PEMBeyond

PEMFC system and low-grade bioethanol processor unit development for back-up and off-grid power applications

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Deliverable 6.1
System and subsystem specification report

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Summary

This document defines system requirements for the back-up power system based on fuel cell and bioethanol processor technologies to be built in PEMBeyond project.

The document gives the general system description regarding operational requirements, maintenance concept, definition of subsystems and general constraints. It also gives the targeted system characteristics: performance targets, interface requirements (physical, electrical, communication), design and construction guidelines (e.g. standards, materials) and other such requirements necessary to be determined in this stage of the project.

Confidentiality	Public

Contents

1 Introduction

1.1 Purpose of the document

This document defines system requirement for the back-up power system based on fuel cell and bioethanol processor technologies to be built in PEMBeyond project (from here on referred as ‘the System’).

The technical requirements for the System will be documented through a series of specifications. This document, the System Specification (Type A) defines the System functional baseline and includes the results from the user requirements, operational requirements and the maintenance concept, top-level functional analysis, and identifies the critical technical performance measures (TPMs) and design dependent parameters (DDPs).

This System Specification leads into the following subordinate specifications covering the subsystems, configuration items, equipment, software and other components of the System. These more detailed specification documents (types B&C) will be developed later as subsystem design work advances.

1. System Specification (type A) – includes the technical, performance, operational and support characteristics for the System as an entity. It includes the allocation of requirements of functional areas, and it defines the various functional-area interfaces. The information derived from the operational requirements, maintenance concept, and the functional analysis is covered. It is written in "performance-related" terms, and describes design requirements in terms of the "whats" (i.e., the functions that the system is to perform and the associated metrics).

   Developed later in the project:

2. Subsystem Specifications (non-COTS) (type B)-include the technical requirements for those items below the System level where research, design, and development are required. One Subsystem Specification shall be prepared for each subsystem design. Each Subsystem Specification shall cover equipment items, assemblies, computer programs, facilities, and so on. Each specification shall include the performance, effectiveness, and support characteristics that are required in the evolving of design from the system level and down.

3. COTS Subsystem Specifications (type C)-include the technical requirements for those items below the top System level that can be procured "off the shelf." The COTS Subsystem Specifications shall cover standard system components (equipment, assemblies, units, cables), specific computer programs, and so on. Each COTS Subsystem Specification shall detail any differences in environment, operation, maintenance or handling for use of the product as part of the System as opposed to the product’s design service.

4. Testing and evaluation protocols for different Subsystems and the entire System will be given in a separate document.

1.2 Applicable documents

[A1] *Project plan – Description of Work (DoW)*

2 General Description

The System is an integrated, complete stationary system for backup and off-grid power generation using crude bioethanol as primary fuel and producing electricity. The System consists of four main Subsystems:

- Bioethanol reformer
- PSA (pressure swing adsorption) unit for hydrogen separation/purification
- PEMFC (polymer electrolyte fuel cell) system
- Higher level control system

2.1 Operational requirements

The System is used for supplying electrical power in

- Backup applications: During normal operation the application site is supplied by electrical grid. In case of grid outages the System will switch on and supply either the entire site or only selected critical operations.

  or

- Off-grid applications: Application site is not connected to the grid, and the System will supply the site either continuously or as a back-up for e.g. small wind turbines and/or photovoltaic system.

The main application for the System is telecommunication network sites, but it may be used also for other types of backup applications or in distributed power generation in microgrids.

The primary fuel is crude bioethanol (distilled but not fully purified). Use of crude bioethanol instead of pure bioethanol allows use of locally produced bioethanol from smaller production sites.

The System will be “black-start capable” meaning it can be started up independently without the support from the electricity grid.

The System should meet the most important general operation requirements experienced at telecom sites. These requirements have been studied through discussions with several potential end-user companies, existing knowledge within the project consortium and from literature surveys. The information will continuously updated and complemented throughout the project.

A table with the main operational requirements collected from the end-users and back-up system integrators can be found in Appendix A.

2.2 Functional analysis and system definition

During nominal operation, bioethanol reformer combined with a PSA unit generates a continuous hydrogen stream to a fuel cell system (FCS), which converts it into electric power at 48 VDC voltage. Low-pressure (up to 10 bar) H2 storage between the PSA and the FCS will function both as a start-up fuel storage supplying FCS during reformer start-up cycle, and during nominal operation as a

H2 buffer to allow operating the fuel reformer and PSA at constant average operating point instead of dynamic load-following operation. Electric power required by all the auxiliary components, the reformer, PSA and higher level control system during both start-up and nominal operation is supplied by the FCS and its Li-ion battery.

