MARITIME

RESULT TABLES

EMSA European Maritime Safety Agency

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SAFER, SMARTER, GREENER

Version 0.1

RESULT TABLES

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	cate-gory	Recommended Action	Sr	Or	Dr	cate-gory
1 - Scenario "High Temperature Fuel Cell (HT FC) onboard RoPax ferry and LGC"														
1.1 - Normal operation with NG as fuel														
1.1.1 - Fuel System														
1.1.1.1 - Fuel Tank System														
Storage of LNG, NG in liquid or compressed state	Requirements for the storage of NG in liquid and compressed state are covered by the IGF Code	-	-	-	1.1.1.1-1	Requirements for the storage of NG in liquid and compressed state are covered by the IGF Code	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.1.2 - Distribution line between LNG tank and fuel preparation (LNG; liquid)														
Transport of LNG from tank to fuel preparation	Covered by requirements of the IGF Code	-	-	-	1.1.1.2-1	Covered by requirements of the IGF Code	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.1.3 - Fuel preparation (LNG)														
Evaporation of LNG to NG; heating of NG	Requirements on LNG fuel preparation are covered by the IGF Code	-	-	-	1.1.1.3-1	Requirements on LNG fuel preparation are covered by the IGF Code	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.1.4 - Distribution line between CNG tank and fuel preparation (NG; gaseous)														
Transport of CNG to fuel preparation	Covered by requirements of the IGF Code	-	-	-	1.1.1.4-1	Covered by requirements of the IGF Code	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.1.5 - Fuel preparation (CNG)														
Reduction of CNG to NG	Covered by requirements of the IGF Code	-	-	-	1.1.1.5-1	Covered by requirements of the IGF Code	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.1.6 - Distribution line to Fuel Cell Power System (NG; gaseous)														
Transport of NG from fuel preparation to Fuel Cell Power System	Covered by requirements of the IGF Code	-	-	-	1.1.1.6-1	Covered by requirements of the IGF Code	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.2 - Fuel Cell Power Installation														
1.1.2.1 - Fuel Cell Power System														
1.1.2.1.1 - Piping between fuel preparation and FC power system (primary fuel line)														
Transport of primary fuel to reforming unit	see item 1.1.1.6 "Distribution line to Fuel Cell Power System (NG; gaseous)"	-	-	-	-	Covered by requirements of the IGF Code	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.2.1.2 - Fuel Reforming														
provide process gas for the fuel cells	no primary fuel	no startup of fuel cell power system possible	3	failure of fuel storage and distribution system	1.1.2.1.2-1	redundancy requirements of the IGF-Code	4	1		Start-up procedure should included functional test of primary fuel supply to the reformer	3	3	1	
	loss of primary fuel	no production of electricity, no damage of the fuel cell stacks assumed, reformer temperature will rise due to missing cooling effect from fuel conversion, further damages to the reformer possible (fire hazard)	4	failure of fuel storage and distribution system	1.1.2.1.2-2	redundancy requirements of the IGF-Code	3	1		The design of the reformer unit has to withstand loss of fuel without leading to unsafe situation	3	3	1	
	wrong specification of the primary fuel	performance of the system can be influenced, no hazard assumed	2	fuel quality not checked	1.1.2.1.2-3	sampling / Bunkering note	4	1		Procedure: Fuel quality to be checked after each bunkering acc. to specification of the manufacturer the reformer system	2	3	1	
	wrong temperature of primary fuel (too low at the inlet of the reformer)	no H_2 generation, same effect like no or loss of primary fuel (failure ID's '1.1.2.1.2-1/2)	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	wrong pressure of the primary fuel gas	unreformed fuel can enter the stack, damage of stack and leakage of fuel in the exhaust gas line possible; fuel will be treated by the after burner	3	failure of fuel storage and distribution system or GVU	1.1.2.1.2-4	GVU adjust pressure to needed level after burner in exhaust gas line	3	2		clarify if GVU should be part of the Fuel cell power system Reformer inlet pressure of the primary fuel should be monitored. Shut down of primary fuel supply should be initiated for the corresponding reformer in case of reaching limiting values.	3	3	1	
	degradation of conversion capability	performance of the system can be influenced, not safety related, performance issue	2	deactivation of catalytic material	1.1.2.1.2-4	redundancy requirements of the IGF-Code	4	2		The conversion capability of the reformer should be monitored for preventive maintenance	2	3	1	
	loss of integrity	air getting into the reformer, exothermic reaction with catalytic material resulting high temperature (up to 1000 °C), self ignition of remaining gases is possible	5	mechanical damage, welding failure, untight connections	1.1.2.1.2-5		3	2		"Reformer temperature should be monitored. Shut down of primary and recirculating fuel supply should be initiated in case of reaching temperature limits. The entry of oxygen in the reformer should be avoided by e.g. purging with inert gas"	4	3	1	
