred for the construction or acquisition of the hydrogen refuelling unit, including on-site storage and any upgrade; exclude land costs; exclude hy-drogen production unit. Exclude VAT.
HRU-P.52	Price of the HRU	€	Price of the transaction between manufacturer and buyer. Any grant amount should not be accounted for here (price before any rebates, grants etc.); exclude hydrogen production unit. Exclude VAT. Regarding procurement cost, cost of land and civil works, depreciation period and cost of capital see Table 3-8.

Table 3-7: Descriptive parameters of the external hydrogen delivery
EXT-P = External Hydrogen Delivery, Parameter.

Parameter number	Parameter	Unit	Comments
Regular delivery *(exclusive fuel supply or in parallel to on-site generation)*			
EXT-P.1	Mode of delivery		Gaseous/road, liquid/road and/or gaseous/pipeline
EXT-P.2	On-board or pipeline pressure	bar	
EXT-P.3	Road delivery: Typical amount per trailer	kg	
EXT-P.4	Road delivery: Nominal power for on-board pressurisation/evaporation	kW	
EXT-P.5	Pipeline delivery: min. and max. rate	kg/h	
EXT-P.6	Hydrogen source		Specify (e.g. central steam methane reformer, by-product from chlor-alkali elec-trolysis, …)
EXT-P.7	Distance H_2 production source to station	km	
Backup delivery *(in case of an outage of on-site generation and/or regular external delivery)*			
EXT-P.8	Mode of delivery		Gaseous/road and/or liquid/road
EXT-P.9	On-board pressure	bar	
EXT-P.10	Typical amount per trailer	kg	
EXT-P.11	Road delivery: Nominal power for on-board pressurisation/evaporation	kW	
EXT-P.12	Hydrogen source		Specify (as under EXT-P.6)
Financial			
EXT-P.13	Price of equipment related to external hydrogen delivery (If not included in the HRU investment in the preceding table.)	€	Price of the transaction between the manufacturer and the buyer. Any grant amount should not be accounted for here (price before any rebates, grants etc.). Exclude VAT. Regarding procurement cost, cost of land and civil works, depreciation period and cost of capital see Table 3-8.

Table 3-8: Descriptive parameters of the entire HRS.
HRS-P = Hydrogen Refueling Station, Parameter.

Parameter number	Parameter	Unit	Comments
General information			
HRS-P.1	Overall footprint	m^2	Footprint (enclosure) of the complete HRS with HPU, HRU, and space for external hydrogen delivery, incl. for parking of trailers
Financial (CAPEX items as far as not included in the preceding tables and grand total investment; always excluding VAT)			
HRS-P.2	Procurement cost	€	e.g. for procurement preparation, feasibility, tendering
HRS-P.3	Land cost	€	If land is bought, incurring CAPEX; otherwise see Table 3-13 (OPEX)
HRS-P.4	Civil works cost (incl. engineering)	€	Total costs for civil works, including engineering, authorisation process etc.
HRS-P.5	Other investment cost	€	For electricity supply infrastructure for the conditioning of fuel cells overnight, for electricity supply infrastructure for battery charging in range extender buses or external BEV, etc.
HRS-P.6	Grand total investment for the HRS	€	Including all items for HPU, HRU, external hydrogen delivery and overarching costs
HRS-P.7	Depreciation period	years	
HRS-P.8	Cost of capital	%	Interest rate paid or assumed for financing the investment

3.4 Data points

The data points can be found in the following set of tables, grouped in line with Table 3-1:

- On-site hydrogen production in the HPU (Table 3-9),
- Hydrogen compression, storage, and dispensing in the HRU (Table 3-10),
- External delivery of hydrogen (Table 3-11)
- Aspects related to technical performance of the entire HRS (Table 3-12), and
- Aspects related to financial performance of the HRS (Table 3-13).

The data points have to be sampled regularly. The periods and level of detail (such as “Daily and per electrolyser unit”) can be found in the “Frequency of Collection” columns of the tables. The data points are required for the performance assessment in JIVE and/or MEHRLIN, and many of them also for the TRUST database of the FCH JU.

Table 3-9: Data points for the technical monitoring of the HPU.
New items and items modified compared with the data points specification lists of February 2017 are highlighted green.

Data point number	Data point HPU	Unit	Frequency of Collection	Comments
1.1	Hydrogen produced	kg and unit ID	Daily and per electrolyser/ reformer unit	Capture either reading from electrolyser PLC or install a flow meter after drier
1.2	Power consumption for hydrogen production	kWh and unit ID	Daily and per electrolyser/ reformer unit	
1.3	Power consumption by auxiliaries	kWh and unit ID	Daily	Remaining power consumption of the HPU, but *excluding* lighting and space heating (unit ID only required if power consumption can be allocated to the units under 1.1/1.2/1.4 individually)
1.4	Natural gas consumption	Nm^3 and unit ID	Daily and per reformer unit	Excluding space heating
1.5	Water consumption	litres or m^3	Monthly (Option: Daily)	Total consumption of all units
1.6	Downtime of electrolyser/reformer unit (begin)	dd.mm.yyyy hh:mm and unit ID	Per electrolyser/ reformer unit and per event	The total downtime period is of interest. The duration of e.g. repair work during a downtime period is not relevant.
1.7	Downtime of electrolyser/reformer unit (end)	dd.mm.yyyy hh:mm and unit ID	Per electrolyser/ reformer unit and per event	

Note / explanation re. HPU downtime: Downtime of e.g. one or two of several electrolyser/reformer units results in a temporary reduction in production capacity (which is evaluated in the performance assessment as well) but not in HPU downtime.

HPU downtime occurs when *all* electrolyser/reformer units installed are down. That will affect HPU availability. (A stop of hydrogen production because the station storage is full does *not* constitute downtime.)

Downtime of electrolyser/reformer units should be logged automatically via time stamps. The reasons for unit downtime (next data point) can also be logged automatically, or they can be added manually at the end of each month, evaluating internal protocols, before submitting the data sets to the SoFi system. The latter option was chosen e.g. in the Clean Energy Partnership and worked well.

Data point number	Data point HPU	Unit	Frequency of Collection	Comments
1.8	Reason for unit downtime	Text including unit ID	Per electrolyser/ reformer unit and per event	Explain the reason for downtime and the component causing it, including planned maintenance and external reasons (such as power outage or power surge). Downtime due to planned maintenance and external reasons will not reduce availability but needs to be monitored. Reasons for downtime can be problems with a component, software issues, someone pressing an emergency button etc.
1.9	Component outage *not* causing downtime of electrolyser/reformer unit (begin)	dd.mm.yyyy hh:mm and component ID	Per event	For example, when feed water purification fails but the tank with purified feed water contained enough to continue hydrogen production. When the problem is solved while there is enough water left, fine. When the water tank reaches low level and hydrogen production stops, unit downtime and probably HPU downtime start.
1.10	Component outage *not* causing downtime of electrolyser/reformer unit (end)	dd.mm.yyyy hh:mm and component ID	Per event	
1.11	Reason for component outage	Text including component ID	Per event	See 1.8
1.12	TRL at the end of the timeframe		Annually	See Annex A for the Technology Readiness Levels (TRL)

Table 3-10: Data points for the technical monitoring of the HRU.
New items and items modified compared with the data points specification lists of February 2017 are highlighted green.

<table>
<tr><th>Data point number</th><th>Data point HRU</th><th>Unit</th><th>Frequency of Collection</th><th>Comments</th></tr>
<tr><td>2.1</td><td>Hydrogen refuelled to project buses</td><td>kg</td><td>For each fill</td><td></td></tr>
<tr><td>2.2</td><td>Hydrogen refuelled to other vehicles</td><td>kg</td><td>For each fill</td><td>For correct hydrogen balancing (amounts entering and leaving the HRU),
and for determining the rate of utilisation.</td></tr>
<tr><td>2.3</td><td>Station ID</td><td>code</td><td>For each fill</td><td></td></tr>
<tr><td>2.4</td><td>Dispenser ID</td><td>code</td><td>For each fill</td><td></td></tr>
<tr><td>2.5</td><td>Vehicle ID</td><td>code</td><td>For each fill</td><td>Not required for non-project vehicles in case of confidentiality issues.</td></tr>
<tr><td>2.6</td><td>Vehicle odometer reading</td><td>km</td><td>For each fill</td><td>For project buses only. Via data communication from the bus or typed in manually by the person refuelling.</td></tr>
<tr><td colspan="5">Note / explanation regarding data points related to “Time to fill” below: There are two ways of looking at the time to fill:
A. Time to fill can be the entire refuelling procedure, from arrival at the station and swiping an RFID card (or similar) at the dispenser up to the moment when the station terminates the filling process and signals this. This is the perspective of a bus operator.
B. Time to fill can be the filling process only. Before the refuelling process starts, the PLC of the station will first explore the status of the bus tank via communication with the vehicle (infrared interface between nozzle and receptacle or data cable) and/or via sending a hydrogen pulse into the tank and evaluating pressure response. After the, it will start the filling process as such. This is the technical perspective, e.g. for determining the actual gas flow rate (g/sec or kg/min).
Both are of interest. The difference between the two periods can be more than one minute. Option “A” is requested by the FCH JU for its TRUST (formerly TEMONAS) database.
From previous projects, it seems to be certain that the JIVE target of dispensing faster than 3 kg/min can hardly be reached without data communication between station and bus.</td></tr>
<tr><td>2.7</td><td>Duration of the filling procedure (start)
[“A” above]</td><td>dd.mm.yyyy hh:mm:ss</td><td>For each fill</td><td>For project buses only.</td></tr>
<tr><td>2.8</td><td>Duration of the filling procedure (end)</td><td>dd.mm.yyyy hh:mm:ss</td><td>For each fill</td><td>For project buses only.</td></tr>
</table>