The typical System start-up, operation and shut down cycle follows these steps:

1. Battery starts the FCS
2. The FCS starts up the reformer & PSA
3. The System is ready to supply the load
4. The load is powered by the System at maximum power of 7 kW continuously for some hours depending on the H_2 buffer storage pressure level
5. H_2 is provided by the reformer + H_2 from the buffer
6. After the H_2 buffer storage is emptied, the load is powered by the FCS and the battery at a rated power of around 2 kW corresponding to the nominal H_2 processing capacity (the battery can supply the additional power to reach 7 kW until it reaches the maximum value of depth-of-discharge, DOD)
7. When grid is recovered, the System starts the Shut-down procedure. The Fuel Cell is disconnected and the grid will provide the energy to charge the battery and supply the Reformer + PSA to restore the H2 buffer capacity (@10bar).

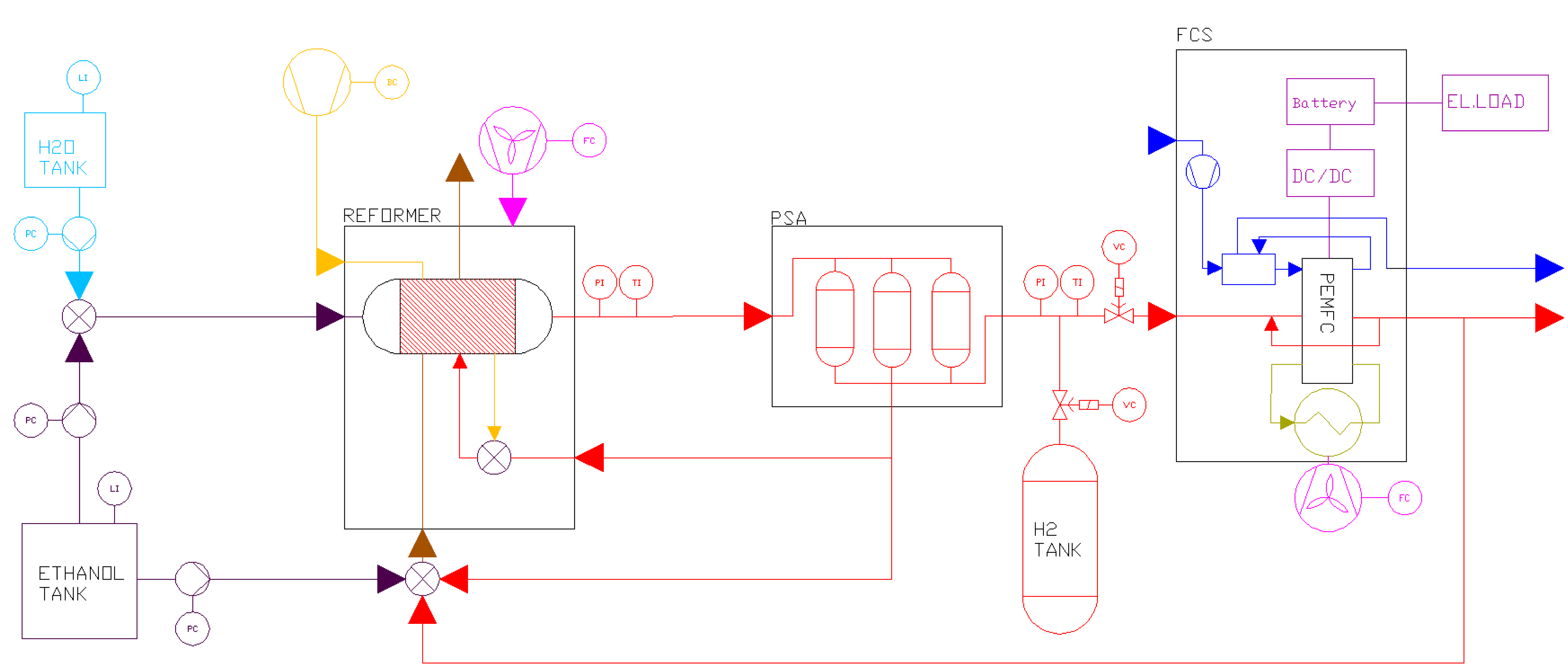

Figure 1. Simplified system PI scheme

2.3 Maintenance Concept

Maintenance interval will be fitted to the normal maintenance schedule of telecom sites. The telecom site is normally visited by personnel two times per year so the System maintenance interval does not have to be longer.

Frequent maintenance points are e.g. filter and coolant changes. Changing main components as fuel cell stack may be scheduled outside the normal maintenance runs if needed.