	external leakage of the reformer	gas will be released in the reformer installation room and detected, shut down of primary fuel supply, ventilation of gas in a safe location	3	mechanical damage, welding failure, untight connections	1.1.2.1.2-6	gas detection inside the fuel cell power system ventilation requirements acc. to IGF Code	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	cate-gory	Recommended Action	Sr	Or	Dr	cate-gory
1.1.2.1.3 - Piping between reformer and fuel cell														
transport of process gas	external leakage	release of fuel gas / hydrogen rich fuel to the fuel cell power system space, self-ignition possible	4	mechanical damage, welding failure, untight connections	1.1.2.1.3	gas detection / fire detection accumulation of hydrogen rich gases shall be avoided by ventilation ESD protected fuel cell space fire extinguishing system	3	1		Detail assessment of hydrogen rich gas release scenarios in respect to (self-) ignition and dispersion to be done	3	3	1	
1.1.2.1.4 - HT Fuel Cell FC Module														
Provision of electrical energy for propulsion and other consumers	wrong qualification of the fuel	decrease of the performance of the stack, internal leakage in the exhaust gas line possible; fuel will be treated by the after burner	3	malfunction of reformer	1.1.2.1.4-1	Redundancy requirements of the IGF-Code	3	2		The fuel gas specification shall be monitored, the system shall be brought into a safe state in case of reaching limiting values,	3	3	1	
	external leakage	gas release out of the fuel cell into the fuel cell module installation space, self-ignition possible	4	mechanical damage, welding failure, untight connections	1.1.2.1.4-2	ESD protected fuel cell space Gas safe fuel cell space type approval / certification of the fuel cell	3	1		"Detail assessment of hydrogen rich gas release scenarios in respect to (self-) ignition and dispersion to be done Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (reduce collision effects)"	3	3	1	
	internal leakage	high stack temperature developing into an internal oxidation / fire, drop in voltage, shut down of related module	4	cracking of plates	1.1.2.1.4-3	temperature monitoring of stack voltage monitoring	4	1		"amount of fuel in the fuel cell space and the corresponding consequences shall be evaluated. Safety devices are designed to handle max. credible release scenario. Combustible material in fuel cell modules are to be minimized"	3	4	1	
	"load jumps: not considered to cause an hazardous event, energy buffer systems installed (e.g. battery system)"	no effect	1	load changes	1.1.2.1.4-4	energy buffer systems	5	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	short circuit	loss of power output, remaining fuel gases in the exhaust air not to be expected	3	electrical failure	1.1.2.1.4-5	short circuit breaker Dielectric strength test acc. to 62282/3-100 provided Monitoring of stack voltage Shut down of fuel supply for related FC Module	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	uncomplete oxidation	hydrogen rich gas remaining in Exhaust gas, oxidation by after burner, no effect as after burner is designed to process 100% fuel in the Exhaust	2	malfunction of reformer	1.1.2.1.4-6	after burner in exhaust gas line, designed to process 100% fuel in exhaust line	4	2		"The after burner should be designed to process 100% fuel in the exhaust line Exhaust gas temperature behind the afterburner should be monitored and shut down to be initiated in case of reaching limiting values"	2	4	1	
	high temperature exhaust	exhaust gas temperature will be monitored, shut down in case of reaching limiting values	3	malfunction of fuel cell	1.1.2.1.4-7	temperature monitoring of exhaust air	3	1		Exhaust gas temperature should be monitored and shut down to be initiated in case of reaching limiting values	-	-	-	-
1.1.2.1.5 - Process Air														
Provide oxygen for the FC process	loss of process air	No or insufficient oxygen provided for the FC process, shut down of the FC power system due to undervoltage, remaining fuel will be processed by the after burner, no release of fuel out of the exhaust gas line	3	failure of ventilation fan	1.1.2.1.5-1	redundancy requirements of the IGF-Code after burner in exhaust gas line: designed to process the highest amount of fuel expected in case of a failure of the fuel cell (at least the amount of fuel at nominal fuel cell load)	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.2.1.6 - Afterburner														
use of the heat from the exhaust, burn remaining fuel in the exhaust	no oxygen	remaining fuel is released to atmosphere (toxic, flammable) if not recirculated to the reformer, amount depending on the utilisation rate of the FC at the actual load	3	failure of the ventilation system	1.1.2.1.6-1	if the presence of explosive and harmful gas concentration in the exhaust can not be excluded the exhaust shall be arranged as a ventilation outlet of a hazardous zone redundancy requirements of the IGF-Code	4	2		Exhaust gas temperature behind the afterburner should be monitored and shut down to be initiated in case of reaching limiting values	3	4	1	
	mechanical damage	"release of fuel residues into the fuel cell space: see external leakage for reformer, piping and fuel cell"	-	-	-	-	-	-	-	-	-	-	-	-
	more than 100 % fuel (excluded at least 2 failures have to occur)	-	-	-	-	-	-	-	-	-	-	-	-	-

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	cate-gory	Recommended Action	Sr	Or	Dr	cate-gory
1.1.2.1.7 - heat (energy) recovery														