Data point number	Data point HRU	Unit	Frequency of Collection	Comments
2.9	Duration of the dispensing process (start) ["B" above]	dd.mm.yyyy hh:mm:ss	For each fill	For project buses only.
2.10	Duration of the dispensing process (end)	dd.mm.yyyy hh:mm:ss	For each fill	For project buses only; typically the same as 2.8.
2.11.1	Fill was successful?	Yes / No / Unknown	For each fill	For project buses only. Consider the definition of "In-use Reliability" in document D3.6 of the NewBusFuel project for deciding on "Yes/No" (pages 7 and 8 there) [NewBusFuel 2016]. Please ensure that the set points for a "Yes/No" decision, based on vehicle tank end pressure (no. 2.13 in this table) and time to fill (2.7/2.8 or 2.9/2.10), can be adjusted in the PLC during the operation phase, because a common "Yes/No" criterion with respect to pressure and duration for JIVE has yet to be agreed on.
2.11.2	Fill was complete?	Yes / No / Unknown	For each fill	For all types of vehicles For the project buses, this is the same as 2.11.1. For cars etc., different criteria will apply.
2.12	Vehicle tank pressure at start of refuelling	bar	For each fill	As determined by the station
2.13	Vehicle tank pressure at end of refuelling	bar	For each fill	As determined by the station
2.14	Ambient temperature	°C	For each fill	
2.15	Vehicle tank temperature at start of refuelling	°C	For each fill	Via data communication with the bus, if in place
2.16	Vehicle tank temperature at end of refuelling	°C	For each fill	Via data communication with the bus, if in place
2.17	Power consumption of the HRU	kWh	Daily	The meter should capture all power consumption of the HRU, but *excluding* lighting and space heating.

Data point number	Data point HRU	Unit	Frequency of Collection	Comments
2.18	Power consumption for compression	kWh and unit ID	Daily and per compressor	Major power consumers
2.19	Power consumption for pre-cooling (ULCF)	kWh	Daily	Major power consumer in stations with 700 bar refuelling
2.20	Power consumption by auxiliaries	kWh	Daily	If further major consumers are foreseen.
2.21	Downtime of dispenser (begin)	dd.mm.yyyy hh:mm and dispenser ID	Per dispenser and per event	Dispenser not available for refuelling. That may be due to due a problem within the dispenser or due to lack of hydrogen in the station storage, due to a gas alarm or an emergency button pressed, due to maintenance etc.
2.22	Downtime of dispenser (end)	dd.mm.yyyy hh:mm and dispenser ID	Per dispenser and per event	
Note / explanation re. HRU downtime: Downtime of e.g. one or two of several dispensers results in a temporary reduction in refuelling capacity (which is evaluated in the performance assessment as well), if refuelling at dispensers in parallel is foreseen, but not in HRU downtime. HRU downtime occurs when *all* dispensers installed are down (e.g. due to lack of hydrogen). That will affect HRU availability. Downtime of dispensers should be logged automatically via time stamps. The reasons for dispenser downtime (next data point) can also be logged automatically, or they can be added manually at the end of each month, evaluating internal protocols, before submitting the data sets to the SoFi system. The latter option was chosen e.g. in the German Clean Energy Partnership and worked well.				
2.23	Reason for dispenser downtime	Text including dispenser ID	Per dispenser and per event	Explain the reason for downtime and the component causing it, including planned maintenance and external reasons (such as power outage) Downtime due to planned maintenance and external reasons will not reduce availability but needs to be monitored. Reasons for downtime can be problems with a component, software issues, someone pressing an emergency button etc.

Data point number	Data point HRU	Unit	Frequency of Collection	Comments
2.24	Component outage *not* causing dispenser downtime (begin)	dd.mm.yyyy hh:mm and component ID	Per event and per component	For example, when one or even all compressors fail, this is just a component outage as long as there is enough hydrogen in the station storage to refuel another bus (i.e. dispenser(s) not down). (Compressor problems, even though not always causing downtime, have been a major concern in previous projects.)
2.25	Component outage *not* causing dispenser downtime (end)	dd.mm.yyyy hh:mm and component ID	Per event	
2.26	Reason for component outage	Text including component ID	Per event	See 2.23
2.27	TRL at the end of the timeframe		Annually	See Annex A for the Technology Readiness Levels (TRL)

Table 3-11: Data points for the technical monitoring of external hydrogen delivery.
New items and items modified compared with the data points specification lists of February 2017 are highlighted green.

Data point number	Data point external hydrogen delivery	Unit	Frequency of Collection	Comments
3.1	Gaseous hydrogen delivered to the site from regular source	kg or Nm^3	Per delivery (road) Daily (pipeline)	
3.2	Liquid hydrogen delivered to the site from regular source	kg or Nm^3	Per delivery	
3.3	Hydrogen delivered to the site from backup source	kg or Nm^3	Per delivery	

Data point number	Data point external hydrogen delivery	Unit	Frequency of Collection	Comments
3.4	Power consumption for hydrogen delivery	kWh	Daily	For the case that delivery/off-loading requires power, e.g. for hydrogen compression/evaporation.

Table 3-12: Data points for the technical monitoring of the entire HRS.
New items and items modified compared with the data points specification lists of February 2017 are highlighted green. These are mainly required for the MEHRLIN performance assessment, which not considered when compiling the data points list in February 2017.

Data point number	Data point entire HRS (technical)	Unit	Frequency of Collection	Comments
4.1	Power consumption of the entire HRS (excluding battery conditioning/charging if this has a separate grid connection, see 4.3)	kWh	Daily	Meter readings
4.2	Power consumption of the entire HRS, (= 4.1 plus transformer losses)	kWh or kVA	Monthly	Figure from monthly power bill. Required to include transformer losses in the overall power balance. Relevant (primarily) for sites with on-site electrolysis.
4.3	Power consumption for battery conditioning/ charging (if this has a separate grid connection)	kWh	Daily	Meter readings
4.4	Power consumption for battery conditioning and for battery charging of range extender vehicles (JIVE buses)	kWh	Daily	Meter readings
4.5	Power consumption for battery conditioning and for battery charging (external vehicles)	kWh	Daily	Meter readings or difference between 4.3 and 4.4
4.6	Power consumption for battery conditioning/ charging (= 4.3 plus transformer losses)	kWh or kVA	Monthly	Figure from monthly power bill. Required to include transformer losses in the overall power balance. Relevant (primarily) for sites with battery charging infrastructure.

Data point number	Data point entire HRS (technical)	Unit	Frequency of Collection	Comments
4.7	Nitrogen delivered to the site	kg	Per delivery	
4.8	Incidents		Per event	Incidents affecting safety and/or fuel quality in particular; using the template as in Annex B, to be implemented in SoFi

Table 3-13: Data points for the financial monitoring of the HRS.
The high level of OPEX detail is for the MEHRLIN project.

Data point number	Data point entire HRS (financial)	Unit	Frequency of Collection	Comments
OPEX – External Hydrogen Delivery (excluding VAT)				
5.1	OPEX – Hydrogen costs	€	Monthly	
OPEX – Entire HRS (excluding VAT)				
5.2	OPEX – electricity cost for the entire HRS (excluding battery conditioning/charging if this has a separate grid connection, see below)	€	Monthly	Figure from monthly power bill
5.3	OPEX – electricity cost for battery conditioning/charging (if this has a separate grid connection, see 4.3/4.6)	€	Monthly	Figure from monthly power bill
5.4	OPEX – electricity cost for the HPU alone	€	Monthly	If a separate cost figure is available
5.5	OPEX – labour (regular station operation)	€	Monthly	
5.6	OPEX – auxiliary gases and water	€	Monthly	Nitrogen, water etc.
5.7	OPEX – other utilities and consumables	€	Monthly	Leasing or rental fee (land and equipment), insurance costs, heating cost (when applicable) etc.

Data point number	Data point entire HRS (financial)	Unit	Frequency of Collection	Comments
5.8	OPEX – maintenance of technical equipment of the HRS	€	Monthly	Maintenance/guarantee contract: regular maintenance, stock material
5.9	OPEX – repair of technical equipment of the HRS	€	Monthly	Repair costs and spare parts, as far as not covered by a maintenance/guarantee contract
5.10	OPEX – maintenance of civil works, building services and security installations	€	Monthly	Maintenance contract for building services (light, heating, water etc.) and security installations (e.g. sprinkler, hydrogen and other sensors)
5.11	OPEX – repair of civil works, building services and security installations	€	Monthly	Repair costs and spare parts, as far as not covered by a maintenance/guarantee contract
5.12	OPEX – any other items	€	Monthly	
Revenues (excluding VAT)				
5.13	Selling price of hydrogen at the pump	€/kg	Monthly	Average price of hydrogen at the pump (*not* costs)
5.14	Revenues from hydrogen sales	€	Daily	All sales inclusive (buses, cars, duty vehicles, other)
5.15	Revenues from battery conditioning/charging	€	Monthly	All sales inclusive
5.16	Revenues from side activities	€	Monthly	e.g. from station shop, coffee bar etc.
5.17	Additional revenues	€	Monthly	e.g. from sale of grid balancing services

3.5 Performance indicators

The indicators for assessing the performance of the hydrogen refuelling infrastructure and its major elements can be found in the following set of tables:

- On-site hydrogen production in the HPU (Table 3-14),
- Hydrogen compression, storage, and dispensing in the HRU (Table 3-15),
- Aspects related to operation of the entire HRS (Table 3-16).