2.4 Allocation of requirements / subsystem definition

The following Subsystems are included in the System:

- Bioethanol reformer

  Bioethanol reformer reforms the crude bioethanol/water mixture feed fed from the fuel vessel into a product reformate gas feed. The reformer is comprised of the combined reformer/burner reactor (RB), the air-cooled water-gas shift reactor (WGS), a combined evaporator/catalytic burner (EVB), and heat exchangers.

  According to the first ASPEN simulations performed for the system, the product reformate gas feed fed to the PSA is expected to have close to the following component mole fraction:

  - 70.8 % H_2,
  - 24.5 % CO_2,
  - 3.6 % CH_4,
  - 0.46 % CO, and
  - 0.66 % H_2O at 40 °C and 10 bar.

  Unlike in other subsystems, control of the bioethanol reformer will be carried out within the Higher level control system.

- PSA unit

  The PSA unit separates the hydrogen from the reformate gas feed fed from the bioethanol reformer. The unit is comprised of four adsorbent columns, valves controlling the flow of gases, and a control system (PLC) controlling the process. An additional compressor is not needed in PSA, as the reformate feed coming from the reformer is already at 10 bar pressure.

  The output hydrogen feed should contain

  - 98 % H_2 and < 20 ppm CO,

  but the limits could be relaxed to

- o 95 % H_2 and < 50 ppm CO,

if necessary mitigation methods will be used within PEMFC system. The hydrogen feed coming from the PSA unit is fed into the PEMFC system and/or the buffer hydrogen vessel.

- PEMFC system

The PEMFC system converts the chemical energy in the hydrogen feed coming from PSA and/or buffer storage into electric energy for the application. The PEMFC system consists of a 100-cell fuel cell stack and the a) air supply, b) hydrogen supply, c) heat management, d) power conditioning, and e) control subsystems. Also a Li-ion battery pack will be integrated in parallel with the fuel cell to supply all the BoP components during system start-up.

The PEMFC system will produce electricity at 48 V DC voltage and maximum power of at least 7 kW. This power is also used to supply other subsystems and components in the System, resulting in an overall net power of at least 5 kW.

- Higher level control system

The higher level control system controls the operation of the complete System. Other Subsystems (with the exception or bioethanol reformer) will have their own control systems controlling different process parameters etc. independently from other Subsystems. Purpose of the higher level control system is to control between switching on, partial power, idle and off modes of different subsystems, safety shutdowns etc.

The higher level control system will be based on industrial automation and will allow data gathering and remote monitoring of the System. It will enable fully automated and independent operation of the System.

This distributed control system architecture (Compact Rio for FCS & battery, PLC for PSA and PLC for the complete System + reformer) will be reviewed during the project to find the optimum techno-economical solution for the future.

Other necessary components for system integration, for example the ISO container, bioethanol vessel, water vessel, ethanol pump, hydrogen buffer storage, will be not part of the above subsystems but will be built around the Subsystems.

The fuel processing stage comprising the bioethanol reformer and the PSA system will be downsized with the regard of PEMFC system's hydrogen feed rate requirement at maximum power. The fuel processing stage will be sized to produce a continuous hydrogen flow of around 0.135 kg/h corresponding to approximately 2 kW, 29% of the PEMFC system 7 kW maximum power.

2.5 General Constraints

As an example, using a buffer hydrogen storage with storage capacity of 1.3 kg H_2 (1.85 m^3 @ 10 bar) would allow operation of the PEMFC system at maximum net power of 7 kW for approximately 3.35 hours*, while continuous nominal power of 2 kW will be supplied after the storage is emptied. This size of buffer storage would allow also operation at 7 kW maximum net power for up to 2.5 hours straight with bioethanol reformer and PSA unit turned completely off (H2 production 0 kg/h).

The final buffer storage size will be set later after determining available commercial storage sizes, FCS pressure reducer characteristics etc.

*) H2 consumption for start-up time not considered (<45min) and assuming that the storage can be emptied down to 2 bar (minimum pressure depends on the FCS pressure reducer characteristics)

2.6 Assumptions and Dependencies

Bioethanol fuel purity will not be measured or analysed continuously during operation. If necessary, such analysis will have to be performed separately e.g. before/during bioethanol fuel tank filling. Fuel purity is assumed to be within the fuel specifications (to be defined).

