Hazard Tracker Register **Updated: 5 January 2021** **Analyst: Chua Eu Chieh**

Hazard ID	Source	System	Sub-system	Hazard	Causes	Effects	Lifecycle phase	Initial risk score	Recommended action for system integrator	Final risk score	Comments	Hazard status	Reason for closure	Action and responsible party
1	PHL-1	Home energy management system, HEMS		To explore further effects of HEMS failing to operate, operating incorrectly, receiving or sending erroneous information.		To be determined	Use	3C		tbd		Open		Utwente - identify impact of HEMS on ESS safety
2	PHL-2	Electrical system		Constant switching on/off of high-power electricity consumer, such as pumps and electrolyser		Power spike or surges, potentially damaging electrical item.	Use	4C				Closed		
3	PHL-3	House structure		Functional: Electrical power supply disruption		Occupant faces hassle	Construct, Use, Dispose	4C	PHA			Closed	Less effect on safety. More relevant as inefficiency aspect	
4	PHL-4	House structure		Super-system: combustible and flammable material of construction		Fire and explosion risk	Construct, Use, Dispose	2E				Closed	Wood as a building material is allowed under Dutch laws, provided the requirements are complied with	
5	PHL-5	House structure		Super-system: High humidity		fungus growth	Construct, Use, Dispose	4C				Closed	Not a safety issue, but a health issue	
6	PHL-6	House structure		Super-system: High temperature		unbearable temperature for occupants; unsuitable operating range for equipment	Construct, Use, Dispose	4E				Closed	More of a health and comfort issue. Where equipment operating ranges are a concern, it is noted in SHA-1	
7	PHL-7	House structure		Super-system: Low temperature		unbearable temperature for occupants; unsuitable operating range for equipment	Construct, Use, Dispose	4E				Closed	As above	
8	PHL-8	House structure		Super-system: Strong winds		structure collapse	Construct, Use, Dispose	1E				Closed	House should be designed to withstand a certain wind load	
9	PHL-9	House structure		System: Electrical shock		Lowest severity scenario: uncomfortable feeling; Worst case scenario - death	Use	1E				Closed	Hazard is noted in other entries, e.g. SHA-6 and -7.	
10	PHL-10	Hydrogen		Functional: Accumulation of hydrogen in an enclosure		LEL (low-level explosion) mixture is reached; can potentially ignite with addition of energy sources	Storage, Use	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
11	PHL-11	Hydrogen		Functional: Electrical shock from electrolyser or fuel cell		Injury to human operator and maintenance personnel	Construct	1E				Closed	Hazard is analysed in other entries, e.g. PHA	
12	PHL-12	Hydrogen		Functional: failure of electrolyser to shut-off during activation of safety devices		Continuous production of hydrogen and oxygen, a combustible condition	Use	1D				Closed	Hazard is analysed in other entries, i.e. PHA-2	HyGear - To be explored further in HAZOP
13	PHL-13	Hydrogen		Functional: malfunction in hydrogen/water separator, specifically on the water transfer line, or membrane perforation leading to formation of H2-O2 ATEX		Formation of combustible mixture	Use	1D			To check during the detailed design phase of the hydrogen system, if such a separator design is used	Closed	Hazard is analysed in other entries, i.e. PHA-2	HyGear - To be explored further in HAZOP
14	PHL-14	Hydrogen		Functional: released hydrogen undetected		Accidental ignition of hydrogen mixture	Storage, Use	1D				Closed	Hazard is analysed in other entries, e.g. PHA	
15	PHL-15	Hydrogen		Operational: Boiling Liquid Expanding Vapour Explosion (BLEVE)		Extensive damage to property and potential loss of human lives	Storage, Use	1F	PHA		Not applicable - only for storage of pressurised liquid	Closed		
16	PHL-16	Hydrogen		Operational: Deflagration and detonation of hydrogen		Damage to equipment, structure and potentiallyhuman injury or fatality	Storage, Use	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
17	PHL-17	Hydrogen		Operational: Filling orientation		Not applicable	Storage	1F			How does this influence safety?	Closed		
18	PHL-18	Hydrogen		Operational: Formation of flammable mixture of hydrogen and oxygen - in electrolyser or fuel-cell			Use	1D			To avoid accumulation of H2 in the process compartment: - control pressure and pressure difference between hydrogen and oxygen lines; - control hydrogen concentration in the container (< 0.4 vol. % H2) - limit as much as possible	Closed	Hazard is analysed in other entries, e.g. PHA	
19	PHL-19	Hydrogen		Operational: Heating effects during refilling of hydrogen storage tanks		LEL (low-level explosion) mixture is reached; can potentially ignite with addition of energy sources	Storage	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
20	PHL-20	Hydrogen		Operational: High heat caused by hydrogen fire		Damage to equipment, structure and potentially human injury or fatality; secondary fires	Use	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
21	PHL-21	Hydrogen		Operational: High pressure hydrogen jets		Injury to skin	Storage	1C				Closed	Hazard is analysed in other entries, e.g. PHA	

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22	PHL-22	Hydrogen		Operational: Ignition of hydrogen		Damage to equipment, structure and potentially human injury or fatality; secondary fires	Storage	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
23	PHL-23	Hydrogen		Operational: Invisible flame of burning pure hydrogen, in daylight		As above	Storage	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
24	PHL-24	Hydrogen		Operational: Pressure peaking phenomenon		As above	Storage	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
25	PHL-25	Hydrogen		Operational: Propagation of hydrogen flames		As above	All	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
26	PHL-26	Hydrogen		Operational: Rapid and smokeless hydrogen burning		As above	Storage	1C			Similar to PHL-29, thus no need to repeat	Closed	Hazard is analysed in other entries, e.g. PHA	
27	PHL-27	Hydrogen		Structural: Hydrogen embrittlement: loss of metal strength		Sudden loss of containment, potentially leading to heavy damage of equipment, adjacent structure and fatality	Storage	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
28	PHL-28	Hydrogen		Structural: Interaction of hydrogen with materials used for liners (metals of plastic): may lead to permeation, embrittlement		Can be similar to effects stated for PHL-31, or if slow permeation of hydrogen, an lead to accumulation of hydrogen to form LEL mixture (if in enclosed space)	Storage	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