There are no performance indicators concerning the external delivery of hydrogen.

The numbers to be derived for the various performance indicators will be used for the performance assessment in JIVE and/or MEHRLIN, in particular for monitoring accomplishment of the KPI targets (Table 3-2 and Table 3-3). Many of the performance indicators also represent items that have to be entered into the TRUST database of the FCH JU. This has to take place for each calendar year with demonstration activities, hence for 2018 to 2022.

Table 3-14: Performance indicators of the HPU.
For diagnostic purposes, monthly or daily evaluations may carried out in addition to what is specified in the "Period" column. Bold items constitute a KPI in JIVE or MEHRLIN or in both projects.

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points required	Explanations and comments
HPU-PI.1	Availability of the HPU	%	Monthly, annually and overall	1.6 and 1.7	Calculated in the same way as the availability of the HRU (= KPI HRI-3); see section 3.2.3 for details
HPU-PI.2	Number of HPU downtime hours		Annually and overall	1.6 and 1.7	
HPU-PI.3	Distribution downtime hours with respect to root causes	%	Annually and overall	1.6 to 1.8	The causes for downtime are categorised, distinguishing between several internal and external reasons, such as outage of sub-units/components, safety concerns or power outages.
HPU-PI.4	Number of hours with component outage reducing production capacity		Annually and overall	1.9 to 1.11	
HPU-PI.5	Number of hours with component outage *not* reducing production capacity		Annually and overall	1.9 to 1.11	
HPU-PI.6	Amount of hydrogen produced by the HPU and by each of its electrolysers/reformers	%	Monthly, annually and overall	1.1	.
HPU-PI.7	Capacity factor of the HPU and of each of its electrolysers/reformers	%	Monthly, annually and overall	1.1 and HPU-PE.18/ HPU-PO.21	Amount of hydrogen actually produced (1.1), divided by the product of nominal production daily capacity (HPU-PE.18/ HPU-PO.22) and the number of days during evaluation period

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points required	Explanations and comments
HPU-PI.8 (**KPI HRI-1**)	**Efficiency of on-site hydrogen production** of the HPU and of each of its electrolysers/reformers	%	Monthly, annually and overall	1.1 to 1.4	JIVE KPI target is > 56% See section 3.2.1 for details
HPU-PI.9	Specific power consumption of the HPU and of each of its electrolysers/reformers	kWh/kg	Annually and overall	1.1 to 1.3	
HPU-PI.10	Specific energy consumption of the HPU and of each of its electrolysers/reformers	kWh/kg	Annually and overall	1.1 to 1.4	Including consumption of power and natural gas
HPU-PI.11	Specific water consumption for hydrogen production	litres/Nm^3 or litres/kg	Monthly, annually and overall	1.1 and 1.5	
HPU-PI.12	Specific OPEX	€/kg	Annually and overall	1.1, 5.2 or 5.4, and 5.5 to 5.12	Per kg hydrogen produced Way of splitting 5.5 to 5.12 between HPU and HRU to be decided
HPU-PI.13	Specific cost of on-site production of hydrogen	€/kg	Annually and overall	1.1 5.2 or 5.4, 5.5 to 5.12, HPU-PE.43/ HPU-PO.40 HRS-P.2 to .5 HRS-P.7 and 8	Including OPEX and CAPEX Per kg hydrogen produced Way of splitting 5.5 to 5.12, HRS-P.2 to .5 and HRS-P.7 and 8 between HPU and HRU to be decided
HPU-PI.14	TRL at the end of the timeframe		Annually and overall	1.12	

Table 3-15: Performance indicators of the HRU.
For diagnostic purposes, monthly or daily evaluations may carried out in addition to what is specified in the “Period” column. Bold items constitute a KPI in JIVE or MEHRLIN or in both projects.

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points and required	Explanations and comments
HRU-PI.1 (= **KPI HRI-3** and **KPI MEHR-4**)	**Availability of the HRU**	%	Monthly, annually and overall	2.21 and 2.22	JIVE KPI target is > 98% with aspirations to achieve > 99% MEHRLIN KPI target is > 99% by the end of the Action See section 3.2.3 for details
HRU-PI.2	Number of HPU downtime hours		Monthly, annually and overall	2.21 and 2.22	
HRU-PI.3	Distribution downtime hours with respect to root causes	%	Monthly, annually and overall	2.21 to 2.23	The causes for downtime are categorised, distinguishing between several internal and external reasons, such as outage of sub-units/components, safety concerns or power outages.
HRU-PI.4	Mean time between failures	hours	Annually and overall	2.21 and 2.22	
HRU-PI.5	Number of hours with component outage reducing production capacity		Monthly, annually and overall	2.24 to 2.26	
HRU-PI.6	Number of hours with component outage *not* reducing production capacity		Monthly, annually and overall	2.24 to 2.26	
HRU-PI.7	Number of bus fills		Monthly, annually and overall	2.1 and 2.5	Across the fleet and per bus
HRU-PI.8	Number of fuelling events		Monthly, annually and overall	2.1 and 2.2	Buses and all other vehicles
HRU-PI.9	Number of incomplete fills		Monthly, annually and overall	2.1, 2.2, 2.5 and 2.11.2	Buses and all other vehicles

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points and required	Explanations and comments
HRU-PI.10	Reliability of the HRU	%	Monthly, annually and overall	2.1, 2.5 and 2.11.1	Percentage of successful fills to total number of project bus fills
HRU-PI.11 (= **KPI HRI-4**)	**Amount of hydrogen dispensed to the project buses** overall and per bus	kg	Monthly, annually and overall	2.1 and 2.3 to 2.5	JIVE KPI target is > 4,500 per bus per year
HRU-PI.12	Amount of hydrogen dispensed to other vehicles	kg	Monthly, annually and overall	2.2 to 2.5	
HRU-PI.13 (= **KPI MEHR-2)**	**Quantity of hydrogen dispensed**	kg	Monthly, annually and overall	2.1 and 2.2	MEHRLIN KPI target is > 72.000 kg dispensed to buses and all other kinds of vehicles during first 18 months of operation
HRU-PI.14 (= **KPI MEHR-3**)	**Capacity factor of the HRU**	%	Monthly, annually and overall	2.1 and 2.2, HRU-P.26	MEHRLIN KPI target is > 60% Amount hydrogen actually dispensed (2.1 and 2.2), divided by the product of nominal daily dispensing capacity (HRU-P.30) and the number of days during evaluation period
HRU-PI.15	Specific power consumption HRU	kWh/kg	Monthly, annually and overall	2.1 and 2.2, 2.17 to 2.20	
HRU-PI.16	Specific power consumption HRU for the buses section	kWh/kg	Monthly, annually and overall	2.1 and 2.2, 2.17, 2.18 and 2.20	Excluding ULCF and compression for storage benches exclusively for cars
HRU-PI.17	Specific power consumption HRU for the cars section	kWh/kg	Monthly, annually and overall	2.1 and 2.2, 2.17 to 2.20	Including ULCF and compression for storage benches exclusively for cars
HRU-PI.18 (= **KPI HRI-5**)	**Speed of dispensing**	kg/min	Monthly, annually and overall	2.1, 2.7 to 2.11, 2.12 to 2.16	JIVE KPI target is > 3 kg/min. The speed of dispensing will be influenced by ambient temperature (2.14), bus tank temperature and tank level at the beginning of refuelling (2.12 and 2.

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points and required	Explanations and comments
					15), and on whether the bus tank is filled up to rated level or only half way (2.16). See section 3.2.5 for further details
HRU-PI.19 (= **KPI MEHR-8**)	**Time to fill**	min	Monthly, annually and overall	2.1, 2.7 to 2.11	MEHRLIN KPI target is < 10 min for a complete fill from empty See section 3.2.5 for details
HRU-PI.20 (= **KPI MEHR-7**)	**Total captive fleet refuelling window**	hours	Monthly, annually and overall	2.7 to 2.10	MEHRLIN KPI target is < 4 hours See section 3.2.5 for details
HRU-PI.21	Average amount of hydrogen dispensed to the buses	kg/fill	Monthly, annually and overall	2.1	
HRU-PI.22	Specific OPEX	€/kg	Annually and overall	2.1 and 2.2 5.2 to 5.12	Per kg hydrogen dispensed (excluding OPEX for the HPU) Way of splitting 5.5 to 5.12 between HPU and HRU to be decided
HPU-PI.23	Specific cost induced by the HRU	€/kg	Annually and overall	2.1 and 2.2 HRU-P.51/52 HRS-P.2 to .5 HRS-P.7 and 8	Including OPEX and CAPEX Per kg hydrogen dispensed Way of splitting 5.5 to 5.12, HRS-P.2 to .5 and HRS-P.7 and 8 between HPU and HRU to be decided
HRU-PI.24	TRL at the end of the timeframe		Annually and overall	2.27	

Table 3-16: Performance indicators of the HRS.
For diagnostic purposes, monthly or daily evaluations may carried out in addition to what is specified in the "Period" column. Bold items constitute a KPI in JIVE or MEHRLIN or in both projects.