FC power system internal heat recovery (fuel re-forming)	"Reformer pressure higher than exhaust air pressure: reformat can leak into the exhaust gas (specific arrangement)"	depending on the concentration ignition possible, toxic gas and remaining fuel will be release through the exhaust gas outlet, damage of exhaust gas line not expected	3	mechanical damage	1.1.2.1.7-1	if the presence of explosive and harmful gas concentration in the exhaust can not be excluded the exhaust shall be arranged as a ven-tilation outlet of a hazardous zone	3	2		Gas detection should be provided in the exhaust gas line. Shut down of the system to be initiated in case of gas detection.	3	3	1	
	"Reformer pressure lower than exhaust air pressure: oxygen will leak into reformer system"	see reforming system; failure ID 1.1.2.1.2-5	5	mechanical damage	1.1.2.1.7-2		3	2		"Exhaust gas fan to be switched of, if applicable, otherwise big amount of oxygen could be pushed into the reforming system Reformer temperature should be monitored. Shut down of primary and recirculating fuel supply should be initiated in case of reaching temperature limits. The entry of oxygen in the reformer should be avoided by e.g. purging with inert gas"	4	3	1	
FC power system internal heat recovery (Process air)	release of process air in the exhaust gas line	see reforming system; see process air fail-ure ID 1.1.2.1.5-1	-	-	-	-	-	-	-	-	-	-	-	-
external heat recovery (various designs avail-able)	internal leakage	leakage of exhaust gas into the heating media system excluded: heating media pressure higher than exhaust gas system (open system)	1	welding failure, material damage	1.1.2.1.7-3	-	1	1		-	-	-	-	-
		leakage of heating media (gaseous or liquid) and release out of the vent mast; no hazards expected; reduced energy recovery	2	welding failure, material damage	1.1.2.1.7-4	-	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	external leakage; see exhaust gas line													
1.1.2.1.8 - exhaust gas line (overpressure)														
transport of exhaust gas	external leakage	Release of exhaust air in the fuel cell power system space, exhaust air will be ventilated	1	mechanical damage, welding failure, untight connections	1.1.2.1.8-1	ventilation requirements acc. to IGF Code	4	2		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	external leakage of exhaust gas with flammable content	not further considered, only in case of two failures (malfunction of the burner) flam-mable and toxic gas can enter the exhaust trunk	3	mechanical damage, welding failure, untight connections	1.1.2.1.8-2	ventilation requirements acc. to IGF Code gas detection after burner	2	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.2.2 - electrical power output conditioning														
Conditioning of electrical output of the FC power system for on-board net integration; Protection of Fuel Cell Power System against reverse power; Galvanic isolation from the grid	short circuit (input side)	Short circuit on the Fuel Cell Power system side does not effect the downstream power electronics in terms of damage, global ef-fect will be the loss of power of the related FC stack / module	3	material failure	1.1.2.2-1	short circuit breaker dielectric strength test acc. to 62282/3-100 provided monitoring of stack voltage shut down of fuel supply for related FC module redundancy requirements of the IGF-Code	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	short circuit (Internal)	High voltage (Grid voltage level) in the Fuel Cell Module, High temperature in the stack, fire possible	4	electrical failure	1.1.2.2-2	circuit breakers at each consumer converter designed to handle short circuits	3	1		Consideration to be given to electrical reveres power	3	3	1	
	short circuit (output side)	Fuel Cell System will be protected, fuel no longer consumed, hydrogen rich gas in ex-haust possible (note: only if system without afterburner)	3	electrical failure	1.1.2.2-3	FC system is designed to safely handle unconverted fuel gas (incl. consideration of black out) afterburner design (if integrated) if the presence of explosive and harmful gas concentration in the exhaust can not be excluded (e.g. no afterburner) the exhaust shall be arranged as a ventilation outlet of a hazardous zone.	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	wrong conversion, e.g. faulty frequency	power grid protected ship-side at Main Switch Board (MSB), FC control system might be affected; damage to the fuel cell system possible, (depending on design)	4	e.g. converter control failure	1.1.2.2-4	FC control system protected from electrical faults (e.g. fail safe mode or UPS) MSB electrical protection	3	1		decentralised grids are to be designed for load fluctuations	-	-	-	-

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	cate-gory	Recommended Action	Sr	Or	Dr	cate-gory
Protection of Fuel Cell Power System against reverse power	covered in above	-	-	-	-	-	-	-	-	-	-	-	-	-
Galvanic isolation from the grid	covered in above	-	-	-	-	-	-	-	-	-	-	-	-	-
1.1.2.3 - Net integration														
Providing required electrical power from FC power system to the electrical board net	overproduction / underproduction	same as for other power sources: load fluctuations to be considered and covered by energy buffer	1	load changes	1.1.2.3-1	energy buffer systems	5	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	too slow reaction to high load fluctuation	will be covered by redundancies in buffer system (design)	1	failure in buffer system	1.1.2.3-2	buffer system design to cope with slow power dynamics PMS buffer system design requires sufficient redundancies -> to be investigated	5	1		Redundancy requirements for buffer system to be investigated	1	3	1	
