Test Case 13

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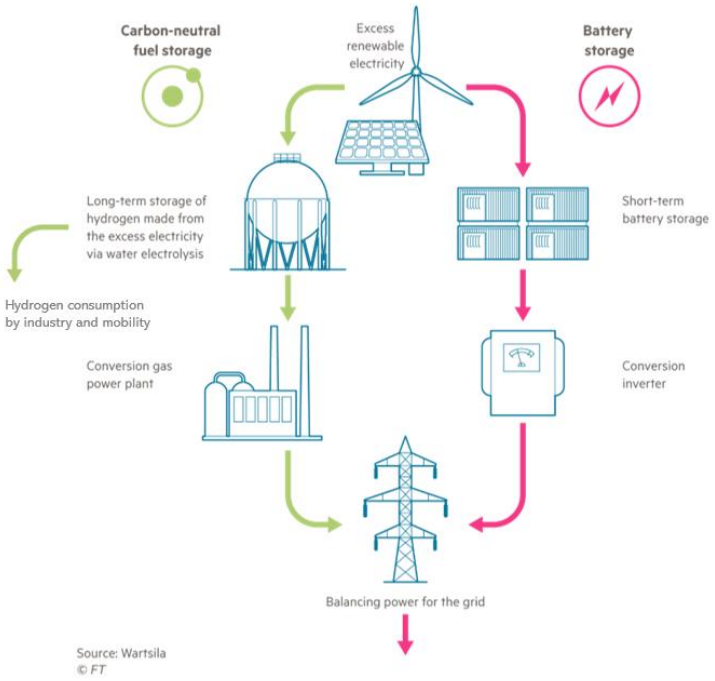
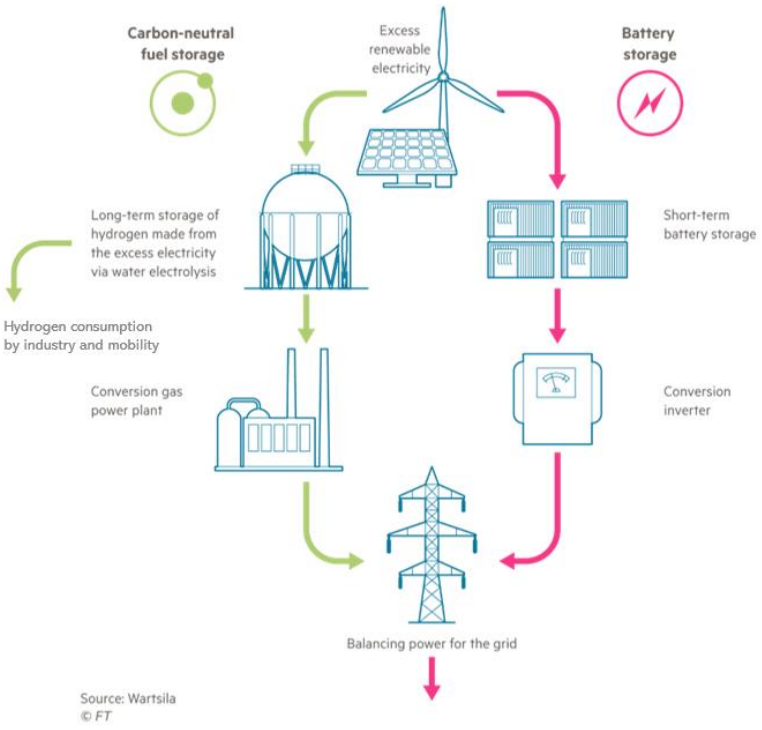
Name of the Test Case	Characterization of hydrogen storage scale for power systems support and services.
Narrative	The amount of volatile renewable energy generated to the power system is rapidly increasing emphasizing the need for proper storage solutions to harness all the produced renewable energy. Without sensible storage solutions the overproduction of renewable energy cannot be used and we need to default back to fossil fuels. While for short term storage batteries and other storage solution in the power systems are crucial, in long term the most promising storage solutions can be found via sector coupling of electrical and hydrogen grids in combination with salvaging the heat produced in the conversion processes and fed to the district heating networks. The main applications for the storages are producing hydrogen for industry with low emission affordable electricity and hydrogen storage for mobility. The harnessing potential of hydrogen storages manifests as time depended consumption impacting the loading levels. This test case focuses especially at assessing the potential of different storage solutions based on their scale and cost benefits.
Function(s) under Investigation (*Ful*) “the referenced specification of a function realized (operationalized) by the object under investigation”	Hydrogen storage provides a long-term solution for storing renewable energy and also potentially could participate to the reserve markets depending on the reaction time.
Object under Investigation (*Oul*) “the component(s) (1..n) that are to be qualified by the test”	Hydrogen storages of different scales.
Domain under Investigation (*Dul*): “the relevant domains or sub-domains of test parameters and connectivity.”	• Electrical • Hydrogen • Heat
Purpose of Investigation *(PoI)* The test purpose in terms of Characterization, Verification, or Validation	• Characterize the optimal scale and location for hydrogen storage to be integrated with power systems and also provide potentially services to the reserve markets while taking into account regulatory requirements based on the site location.
System under Test (*SuT*): Systems, subsystems, components included in the test case or test setup.	SuT comprises of electrical grid, hydrogen network and heat network. The electrical system includes a medium (?) voltage grid with battery storage and renewable generation with integration to reserve markets. The hydrogen network will include fuel cells, conversion gas power plants, hydrogen storages, hydrogen consumption, e.g. industry and mobility. The heat network will include components for conversion to from the other