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points and required	Explanations and comments
HRS-I.1	Hydrogen balance	kg and %	Monthly, annually and overall	1.1, 2.1 and 2.2, 3.1 to 3.3	Hydrogen produced at the site (1.1) plus hydrogen delivered from external sources (3.1/3.2/3.3) minus hydrogen dispensed to the project buses (2.1) and to other vehicles (2.2). Percentage figures are calculated by dividing the difference by the total amount dispensed.
HRS-I.2 (**KPI HRI-2**)	**Efficiency of on-site hydrogen supply chain**	%	Monthly, annually and overall	1.2 to 1.4, 2.17, 2.18 and 2.20, 3.4, 4.1/4.2	JIVE KPI target is > 51%. Only meaningful for sites without exter-nal supply of hydrogen See section 3.2.2 for details
HRS-I.3	Specific energy consumption along the on-site hydrogen supply chain	kWh/kg	Monthly, annually and overall	1.2 to 1.4, 2.17, 2.18 and 2.20, 3.4, 4.1/4.2	
HRS-I.4	Specific OPEX	€/kg hydrogen dispensed	Annually and overall	2.1 and 2.2, 5.1 to 5.12	Includes analysing the major cost factors (5.3 to 5.12)

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points and required	Explanations and comments
HRS-I.5 (= **KPI HRI-6** and **KPI MEHR-5**)	**Cost of hydrogen dispensed**	€/kg hydrogen dispensed	Annually and overall	2.1 and 2.2 5.1 to 5.12 HPU-PE.43/ HPU-PO.40, HRU-P.51/52, HRS-P.2 to .8	Average cost of hydrogen at the pump, considering CAPEX and OPEX JIVE KPI target is ≤ 9 €/kg dispensed at the end of the project. MEHRLIN KPI target is ≤ 10 €/kg with aspirations to achieve < 8 €/kg See section 3.2.6 for details
HRS-I.6	Revenue	€	Annually and overall	5.13 to 5.17	
HRS-I.7 (= **KPI HRI-5** and **KPI MEHR-6**)	**Number of incidents affecting fuel quality**		Annually and overall	4.8	JIVE and MEHRLIN KPI target is to always keep a quality of 99.999% hydrogen purity or better. See section 3.2.7 for details.
HRS-I.8	Number of incidents		Annually and overall	4.8	
HRS-I.9	Specific nitrogen consumption	kg/tonne dispensed	Annually and overall	2.1 and 2.2, 4.7	

4 Fuel Cell and Reference Buses

4.1 Introduction

This chapter is structured similar to chapter 3 on the hydrogen infrastructure. Table 4-1 provides an overview of this chapter in terms of tables that it contains. Since the performance of the fuel cell buses will be compared with a reference bus technology (generally diesel), similar data, however with a reduced scope, has to be collected for it.

The table starts with the descriptive parameters, i.e. the techno-economic specifications of the FC and reference buses (see Table 4-3 and Table 4-4). The data points that will be regularly monitored are described in Table 4-5 for FC bus operation6, in Table 4-6 for FC bus refuelling and recharging, and in Table 4-7 for reference bus operation. The general set of performance indicators is depicted in Table 4-8 for FC bus operation, Table 4-9 for FC bus refuelling, and Table 4-10 for reference bus operation. The KPIs for FC bus operation shown in Table 4-2 are a subset of the list of performance indicators for which target figures are stated in the projects' work programmes (see section 2.1.4).

Due to their importance, first, the KPIs are described in detail, including the used data points and how the KPIs are calculated (section 4.2). This is followed by a description of the descriptive parameters (section 4.3), data points (section 4.4) and finally the performance indicators (section 4.5).

[6] Table 4-5 also comprises basic information on incidents, while for the formal incident reporting Annex B has to be considered.

Table 4-1: Overview of tables with the descriptive parameters, data points and (key) performance indicators related to the buses.

Groups of Items (and Identifier)	**Fuel cell buses**		**Reference buses**
	Operation	**Refuelling and recharging**	
Descriptive Parameters	**Table 4-3** (FCB.Pxx)		**Table 4-4** (RB.Pxx)
Data Points	**Table 4-5** (1.xx)	**Table 4-6** (2.xx)	**Table 4-7** (3.xx)
Performance Indicators including KPIs	**Table 4-8** (FCB-PI.xx)	**Table 4-9** (FCB-PI.xx)	**Table 4-10** (RB-PI.xx)
KPIs	**Table 4-2** (FCB-x)	None	None

4.2 Key Performance Indicators

Table 4-2: Key Performance Indicators and performance targets for the fuel cell buses.

KPI no.	Parameter	FCH JU 2016 AWP target	JIVE targets (KPIs)
FCB-1	Vehicle operational lifetime	>20,000 operating hours initially, with minimum 25,000 operating hours as project target	Manufacturer's warranty for bus operation > 8 years.
FCB-2	Distance travelled	Minimum 100,000 km per bus in 3 years	Minimum distance travelled of 44,000 km/year
FCB-3	Operating hours per fuel cell system	Number of hours according to manufacturer's warranty	15,000 hours or 5 years (whichever is lower) at the project start, >20,000 hours by project end – stack replacements built into maintenance costs.
FCB-4	Availability of bus	> 90% on a fleet basis after an initial 6 month ramp-up phase.	> 90% after an initial 6 month ramp-up phase.
FCB-5	Mean distance between failures *MDBF*	Fuel cell MDBF >2,500 km.	An MDBF of >2,500 km (after teething period)

KPI no.	Parameter	FCH JU 2016 AWP target	JIVE targets (KPIs)
FCB-6	Specific fuel consumption	< 9 kg / 100 km (solo bus, 12–13.5 m), < 14 kg / 100 km (articulated bus, 18 m).	< 9 kg / 100 km (solo bus, 12–13.5 m), < 14 kg / 100 km (articulated bus, 18 m).
FCB-7	Efficiency	Tank-to-wheel efficiency >42%, on the SORT 1 & 2 drive cycles.	Tank-to-wheel efficiency >42%, on the SORT 1 & 2 drive cycles.
FCB-8	Vehicle CAPEX	< 650,000 € per standard single deck 12m bus < 1,000,000 € for articulated buses.	< 650,000 € for a base 12 m bus, excluding additional parts (CCTV, extra doors, Wi-Fi etc.). < 1,000,000 € for articulated buses.
FCB-9	Vehicle OPEX	No target.	Maximum of 100% more than the equivalent cost of maintaining a diesel bus, aiming at 50% more by the end of the project.

4.2.1 Vehicle operational lifetime

The limited duration of the project does not allow the measurement and verification of the target operational lifetime. Thus, the appropriate lifetime has to be ensured by tender specifications and contractual arrangements, which oblige bus manufacturers to furnish a corresponding warranty for at least 8 years on their vehicles and equipment.

4.2.2 Distance travelled

For JIVE, a minimum distance travelled of 44,000 km/year has been set. The travelled distance is recorded straightforward by data point 1.4 (see Table 4-5). The fulfilment of the indicator will be calculated taking the arithmetic average of the monthly values, multiplied by 12.

4.2.3 Operating hours per fuel cell system

The JIVE target for the FC systems are 15,000 operating hours (or 5 years) at the project start and > 20,000 hours at the project end. As for the vehicle lifetime, the limited duration of the project does not allow the measurement and verification of the target FC operational lifetime.

To check if the target (>20,000 h by project end) is achieved, the indicator will be estimated by extrapolating the average operating hours per month of the FC system (derived from data point 1.2, see Table 4-5) to the vehicle operational lifetime (see section 4.2.1), i.e. by multiplying them with 96 (12 months times 8 years).

4.2.4 Availability of bus

After an initial ramp-up phase during the first 6 months of operation, the target vehicle availability is > 90%. It is based on the general round-the-clock (24/7) readiness for services (i.e. 24 hours times number of days per month (*DpM, monthly availability)*, minus the downtime. Downtime hours are derived from the time stamps of transfer to workshop and back to operation (data points 1.11 and 1.12). Furthermore, periods during which the bus is not in service due to scheduled maintenance or upgrade (*SMU*, data point 1.13.1) do not count as downtime. The availability is thus calculated as:

$$Monthly\ Avaibility = \frac{24 * DpM - SMU - Downtime}{24 * DpM - SMU} * 100\% \qquad (Equation\ 3)$$

$$Annual\ Avaibility = \frac{8760 - SMU - Downtime}{8760 - SMU} * 100\% \qquad (Equation\ 4)$$

The required availability shall be ensured by corresponding manufacturer's warranties as part of the tender specifications and contracts.

4.2.5 Mean distance between failures

The KPI mean distance between failures *MDBF* is directly related to the KPI availability. A target MDBF > 2,500 km is set after an initial 6-month ramp-up phase.