	electrical load sharing failures in decentralized grid	Reverse power from the grid	3	failure of power management system	1.1.2.4-1	Power management system	4	1		Consideration to be given to electrical reveres power	3	3	1	
1.1.2.4 - Fuel Cell control system														
process control	General	The Fuel Cell control system shall be designed in a way, that the fuel cell power system will be automatically set in a safe state in case of an unsafe situation	-	-	1.1.2.4-1	The Fuel Cell control system shall be designed in a way, that the fuel cell power system will be automatically set in a safe state in case of an unsafe situation	-	-	-	The Fuel Cell control system shall be designed in a way, that the fuel cell power system will be automatically set in a safe state in case of an unsafe situation	-	-	-	-
	external communication failure with ship automation	temporary over- or underproduction; following the net	3	loss of communication link to ship automation	1.1.2.4-2	FC system has internal process control (follow the net) (system must maintain safe state or bring itself into a safe state) no-communication alarm	4	1		develop re-connection procedure to reconnect to the ship automation	3	3	1	
	mismatch of fuel, water and energy production	overrun of safety relevant parameter limits, safety control system takes over, hard shut down will be initiated	3	e.g. internal communication failure or sensor failure	1.1.2.4-2	certified safety system shut down of the system to a safe state	3	1		the safe state of the fuel cell power installation has to be defined for all possible modes of shut down	-	-	-	-
	loss of control system	overrun of safety relevant parameter limits, safety control system takes over, hard shut down will be initiated	3	e.g. internal communication failure or sensor failure	1.1.2.4-3	certified safety system shut down of the system to a safe state	3	1		the safe state of the fuel cell power installation has to be defined for all possible modes of shut down	-	-	-	-
1.1.2.5 - Fuel Cell safety control system														
Control of Fuel Cell safety system	General	safety control system required acc. to IGF Code and established rules and regulations	-	-	1.1.2.5-1	safety control system required acc. to IGF Code and established rules and regulations	-	-	-	safety control system required acc. to IGF Code and established rules and regulations	-	-	-	-
1.1.3 - Ventilation system for ESD protected fuel cell spaces														
Transport of possible leaking gases out of the ESD protected fuel cell space to a safe location	failure of ventilation	loss of one safety barrier, controlled shut down initiated: complete loss of ventilation not expected due to redundancy requirements	3	electrical failure, mechanical damage	1.1.3-1	monitor functioning of ventilation system redundancy requirements of the IGF-Code	2	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.4 - Ventilation system for gas safe fuel cell spaces														
no requirements on ventilation of gas safe fuel cell space but for the gas interbarrier space	loss of ventilation	loss of one safety barrier, controlled shut down initiated: complete loss of ventilation not expected due to redundancy requirements	3	electrical failure, mechanical damage	1.1.4-1	gas interbarrier space needs to be monitored redundancy requirements of the IGF-Code	2	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.5 - Onboard energy buffer														
Backup power in case of shut down of the whole fuel cell power plant	Loss of fuel cell power output	loss of fuel cell power output, electrical energy is to be provided by other energy converters, depending on the hybrid concept the energy could be provided by the energy buffer, in this case the energy buffer must be capable to ensure a minimum power supply for a certain time (see SOLAS requirements)	3	loss of fuel cell installation space in case of centralized installation	1.1.5-1	redundancy requirements of the IGF-Code decentralised power supply	3	1		Redundancy requirements for buffer system to be investigated	-	-	-	-
	thermal runaway, fire	Thermal runaway and fire	4	internal battery failure	1.1.5-2	temperature switch temperature monitoring storage between reformer and fuel cell stack excluded by current draft provisions of IGF Code	3	1		Functional safety requirements for battery installation to be considered as e.g. defined in DNV GL guideline for large maritime battery systems	3	3	1	

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Accommodate for load fluctuations	see net integration failure ID 1.1.2.3-2	-	-	-	-	-	-	-	-	-	-	-	-	-
Active purging system - not applicable for this technology														
1.1.6 - Inert gas system														
Inerting of FC Power System	no inert gas	inerting not possible	4	intert gas consumed	1.1.6-1	monitoring of inertgas storage alarm level to be defined where the inertgas storage reaches the an amout, which is suitable for a last complete inertign process of the system	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
1.1.7 - External events														