	networks and heat loads. 
Functions under Test (*FuT*) Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. OuI and SuT.	• electrical and hydrogen exchange at the PCC (point of common coupling) • storing of hydrogen and reaction time to access
<u>Test criteria</u> (*TCR)***:** Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.	TCR aims to optimize the scale of the hydrogen storage to support power system and provide potentially balancing power to the power systems while also considering sustainability and cost benefits.
Target Metrics (*TM)* Measures required to quantify each identified test criteria	• electrical and hydrogen exchange • capacity of hydrogen storage • reaction time of exchange
Variability Attributes *(VA)* controllable or uncontrollable factors and the required variability; ref. to PoI.	• capacity of hydrogen storage • material and life cycle aspects of the hydrogen • activation of exchange • demand (electrical and hydrogen) • renewable generation • electricity market price
Quality Attributes *(QA)* threshold levels for test result quality as well as pass/fail criteria.	• sustainability of hydrogen storage lower than traditional solutions • cost of hydrogen storage not covered by earned profits

Qualification Strategy

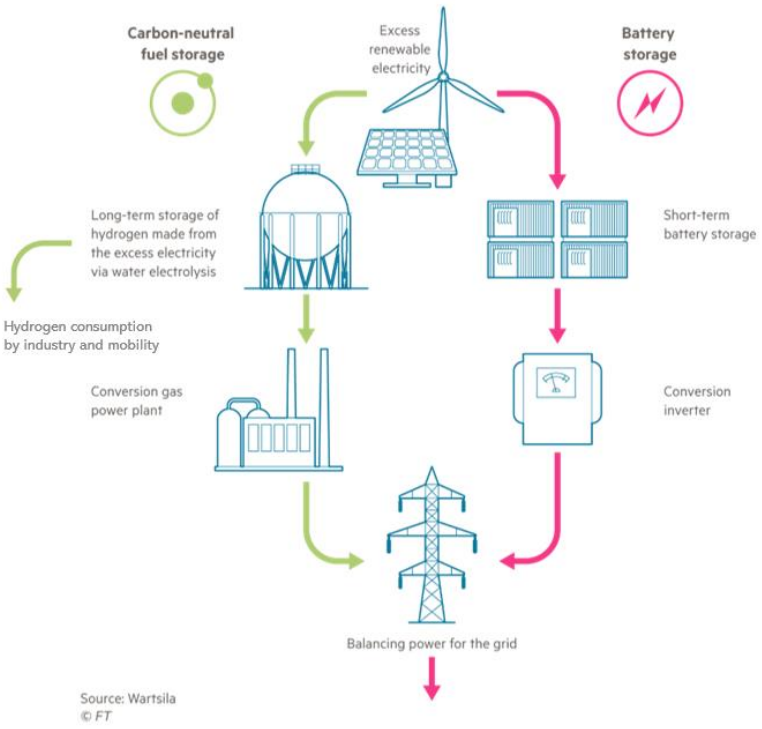
There are three (3) Test Specifications to assess the scale of the hydrogen storage to meet the PoI. TS13.01 considers existing empty storage suitable for hydrogen, TS13.02 considers specifically extracted hydrogen storage and TS13.03 considers separate metal containers as a storage option.

Test Specification 13.01

Reference to Test Case	*TC13*
Title of Test	***Verification of large scale existing hydrogen storage for power system support***
Test Rationale	*The aim of the test is to verify the cost benefits and sustainability of large scale existing hydrogen storages for supporting and providing services to power systems.*
Specific Test System (graphical)	The system uses in particular an existing empty storage for hydrogen such as an empty natural gas storage or salt mine. For mobility applications the hydrogen requires new cleaning when geological storage is used. 
Target measures	*The test is successfully passed if the hydrogen storage can meaningfully support the power system balancing and via this remain profitable and sustainable.*
Input and output parameters	• *Point of common coupling measurements* • *setpoints for control of the hydrogen storage* • *Reaction time of storage* • *Profit*
Test Design	*This test needs to run in non-real-time for several years or seasons depending on the reaction time.*
Initial system state	• *Networks operating on nominal power, temperature and pressure* • *Storages are empty*