Based on the daily driven distance (data point 1.4), the *MDBF* can be calculated as the sum of daily driven kilometres divided by the number of failures, with the number of failures being derived from the count of downtime reasons (data points 1.14.1-7).

$$MDBF = \emptyset \left(\frac{\sum Distance\ travelled}{\sum Failures} \right) \qquad (Equation\ 5)$$

This KPI is provided if minimum one failure occurs within the reporting period. As for the general availability, the required *MDBF* shall be stipulated in the procurement contracts.

Note: The *Mean distance between road calls (MDRC)* is not a KPI but a performance indicator (see section 4.5) and is calculated following the same logic using the sum of all road calls as denominator.

4.2.6 Specific fuel consumption

The fuel consumption of buses generally strongly depends on their length. Therefore, a hydrogen consumption of < 9 kg H_2/100 km for a solo bus (12–13.5 m) and < 14 kg H_2/100 km for an articulated bus (18 m) are stipulated in the FCH JU 2016 AWP. These figures are already included as a minimum efficiency requirement in the procurement documents.

The average hydrogen consumption is calculated specifically for each bus based on the total hydrogen refueled (sum of data point 2.1) and the total distance driven (odometer reading at the time of refueling minus odometer reading at the first refueling).

$$Fuel\ consumption = \frac{\sum_0^n Hydrogen\ refuelled}{Odometer\ reading_n - Odometer\ reading_0} \qquad (Equation\ 6)$$

If data points 1.19 and 2.1 are both available, the KPI will be calculated for both data points and used for cross-checking.

As some buses in CHIC did already consume less, a consumption level below 9 kg H_2/100 km for solo buses is anticipated. However, if all suppliers achieve the levels, there will be an improvement of over 30 % compared to some buses in CHIC. Based on previous experiences, attention may need to be given to (pro-longed) idling periods between services, i.e. the driver does not shut down the bus during a break since e.g. there is usually no or only little noise coming from the bus when idling.

4.2.7 Efficiency

A Tank-to-Wheel (TtW) efficiency of > 42% on the SORT 1 & 2 drive cycles[7] is required by the FCH JU 2016 AWP. The TtW efficiency is defined as the ratio of mechanical work at the wheel to the lower heating value of the hydrogen consumed. The fulfilment of this indicator has to be stipulated in the procurement specifications

[7] A description and graphical representation of the SORT cycles can be found in http://bit.ly/2olfGko

and demonstrated by the suppliers as part of their factory sign off. However, it is recommended to have verified compliance by an independent third party.

$$Efficiency = \frac{\sum mechanical\ work\ at\ the\ wheel}{\sum Hydrogen\ consumed} \qquad (Equation\ 7)$$

4.2.8 Vehicle CAPEX

The investment for FC buses is limited to 650,000 € per standard single deck 12 m bus and 1,000,000 € for articulated buses, yet excluding special equipment like CCTV, extra doors, Wi-Fi etc.. Articulated bus tenders require an investment of less than 1 Mio. €, again excluding special equipment. The investment comprises the purchasing price excluding any service contract and VAT. It is evaluated via the parameter vehicle price (FCB.P32).

These figures should already have been adopted in the tenders for procurement.

4.2.9 Vehicle OPEX

According to the target defined by the JIVE consortium, operating costs shall not exceed the equivalent costs of a conventional bus by more than 100%, aiming to stay below 50% extra costs at the end of the project. Operating costs will be determined as specific operating costs per kilometer driven over a period of one year. For their calculation, a whole set of parameters and data points is considered:

FC bus

- The driven distance (data point 1.4) for one year will be used to be coherent with operating cost statements.
- Cost of service contract FC bus (FCB.P36)
- Insurance cost FC bus (FCB.P37)
- Hydrogen fuel cost (data point 2.11) and hydrogen refuelled (data point 2.1)
- Operational and maintenance cost FC bus (data point 1.20)

Reference bus:

- Driven distance reference bus (data point 3.2)
- Cost of service contract reference bus (RB.P23)

- Insurance cost reference bus (RB.P24)
- Fuel cost reference bus (data point 3.13) and fuel consumption (data point 3.11)
- Operational and maintenance cost reference bus (data point 3.14)
- Filling station usage base fee (RB.P25)

To determine the specific operating costs, all costs that can arise within one year will be summarized and divided by the sum of the distance travelled within that year.

4.3 Descriptive parameters

In order to be able to conduct a comparative analysis the collection of data for reference buses (typically diesel of alternatively CNG powered) is also required. The parameters characterising the technical and other specifications of the FC and reference buses can be found in Table 4-3 and Table 4-4, respectively. The parameter identifiers are defined as follows:

- FCB-P stands for “Fuel Cell Bus, Parameter”,
- RB-P stands for “Reference Bus, Parameter”.

The descriptive parameters only have to be supplied once, or when relevant modifications are made. Most parameters are requested for the TRUST (formerly TEMONAS) database of the FCH JU (Reference “T”). Some will also be used for the performance assessment and the calculation of the KPIs (see section 4.2).

Table 4-3: Descriptive parameters of the FC buses.
To be provided once or when modifications were made. T = Required for TRUST database of the FCH JU and brown coloured cell fill. Definitions provided in TRUST are included in the Comments column.

Parameter number	Parameter	Unit	Comments	Ref-er-ence
General information				
FCB.P1	Deployment date	dd/mm/yy	Date at which the bus was put in operation	T
FCB.P2	Bus Manufacturer	Name	Manufacturer of the bus	T
FCB.P3	Bus model	-	Vehicles' model	T
FCB.P4	Production year		Year in which the vehicle has been produced.	T
FCB.P5	HV Battery Type and Supplier	-	e.g. NMC from Akasol	
FCB.P6	Service and maintenance contract	Yes /No	If yes, please specify type of service contract	

Parameter number	Parameter	Unit	Comments	Ref-er-ence
FCB.P7	Insurance	-	How is the vehicle insured, e.g. self-insured, insurance company?	
FCB.P8	Expectation of technological readiness of deployed FC buses at start of operation and after 36 months of operation	TRL 1-9	Please use TRL scale ranging from 1 to 9 as provided in the Annex of this document	
Technical parameters				
FCB.P9	Drivetrain power	kW	Maximum power that can be provided to the vehicles' wheels, as rated by the manufacturer,	T
FCB.P10	Number of stacks	#	Indicate how many fuel cell stacks are comprised in the drivetrain	T
FCB.P11	Drivetrain weight	kg	Overall weight of the propulsion system (including fuel cell system, batteries, controllers, motor, transmission, cooling and exhaust sys-tem)	T
FCB.P12	Maximum speed	km/h	Vehicle's maximum speed, as rated by the manufacturer. Please indi-cate in case the specified max speed is determined by another meas-ure than OEM specs, e.g. by operator requirements	T
FCB.P13	Acceleration time 0-50 km/h	s	Time to reach 50 km/h from start-up (0 km/h) - as rated by the manu-facturer	T
FCB.P14.1	Range (SORT 1)	km	Maximum distance that the vehicle can travel, without refuelling, ac-cording to the Standardised On-Road Test (SORT) 1 driving cycle	T
FCB.P14.2	Range (SORT 2)	km	Maximum distance that the vehicle can travel, without refuelling, ac-cording to the Standardised On-Road Test (SORT) 2 driving cycle	T
FCB.P15.1	Empty weight	kg	Empty vehicle weight as provided by OEM	T
FCB.P15.2	Max. allowable weight	kg	Maximum allowable vehicle weight as provided by OEM	
FCB.P16.1	Height	m	Vehicle height	T
FCB.P16.2	Length	m	Vehicle length	T
FCB.P16.3	Width	m	Vehicle width	T

Parameter number	Parameter	Unit	Comments	Reference
FCB.P17.1	Number of seated passengers	#	Maximum number of seated passengers for which the bus model is homologated - excluding the driver. Please indicate in case the specified number is determined by another measure than weight restrictions of the vehicle, e.g. by operator requirements	T
FCB.P17.2	Number of standing passengers	#	Maximum number of standing passengers for which the bus model is homologated - excluding the driver. . Please indicate in case the specified number is determined by another measure than weight restrictions of the vehicle, e.g. by operator requirements	T
FCB.P18	Hydrogen storage capacity	kg	Total weight of hydrogen that can be stored in the vehicle tank	T
FCB.P19	Hydrogen tank pressure rating	bar	Pressure rating for the vehicle tank, e.g. 350 bar	T
FCB.P20.1	TTW consumption SORT 1	kg/100 km	Hydrogen consumption for 100 km driven according to the Standardised On-Road Test (SORT) cycle 1	T
FCB.P20.2	TTW consumption SORT 2	kg/100 km	Hydrogen consumption for 100 km driven according to the Standardised On-Road Test (SORT) cycle 2	T
FCB.P21.1	FC system efficiency SORT 1	% (LHV)	Ratio Electricity generated to hydrogen consumed on the Standardised On-Road Test (SORT) cycle 1	
FCB.P21.2	FC system efficiency SORT 2	% (LHV)	Ratio Electricity generated to hydrogen consumed on the Standardised On-Road Test (SORT) cycle 2	
FCB.P21.3	FC system efficiency	% (LHV)	Peak, please specify if different	
FCB.P22	Bus durability	years	Vehicle durability, as rated by the manufacturer	T
FCB.P23	Fuel cell system durability	h	Fuel cell system durability as guaranteed by the manufacturer Please specify if different lifetimes for system and stack are guaranteed.	T
FCB.P24.1	Minimum operating temperature	°C	Minimum allowed ambient temperature for vehicle operation	T
FCB.P24.2	Maximum operating temperature	°C	Maximum allowed temperature for vehicle operation	T
FCB.P24	Rated power (FC system)	kW	Net, please specify if different	