External events acting on the Fuel and / or Fuel Cell Power Installation	Fire in FC power installation place	fire will be contained in space (active and passive fire protection), automatic shut down of fuel cell by safety system and shut down of fuel system to affected space	3	fuel self ignition, reverse power	1.1.7-1	active and passive fire protection systems acc. to IGF Code require-ments safety system with ESD function	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	black-out	FC system designed to be fail safe; black-out recovery will be considered in ship design	3	e.g. electrical net failure	1.1.7-2	Black-out recovery	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	"LGC specific: ESD of cargo system"	ESD during cargo transfer, loss of fuel if fuel used from the cargo for auxiliary power supply by FC during port stay	3	e.g. activation of ERC jetty	1.1.7-3	separation of ESD system of primary fuel and cargo system	4	1		-	-	-	-	-
	flooding	short circuits (nothing specific to FC tech-nology), FC system will be shut down by the safety system, electrical power supply by other power system (redundancy)	3	e.g. collision	1.1.7-4	same requirements than for con-ventional engine spaces redundancy requirements of the IGF-Code decentraliced power supply	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	blockage of exhaust	loss of performance and shut down of fuel cells due to deviation of process parame-ters	3	blockage of exhaust pipe	1.1.7-5	T monitoring of after burner monitoring of fuel cell process parameter	3	1		Exhaust gas outlet shall be designed in a way, that blockage by e. g. particles is avoided.	-	-	-	-
	out of range ambient T (low T)	freezing at out of range T could cause dam-age - no safety relevant failures expected	-	-	-	-	-	-	-	-	-	-	-	-
	Fire in Tank hold space: containment issue not directly fuel cell related	covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	Fire in adjacent rooms to tank hold space	covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	Fire in fuel preparation room	covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	Fire adjacent to fuel preparation room	covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	Fire in the vicinity of distribution line (LNG)	covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	Fire in the vicinity of distribution line (NG)	covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	RoPax specific: Fire on car deck or open deck structural fire protection acc. to SOLAS and IGF	covered by requirements of the IGF Code	-	-	1.1.7-6	Fuel piping routed through the RoRo deck must be protected against possible fire	-	-	-	Fuel piping routed through the RoRo deck must be protected against possible fire	-	-	-	-
	Ship / Ship collision	damage of outer shell, damage of adjacent systems possible	3	human error	1.1.7-7	distance requirements for fuel piping shall be also applied to fuel cell stacks	3	1		Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (re-duce collision effects)	-	-	-	-
	Shore / Ship collision	damage of outer shell, damage of adjacent systems possible	3	human error	1.1.7-8	distance requirements for fuel piping shall be also applied to fuel cell stacks	3	1		Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (re-duce collision effects)	-	-	-	-

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External events acting on the Fuel and / or Fuel Cell Power Installation	"RoPax specific: vehicle crash"	damage of shell, damage of adjacent systems possible	4	human error	1.1.7-9		3	1		"Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (reduce collision effects) Shells of space facing the car deck where parts of the Fuel Cell Power Installation and related fuel storage, distribution and storage systems are installed must be protected aigainst possibel impact of vehicles or cargo Fuel piping routed through the RoRo deck must be protected against possible impacts by vehicles or cargo"	3	3	1	
	blockage of vent mast outlet (by weather conditions)	rain water entering the vent mast, icing possible, no (or limited) venting possible	3	e.g. rain	1.1.7-10	rain cap and water drainage system for the vent mast	3	1		The vent mast outlet shall be designed in a way, that blockage by particles and entering rainwater is avoided. In case of high pressure release these design solutions must still ensure an upturned release out of the vent mast outlet	-	-	-	-
1.2 - Bunkering LNG, NG														
Transport of LNG or NG in liquid or compressed form from a bunker source to the ships	"IGF Code requirements for bunker station locations and hazardous zone definition to be considered. Additional functional requirements for bunkering LNG or NG are ISO TS 18683 and DNV GL recommended practice, for this study an analysis for bunkering Hydrogen as fuel will be done"	-	-	-	1.2-1	"IGF Code requirements for bunker station locations and hazardous zone definition to be considered. Additional functional requirements for bunkering LNG or NG are ISO TS 18683 and DNV GL recommended practice, for this study an analysis for bunkering Hydrogen as fuel will be done"	-	-	-	For RoPax vessels special attention to possible impact on Passengers and vehicle traffic during bunkering shall be paiyed. Safety and security zones are to be established. Most credible release sceanrios are to be analysed according to possible influence on passengers, crew and ship; especially for this ship type influences on balconies, cabins, open passenger decks, open roro-and cargo decks, passenger bridges as well as passenger ways and vehicle routes on terminal side shall be taken into account. For LGC special attention shall be payed to the primary fuel if it is different from the cargo. In this case additional means for bunkering the promary fuels are necessary which differ from the normal cargo transfer. Additional gas detection systems, safety and security zones (e.g. in case of truck to Ship bunkering), training and instruction may be necessary	-	-	-	-
