Ref. Ares(2017)2714217 - 30/05/2017

New Bus ReFuelling for European Hydrogen Bus Depots

Grant agreement No: 671426

Deliverable No. 3.6

Agreed definition of availability and reliability for bus depot fueling stations and recommendations for appropriate availability enforcement mechanisms

Status: F

(D-Draft, FD-Final Draft, F-Final)

Dissemination level: PU

(PU – Public, RE – Restricted, CO – Confidential)

17/11/2016

Contents

1 Introduction

For a large hydrogen bus refuelling system, the issue of reliability is of central importance. If a significant portion of a city's public transport fleet is dependent on the supply of hydrogen from a single source, then it is essential that the hydrogen supply is not disrupted, otherwise the daily transport of the city will be severely interrupted. The incumbent fuel (diesel) does not suffer from issues of fuel reliability and hence for hydrogen to compete, an equivalent level of reliability will need to be offered. This issue is made more acute for hydrogen than for other fuels, as it is likely that in the early years hydrogen will only be present at a limited number of bus depots, so a solution involving refuelling buses at an alternative depot is unlikely to be available. Hence, refuelling stations need to be made reliable by design.

NewBusFuel task 3.5 involves a working group dedicated to understanding station reliability and availability requirements for bus operators in the project. Emerging conclusions from an initial consultation exercise enabled common definitions of required HRS reliability and availability to be developed, and are described in this document. In particular, the reliability expectations and methodologies to assess reliability at the design stage and in use are set out. This document does not make recommendations on contractual guarantees which will be put in place in the event of reliability falling below a given level. It is recommended that failings to meet pre-agreed availability standards should be contractually controlled (e.g. in the form of liquidated damages equivalent to the lost productivity of the public transport system).

All NewBusFuel partners were requested to work with the definitions described in this document for all project related engineering design studies to allow simple comparison of findings across the different design studies. Furthermore, this document could be used as guidance for similar activities beyond the scope of NewBusFuel.

For the avoidance of doubt, we have adopted the following definitions throughout this document:

- **Availability** is based on time the refuelling system is able to refuel the buses which is in line with the provisions of the FCH JU annual work programme. More details on its definition can be found in chapter 2
- **Reliability** is calculated based on the ability to refuel the buses as planned. The proposed measurement methodology is based on successful refuelling events, for which the methodology is discussed in chapter 3 of this document.

2 HRS availability (time-based)

2.1 Definition

The availability of an HRS is based on time the refuelling system is able to refuel the buses. In line with the provisions of the FCH JU annual work programme HRS availability is defined as set out in e.g. the CHIC project, based on the provisions of the HyLIGHTS project.

Availability [%] = actual operating time [h] / potential operating time [h]

- Actual operating time [h] = potential operating time [h] – total downtimes [h]
- Potential operating time [h] = HRS opening hours during the reported project time period (e.g. 24 h, 7 days per week = 8760 hours per year or 9 hours per day, during 365 days = 3,285 h) excluding any planned maintenance
- Total downtime[1,] [h] = total time that hydrogen refuelling is not possible at the HRS (= unavailability of HRS, see below)

For a bus operator it is recommended to use for the definition of the 'potential operating time' the standard refuelling time window of the operator that he is using in its regular operation window from on the number of weekdays that he is normally using for refuelling.

2.2 Unavailability of HRS

The unavailability to refuel hydrogen vehicles at the HRS e.g. due to repairs, unplanned or planned maintenance of the HRS has to be reported to the bus operator by the refuelling station operator:

- At the start of the period of unavailability to refuel hydrogen at the HRS (start / recognition of the problem) and
- At the end of the period of unavailability (end of repair or maintenance).

[1] Excluded are problems / incidents caused by the vehicle (e.g. problem with the vehicle storage) or problems / incidents caused by the failure of the primary energy supply (e.g. electricity supply for hydrogen generation, NG, LPG or other fuels). However it is recommended to monitor those downtime periods as well to have a complete picture of the up- and downtimes of the HRS

The duration of an incident or repair that affects the capability of the HRS to refuel hydrogen (down-time) is derived from the above described unavailability reporting (start and end of the problem to refuel hydrogen vehicles). The downtime is calculated from HRS operational hours, see the following examples:

Example 1: A hydrogen refuelling station that is open for 24 hours per day reports the start of a major problem (no hydrogen refuelling is possible) on Monday at 13:00 and the successful repair on Tuesday at 14:00. Considering the HRS opening hours, the duration of hydrogen unavailability is 25 hours.

Example 2: Due to a technical problem the HRS is not able to refuel hydrogen buses. The operator reports the start of the problem at 18:00 on Monday. Because the repair of the compressor is impossible, a new part one must be ordered by the equipment manufacturer. Due to a delivery delay, the repair of the HRS takes more time than expected and the HRS is fully operational on Thursday at 13:00. The operating hours of the HRS are defined with 9 hours per day representing the refuelling window from 17:00 until 02:00 when refuelling personnel is present at the refuelling station. The down-time of the HRS is calculated as follows:

- Monday: 1 hour operation, 8 hours out of operation
- Tuesday - Wednesday: 2 days, each 9 hours out of operation = 18 hours out of operation
- Thursday: 9 hours of operation

Total downtime: 26 hours out of operation.