29	PHL-29	Hydrogen		Structural: Loss of containment causing microleaks and macroleaks		Similar to PHL-33. Can also lead to localised flames	Storage	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
30	PHL-30	Hydrogen		Structural: Overpressure of system		Similar to PHL-32. worst-case scenario - rupture of storage tank, Structural: fireball, blast waves and burning projectiles	Use	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
31	PHL-31	Hydrogen		Super-system: External fire/heat or thermal radiation causes mechanical rupture of storage tank		Similar to PHL-33	Storage	1C			Depending on fire-resistsant, e.g. 12 minutes	Closed	Hazard is analysed in other entries, e.g. PHA	
32	PHL-32	Hydrogen		Thermal pressure relief device (TPRD) malfunction:		Similar to PHL-34	Storage	1C				Closed	Hazard is analysed in other entries, e.g. PHA	
33	PHL-33	Hydrogen		Unfamiliarity of first-responders, or fire-brigade with the associated hazards and mitigation techniques against hydrogen or battery fires		Ineffective or inadequate emergency response; escalation of fire	Design	1D				Closed	Hazard is analysed in other entries, e.g. PHA	
34	PHL-34	Li-ion battery		Function: Battery Management System malfunctions		Loss of control of safe charging	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
35	PHL-35	Li-ion battery		Operational: Electric shock during operation, maintenance and emergency response		Injury to occupants or maintenance personnel	Use	1E				Closed	Hazard is analysed in other entries, e.g. SHA	
36	PHL-36	Li-ion battery		Operational: Incorrect fire-fighting techniques		Uncontrollable chemical reaction; fire not extinguished	Use	1D			Li-ion: ok to use water; Li metal: should not use water, but Class D fire-extinguisher	Closed	Hazard is analysed in other entries, e.g. PHA	
37	PHL-37	Li-ion battery		Operational: Physical damage due to misuse / abuse (to define exactly misuse actions)		Internal short circuiting, leading to overheating and fire	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA 14-16	
38	PHL-38	Li-ion battery		Operational: Stranded/residual energy during emergency response.		Arc flash, electric shock (if system is > 100 V)	Production, Transport, Use, Dispose	2C				Closed	Not applicable for LIFE project, since max voltage is 48 V	
39	PHL-39	Li-ion battery		Structural: metallic particles punctures separators causes thermal runaway		Shorting, and subsequent overheating , fire	Production	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
40	PHL-40	Li-ion battery		Sub-system: durign emergency (i.e. fire), the *uitgangspuntendocument (UPD, or principle document)* is not available to first-responders		Ineffective or inadequate emergency response; escalation of fire	Use	1D				Closed	Hazard is analysed in other entries, e.g. PHA	
41	PHL-41	Li-ion battery		Sub-system: Pressure build up within casing/construction		More severe reaction than controlled release design	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
42	PHL-42	Li-ion battery		Super system: during transportation, mishandling causes internal short circuiting		Overheating and fire	Transport	1F				Closed	Not applicable for use-phase of LIFE project	
43	PHL-43	Li-ion battery		Super-system: adjacent systems emit vibrations, causing connectors to loosen		Shorting, and fire	Use	2C		2D		Open		Utwente - to check if any source of vibrations from adjacent systems (e.g. pumps)
44	PHL-44	Li-ion battery		Super-system: Battery disposed not using proper channels		Environmental pollution	Dispose	2C		2D		Open		Utwente, HyGear, SuperB, Volterion - guidelines for safe disposal
45	PHL-45	Li-ion battery		Super-system: Battery-management system interface cables inadvertently is disconnected		In-build protection for over-charging and thermal runaway is removed.	Use	2C		2D		Open		SuperB - verify if design allows this to occur

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46	PHL-46	Li-ion battery		Super-system: During burning scenario, release of toxic (hydrogen fluoride, others?) gas		serious toxic threat and the results are crucial findings for risk assessment and management, especially for large Li-ion battery packs.	Design	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
47	PHL-47	Li-ion battery		Super-system: during transportation, connectors become loose		Shorting, and fire	Construct	2C		2D		Open		Utwente - To verify if post-installation checks include inspection for connection-tightness
48	PHL-48	Li-ion battery		Super-system: During venting reaction (i.e. no ignition), release of flammable by-product gas		Fire and explosion risk	Design	2C			Does LiFeP produce hydrogen as a vent gas? - Yes	Closed	Hazard is analysed in other entries, e.g. PHA	
49	PHL-49	Li-ion battery		Super-system: External fire causes battery to have runaway-temperatures		Causes instability to battery internals, leading to overheating with cascading effect to adjacent batteries	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
50	PHL-50	Li-ion battery		Super-system: Flooding from water pipe burst, or adjacent equipment		Battery and auxilliary circuitry damage	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
51	PHL-51	Li-ion battery		Super-system: Humidity variation		Only a risk during production of lithium cells as it affects the quality, performance, and shelf life of the batteries.	Use	2F				Closed	Not applicable to use phase of LIFE	
52	PHL-52	Li-ion battery		Super-system: Projectiles of construction materials caused by exploding battery		Injury and damage	Use	2C				Closed	Hazard is mentioned in a separate entry, e.g. PHA	
53	PHL-53	Li-ion battery		Super-system: recycling is not optimal		Environmental pollution and health risk	Dispose	1D				Closed	Hazard is mentioned in a separate entry, i.e. PHL-100	
54	PHL-54	Li-ion battery		Super-system: Run-off / residue water used in fire-fighting/cooling efforts is contaminated with chemicals		Environmental pollution and health risk	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
55	PHL-55	Li-ion battery		Super-system: temperature too high or too low during charging and discharging		Stressed battery, leading to instability, excessive heating, and other anomalities	Use	2C			Operating range: 5-45 *C?	Closed	Hazard is analysed in other entries, e.g. PHA	
56	PHL-56	Li-ion battery		System: aged battery / battery reaches end- of-life		Unstable charging/discharging, leading to thermal runaway	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
57	PHL-57	Li-ion battery		System: charging below freezing temperatures (0*C)		None. Only leads to reduced battery life and also onset of thermal runaway.	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