					58	with failure ID								
					16	without failure ID								
					74	Total								
					26	from 74 not ranked (with and without ID)								
					48	from 74 ranked								

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	cate-gory	Recommended Action	Sr	Or	Dr	cate-gory
2 - Scenario "High Temperature PEM Fuel Cell (HT PEMFC) on-board RoPax ferry and LGC"														
2.1 - Normal operation with Methanol as fuel														
2.1.1 - Fuel System														
2.1.1.1 - Fuel Tank System														
Storage of methanol	covered by draft provisions for the use of methanol in the IGF Code toxicity to be considered	-	-	-	2.1.1.1-1	covered by draft provisions for the use of methanol in the IGF Code toxicity to be considered	-	-	-	Toxicity of Methanol to be considered Hazardous zone dimensioning for e.g. vent line outlets of tank safety valves are to be aligned to the characteristics and dispersion behaviour of methanol (different to Natural Gas)	-	-	-	-
2.1.1.2 - Distribution line between methanol tank and fuel preparation														
Transport of methanol from tank to fuel preparation	covered by draft provisions for the use of methanol in the IGF Code toxicity to be considered	-	-	-	2.1.1.2-1	covered by draft provisions for the use of methanol in the IGF Code toxicity to be considered	-	-	-	Toxicity of Methanol to be considered	-	-	-	-
2.1.1.3 - Fuel preparation														
Premixing with water for reforming process	wrong mixture	methanol / water mixture not matching needed content, too less or too much Hydrogen generated in downstream reforming process, detection by reformer temperature	3	failure of process water system	2.1.1.3-1	afterburner in exhaust gas line	4	2		Reformer temperature should be monitored. Shut down of primary and recirculating fuel supply should be initiated in case of reaching temperature limits.	3	4	1	
2.1.1.4 - Distribution line to fuel cell power system (liquid)														
integrity	liquid leak	leakage of liquid Methanol or Methanol / Water mixture, creation of Methanol vapor (volatil) and ignitable gas mixtures (low flashpoint between 12° - 20° depending on water content) toxidity could harm human	3	loss of integrity	2.1.1.4-1	methanol detection (liquid or vapor) Hazardous Area definition Ex-proofed equipment if applicable methanol sensor for fuel cell spaces safety requirements acc. to IGF Code Personal methanol alert for crew	3	1		Gas detection system and personal gas alert shall be capable to detect Methanol liquid and / or vapour	-	-	-	-
2.1.2 - Fuel Cell Power Installation														
2.1.2.1 - Fuel Cell Power System														
2.1.2.1.1 - Piping between fuel preparation and FC power system														
Transport of primary fuel to reforming unit	see item 2.1.1.3 "Distribution line to fuel cell power system (liquid)"	-	-	-	-	-	-	-	-	-	-	-	-	
2.1.2.1.2 - Fuel Reforming														
provide the fuel gas	no primary fuel	same as for HTFC see item 1.1.2.1.2 : no startup of fuel cell power system possible	3	failure of fuel storage and distribution system	2.1.2.1.2-1	redundancy requirements of the IGF-Code	4	1		Start-up procedure should included functional test of primary fuel supply to the reformer	3	3	1	
	loss of primary fuel	same as for HTFC see item 1.1.2.1.2: no production of electricity, no damage of the fuel cell stacks assumed, reformer temperature will rise due to missing cooling effect from fuel conversion, further damages to the reformer possible (fire hazard)	4	failure of fuel storage and distribution system	2.1.2.1.2-2	redundancy requirements of the IGF-Code	3	1		The design of the reformer unit has to withstand loss of fuel without leading to unsafe situation	3	3	1	
	wrong specification of the primary fuel	same as for HTFC see item 1.1.2.1.2: performance of the system can be influenced, no hazard assumed	2	fuel quality not checked	2.1.2.1.2-3	sampling / Bunkering note	4	1		Procedure: Fuel quality to be checked after each bunkering acc. to specification of the manufacturer the reformer system	2	3	1	

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	cate-gory	Recommended Action	Sr	Or	Dr	cate-gory
	wrong temperature of primary fuel (too low at the inlet of the reformer)	Methanol is superheated - not an issue	-	-	-	-	-	-	-	-	-	-	-	-
	wrong pressure of the primary fuel	n/a as liquid	-	-	-	-	-	-	-	-	-	-	-	-
	degradation of conversion capability	not safety related, performance issue	-	-	-	-	-	-	-	-	-	-	-	-
	loss of integrity	air getting into the reformer, high temperature (until 600 °C), self ignition of remaining gases is possible	4	mechanical damage (highly unlikely due to rack and casing, other failures not expected)	2.1.2.1.2-4		3	2		Reformer temperature should be monitored. Shut down of primary and recirculating fuel supply should be initiated in case of reaching temperature limits. The entry of oxygen in the reformer should be avoided by e.g. purging with inert gas	3	3	1	
	external leakage of the reformer	gas will be released and detected, shut down of primary fuel supply	3	mechanical damage	2.1.2.1.2-5	gas detection inside the fuel cell power system ventilation requirements acc. to IGF Code	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