3 System Characteristics

3.1 Performance and physical characteristics

Table 1. Draft of the system data sheet

		PEMBeyond system	Notes
Performance	Bioethanol reformer		
	Operating temp (°C)	800	
	Start-up time	< 45 min	
	Product gas feed to PSA in nominal operation (kg/h)	1.76	
	Estimated product gas characteristics	- 70.8 % H2, - 24.5 % CO2, - 3.6 % CH4, - 0.46 % CO, - 0.66 % H2O at 40 °C / 10 bar	All values Vol.% According to first ASPEN simulation results from Fraunhofer-IMM.
	PSA unit		
	Operating temp (°C)	30-40	
	Start-up time	< 45 min	
	Product gas feed to FCS in nominal operation (kg/h)	0.135	
	Expected product gas characteristics (estimated)	> 98 % H2 and < 20 ppm CO, at 40 °C / 10 bar	
	Fuel Cell system		
	Net power output (kW)	7	Net output after FCS BoP and power electronics related losses
	Efficiency (%)	> 45	FCS efficiency

	Start-up time	< 30 sec	Buffered by Li-ion battery that starts up in a few ms
	Operating temp (°C)	> 60	
	Complete integrated system		
	Net Power output (kW)	> 5	Net complete system output after reformer, PSA, control system etc. losses
	Voltage output (VDC/VAC)	48 VDC	
	Efficiency (%)	> 30	Complete system efficiency
	Start-up time (min)	Buffered start-up few ms, Full operation < 45 min	Buffered by a Li-ion battery until FCS starts (milliseconds), and buffer H2 storage until fuel processing starts up (< 45 minutes)
	Dynamic performance (kW/s)	0,1	
	Operating life (h)	10 000	In continuous operation 20 000 h/stack
	Start-stop cycles (#)	> 1000	
	Availability / reliability	98 %	
	Back-up time (h)	168	7 days, with a cycle of 3.3h @ 7kW and remaining time @ 2kW. If the system is operated below 2kW, the buffer storage fills up and offers a possibility for a new 7kW cycle.
	Capability to start-up without grid support	yes	
Physical	Form factor / footprint	10ft. ISO cntr.	Not including the H2 buffer storage, which may be placed outside the container space
	Weight (kg)	< 500	not including the ISO container
Emissions	Sound level (dB)	< 60	
	Product water (kg/h)	~ 2 kg/h @ 2 kW net power, ~3.5 kg/h @ 7 kW net power	Total from FCS and reformer. Condensed product water may be utilized in fuel reformer fuel feed.
	Other emissions	- Oxygen depleted air (FCS) - N2, O2, CO2 (reformer)	
	EMC compliance	none	Not studied under PEMBeyond project, but EMC (immunity) EN 55022 / 61000-4-2 EMC (emission) EN 55022 (Class A) should be reached in the future.

Fuel/power supply	Aux power input (kW)	< 1	Option to use grid support for start-up where available.
	Voltage input (V)	48VDC/230VAC	
	FCS coolant type	antifreeze	Dynalene FC / BASF FC G20 or other fuel cell compatible coolant
	Coolant grade/conductivity (µS/cm)	< 2000	
	Fuel grade / impurities	Crude bioethanol	”minimum fuel quality used” with limits for main impurities will be given after further analysis of crude bioethanol and testing of reformer catalysts
	Fuel consumption	0.94 kg/h ethanol 2.1 kg/h water	Part of the water may be condensed from FCS cathode out air and reformer product water.
	Fuel tank capacity	> 160 l ethanol	> 7 days back-up capacity
Environmental rating and conditions	IP-rating	20	Higher rating targeted after PEMBeyond prototype
	Ex-rating	Zone 2	
	CE marking	no	Not during PEMBeyond, but necessary for commercialized system/subsystems
	Ambient temp range (°C)	-20 - + 40	
	Ambient humidity (RH%)	non-cond.	
	Ambient air quality	normal	
	Altitude (m)	0 – 1000	
	Vibration (g)	-	Not considered/tested in PEMBeyond
Maintenance targets	Maintenance interval (site visits per year/1000h)	2	1 x every 2 years is normal site maintenance interval. Might depend on end-user, but this is the interval of person visiting the site in any case.

3.2 Interface Requirements

3.2.1 Process flow interfaces

Fuel supply process flow interfaces are specified here by directional values. Specifications may be changed if seen viable when design work progresses. In such cases the possible changes should be communicated in advance to concerning partners to ensure physical compatibility of subsystems.