58	PHL-58	Li-ion battery		System: During parallel charging of batteries of varying ages or state of charge		Stressed battery, leading to instability, excessive heating, and other anomalities	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
59	PHL-59	Li-ion battery		System: Electrolyte separator failure		Failure to prevent overheating; internal short circuiting / self-discharge	All	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
60	PHL-60	Li-ion battery		System: Fault current		Overheating of equipment and conductors, excesses forces, and at times even serious arcs, blasts, and explosions.	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
61	PHL-61	Li-ion battery		System: Toxic gas released by venting (burning) LiO cells		Harm to personnel	Use	2C	PHA			Closed	Hazard is analysed in other entries, e.g. PHA	
62	PHL-62	Li-ion battery		System: gradual temperature increase		Stressed battery, leading to instability, excessive heating, and other anomalities	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
63	PHL-63	Li-ion battery		System: Inadequate natural cooling to stop temperature runaway of batteries		Fire and explosion risk	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
64	PHL-64	Li-ion battery		System: overcharged batteries		Stressed battery, leading to instability, excessive heating, and other anomalities	Use	2C				Closed	Hazard is analysed in other entries, e.g. PHA	
65	PHL-65	Li-ion battery		System: Storage in fully discharged state (< 2V/cell)		Partial electrical short, leading to instability during recharge	All	2C		2D		Open		SuperB - design consideration
66	PHL-66	Li-ion battery		System: ultra-fast charging is used		Stressed battery, leading to instability, excessive heating, and other anomalities	Use	2C			To check if fast-charging is possible on SuperB batteries	Closed	Less of a safety issue, and more of battery longevity issue	
67	PHL-67	Li-ion battery		System: Weight of battery components causes heavy load		Injury during lifting; inadequate strength of mounting components	All	2C			LIFE: 18.5kg per pack x 48 packs per house = 888 kg?	Closed	Duplicate in SHA-23	
68	PHL-68	Li-ion battery		Use of second life batteries		possible growth of internal cell dendrites resulting from the continued charge/ discharge cycles until the capacity has degraded to 80% of nominal, increasing risk of internal short circuiting and later thermal runaway	Use	2C		2D	Normally in automotive cars, where cost of battery renewal can cost as much as an ICE	Open		Utwente, SuperB - guidelines for second-life use

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69	PHL-69	VRB		Cooling system failure		overheating of cells	Use	4F				Closed	Overheating of cells is not possible in VRB systems	
70	PHL-70	VRB		Corrosive electrolyte (sulfuric-acid based solution) leading to membrane failure		Internal short-circuiting of battery, leading to overheating of electrolyte	Production, Use, Dispose	2D	To check if the internal short-circuiting will cause VRB to auto-shutdown?	2E	Content: VRB electrolyte is 15% vanadium, 25% sulfuric acid, 60% water (by volume) ?	Open		Volterion - confirmation on design feature
71	PHL-71	VRB		Corrosive eletrolyte (pH < 1) leads to stainless steel corrosion		Loss of containment of electrolyte, leading to environmental pollution and possible harm to human health	Production, Use, Dispose	3D			https://sciencing.com/corrosion-stainless-steel-sulfuric-acid-8723157.html https://www.bssa.org.uk/topics.php?article=33	Closed	Hazard is analysed in other entries, e.g. PHA	
72	PHL-72	VRB		Electrolyte temperature < 5*C leads to precipitation of V2+/V3+ in the negative electrode		Lower battery efficiency	Use	4F	PHA			Closed	Lower efficiency, rather than safety issues	
73	PHL-73	VRB		Electrolyte temperature > 40*C leads to precipitation of V5+ in the positive electrode		Lower battery efficiency	Use	4F	PHA			Closed	Lower efficiency, rather than safety issues	
74	PHL-74	VRB		Leakage of electrolyte		Damage to adjacent and anciliary equipment; health hazard to people	Transport, Use, Dispose	3D				Closed	Leak scenario during use phase is mentioned in a separate entry, e.g.PHA and SHA	
75	PHL-75	VRB		Overcharging, leading to elevated electrolyte temperature and hydrogen production (?)		Can lead to thermal runaway situation	Use	4F				Closed	VRB does not incur thermal runaway	
76	PHL-76	VRB		Pump running dry		Damage to pumps components; potential leakage upon re-starting	Use	4F				Closed	Leaked electrolyte would result in auto-shutdown of VRB systems, including the pumps. Dry-running is not possible	
77	PHL-77	VRB		Solid ion exchange cell membranes can be highly acidic or alkaline		Corrosive; health hazard	Dispose	4F				Closed	Less of a safety issue, and more of battery longevity issue	
78	PHL-78	VRB		Toxicity of vanadium in power form (before being mixed into liquid form during operations)			Production	4F			In liquid form, Vanadium is not toxic	Closed	No impact of toxicity during use-phase of VRB in LIFE building	
79	PHL-79	Hydrogen		Functional: Forced-ventilation does not function		Loss of protection against formation of LEL, and pressure-peaking phenomenon	Use	3C				CLosed	Hazard is analysed in other entries, e.g. SHA-8	
80	PHL-80	House structure		Emergency response vehicles not able to be in proximity of houses due to narrow access, blocked access, or soft ground		Fire-fighting efforts adversely impacted	Use	1D		tbd		Open		Martijn - considerations for external facilities for emergency response
81	PHL-81	Water system		Contamination of blue/white water by grey and/or black water		Upon contact, there could be health impact to humans and to plants; pollution to environment due to drainage water	Use	3D				Closed	Health, rather than safety, hazard	
82	PHL-82	Water system		Water pipe leakage		Damage to household equipment, or the building itself, depending on severity of leak. If the leak is from black or grey water, there might be impact to human health.	Use	4E				Closed	Asset loss, rather than safety hazard	
83	PHL-83	Water system		Low or high water pressure		For low pressure, the impact is hassle for user due to insufficient water volume. For high pressure, it may lead to leakage at outlets or piping joints.	Use	4E				Closed	Asset loss, rather than safety hazard	
84	PHL-84	Water system		Growth of microorganism in pipes and storage		Health impact to humans, such as diarrhea, vomitting, irritation to skin and eyes, respiratory problems (non exhaustive list), depending on microorganism type.	Use	3D				Closed	Health, rather than safety, hazard	
85	PHL-85	Water system		Insufficient treatment of water by the Grey and Blue boxes		Upon contact via direct or indirect methods, there could be health impact to humans and to plants; pollution to environment due to drainage water.	Use	3D	PHA			Closed	Environmental and health, rather than safety, hazard	