Parameter number	Parameter	Unit	Comments	Ref-er-ence
FCB.P25	FC system efficiency	% (LHV)	Peak, please specify if different	
FCB.P26	Rated power (HV Battery)	kW		
FCB.P27.1	Capacity (HV Battery)	kWh		
FCB.P27.2	Usable capacity (HV battery)	kWh	Alternatively provision of min/max SOC [%]	
FCB.P28	HVAC system	Type and kW	E.g. electric AC 24 kW and electric heater 30 kW. please also provide temperature set point for AC and heating, if appli-cable	
FCB.P29	External HV battery recharging capability	Yes/No	If Yes, type of connection and charging power [kW] to be specified, also where amount of energy recharged is measured (e.g. at battery input terminal or before/ after inverter)	
FCB.P30	Data communication for refuelling	Yes/No	Please specify applied communication protocol, e.g. SAE 2799	
FCB.P31	Freeze protection System installed	Yes/No	If Yes, specify operating voltage	
Financial parameters				
FCB.P32	Vehicle price	EUR	Price per vehicle of the transaction between the bus manufacturer and the bus buyer. Any grant amount should not be accounted for here (price before any rebates, grants etc.) Purchase price excluding any service contract and VAT	T
FCB.P33.1	Bus cost	EUR	If available, cost of manufacturing the vehicle	T
FCB.P33.2	Est. bus cost @ mass prod.	EUR	Estimated vehicle cost at an assumed up-scaled production level - please specify the production level assumed in the comment field	T
FCB.P34.1	Fuel cell system cost	EUR/kW	Actual cost of the fuel cell system, including hydrogen tank, fuel cell stack, air compressor, DC/DC converter - excluding overheads and profits	T
FCB.P34.2	Est. FC system cost @ mass prod.	EUR/kW	Estimated fuel cell system cost at an assumed up-scaled production level - please specify the production level assumed in the comment field	T

Parameter number	Parameter	Unit	Comments	Ref-er-ence
FCB.P35	Funding received	EUR	Funding received by each funding source	
FCB.P36	Cost of service contract	EUR/a	If FCB.6 is yes, please specify yearly cost	
FCB.P37	Insurance cost	EUR/a	Yearly insurance cost	

Table 4-4: Descriptive parameters of the reference buses.
Provided once or when modifications were made. T = Required for TRUST database of the FCH JU and brown coloured cell fill. Definitions provided in TRUST are included in the Comment column.

Parameter number	Parameter	Unit	Comments	Refer-ence
General information				
RB.P1	Deployment date	dd/mm/yy	Date at which the bus was put in operation	
RB.P2	Bus Manufacturer	Name	Manufacturer of the bus	
RB.P3	Bus model	-	Vehicles' model	
RB.P4	Production year		Year in which the vehicle has been produced.	
RB.P5	Type of bus		e.g. diesel or CNG (200 bar)	
RB.P6	Service and maintenance contract	Yes /No	If yes, please specify type of service contract	
RB.P7	Insurance	-	How is the vehicle insured, e.g. self-insured, insurance company?	
Technical parameters				
RB.P8	Drivetrain power	kW	Maximum power that can be provided to the vehicles' wheels, as rated by the manufacturer,	
RB.P9	Drivetrain weight	kg	Overall weight of the propulsion system (including fuel cell system, batteries, controllers, motor, transmission, cooling and exhaust system)	

Parameter number	Parameter	Unit	Comments	Refer-ence
RB.P10	Maximum speed	km/h	Vehicle's maximum speed, as rated by the manufacturer. Please indicate in case the specified max speed is determined by another measure than OEM specs, e.g. by operator requirements	
RB.P11	Acceleration time 0-50 km/h	s	Time to reach 50 km/h from start-up (0 km/h) - as rated by the manufacturer	
RB.P12.1	Range (SORT 1)	km	Maximum distance that the vehicle can travel, without refuelling, according to the Standardised On-Road Test (SORT) 1 driving cycle	
RB.P12.2	Range (SORT 2)	km	Maximum distance that the vehicle can travel, without refuelling, according to the Standardised On-Road Test (SORT) 2 driving cycle	
RB.P13.1	Empty Weight	m	Empty vehicle weight as provided by OEM	
RB.P13.2	Max. allowable weight	kg	Maximum allowable vehicle weight as provided by OEM	
RB.P14.1	Height	m	Vehicle height	
RB.P14.2	Length	m	Vehicle length	
RB.P14.3	Width	m	Vehicle width	
RB.P15.1	Number of seated passengers	#	Maximum number of seated passengers for which the bus model is homologated - excluding the driver. Please indicate in case the specified number is determined by another measure than weight restrictions of the vehicle, e.g. by operator requirements	
RB.P15.2	Number of standing passengers	#	Maximum number of standing passengers for which the bus model is homologated - excluding the driver. . Please indicate in case the specified number is determined by another measure than weight restrictions of the vehicle, e.g. by operator requirements	
RB.P16.1	TTW consumption SORT 1	l Diesel/100 km kg CNG/100 km	Fuel consumption for 100 km driven according to the Standardised On-Road Test (SORT) cycle 1	
RB.P16.2	TTW consumption SORT 2	l Diesel/100 km kg CNG/100 km	Fuel consumption for 100 km driven according to the Standardised On-Road Test (SORT) cycle 2	
RB.P17	Bus durability	years	Vehicle durability, as rated by the manufacturer	

Parameter number	Parameter	Unit	Comments	Refer-ence
RB.P18.1	Minimum ambient temperature	°C	Minimum allowed ambient temperature for vehicle operation	
RB.P18.2	Maximum ambient temperature	°C	Maximum allowed ambient temperature for vehicle operation	
RB.P19	HVAC system	Type and kW	E.g. mechanic AC 24 kW and diesel heater 30 kW. please also provide temperature set point for AC and heating, if appli-cable	
RB.P20	Tank Capacity	l/kg	Litres of diesel or kg of CNG, for CNG also working pressure, e.g. 200 bar	
Financial parameters				
RB.P21	Vehicle price	EUR	Price per vehicle of the transaction between the bus manufacturer and the bus buyer. Any grant amount should not be accounted for here (price before any rebates, grants etc.) Purchase price excluding any service contract and VAT	
RB.P22	Funding received	EUR	Funding received by each funding source	
RB.P23	Cost of service contract	EUR/a	If RB.6 is yes, please specify yearly cost	
RB.P24	Insurance cost	EUR/a	Yearly insurance cost	
RB.P25	Filling station usage base fee	EUR/a	If applicable, please specify any yearly “base” fees which may apply in the context of fuel provision	

4.4 Data points

Table 4-5: Data points for monitoring FC bus operation.
T = Required for TRUST database of the FCH JU and brown coloured cell fill. Definitions provided in TRUST are included in the Comment column.

FCB Data point no.	Data point	Unit	Frequency of Collection	Comments	Refer-ence
1.1	Hours of bus operation	h	Daily	Alternatively, this can be provided via time stamps for ignition on/off [dd/mm/yyyy] [hh:mm:ss].	T
1.2	Operating hours FC system	h	Daily and per FC system if more than one system installed	Depending on the operating regime implemented by the vehicle OEM the values for this data point may be lower than the values recorded for data point 1.1	T
1.3	Operating hours on route	h	Daily	Optional for operators using this metric	
1.4	Distance driven	km	Daily		T
1.5	Driven distance on route	km	Daily	Optional for operators using this metric	
1.6	Odometer reading	km	monthly		
1.7	Route/ run number	#	Daily		
1.8	Electricity generation FC system	kWh	Daily		
1.9	Electricity consumption electric engine	kWh	Daily	If available, for determining energy consumption for traction	
1.10	Electricity generation electric engine	kWh	Daily	If available, for determining recuperation energy	
1.11	Electricity consumption HVAC	kWh	Daily	If available, separated by heating and AC and for driver and passenger cabin (if separate)	
1.12	Availability status: Out of service	[dd/mm/yyyy] [hh:mm:ss]	Event based	Timestamp for transfer to workshop (out of service message)	
1.13	Availability status: Back to service	[dd/mm/yyyy] [hh:mm:ss]	Event based	Timestamp for transfer back to operations (back to service message)	