Table 2 a.-d. Process flow interface specifications

a) Ethanol pipelines from tank(s) to reformer

Bioethanol-water mixture feed for reforming:

	min	nom	max
Flow Medium			
Pressure		10 bar(a)	
Temperature	-20°C	20°C	40°C
Flow rate		3.0 kg/h, 0.05 lpm	
Bioethanol mass fraction		29.9%	
Pipe Specifications			
Material		SS316L	
Pressure drop		< 10 mbar	
Diameter		OD 6mm/ID 4mm	
Upstrm port / fitting		6 mm Swagelok	
Downstrm port / fitting		6 mm Swagelok	

Pure bioethanol feed for combustion:

	min	nom	max
Flow Medium			
Pressure		1 bar(a)	
Temperature	-20°C	20°C	40°C
Flow rate		48 g/h, 0.002 lpm	
Pipe Specifications			
Material		SS316L	
Pressure drop		< 10 mbar	
Diameter		OD 3mm/ID 2mm	
Upstrm port / fitting		3 mm Swagelok	
Downstrm port / fitting		3 mm Swagelok	

b) Reformate pipeline from reformer to PSA

	min	nom	max
Flow Medium			
Pressure		10 bar(a)	
Temperature		40 °C	
Flow rate		1.76 kg/h (5.9 dm^3/min @ 10 bar(a), 40 °C)	
Pipe Specifications			

Material		SS316L	
Pressure drop		< 10 mbar	
Diameter		OD 10mm/ID 8mm	
Upstrm port		10 mm Swagelok	
Downstrm port		10 mm Swagelok	

c) Hydrogen pipeline from PSA to FCS pressure regulator including buffer storage branch

	min	nom	max
Flow Medium			
Pressure		10 bar(a)	
Temperature		30-40 °C	
Flow rate		0.135 kg/h (3.0 dm^3/min @ 10 bar(a), 40 °C)	
Pipe Specifications			
Material		SS316L	
Pressure drop		< 10 mbar	
Diameter		OD 8mm/ID 6mm	
Upstrm port		8 mm Swagelok	
Downstrm port		8 mm Swagelok	

d) Unused hydrogen pipeline from FCS to catalytic burner

	min	nom	max
Flow Medium			
Pressure	Atm	1,1 bar(a)	1,5 bar(a)
Temperature		< 60 °C	
Flow rate		< 3 nlpm	
Pipe Specifications			
Material		Silicone/PTFE	
Pressure drop		< 10 mbar	
Diameter		OD 10mm/ID 8mm	
Upstrm port		10 mm Swagelok	
Downstrm port		10 mm Swagelok	

3.2.2 Electrical interfaces

Electricity produced by the fuel cell is fed directly to the “intermediate” circuit of a telecom backup station at 48VDC.

Power conditioning/conversion is still needed to power the auxiliary equipment of all the subsystems. Unless otherwise stated in subsystem design documents, this power is drawn from the 48VDC supply that the fuel cell is feeding. Preferably, maximum of three different converter modules would be needed for voltage levels of 12VDC, 24VDC and 230VAC. Use of 48VDC system components should be preferred, as they will be supplied directly from the 48VDC supply. These additional voltage converters to supply auxiliary components will not be part of the FCS, but will be integrated either at the System level or as part of the Higher level control system.

Goal of the system design is to achieve <20% parasitic electric losses in the system due to auxiliary equipment (FCS BoP, PSA and reformer control systems, high level control system etc.)

Uninterrupted power supply (UPS) due to external 48VDC supply grid outages is not needed as off-grid start-up capability will be reached by using FCS and its battery to power other subsystems during start-up. Auxiliary power input option will be implemented to allow use of grid support in start-up phase in case the grid is available.

3.2.3 Communication Interfaces

There will be several communication interfaces between the subsystems, the high level control system (Schneider PLC) and the monitoring and data storage hardware. These interfaces are shown in figure 2 below.