86	PHL-86	Water system		Contaminant in grey-water: chemicals such as boron and phosporus		Upon contact via direct or indirect methods, there could be health impact to humans and to plants; pollution to environment due to drainage water.	Use	3D	PHA			Closed	Health, rather than safety, hazard	
87	PHL-87	Water system		Contaminant in grey-water: detergents and cleaning products		Upon contact via direct or indirect methods, there could be health impact to humans and to plants; pollution to environment due to drainage water.	Use	3D	PHA			Closed	Health, rather than safety, hazard	

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88	PHL-88	Water system		Contaminant in grey-water: bleach and disinfectants		Upon contact via direct or indirect methods, there could be health impact to humans and to plants; pollution to environment due to drainage water.	Use	3D	PHA			Closed	Health, rather than safety, hazard	
89	PHL-89	Water system		Contaminant in grey-water: faeces and vomit		Upon contact via direct or indirect methods, there could be health impact to humans and to plants; pollution to environment due to drainage water.	Use	3D	PHA			Closed	Health, rather than safety, hazard	
90	PHL-90	Water system		Level of acidity/alkaline is unsuitable for vegetation and soil organisms		Perishing and growth disruption of plants	Use	4D	PHA			Closed	Environmental, rather than safety, hazard	
91	PHL-91	Electrical system		Electrocution or fire hazard caused by improper or deteriorated installations (e.g. wiring), inadequate electrical protection, overload due to new device installations, improper usage, or intentional abuse		Electrocution, or fire - leading to loss of lives and/or property and equipment damage. Depending on the magnitude of electrical current, effects range from mild discomfort to serious injuries such as burns, tissue damage, cardiac arrest, which can be fatal.	Use	3D			For risk related to household equipment - see LVD, Machinery Directive, or General Product Safety Directive	Closed	Despite its importance, the electrical hazards are not the focus of the study and is deemed to be well-managed by the respective equipment manufacturers, and electrical circuit designer and construction company	
92	PHL-92	Electrical system		Thermal effects		Excessive generation of heat, bringing risk of fire or damage to the electrical item.	All	3D				Closed	As above	
93	PHL-93	Electrical system		Over current		Excessive current that can lead to effects similar to electrocution and damage to electrical equipment	All	3D				Closed	As above	
94	PHL-94	Electrical system		Fault current		Excessive current/amperes that lead to tripping of relays, damage to insulation and components. The latter may lead to fire and electrocusion hazards	All	3D				Closed	As above	
95	PHL-95	Electrical system		Voltage disturbances and electromagnetic influences (EMI)		Degrades performance of electrical circuits, leading to malfunctioning or loss of equipment's function.	All	3D				Closed	As above	
96	PHL-96	Electrical system		Power supply interruption		Loss of electrical equipment's function.	All	3D				Closed	Safety concerns are described in other entries, e.g. SHA	
97	PHL-97	Overall system		Worksite safety hazards due to civil, earthwork and structure construction. See See Table B.3 in ISO 12100.		Injury due to cuts, falling objects, tripping, falling from heights, crushing, physical over-burdened and activities done in confined spaces, lifting, grinding, welding and cutting activities.	Construct	3D		tbd		Open		Utwente - ensure worksite safety procedures are available and adhered to.
98	PHL-98	Thermal energy system		Hot surfaces of heated medium		Scalding and burns	Use	3D				Closed		
99	PHL-99	PV electricity generation		Electrical hazards, such as electrocution		Personnel injury and potential building fire	All	3D		tbd	Despite its importance, the electrical hazards are not the focus of the study and is deemed to be well-managed by the respective equipment manufacturers, and electrical circuit designer and construction company	Open		Utwente and project partners - ensure clear responsibilities for equipment and integrated system, throughout the design, installation and testing
100	PHL-100	PV electricity generation		Material recycling and disposal		Health and safety impact on personnel handling materials during disposal and recycling process. There is also environment hazard if materials (such as lead, cadmium, silicon and other toxic chemical) sare not properly handled and disposed	Dispose	1D		tbd		Open		Utwente- produce guideline for safe disposal of PV panels
101	PHA-1	Hydrogen	Hydrogen production	Formation of flammable gas mixture of hydrogen and oxygen	Unintended release of hydrogen, leading to formation of hydrogen mixture falling within the lower explosion (LEL) and upper explosion limits (UEL) in the atmosphere	Ignition, deflagration or detonation of mixture. High flame temperaturea and pressure shock wave will lead to property damage, personnel injury and potential fatality	Use	1C	Conduct a more detailed analysis (e.g. HAZOP and Bowtie studies) to understand how the hazard can be prevented and mitigated. Use a Quantitative Risk Assessment (QRA) to determine the safe distance for the individual and the public.	2C		Open		HyGear - provide input for QRA
102	PHA-2	Hydrogen	Electrolyser	Formation of flammable gas mixture of hydrogen and oxygen	Mixing of hydrogen and oxygen within the electrolyser sub-system	Ignition, deflagration or detonation. Property damage and potential fatality	Use	1D	Similar to PHA-1 recommendations. Ensure the design of electrolyser sub-systems prohibits the mixing of hydrogen and oxygen, particularly in the gas separator, and to minimize the accumulation of hydrogen and oxygen.	1D	Re-evaluate risk after the design of the electrolyser system has been completed	Open		HyGear - conduct HAZOP study

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103	PHA-3	Hydrogen	Electrical components	Electrical injury	Improper electrical design, low manufacturing quality, and equipment damaged during installation and maintenance	Electrocution, fire hazard, damaged electrical equipment and personnel injury	Construct and operation	3D	Design and test equipment according to relevant standards, such as NEN 1010. Underlying severity is low since low-voltage systems are used, and the presumption that electrical equipment has undergone testing and complies with relevant standards	3D		Closed	Procured EES already have CE mark, thus would have adhered to relevant standards.	