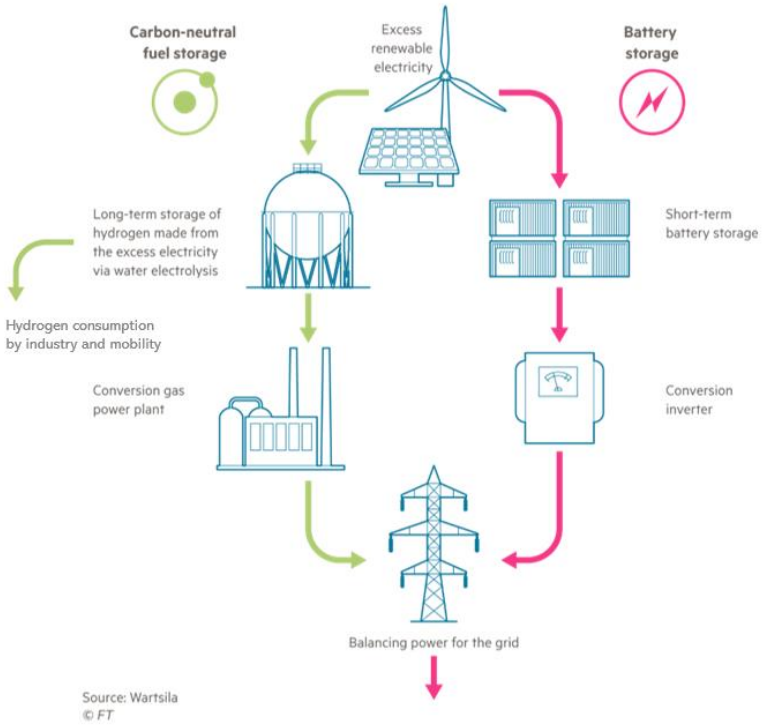
Evolution of system state and test signals	• *The storages are filled based on the overproduced renewable generation* • *Based on price signals the storages react and balance the power system*
Other parameters	• *Consumption by industry or mobility*
Temporal resolution	*Dynamic, variable step size*
Source of uncertainty	*Calculation accuracy of the life-time emissions and state of loading.*
Suspension criteria / Stopping criteria	• *Critical violation of network operation constraints* • *Networks becoming unstable*

Test Specification 13.03

Reference to Test Case	*TC13*
Title of Test	***Verification of specifically extracted storage for hydrogen for power system support***
Test Rationale	*The aim of the test is to verify the cost benefits and sustainability of specifically extracted hydrogen storages for supporting and providing services to power systems.*
Specific Test System (graphical)	The system uses in particular a hydrogen storage specifically extracted for this purpose. 
Target measures	*The test is successfully passed if the hydrogen storage can meaningfully support the power system balancing and via this remain profitable and sustainable.*
Input and output parameters	• *Point of common coupling measurements* • *setpoints for control of the hydrogen storage* • *Reaction time of storage* • *Profit*
Test Design	*This test needs to run in non-real-time for several years or seasons depending on the reaction time.*
Initial system state	• *Networks operating on nominal power, temperature and pressure* • *Storages are empty*
Evolution of system state and test signals	• *The storages are filled based on the overproduced renewable generation*

	• *Based on price signals the storages react and balance the power system*
Other parameters	• *Consumption by industry or mobility*
Temporal resolution	*Dynamic, variable step size*
Source of uncertainty	*Calculation accuracy of the life-time emissions and state of loading.*
Suspension criteria / Stopping criteria	• *Critical violation of network operation constraints* • *Networks becoming unstable*

Test Specification 13.02

Reference to Test Case	*TC13*
Title of Test	***Verification of metal containers as hydrogen storage for power system support***
Test Rationale	*The aim of the test is to verify the cost benefits and sustainability of metal containers as hydrogen storages for supporting and providing services to power systems.*
Specific Test System (graphical)	The system uses in particular metal containers as a storage for hydrogen. 
Target measures	*The test is successfully passed if the hydrogen storage can meaningfully support the power system balancing and via this remain profitable and sustainable.*
Input and output parameters	• *Point of common coupling measurements* • *setpoints for control of the hydrogen storage* • *Reaction time of storage* • *Profit*
Test Design	*This test needs to run in non-real-time for several years or seasons depending on the reaction time.*
Initial system state	• *Networks operating on nominal power, temperature and pressure* • *Storages are empty*
Evolution of system state and test signals	• *The storages are filled based on the overproduced renewable generation* • *Based on price signals the storages react and balance the power system*

Other parameters	• *Consumption by industry or mobility*
Temporal resolution	*Dynamic, variable step size*
Source of uncertainty	*Calculation accuracy of the life-time emissions and state of loading.*
Suspension criteria / Stopping criteria	• *Critical violation of network operation constraints* • *Networks becoming unstable*