integrity	liquid leak	toxicity could harm human	3	loss of integrity	2.1.2.1.2-6	methanol sensor for fuel cell spaces safety requirements acc. to IGF Code	3	1		Gas detection system and personal gas alert shall be capable to detect Methanol liquid and / or vapour	-	-	-	-
2.1.2.1.3 - Piping between reformer and fuel cell														
feed the fuel for the fuel cell	external leakage	release of fuel gas / hydrogen rich fuel to the fuel cell space, gas accumulation possible, self-ignition not expected (gas temperature too low)	3	mechanical damage	2.1.2.1.3-1	process Temperature deviation in afterburner accumulation of hydrogen shall be avoided by ventilation gas detection / fire detection ESD protected fuel cell space fire extinguishing system	3	1		Detail assessment of hydrogen rich gas release scenarios in respect to ignition and dispersion to be done	-	-	-	-
2.1.2.1.4 - HT PEM Fuel Cells Module														
Provision of electrical energy for propulsion and other consumers	wrong qualification of the fuel	same as for HTFC; see item 1.1.2.1.4: decrease of the performance of the stack, internal leakage in the exhaust gas line possible; fuel will be treated by the after burner	3	malfunction of reformer	2.1.2.1.4-1	redundancy requirements of the IGF-Code	3	2		The fuel gas specification shall be monitored, the system shall be brought into a safe state in case of reaching limiting values	3	3	1	
	external leakage	gas release out of the fuel cell into the fuel cell module installation space, no self-ignition possible (gas temperature too low)	3	mechanical damage, welding failure, untight connections	2.1.2.1.4-2	ESD protected fuel cell space Gas safe fuel cell space type approval / certification of the fuel cell	3	1		Detail assessment of hydrogen rich gas release scenarios in respect to ignition and dispersion to be done Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (reduce collision effects)	-	-	-	-
	internal leakage	same as for HTFC; see item 1.1.2.1.4: high stack temperature developing into an internal oxidation / fire, drop in voltage, shut down of related module	4	cracking of plates	2.1.2.1.4-3	temperature monitoring of the stack voltage monitoring	4	1		Amount of fuel in the fuel cell space and the corresponding consequences shall be evaluated. Safety devices are designed to handle max. credible release scenario. Combustible material in fuel cell modules are to be minimized	3	4	1	
	load jumps: not considered to cause an hazardous event, energy buffer systems installed (e.g. battery system)	same as for HTFC; see item 1.1.2.1.4: no effect	1	load changes	2.1.2.1.4-4	energy buffer system	5	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	cate-gory	Recommended Action	Sr	Or	Dr	cate-gory
	short circuit	same as for HTFC; see item 1.1.2.1.4: loss of power output, remaining fuel gases in the exhaust air not to be expected	3	electrical failure	2.1.2.1.4-5	short circuit breaker dielectric strength test acc. to 62282/3-100 provided monitoring of stack voltage shut down of fuel supply for related FC module	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	uncomplete oxidation	same as for HTFC; see item 1.1.2.1.4: hydrogen rich gas remaining in Exhaust gas, oxidation by after burner, no effect as after burner is designed to process 100% fuel in the Exhaust	2	malfunction of reformer	2.1.2.1.4-6	after burner in exhaust gas line, designed to process 100% fuel in exhaust line	4	2		The after burner should be designed to process 100% fuel in the exhaust line Exhaust gas temperature behind the afterburner should be monitored and shut down to be initiated in case of reaching limiting values	2	4	1	
	high temperature exhaust	same as for HTFC; see item 1.1.2.1.4: exhaust gas temperature will be monitored, shut down in case of reaching limiting values	3	malfunction of fuel cell	2.1.2.1.4-7	temperature monitoring of exhaust air	3	1		Exhaust gas temperature should be monitored and shut down to be initiated in case of reaching limiting values	-	-	-	-
2.1.2.1.5 - liquid cooling														
stack temperature control	loss of cooling	ramp down of the system	3	failure of cooling pump	2.1.2.1.5-1	process control incl. coolant Tem-perature and pressure safety system redundancy requirements of the IGF-Code	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	internal leakage	Methanol in coolant unlikely as higher coolant pressure	3	material or welding failure	2.1.2.1.5-2		3	3		Methanol detection for heating media of heating devices to be considered	3	3	1	
	external leakage of coolant	hazards by coolant liquid to be considered, not a fuel cell specific topic	-	-	-	-	-	-	-	-	-	-	-	-
2.1.2.1.6 - Process Air														
Provide oxygen for the FC process	same as for HTFC; see item 1.1.2.1.5: loss of process air	No or insufficient oxygen provided for the FC process, shut down of the FC power system due to undervoltage, remaining fuel will be processed by the after burner, no release of fuel out of the exhaust gas line	3	failure of ventilation fan	2.1.2.1.6-1	redundancy requirements of the IGF-Code after burner in exhaust gas line: designed to process the highest amount of fuel expected in case of a failure of the fuel cell (at least the amount of fuel at nominal fuel cell load)	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
2.1.2.1.7 - Afterburner														