104	PHA-4	Hydrogen	Storage tanks	Unintended release of hydrogen	Integrity of hydrogen storage vessel or piping compromised, resulting in leaks	Unignited or ignited gas release. Unignited release displaces oxygen, leading to asphyxiation. If release rate is sufficiently high, pressure peaking phenomena may occur leading to collapse of structure housing the hydrogen system. High pressure hydrogen jets can cut bare skin. Ignited release is described in PHA-1.	Use	1C	Similar to PHA-1 recommendations. To consider mitigation for high-pressure storage design, fire-resistant rating for storage tanks, suitable construction materials for gaseous hydrogen, siting of storage outdoors, safe separation distance, and use of thermally activated pressure relief valves. Apply periodic inspection and maintenance of equipment.	1D	Re-evaluate risk after design of hydrogen system has been completed	Open		HyGear - design, maintenance recommendations
105	PHA-5	Hydrogen	Hydrogen detection equipment	Presence of hydrogen in the atmosphere is undetected	The inability of odourants in providing early warnings due to bouyancy and diffusivity of hydrogen atoms. High hydrogen purity requirement in fuel-cell may also exclude the usage of odourants	Late detection of hydrogen leads of formation of flammable mixture and/or personnel injury or fatality	Use	1D	Use proper construction materials for equipment. Ensure proper fitting of hydrogen system components. Proper inspection and maintenance programme to preserve the integrity of fittings. Combine the usage of point detectors and ultrasonic gas leak detectors to detect leakage of hydrogen. Proper positioning of detectors and sensors.	1E		Open		HyGear - design
106	PHA-6	Hydrogen	Hydrogen detection equipment	Hydrogen fire is undetected	Hydrogen flame is nearly invisible in daylight	Personnel exposure will lead to severe injury or fatality	Use	1D	Use of flame detectors. Restrict access to the storage and production area.	1E		Open		HyGear - design
107	PHA-7	Hydrogen	Hydrogen detection equipment	Hydrogen fire	Ignition of hydrogen or hydrogen mixture	High temperatures, leading to personnel injury and/or causing secondary fires on adjacent equipment	Use	1D	Develop fire-fighting strategy for first responders. Minimise pipe diameters so that flame length is minimised. Minimise hydrogen pressure and inventory in the system. Consider the usage of fire barrier walls. Ensure proper positioning of outlet for ventilation and from thermal pressure-release devices.	1E		Open		HyGear - design Utwente - emergency response guidelines
108	PHA-8	Li-ion battery	Cells	Cascading thermal runaway	Chemical reactions within the lithium-ion cell, initiated from any of these five causes: thermal abuse, mechanical abuse, electrical abuse, poor cell electrochemical design, internal cell faults due to manufacturing defects;	Release of combustible and toxic gases, leading to possible fire	Use	2C	For commercial-off-the-shelf batteries, ensure that the batteries are compliant to the relevant standards. Ensure that the design, installation and usage of batteries address the five mentioned causes of thermal runaway. The battery supplier should have performed safety assessments, such as FMEA or Bowtie, to identify possible causes and mitigation for thermal runaway.	2D		Closed	Adequate barriers installed in SuperB's system. Furthermore, the probability is assumed 1 in 1E6 cells. Phase 1 of LIFE project uses only 48 cells, and therefore the probability is considered 'remote'.	
109	PHA-9	Li-ion battery	Cells	Electrical injury	Electrical charges stored within the batteries	Amperes used in LIFE Li-ion system can reach up to 300A.	Construct, Use, Dispose	1D	Ensure that only trained personnel can access and maintain batteries. Batteries should be de-energised before attempting any handling. Perform periodic maintenance on electrical safety devices	1E	0.01A and more can cause severe personnel injury; 0.1 - 0.2A can cause fatality.	Open		SuperB - maintenance recommendations
110	PHA-10	Li-ion battery	Cells	Release of toxic gas, such as HCl, HF, CO, HCN, and potential SO2 and H2S	During the thermal runaway phenomenon, the high temperatures within the cells cause deterioration of electrolytes and melting of the plastic casing.	A range of adverse effect on personnel, such as irritation, blistering and inhalation-related injuries.	Use	2C	Design of the battery should prevent thermal runaway phenomenon. If the occurrence of thermal runaway is unavoidable, then recovery barriers, such as the installation of an adequate ventilation system at the battery storage location, should be implemented.	2D		Open		SuperB - provide assurance on design
111	PHA-11	Li-ion battery	Cells	Onset of overheating	Growth of lithium dendrite in the electrolyte, electrolyte separator flaws, overcharging, external force/pressure	The onset of the thermal runaway phenomenon	Use	2C	Use batteries supplied by reputable manufacturers and have been certified and tested according to relevant standards. Design of the battery should prevent thermal runaway phenomenon.	2D		Closed	Adequate barriers are included in the system design. Furthermore, the risk of flammable and toxic gas is still a hazard that requires mitigation.	