FCB Data point no.	Data point	Unit	Frequency of Collection	Comments	Refer-ence
1.14	Reason(s) for Downtime		Event based	Linked to 1.12, please give reason for downtime and/ or select from provided list; if multiple downtime reasons please provide (estimated) share of downtime for each reason	
1.14.1	Downtime for scheduled mainte-nance/upgrades SMU	-	Event based		T
1.14.2	Downtime due to FC stack issues	-	Event based		T
1.14.3	Downtime due to FC balance of plant	-	Event based	e.g. humidifier, air compressor	
1.14.4	Downtime due to electrical components	-	Event based	e.g. electric engine, steering pump	T
1.14.5	Downtime due to the on-board hydrogen storage tank	-	Event based		T
1.14.6	Downtime due to the high voltage battery	-	Event based		T
1.14.7	Downtime due to peripheral mechanical components	-	Event based	e.g. doors, suspension	T
1.15	Repair time	h	Event based	If available from Maintenance system. Actual labour time spent for carried out maintenance/ re-pairs specified in 1.12.	
1.16	Road call	[dd/mm/yyyy] [hh:mm:ss]	Event based	Indicates unplanned termination of service due to a failure with date and time stamp. Please specify reason for road call	
1.17	Incidents	[dd/mm/yyyy] [hh:mm:ss]	Event based	If yes, information with time stamp and classification ac-cording to provided list below. In addition safety incident reporting to be carried out according to 1.18, not required for “regular” traffic accident w/o injury	T
1.17.1	Event type 1: Vehicle incident/ injury/ H2 release	-	Event based		
1.17.2	Event type 2: Vehicle incident/ injury/ no H2 release	-	Event based		

FCB Data point no.	Data point	Unit	Frequency of Collection	Comments	Refer-ence
1.17.3	Event type 3: Vehicle incident/ no injury/ H2 release	-	Event based		
1.17.4	Event type 4: Vehicle incident/ no injury/ no H2 release	-	Event based		
1.17.5	Event type 5: Near Miss	-	Event based		
1.18	Safety related incidents		Event based	Incidents affecting safety using the template as in Annex B	
1.19	Hydrogen consumption	kg	Daily	Measured on the bus, will be used to cross check with H2 refuelling data (data points 2.1, 2.3)	
1.20	Operational, maintenance and fixed cost	EUR/ local currency	yearly	Incl. material and labour, insurance and any service contract fees excl. fuel cost (see 2.11) and VAT	

Table 4-6: Data points for monitoring FC bus refuelling and recharging.

T = Required for TRUST database of the FCH JU and brown coloured cell fill. Definitions provided in TRUST are included in the Comment column.

FCB Data point no.	Data point	Unit	Frequency of Collection	Comments	Refer-ence
2.1	Hydrogen refuelled	kg	Event based		T
2.2	Station ID	-	Event based	If available	
2.3	Odometer reading	km	Event based		T
2.4	Start of refuelling process	dd.mm.yyyy hh:mm:ss	Event based		
2.5	End of refuelling process (end)	dd.mm.yyyy hh:mm:ss	Event based	Alternatively duration of refuelling process is tracked in [mm:ss]	
2.6	Ambient temperature	°C	Event based	at start of refuelling	

FCB Data point no.	Data point	Unit	Frequency of Collection	Comments	Refer-ence
2.7	Vehicle tank temperature at start of refuel-ling	°C	Event based	Please specify once where the temperature is measured, e.g. using a witness tank	
2.8	Vehicle tank temperature at end of refuel-ling	°C	Event based		
2.9	Vehicle tank pressure at start of refuelling	bar	Event based		
2.10	Vehicle tank pressure at end of refuelling	bar	Event based		
2.11	Hydrogen fuel cost	EUR or lo-cal curren-cy/l or kg	Once / if changed	Average H2 fuel cost excl. VAT	
2.12	Electricity consumption during (overnight) parking	kWh	Daily	If applicable, e.g. anti-freeze protection, cabin heating, HV battery balancing collection frequency depends on where the electricity consumption is measured: daily – if measured from the vehicle side, monthly – if measured from the infrastructure side	
2.13	Electricity charged	kWh	Event based	If external HV battery recharging capability	
2.14	Start SOC	%	Event based	If external HV battery recharging capability	
2.15	End SOC	%	Event based	If external HV battery recharging capability	

Table 4-7: Data points for monitoring reference bus operation.
T = Required for TRUST database of the FCH JU and brown coloured cell fill. Definitions provided in TRUST are included in the Comment column.

RB Data point no.	Data point	Unit	Frequency of Collection	Comments	Refer-ences
3.1	Hours of bus operation	h	Daily	Alternatively, this can be provided via time stamps for igni-tion on/off [dd/mm/yyyy] [hh:mm:ss].	T
3.2	Distance driven	km	Daily		T
3.3	Driven distance on route	km	Daily	Optional for operators using this metric	

RB Data point no.	Data point	Unit	Frequency of Collection	Comments	Refer-ences
3.4	Odometer reading	km	Monthly		
3.5	Route/ run number	#	Daily		
3.6	Availability status: Out of service	dd/mm/yyyy hh:mm:ss	Event based	Timestamp for transfer to workshop (out of service message)	
3.7	Availability status: Back to service	dd/mm/yyyy hh:mm:ss	Event based	Timestamp for transfer back to operations (back to service message)	
3.8	Reason(s) for Downtime		Event based	Linked to 3.6, please give reason for downtime and/ or select from provided list; if multiple downtime reasons please provide (estimated) share of downtime for each reason	T
3.8.1	Downtime for scheduled maintenance/upgrades SMU	-	Event based		T
3.8.2	Downtime due to electrical components	-	Event based	e.g. electrical air compressor, steering pump, if applicable	T
3.8.3	Downtime due to peripheral mechanical components	-	Event based	e.g. doors, suspension	T
3.9	Repair time	h	Event based	If available from Maintenance system. Actual labour time spent for carried out maintenance/ repairs specified in 3.6	
3.10	Road call	dd/mm/yyyy hh:mm:ss	Event based	Indicates unplanned termination of service due to a failure with date and time stamp. Please specify reason for road call	
3.11	Diesel / CNG refuelled	l / kg	Event based	litres of diesel or kg of CNG	
3.12	Odometer reading at refuelling	km	Event based		
3.13	Fuel cost	€ or local currency/ l or kg	Once / if changed	Average fuel cost excl. VAT	
3.14	Operational, Maintenance and fixed cost	EUR/ local currency	Yearly	Incl. material and labour, insurance and any service contract fees, excl. fuel cost (see 3.13) and VAT	

4.5 Performance indicators

The indicators for assessing the performance of the FC buses and reference buses can be found in Table 4-8 and Table 4-10.

Many of the performance indicators also represent items that have to be entered into the TRUST (formerly TEMONAS) database of the FCH JU (Reference “T”). This has to take place for every calendar year with demonstration activities.

Table 4-8: Performance indicators of FC bus operation.
For diagnostic purposes, monthly or daily evaluations may carried out in addition to what is specified in the “Period” column.
T = Required for TRUST database of the FCH JU. Definitions provided in TRUST are included in the Comment column.

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points required	Comments	Refer-ence
FCB-PI.1 (**KPI FCB-4**)	Availability of bus	%	Monthly, an-nually and overall	1.12, 1.13	KPI target is > 90% See section 4.2.4 for details	T
FCB-PI.2 (**KPI FCB-5**)	Mean distance between failures (MDBF)	Km	Annually and overall	1.4 and count of 1.12	KPI target is >2,500 km See section 4.2.5 for details	T
FCB-PI.3	Mean distance between road calls (MDRC)	km	Annually and overall	1.4 and count of 1.16		
FCB-PI.4	Distribution downtime hours with respect to root causes	%	Annually and overall	1.14.1 to 1.14.7	The causes for downtime are categorised, distinguishing between the provided cate-gories	
FCB-PI 5	Ratio between actual repair time and Downtime	%	Annually and overall	1.14.1 to 1.14.7, 1.15	This PI will allow to elaborate e.g. on wait-ing time for support, parts in comparison to reference buses	
FCB-PI.6	TRL	-	Start/ middle/ end of project	FCB.8		T

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points required	Comments	Refer-ence
FCB-PI.7 (**KPI FCB-2**)	Distance travelled	km	Monthly, an-nually and overall	1.4	KPI target is minimum annual distance of 44,000 km per bus See section 4.2.2 for details	T
FCB-PI.8 (**KPI FCB-6**)	Specific fuel consumption	kg H2/ 100 km	Monthly, an-nually and overall	2.1/ 1.19, 2.3	KPI target is in average < 9 kg H_2/100 km See section 4.2.6 for details.	T
FCB-PI.9	Deviation of refuelling data	%	Annually and overall	2.1/ 1.19, 2.3	If data points 2.1 and 1.19 are both availa-ble, deviation between the two H_2 refuelling data points	
FCB-PI.10 (**KPI FCB-7**)	Efficiency	%	Once	FCB.P21.1/.2	KPI target is > 42% See section 4.2.7 for details	
FCB-PI.11 (**KPI FCB-1**)	Vehicle operation lifetime	years	Once	FCB.P22	KPI target is > 25.000 h See section 4.2.1 for details	T
FCB-PI.12 (**KPI FCB-3**)	Operating hours per fuel cell system	hours	Monthly, an-nually and overall	1.2	KPI target is > 15.000 h See section 4.2.3 for details	T
FCB-PI.13 (**KPI FCB-8**)	CAPEX	EUR	Once	FCB-32	KPI target < 650 k€ for 12 m bus, < 1 M€ for 18m bus (excl. operator specific equip-ment. and taxes) See section 4.2.8 for details.	T
FCB-PI.14 (**KPI FCB-9**)	OPEX	EUR/km	Annually and overall	1.4, 1.20, 2.11, FCB.P36, FCB.P37	KPI target < 150 % of the equivalent costs for a conventional bus. See section 4.2.9 for details.	T
FCB-PI.15	Diesel fuel replaced	l	Annually and overall	3.11		

Table 4-9: Performance indicators of FC bus refuelling.
Indicator is taken from Table 3-15 on HRU.
Note: This table may need to be extended to account for battery charging in case FC buses with plug-in functionality will be deployed.