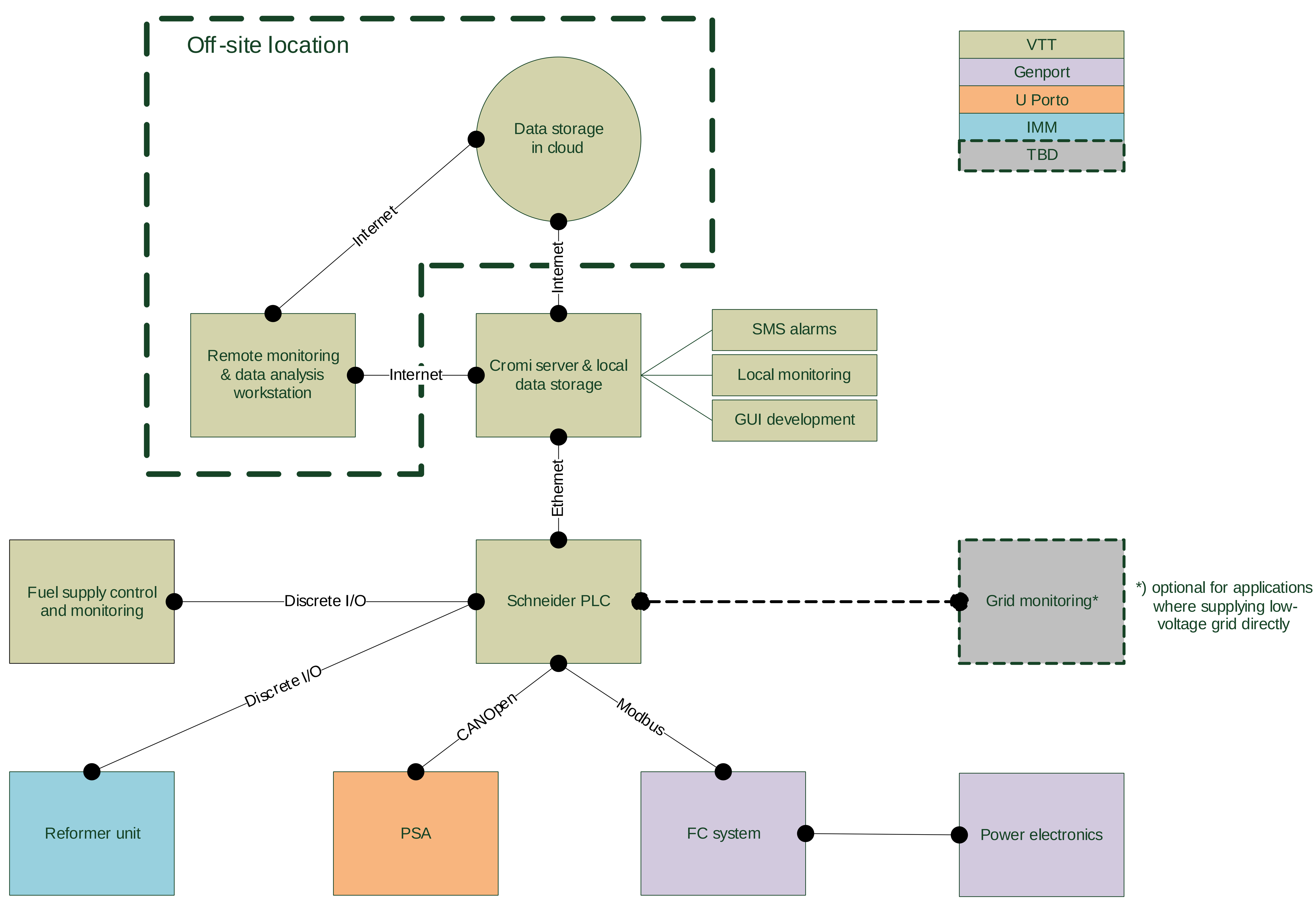

Figure 2. Communication interfaces between subsystems, higher level control system and data collection and monitoring equipment.

1) Communication between the high level control system and reformer unit and fuel supply control and monitoring will be implemented by directly connecting the instruments to PLC I/O modules.

2) Communication between the high level control system and PSA subsystem will be implemented preferably by CANopen (to be confirmed).

3) Communication between the high level control system and fuel cell subsystem will be implemented using Modbus RTU.

Protocol	Modbus RTU
physical interface	RS-485
baudrate	19200 bps

4) The interface between fuel cell and power electronics will be implemented within the FCS subsystem, and necessary communication is therefore implemented only between FCS and high level control system.

5) When the system is used to supply a 48 VDC telecom site or other similar application, no separate grid monitoring equipment is needed. All necessary monitoring of the load side (voltage, current measurement etc.) is done within the FCS power electronics. There is, however, an option to implement such equipment if the system is used to supply low-voltage AC grid directly.

6) The communication interface between the high level control system and local monitoring & data collection equipment (Cromi server) will be implemented using Ethernet local area network.

7) Remote monitoring and (possibly) cloud based data storage will connect to the local monitoring and data collection equipment using a broadband internet connection. Required connection speed and physical implementation are to be defined based on demonstration site capabilities.

3.2.4 User Interfaces

1) The system will normally be operated through a remote interface using a SCADA setup based on the Cromi software.

2) In Cromi, the communication of variables is based on OPC connection between the SCADA server software and the high level control system (Schneider PLC) and data is logged into SQL database (local, remote or both).

3) A cloud based SQL database will be set up that will allow the project stakeholders to access the operational data over the internet.

4) VTT has Matlab scripts written for extracting the data from the SQL database that may be shared to the project participants. Participants may also develop their own tools to access the data on the server, if preferred.