112	PHA-12	Li-ion battery	Cells	Heat accumulation and flammable gas release	Decomposing separator, decomposing solid electrolyte layer interface, exposure of anode. Exothermic reactions happen in adiabatic conditions causes heat accumulation within cells.	Temperature increase and oxygen accumulation within the cell creates a combustible environment. The toxic gas release has harmful effects on personnel.	Use	2C	As above	2D		Closed	As above	
113	PHA-13	Li-ion battery	Cells	Combustion and explosion	Presence of oxygen, heat (both as a by-product of reactions in stage 2) and fuel (from inorganic electrolytes)	Damage to the battery, adjacent equipment and potential harm to personnel	Use	2C	As above	2D		Closed	As above	
114	PHA-14	Li-ion battery	Cells	Thermal abuse	Cell exposure to elevated temperature > 70 degrees Celcius, typically from external heat sources	Can trigger the onset of overheating	Use	2C	Avoid the storage of combustible products in the vicinity of battery rack, and also heat sources (e.g. thermal radiators, stoves and ovens). Consider installing a fire-extinguishing system in the battery location.	2D		Open		Utwente and SuperB - decide if fire-extinguishing system is required

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115	PHA-15	Li-ion battery	Cells	Mechanical abuse	External impact, e.g. from piercing and crushing	Damage to electrolyte separators, leading to internal circuit shorting.	All phases	2C	Design of the battery should prevent thermal runaway phenomenon. Do not use batteries that have suffered mechanical damage.	2D		Closed	SuperB's cell is encased by hard polymer casing. Collision/impact hazard is noted in a separate item	
116	PHA-16	Li-ion battery	Cells	Electrical abuse	Overcharging; Excessive rate of charging or discharging, external short-circuiting, over-discharge and subsequent re-charging.	Can trigger the onset of overheating	Use	2C	Design of the battery should prevent thermal runaway phenomenon.	2D	Higher battery capacity and sizes also lead to a higher likelihood of internal impedance heating	Open		SuperB - provide assurance on design
117	PHA-17	Li-ion battery	Cells	Poor cell electrochemical design	Incomplete or poor understanding of electrochemical interactions occurring in the cell components.	Triggers the onset of overheating	Use	2C	Design of the battery should prevent thermal runaway phenomenon.	2D		Closed	SuperB's batteries are of lithium-iron-phosphate type, which is less succeptible to thermal runaway	
118	PHA-18	Li-ion battery	Cells	Internal cell faults due to manufacturing defects	Manufacturing defects introduced and not detected during the cell production, assembly and handling	Triggers the onset of overheating	Production	2C	See check-list of good lithium battery design features. Use batteries supplied by reputable manufacturers and have been certified and tested according to relevant standards.	2D		Closed	SuperB has assurance processes that supports the CE certification	
119	PHA-19	Li-ion battery	Cells	Leakage of electrolyte	Internal corrosion or mechanical damage to the casing	Solvents and salts in the electrolyte are volatile and toxic to humans	All phases	2C	Ensure a leak-proof packaging is used, especially if a soft-pouch cell is used.	2D		Closed	Cell case is made of leak-proof, hard non-corrosive polymer.	
120	PHA-20	VRB	Electrolyte	Deflagration	Not possible; the aqueous electrolyte is not flammable	none	Use	3F		3F		Closed	Hazard can be considered eliminated. No further action required	
121	PHA-21	VRB	Cells	Overheating	Internal and external short-circuiting effects on electrolytes	Leakage of electrolyte due to high-temperature degradation of containment (e.g. tanks and seals)	Use	3E	Ability to warn and automatically discontinue the battery operation in a short-circuiting event or at an abnormal elevated operating temperature.	3F	The thermal mass of electrolyte tanks is sufficient to absorb any temperature increases caused by internal and external short-circuiting scenarios.	Closed	Inherent safet design of VRB against overheating	
122	PHA-22	VRB	Electrolyte	Corrosion	Sulphuric acid is a strong acid, and has pH < 1.	Degradation of containment; harm to environment and personnel	Production, Operation, Dispose	3C	Use corrosion-resistant materials for containment, such as stainless steel 316L. Install leak detector. Perform periodic maintenance and inspections. Prevent pumps from dry-running, to avoid seal damage and subsequent leakage	3D		Closed	Volterion provided assurance of leak-protection	
123	PHA-23	VRB	Electrolyte	Toxicity	Material characteristics. Vanadium is possibly carcinogenic. It is hazardous to health when in powder form, before being mixed into liquid form in the battery electrolyte. When the acidic electrolyte is exposed to high heat, toxic fumes of sulphur oxides is emitted.	Harmful if swallowed; Upon contact with personnel, causes severe skin burns, eye damage and respiratory problems.	Production	3C	Use personnel protective equipment (PPE) when handling electrolyte. Ensure material Safety Data Sheet is available on-site for easy reference. Ensure sufficient ventilation at the storage area	3D		Open		Utwente - ventilation design
124	PHA-24	VRB	Cells	Electrical injury	Contact with electrical energy stored in cells, or with electricity powering the pumps	Injury to personnel	Use	2D	Ensure that only trained personnel can access and maintain batteries. Batteries should be de-energised before attempting any handling.	2E		Open		SuperB and Volterion - user interface design and de-energising features
125	SHA-1	Li-ion battery	Battery ambient temperature control	Battery charges at low temperatures (below 0*C)	Charge controller does not stop the charging process at low temperatures	Anode plating, increasing the risk of thermal runaway initiation	Use	3C	To ensure this scenario is taken into consideration when designing the battery charge controllers	3D		Open		SuperB - provide assurance on design
126	SHA-2	Li-ion battery	Battery siting/location	Flooding	Heavy rains and capacity of the drainage system is exceeded	External short-circuiting of batteries and electrical shock hazards	Use	2C	Place the battery systems at a safe height beyond the historical water flood level.	2D	Historical water-level heights/flooding data are available	Closed	Location has not been flooded in the past 10 years, even during heavy downpour in 2015	
127	SHA-3	Li-ion battery	Battery siting/location	Mechanical impact	Accidental collision by vehicles, falling of overhead tree branches, or collapse of the housing structure	The onset of lithium battery internal thermal runaway	Use	3C	Locate the battery away from heavy traffic flow (e.g. cars, etc.), and out of reach of falling tree trunks, with collision-protection barriers.	3D		Open		Utwente - battery siting
128	SHA-4	Hydrogen	Civil structure integrity	The high release rate of hydrogen into an indoor atmosphere	Loss of containment from the indoor hydrogen system	Pressure-peaking phenomena, leading to roof blowout, or structural collapse of the building containing hydrogen systems.	Use	1C	Design the building capable of withstanding the pressure-peaking phenomena, for indoor hydrogen systems.	1D		Open		HyGear - recommendations for ventilation system requirements
148	SHA-23	Li-ion battery	Civil structure integrity	Weight of battery	LIFE: 18.5kg per pack x 48 packs per house = 888 kg	Building structure unable to bear load, leading to structure failure	Install; Use	2C	To consider load-bearing capacity of battery room	2E		Open		Utwente - design review
129	SHA-5	VRB	Containment and disposal of VRB electrolyte	Significant release of electrolyte from the containment system	Mechanical impact	Harm to personnel when in contact and inhalation due to strong acidity of electrolyte. Negligible eco-toxicity	Use	3D	No further action necessary, as a built-in sensor to detect and warn of primary containment leak is sufficient to mitigate the hazard	3D	Refer to Safety Data Sheet for VRB electrolyte	Closed		
130	SHA-6	Electrical system	Electrical safety	Frequent inverter on/off occurrence during the day	Insufficient sun-light, power outage/ disruption, inverter failure, and high voltage output at the inverter.	Intermittent charging of batteries and hydrogen production (frequent on/off operations). Potential inverter/controller circuitry damage?	Use	4B	To check with Partners on possible effects. Any impact on the condition of batteries?	4B		Closed	Presumably, the intermittent nature of battery charging and discharging does not result in a safety hazard (Gerwin).	