3 HRS reliability (event-based)

As mentioned in the introduction chapter it is recommended that the Reliability is calculated based on the ability to refuel the buses as planned. The proposed measurement methodology is based on successful refuelling events, for which the methodology is discussed in chapter 3 of this document.

3.1 Reliability expectations

All bus operators in the project are clear that for a large bus depot, relying on a hydrogen station for over 50 buses, the **target level of reliability of the station should be 100%.** This means that all buses requiring hydrogen must be able to refuel every day.

Operationally, this implies that hydrogen must be available in one or multiple pre-defined refuelling windows every day. There will be scope for the station to have planned downtime outside of this daily window(s), but this downtime could not last a full day (i.e. the station would need to be up and running before the next daily fuelling window). There may also be some scope for the refuelling window to be lengthened in the event of problems with the station and/or planned maintenance, but this would need to be discussed on a local basis, and may carry contractual penalties.

This level of reliability will be assured in two ways – by design and during operation.

3.2 Reliability by design

Station providers will need to demonstrate at the design stage that their systems have built in sufficient redundancy so that any given failure does not cause the ability of bus operators to refuel to fall below the target level of 100%. The station providers should demonstrate this through a failure mode analysis. This would involve the following steps:

1. Identify each source of failure and its realistic likelihood
2. Demonstrate the mitigation solutions which have been implemented within the station (or the operator's logistics chain in the event of e.g. bringing in a back-up supply) to cope with this incident. Explanation should be given for how these systems will respond to the source of the failure and how this will ensure no interruption in the ability to refuel buses.

The consensus between the studies here is to generally work on an “n+1” basis. This means that the design should be robust in the event of a single unplanned and unlikely failure, but that it is not necessary to plan for multiple unlikely failures happening in tandem. Deviating from this principle is of course possible at the discretion of the operator or the technology provider as there might be alternative approaches and solutions that provide the desired level of reliability.

In addition it is recommended that already at the design stage, the suppliers should explain the scheduled maintenance strategy and how this will either completely avoid interruption in the ability to supply fuel (e.g. by being able to isolate a component for maintenance without affecting the rest of the system) or limit disruption to ensure the station is operational before the next main refuelling window.

Further details on how the desired levels of availability and reliability can be achieved are provided in the Deliverable D3.7: Review of strategies to ensure adequate availability/ redundancy of HRS.

3.3 In-use Reliability

In addition to demonstrating that the hydrogen supply is 100% reliable by design, it is also likely that contracts will be implemented to ensure that the stations are reliable in practice. The refuelling stations will use the consistent definition of reliability as part of the ongoing contract management. It is expected that when performance falls below 100% reliability, as measured in use, that contractual penalties will be implemented. The loss of one day’s bus operation is difficult to be valued and shall be mutually agreed upon.

The proposed definition is “event based”, whereby the ability to fill buses is the key metric determining station performance. The definition is described below:

- Number of planned buses (x) to be refuelled will be defined by the HRS design specification
- Number of successfully refuelled buses tracked by dispenser (z)
- Number of vehicles not refuelled on a given day in case of failure (y):
    - in case of an interruption during filling y = x-z, time of failure to be tracked by refuelling personal and/or appropriate technical measures
    - in case complete failure prevents refuelling then y = x for each day w/o refuelling,

- The definition of complete/incomplete refuelling events is via an agreed minimum end pressure (e.g. min. 320 bar (temperature corrected)) and maximum fill duration exceeded by n minutes (defined by operator))[2]
- Duration of refuelling also to be logged by dispenser (to be able to monitor “impacted operation”)

Reliability r: $\mathrm{r} = \frac{\sum z}{\sum x}$ [%]
with x (# of buses to be refuelled per day as per HRS design) and z (buses successfully refuelled on a day), x and z being tracked on a daily basis and accumulated over time (i.e. days)

Quality indicator for refuelling process: = $q_{rp} = \sum i$
with i (# of incomplete refuelings (either not meeting the min. pressure or max duration requirement) being tracked on a daily basis and accumulated over time (i.e. days)

[2] This may require communication between bus and dispenser for temperature corrected refuelling

4 ANNEX - Proposals from T3.5 questionnaire evaluation

All studies have been requested to contribute to Task 3.5 of the NewBusFuel WP3 Joint Questionnaire. Evaluation of responses enabled a consistent definition of infrastructure reliability requirements to be developed. This definition is discussed below and once finalised, will form the basis of the engineering studies.

The importance of evaluating reliability on two levels was highlighted:

- **Failure mode analysis** at the design stage must be included within the Engineering studies. Furthermore, the infrastructure provider must demonstrate their ability to meet 100% operational reliability confirmed by contractual provisions.
- **In-use reliability and monitoring.** Contractual arrangements between operator and infrastructure provider should be established with penalties for failing to meet agreed reliability targets**.** Equipment performance must be consistent, therefore solutions must be in place for each component if it fails. This can be ensured through many strategies, e.g. equipment redundancy or fast-response logistics.

Reliability can be defined by multiple factors:

- **Time based;** comparing total HRS run hours against downtime and planned maintenance time; (total hours - time for scheduled maintenance - downtime)/(total hours - time for scheduled maintenance); unit [%]
- **Event based**; comparing number total buses refuelled and not refuelled against total expected refuelling for a given period; (target # buses refuelled per day as per HRS design - # buses not refuelled per day) / (target # buses refuelled per day as per HRS design)