3.3 Design and Construction

3.3.1 CAD/CAM requirements

1) The CAD-drawings of the total system integration will be produced using Autodesk Inventor 2013

2) The subsystem and component 3D models should be implemented in a format that is compatible or easily transferrable into the Autodesk Inventor file format. These formats include at least: files from Autodesk Inventor, Alias, Catia V4&V5, IGES, Rhino, SolidWorks, STEP.

3.3.2 Mounting and labelling

1) Appropriate warning signs shall be used to indicate hazards as instructed by the safety standards to be applied

    a. Hydrogen / Ex-classified compartments

    b. Hazardous voltage levels (> 120 VDC / 50 VAC,rms)

    c. Pressurized containers / pipelines (> 1.5 bar,a)

    d. Hot surfaces / exhaust ports

2) Main pipelines/interfaces to other subsystems (e.g. feed inlets and outlets, electric connectors) should be labelled to make testing and mounting work easier.

3.3.3 Standard Compliance

The following list of standards is followed during the design process of the system. Once finished, it is assumed that the system fulfils the requirements stated in these design and safety standards:

Table 3. Standards compliance of the system

Standard name	Edition/Date	Description
IEC 60950-1	2.2 / 2013-05	Information technology equipment – Safety
ISO/TR 15916	1st / 2004-02-15	Basic considerations for the safety of hydrogen systems
IEC 60664-1	2.0 / 2007-04-26	Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests
IEC 62282-3-3	1.0 / 2007-11	Fuel Cell Technologies - Part 3-3: Stationary fuel cell power systems - Installation
IEC 62282-3-200	1.0 / 2011-10	Fuel Cell Technologies - Part 3-200: Stationary fuel cell power systems - Performance test methods
IEC 62282-3-100	1.0 / 2012-02	Fuel Cell Technologies - Part 3-100: Stationary fuel cell power systems - Safety
IEC 60364 / SFS 6000	XX	Low-voltage electrical installations

As a guideline, deviations from the standard recommendations should always be documented and discussed between the relevant stakeholders. For example, the performance testing standard IEC 62282-3-200 will be followed to an extent that is practical for the scope and duration of the experimental phase of the project.

In addition to the standards listed above, these standards listed below related to use of the System for distributed power generation as a part of low-voltage grids are followed where seen viable:

Table 4. Additional standards followed during project (compliance not required)

Standard name	Edition/Date	Description
IEEE 1547	x / 2003-07-28	Standard for Interconnecting Distributed Resources with Electric Power Systems
EN 50438	x / 2013-12-31	Requirements for micro-generating plants to be connected in parallel with public low-voltage distribution networks

Complying to these standards is not necessary in normal telecom site back-up applications (supplying 48 VDC site), but will be if the System is connected to low-voltage AC distribution network.

3.3.3.1 General design standards

1) Due to planned demonstration site location being in Finland, compliance of the system itself and also the possible site integration needs to comply with the national standard SFS 6000 concerning low voltage electrical installations. The SFS 6000 standard is based on the international IEC 60364 standard.

3.3.3.2 EMC

1) Compliance to EMC regulations is not required from the PEMBeyond prototype system. EMC compliance will be required from possible commercial units to be developed based on the advanced concept study conducted in WP7.4.

2) When practically possible, the EMC compliance may be considered already in the prototype system design and construction stages.

3.3.3.3 Safety

1) Hydrogen safety related standards - ISO/TR 15916 and IEC 62282-3-100

2) Information technology equipment – Safety IEC 60950-1

3.3.4 Materials, processes and parts

BoP components specifically designed for fuel cell systems should be utilized when available.

Non-FC certified equipment should be evaluated based on existing knowledge about materials compatibility and suitability of operating principle. This is done on case by case basis, but at least the following guidelines should be followed:

Piping and fitting materials selection should be made so that potential contamination into the flow medium is minimal. Good practices in this should be evaluated by the subsystem designers based on the flow medium, temperature, pressure and other possible relevant factors.

1) Anode high-pressure pipes and fittings should primarily be made of stainless steel grade 316L

2) Low-pressure fuel supply lines can be made of silicon or PTFE when the flow medium and sealing method of the pipelines allows this

3) Cathode pipelines and fittings can be made of stainless steel, silicon, PTFE or polypropylene (PP)

4) Coolant pipelines and fittings can be made of stainless steel, silicon, PTFE or polypropylene (PP)

Sealants containing oil should be avoided. PTFE tape can be used as sealing material for fittings, but care must be taken to prevent possible shreds of the tape entering sensitive equipment downstream in the system (valves, regulators or the FC stacks). Use of rough mesh filters should be considered with sensitive equipment if such risk is identified.