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131	SHA-7	Electrical system	Electrical safety	Emergency power-down of batteries and hydrogen systems	The development of hazardous conditions triggers safe-shutdown of EES	Safety-related systems lose power and do not provide the required functions	Use	2C	To ensure that safety-related systems - such as forced ventilation, gas detectors, alarms and emergency lighting, gas-flooding system - has an alternate power supply, and will still function during an emergency	2D		Open		Utwente, SuperB, Volterion, HyGear - decide on safety-related systems and the need for back-up power supply for these systems
132	SHA-8	Hydrogen; Li-ion	Gas and fire detection system; Ventilation system	Detection and/or ventilation system malfunctions	Malfunction or failure of any one of the equipment or components;	Decreased ability to mitigate a potentially catastrophic event (e.g. fire and explosion)	Use	3C	Perform a Bow-tie analysis to a more detailed study on the preventive and reactive barriers to prevent catastrophic events from occurring. If feasible, use natural ventilation as opposed to induced ventilation. Implement an inspection and maintenance programme for the gas detection and ventilation equipment	3D	The initial risk score is similar to that derived from PHA for the hydrogen system	Open		Utwente, SuperB, Volterion, HyGear - decide on safety-related systems and functional-safety aspects
133	SHA-9	Hydrogen; Li-ion	Gas and fire detection system; Ventilation system	Detection and/or ventilation system malfunctions	No power supply to the induced ventilation system	Decreased ability to mitigate a potentially catastrophic event (e.g. fire and explosion)	Use	3C	Incorporate a status-indicator to alert the user to the malfunctioning of safety protection equipment.	3D	Creating an interlocking relationship, i.e. malfunctioning of the gas detection and ventilation system would result in the shutdown of the hydrogen and battery systems, might cause a nuisance to the users.	Open		Utwente, SuperB, Volterion, HyGear - decide on safety-related systems and user-interface requirements
134	SHA-10	Hydrogen; Li-ion	Gas and fire detection system; Ventilation system	The user intentionally disables the system	Human error	Similar to the above	Use	3C	As above	3D		Open		Utwente, SuperB, Volterion, HyGear - decide on safety-related systems and user-interface requirements
135	SHA-11	Overall system	General systems	Intentional abuse/vandalism electrical components of energy storage systems	Components are physically exposed, coupled with malicious intentions	Potential electrical injury by the perpetrator, malfunction of energy storage systems	Use	3D	Limit the accessibility of battery and hydrogen systems in a secured place to only authorised personnel (e.g. home inhabitants and maintenance personnel). Minimise exposure of components (e.g. wiring) to external elements—for example, use of cable conduits.	3D	To check with UT's campus housing management on what types (if any) acts of vandalism is prevalent in the campus or accommodation	Open		Utwente - access restriction
136	SHA-12	Hydrogen	Hydrogen production and storage	Capacity or purpose of the area in the vicinity of hydrogen production and storage is changed (e.g. Addition of buildings/installations in the vicinity)	Planned changes in the surrounding layout	Safety distance is compromised	Use	1C	Ensure proper zoning for material storage and siting. Implement a Management of Change process to take into account such changes.	1D	The initial risk score is similar to that derived from PHA for the hydrogen system	Open		Utwente - verify if a management of change procedure is in place
137	SHA-13	Hydrogen	Hydrogen production and storage	Storage/siting of flammable materials in the vicinity of hydrogen storage and production	Intentional or unintentional material storage	Increased risk of fire and explosion	Use	1D	Ensure proper zoning for material storage and siting, and perform regular housekeeping of the area.	1D	Procedural measures is not a reliable barrier	Open		Utwente - storage area management
138	SHA-14	Hydrogen	Hydrogen production and storage	Addition of hydrogen production and storage capacity	Increased demand for hydrogen/electricity	Increased risk of fire and explosion	Use	1C	Ensure that the threshold of hydrogen production and storage, as calculated in the qualitative risk assessment (QRA), is not exceeded. If an exceedance is unavoidable, re-evaluate the QRA.	1D		Open		Utwente - verify if a management of change procedure is in place
139	SHA-15	Hydrogen	Hydrogen production and storage	Electrolyser and fuel-cell cooling system malfunction	To be investigated in sub-system design	Hydrogen system shutdown, leading to loss of production	Use	4F	In the hydrogen system design, the occurrence of the hazard should trigger an automatic shutdown of hydrogen production	-	Safe system shutdown has negligible safety risks.The HAZOP should consider the impact of safe shutdown.	Closed	Low safety consequences	HyGear - to consider in HAZOP study
140	SHA-16	Hydrogen	Hydrogen production and storage	Water supply disruption	To be investigated in sub-system design	Hydrogen system shutdown, leading to loss of production	Use	4F	As above	-	As above	Closed	Low safety consequences	HyGear - to consider in HAZOP study
141	SHA-17	Hydrogen	Hydrogen production and storage	Incoming water quality out of specifications	Incoming water contains, or exceeds the level of contaminants that can be conditioned by the water treatment system	More load is exerted on the water treatment (Reverse osmosis / electrodesionisation - RO/EDI) system, and could result in more frequent maintenance and potential operational disruptions.	Use	4D	To find out what specific input water quality specifications are needed. No additional actions required, as negligible operational safety hazard is expected. Routine maintenance safety precautions to be undertaken.	-		Closed	Not a safety concern	