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points required	Comments
FCB-PI.16 (= HRU-PI.11)	Amount of hydrogen dispensed to the project buses overall and per bus	kg	Monthly, annually and overall		Used to double-check specific hydrogen consump-tion.

Table 4-10: Performance indicators of reference bus operation.

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points required	Comments	Refer-ence
RB-PI.1	Availability of bus	%	Monthly, annually and overall	3.6, 3.7		
RB-PI.2	Mean distance between failures (MDBF)	km	Annually and overall	3.2 and count of 3.6		
RB-PI.3	Mean distance between road calls (MDRC)	km	Annually and overall	3.2 and count of 3.10		
RB-PI.4	Distribution downtime hours with respect to root causes	%	Annually and overall	3.8.1 to 3.8.3	The causes for downtime are categorised, distinguishing between the provided cate-gories	
RB-PI 5	Ratio between actual repair time and Downtime	%	Annually and overall	3.8.1 to 3.8.3, 3.9	This PI will allow to elaborate e.g. on wait-ing time for support, parts in comparison to FC buses	

Performance indicator number	Performance indicator	Unit	Period	Parameters and data points required	Comments	Refer-ence
RB-PI.6	Distance travelled	km	Monthly, annually and overall	3.2		
RB-PI.7	Specific fuel consumption	l Diesel/ 100 km kg CNG/ 100 km	Monthly, annually and overall	3.11, 3.12	litres of diesel or kg of CNG per 100 km	
RB-PI.8	Vehicle operation lifetime	years	Once	RB.17	Vehicle durability, as rated by the OEM	
RB-PI.9	CAPEX	EUR	Once	RB-21		
RB-PI.10)	OPEX	EUR/km	Annually and overall	3.2, 3.13, 3.14, RB.23, RB.24	Maintenance and operation costs, includ-ing hydrogen, insurances, running costs (tyres, service, parts and labour), mainte-nance, repairs. Taxes excluded	

Annex A Technology Readiness Levels

Technology Readiness Levels as specified by HORIZON 2020 – WORK PROGRAMME General Annexes

Where a topic description refers to a TRL, the following definitions apply, unless otherwise specified:

- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 7 – system prototype demonstration in operational environment
- TRL 8 – system complete and qualified
- TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies)

Annex B Incident reporting forms

INFRASTRUCTURE INCIDENT REPORT FORM – rev 3

Incident category (definitions in page 2):

☐ Dangerous condition	☐ Lost Time Injury (LTI)	☐ Major technical problem
☐ Near miss	☐ Security attempt	
☐ Accident	☐ Security breach	

Reported by:	**Job title:**	**Company:**
Phone nr.:	**Date**:	**Station identification:**

Component category (mark with x or shadow in the box):

Affected unit:	**Device:**	**Others:**
☐ Production	☐ Connection	
☐ Storage	☐ Regulation	
☐ Compressor	☐ Measurement	
☐ Dispenser		
☐ FC-bus		

Event category:

Non-conformance:	**Incident/abnormal situation:**	**Accident:**
☐ Off-spec hydrogen gas quality	☐ Affecting people	☐ Minor injury
☐ FC-bus stop	☐ Affecting the environment	☐ First aid injury
☐ Safety system out of order	☐ Affecting on-site equipment	☐ Injury, medical treatment
☐ Operation interrupted	☐ Affecting off-site material	☐ Material damage
	☐ Emergency shut down	☐ Environmental damage
	☐ Leakage (describe below)	

Leakage details:

Location / affected component:

Leakage size (% vs piping cross-section, kg/h, etc):

Event description:

Description:	**Discovered**	☐ Man.	☐ Aut.
	During operation:	☐	☐
	During inspection:	☐	☐
	During maintenance:	☐	☐

Cause:

Accident details:		
Injury to people: Separate report prepared: ☐ Yes ☐ No Personal protection equipment ☐ Used ☐ Not used	**Environmental damage:**	**Damaged object:**
Immediate corrective actions if any:		
Description: Will this incident require further investigation and a final report further corrective action: ☐ Yes ☐ No ☐ Proposed ☐ Planned ☐ Implemented		
Lessons learnt:		

GLOSSARY

Incident: Collective term, including dangerous conditions, near misses, accidents, injuries, security attempts, security breaches and major technical problems.

Dangerous condition: Unintended work-related condition with no consequence, but which under slightly different circumstances, could have become a near miss or an accident.

Near miss: Sudden, unintended work-related event with no consequence, but which under slightly different circumstances, could have become an accident.

Accident: Sudden, unintended work-related incident that results in personal injury and/or business interruption and/or damage to property, the environment or a third party.

Lost Time Injury (LTI): Personal injury at work that leads to unfitness for work and absence beyond the day of the accident.

Security attempt: Averted, deliberate attempt to harm the owner's personnel, property, operation or other interests.

Security breach: Conscious or negligent unauthorised act that harms the owner's personnel, property, operations or other interests.

Major technical problem: Incident related to components, with or without interruption of the hydrogen dispensing operations to vehicles, i.e. affecting or not the infrastructure availability.

BUS INCIDENT REPORT FORM v1

Use this incident report form in case of the following events:

- Vandalism on hydrogen or high voltage components
- Accidents caused by the bus driver and other parties (e.g. traffic accident)
- Fire/braise of hydrogen, high voltage an conventional components

Incident category (definitions on page 2):

☐ Vandalism ☐ Accident ☐ Fire/braise

Reported by:	**Job title:**	**Company:**
Phone nr.:	**Date/time:**	**Bus identification:**
Picture: please add a picture of the incident to this report form		

Specific definition (mark with x or shadow in the box)

Vandalism:	**Accident:**	**Fire/braise:**
☐ Hydrogen components ☐ High voltage components	☐ Hydrogen components (roof) ☐ High voltage components (roof & Rear) ☐ Accident (bus driver and other parties involved, e.g. traffic accident)	☐ Hydrogen components ☐ High voltage components ☐ Standard bus components

Component category

Affected unit:	**Device:**	**Others:**
☐ Tanks ☐ Pipe ☐ Fuel Cell ☐ High voltage battery ☐ Cable ☐ Converter	☐ Connector ☐ Regulation/ Valve ☐ Sensor	

Event category:

Non-conformance:	**Incident/abnormal situation:**	**Accident:**
☐ Failure of the driver ☐ Safety system out of order ☐ Deficient maintenance Others:	☐ Affecting people ☐ Affecting the environment ☐ Affecting bus equipment ☐ Affecting off-bus equipment (e.g. bus stand, maintenance hall) ☐ Emergency shut down ☐ Leakage (describe below)	☐ Minor injury ☐ First aid injury ☐ Injury, medical treatment ☐ Material damage ☐ Environmental damage

Leakage details:

Location / affected component:

Leakage size (% vs piping cross-section, kg/h, etc):

Event description:

Description:	**Discovered**	Man.	Aut.
	During operation:	☐	☐
	During inspection:	☐	☐
	During maintenance:	☐	☐

Cause:

Accident details:

Injury to people:	**Environmental damage:**	**Damaged object:**
Separate report prepared: ☐ Yes ☐ No Personal protection equipment: ☐ Used ☐ Not used		

Immediate corrective actions if any:

Description:

Will this incident require further investigation and a final report further corrective action: ☐ Yes ☐ No

☐ Proposed ☐ Planned ☐ Implemented

If so, please describe these corrective actions:

GLOSSARY

Incident: Collective term, including vandalism, accident, fire and braise.

Vandalism: Criminal damage of hydrogen or high voltage components. Damage such as graffiti, scratch or pollution is not part of this.

Accident: Sudden, unintended damage of hydrogen or high voltage system that is caused by the bus driver and other parties (e.g. traffic accident). Body damage (e.g. window, mirror, door) caused by the bus driver is not part of this. Also excluded are accidents of passengers (stumble, tumble).

Fire/braise: Vehicle braise or fire of hydrogen, high voltage and standard bus components.

Annex C Changes Made to the Document

Version	Date	Changes made

Annex D References

[Faltenbacher, Stolzenburg et al. 2011/14]
Faltenbacher, M.; Stolzenburg, K.; Bos, U; Reijalt, M; Lozanovski A.: Project Assessment Framework (CHIC deliverable 3.1), 2011/2014.

[Stolzenburg/Graham 2016] Stolzenburg, K; Graham, S.: Publishable Executive Summary of the restricted Report on Hydrogen Infrastructure Operation and Performance (CHIC Deliverable 1.5), 2016.

[Stolzenburg/Glatthor 2014] Stolzenburg, K; Glatthor, K.; Data Specification for the Project (HyTransit Deliverable 4.1a), 2014.

[NewBusFuel 2016] New Bus ReFuelling for European Hydrogen Bus Depots: Agreed definition of availability and reliability for bus depot fuelling stations and recommendations for appropriate availability enforcement mechanisms (NewBusFuel Deliverable No. 3.6), 2016.