NREL is currently developing a tool for quick screening of some known materials for fuel cells that should be considered as a guideline for materials selection: http://www.nrel.gov/hydrogen/system_contaminants_data/

The tool is still under development, but might provide useful information for materials selecting later on.

3.4 Other Requirements

3.4.1 Security

In outside installations the System should withstand "mild" vandalism (robust structure/lockable). This will be mostly reached through integration in a container. (Except for buffer hydrogen storage)

3.4.2 Maintainability

The system maintenance interval is expected to be dominated by certain BoP components, like filters and coolant degradation. One of the main principles in system design and component selection should be to minimize potential mechanical component failures by all means possible and in case of failures, reasonably easy replacement of broken components is required.

According to telecom operators, a typical routine maintenance interval of a site is approx. once every six months. This is therefore sufficient target for the developed back-up system also.

3.4.3 Reliability

Reliability of the system includes on the other hand the probability of the system functioning as intended when automatic start-up routine is initiated and on the other hand the durability of the system in various conceivable operating conditions it is exposed during normal operation in its specified operating environment. As with maintainability, system design and detailed discussion with component suppliers is important for successful outcome.

System reliability of operation links directly to maintainability and costs involved therein. Assuming the system design is done properly, the cost targets during the lifetime of the system (20 000h @ 5kWe) are expected to be:

1) 0,2€/kWh for maintenance (including visits on-site and maintenance work... etc.)

2) 0,07€/kWh for spare parts

3.4.4 Data Management

1) Data will be collected to a database using SQL. MySQL has been selected as the platform to implement the data storage server.

2) As a general rule, data points will be recorded at least at rate of one sample per second (or 1 Hz) unless otherwise noted.

3) Subsystems may implement their internal data storage routines if the subsystem supplier so wishes.

4) Primary source data utilized to report the project results shall be the data collected to SQL database by the high level control system / Cromi.

3.4.5 Site Adaption

Site adaption of the complete back-up system will be made in cooperation with the field-test site owner or operator.

Final selection of the application site will be made according to compliance of the site and its requirements to the System specifications and PEMBeyond project needs.

3.4.6 Personnel training and support

Partners developing the Subsystems should provide necessary support to VTT in commissioning and first testing of the equipment. This may require sending technical personnel to assist in commissioning of the equipment.

Spare parts for the main Subsystem components (most probable to require replacement) should be made available by the Subsystem developers during the complete system testing and field-trial periods.

3.4.7 Documentation

1) Installation and Operating manuals should be developed by Subsystem developers for the supplied equipment to facilitate commissioning and System integration work

2) Documentation of the Subsystem and System development process will be developed according to the Project plan – Description of Work (DoW).

Appendix A

Compilation of main operation requirements collected from telecom operators and back-up system integrators. Information will be complemented and updated throughout the project.

Operational requirements	*Output voltage(s) (Vac, Vdc)*	48 Vdc is the standard voltage level used.
	Peak power required (kW)	3 - 25 kW depending on site
	Average power required (kW)	1 - 20 kW depending on site
	Back-up capacity (kWh)	2-12 h, or up to 7 days. 3 h is the most typical, from where deviation to longer and shorter in exceptive cases.
	Typical operation/idle ratio (%)	Blackouts 12 h x 1 per year? = 0,14 % (~worst case scenario in developed countries?)
	Response time requirement	Not critical from operator side unless stated by legislation or other regulation. 1 minute downtime is still not critical for the site itself.
Environmental condition requirements	*Temperature range*	Inside installations 0…40 °C, outside installations -40…+40 °C
	Humidity range	Inside installations 20…90 %, outside installations 20…100 %
	Air quality (dust, salt, other impurities?)	Filtered air in inside installations, Outside installations: normal
Application site limitations	*Size limitations? (cm x cm x cm / kg)*	80x80x1800 If installed inside (considering installing in existing sites, new sites may be built for different dimensions)

	Noise limitations (dB)	< 60 dB
	Main applicable standards and/or legistlation	IEC 60364 / SFS 6000 in Finland Safety IEC 60950-1
	EMC compatibility requirements	EMC (immunity) EN 55022 / 61000-4-2 EMC (emission) EN 55022 (Class A)
Maintentance concept / Life cycle	*Independent operation minimum requirement (fueling interval, maintenance interval)*	2 per year is the basic telecom site maintenance interval nowadays.
Others	*Other possible comments*	In outside installations should withstand "mild" vandalism (structure/lockable). In many telecom sites the back-up system has capability to drop off some parts of the load (less crucial parts of the grid) when needed.