142	SHA-18	Hydrogen	Hydrogen production and storage	Hydrogen gas ignite during maintenance or upkeep operations	Hot-work is performed in the presence of combustible gas, wrong commissioning after maintenance, leak caused by poor maintenance and electrical failures	Introduction of the hazardous situation leading to injury, loss of life and asset damage	Use	1C	The threat is mitigated if the hydrogen system is purged-free from hydrogen gas before the start of maintenance, either through procedural or hardware means. Only trained personnel should perform maintenance. Maintenance procedure should emphasize safety measures during all stages of maintenance operations.	1D	Based on industry statistics, ARIA	Open		HyGear - design for maintenance, and recommendations for safe maintenance
143	SHA-19	Li-ion battery	Lithium battery ambient temperature controls	System malfunction	Malfunction or failure of any one of the equipment or components; or interrupted power supply	Temperatures not maintained within the operating range of batteries.	Use	4C	Outside the operating temperature range, the charge controller should stop the charging and discharging process. The decision to install ambient temperature controls depends on the purpose of batteries and seasonal operating modes, and the expected ambient temperature (based on historical values and future projections). To consider installing a back-up power supply to the ambient temperature control system, if the functionality is required throughout the year.	4C		Closed	Not a safety concern, more of issue of battery availability	

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144	SHA-20	Li-ion battery	Lithium battery ambient temperature controls	BMS malfunctions resulting in its inability to monitor the charging and discharging rate of the battery pack	Malfunction or failure of any one of the electronic components	Potential electrical abuse on battery cells, resulting in the onset of internal thermal runaway	Use	3C	Incorporate a status-indicator to alert the user to the malfunctioning of safety protection equipment. An automatic halt of battery operations until the functionality of BMS has been restored.	3D		Open		SuperB - provide assurance on design
145	SHA-21	Li-ion battery	Lithium battery ambient temperature controls	The system is intentionally disabled by the user	Human error	Similar to the above	Use	4C	The automatic halt of battery operations until the functionality of BMS has been restored.	4C		Closed	Not a safety concern, more of issue of battery availability	
147	PHL-101	Hydrogen	Storage tanks	High noise from the release of pressurised hydrogen from pressure relief valve (PRV)	Pressure relief valve release, or accidental storage leak	Up to 140 dB noise can be generated from a 200 barg release, causing permanent loss of hearing for personnel in close proximity (within 50 m)	Use	2C	Install sound dampener at PRV outlet	2D		Open		HyGear - design considerations
146	SHA-22	Hydrogen	Oxygen production	Pure oxygen	Oxygen is directed to an unsafe location	Oxidizing agent; causes violent reactions or fires with materials such as oil and grease. Some materials will combust spontaneously in the presence of pure oxygen.	Use	1D	In the absence of an oxygen storage capability, the pure oxygen should be routed to a safe location in the atmosphere, where contact with flammable material or humans is avoided.	1E	High-pressure oxygen can cause nausea, dizziness, loss of muscle control, fits or loss of consciousness. However, the LIFE system does not produce pressurised oxygen.	Open		HyGear - design considerations
149	PHL-102	Hydrogen		Operation: User misoperate, or unintentionally abuse the system	Unfamiliarity with technology / equipment	Equipment malfunction, leading to unsafe conditions	Use	1C	To investigate further during detailed design	tbd		Open		HyGear - conduct HAZOP study
150	PHL-103	Overall system		Operation: User misoperate, or unintentially abuse the system	Mischief, curiousity, equipment is easily targetted	Equipment malfunction, leading to unsafe conditions	Use	2C	To investigate further during detailed design for each EESS	tbd		Open		Utwente, SuperB, Volterion and HyGear - to analyse Operational hazards
151	PHL-104	Home energy management system, HEMS		Imbalance between supply and demand during autarkic mode	Electrical overload	Frequent power outage, or inability to obtain power when required	Use	4D				Closed	Less of a safety issue, but causes inconvenience	
152	PHL-105	Overall system		House dweller unaware, or lack basic understanding on operation of EESS installed in the building	Ineffective or inadequate communication between home owner and house occupant	House occupant unable to provide satisfactory response to abnormal conditions	Use	3C	Assuming that the EESS have inherently-safe design, then the impact of mis-use by User should be minimised	tbd		Open		Utwente, SuperB, Volterion and HyGear - to analyse Operational hazards
153	PHL-106	Overall system		Home owner unaware, or lack basic understanding on operation of EESS installed in the building	Ineffective or inadequate communication between equipment supplier and partner	Home owner unable to provide satisfactory response to abnormal conditions	Construction	3C	Assuming that the EESS have inherently-safe design, then the impact of mis-use by User should be minimised	tbd		Open		Utwente, SuperB, Volterion and HyGear - to analyse Operational hazards
154	PHL-107	Overall system		Home owner installs EESS without complying with spatial planning requirements	Home owner is unaware of requirements	Places home and surrounding in potentially hazardous conditions	Design	1E				Closed	Impossible to occur, as permitting is strictly regulated in NL	
155	PHL-108	PV electricity generation		Too much locally-generated electricity is fed back into the grid	Grid capacity is limited	Grid voltage disturbances and transformer tripping, leading to localised power outage	Use	3D				Closed	Less of a safety issue; this should be managed by the Grid supplier	
156	PHL-109	Overall system		Energy generation or storage systems does not match required usage	Wrong estimation of demand	Equipment does not perform up to expectations; disruptions to quality of living in the house	Design	3D				Closed	Not a safety issue	