use of the heat from the exhaust, burn remaining fuel in the exhaust	same as for HTFC; see item 1.1.2.1.5: no oxygen	remaining fuel is released to atmosphere (toxic, flammable) if not recirculated to the reformer, amount depending on the utilisa-tion rate of the FC at the actual load	3	failure of the ventilation system	2.1.2.1.7-1	if the presence of explosive and harmful gas concentration in the exhaust can not be excluded the exhaust shall be arranged as a ven-tilation outlet of a hazardous zone redundancy requirements of the IGF-Code	4	2		Exhaust gas temperature behind the afterburner should be monitored and shut down to be initiated in case of reaching limiting values	3	4	1	

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	cate-gory	Recommended Action	Sr	Or	Dr	cate-gory
2.1.2.1.8 - heat (energy) recovery														
FC power system internal heat recovery (fuel re-forming)	same as for HTFC see item 1.1.2.1.7: reformer pressure higher than exhaust air pressure: reformat can leak into the exhaust gas (specific arrangement)	depending on the concentration ignition possible, toxic gas and remaining fuel will be release through the exhaust gas outlet, damage of exhaust gas line not expected	3	mechanical damage	2.1.2.1.8-1	if the presence of explosive and harmful gas concentration in the exhaust can not be excluded the exhaust shall be arranged as a ven-tilation outlet of a hazardous zone	3	2		Gas detection should be provided in the exhaust gas line. Shut down of the system to be initiated in case of gas detection.	3	3	1	
	same as for HTFC see item 1.1.2.1.7: reformer pressure lower than exhaust air pressure: oxygen will leak into reformer system	see reforming system	5	mechanical damage	2.1.2.1.8-2		3	2		Exhaust gas fan to be switched of, if applicable, otherwise big amount of oxygen could be pushed into the reforming system Reformer temperature should be monitored. Shut down of primary and recirculating fuel supply should be initiated in case of reaching temperature limits. The entry of oxygen in the reformer should be avoided by e.g. purging with inert gas	4	3	1	
FC power system internal heat recovery (Process air)	same as for HTFC see item 1.1.2.1.7 release of process air in the exhaust gas line	see reforming system	-	-	-	-	-	-	-	-	-	-	-	-
external heat recovery (various designs availa-ble)	same as for HTFC see item 1.1.2.1.7: internal leakage	leakage of exhaust gas into the heating media system excluded: heating media pressure higher than exhaust gas system (open system)	1	welding failure, material damage	1.1.2.1.7-3	-	1	1		-	-	-	-	-
		leakage of heating media (gaseous or liquid) and release out of the vent mast; no hazards expected; reduced energy recovery	2	welding failure, material damage	1.1.2.1.7-4	-	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
2.1.2.1.9 - exhaust gas line (overpressure)														
transport of exhaust gas	same as for HTFC see item 1.1.2.1.8: external leakage	release of exhaust air in the fuel cell power system space, exhaust air will be ventilated	1	mechanical damage, welding failure, untight connections	2.1.2.1.9-1	ventilation requirements acc. to IGF Code	4	2		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC see item 1.1.2.1.8 external leakage of exhaust gas with flammable content	not further considered, only in case of two failures (malfunction of the burner) flam-mable and toxic gas can enter the exhaust trunk	3	mechanical damage, welding failure, untight connections	2.1.2.1.9-2	ventilation requirements acc. to IGF Code gas detection after burner	2	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
2.1.2.2 - electrical power output conditioning														
Conditioning of electrical output of the FC power system for on-board net integration; Protection of Fuel Cell Power System against reverse power; Galvanic isolation from the grid	same as for HTFC see item 1.1.2.2 short circuit (input side)	same as for HTFC see item 1.1.2.2	3	same as for HTFC see item 1.1.2.2	2.1.2.2-1	same as for HTFC see item 1.1.2.2	4	1		same as for HTFC see item 1.1.2.2	-	-	-	-
	same as for HTFC see item 1.1.2.2 short circuit (internal)	same as for HTFC see item 1.1.2.2	4	same as for HTFC see item 1.1.2.2	2.1.2.2-2	same as for HTFC see item 1.1.2.2	3	1		Consideration to be given to electrical reverse power	3	3	1	
	same as for HTFC see item 1.1.2.2 short circuit (output side)	same as for HTFC see item 1.1.2.2	3	same as for HTFC see item 1.1.2.2	2.1.2.2-3	same as for HTFC see item 1.1.2.2	3	1		same as for HTFC see item 1.1.2.2	-	-	-	-
	same as for HTFC see item 1.1.2.2 wrong conversion, e.g. faulty frequency	same as for HTFC see item 1.1.2.2	4	same as for HTFC see item 1.1.2.2	2.1.2.2-4	same as for HTFC see item 1.1.2.2	3	1		decentralised grids are to be designed for load fluctuations	-	-	-	-
Protection of Fuel Cell Power System against reverse power	same as for HTFC see item 1.1.2.2: covered in above	-	-	-	-	-	-	-	-	-	-	-	-	-
Galvanic isolation from the grid	same as for HTFC see item 1.1.2.2: covered in above	-	-	-	-	-	-	-	-	-	-	-	-	-

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	cate-gory	Recommended Action	Sr	Or	Dr	cate-gory
2.1.2.3 - Net integration														
Providing required electrical power from FC power system to the electrical board net	same as for HTFC, see item 1.1.2.3: overproduction / underproduction	same as for HTFC, see item 1.1.2.3:	1	same as for HTFC, see item 1.1.2.3:	2.1.2.3-1	same as for HTFC, see item 1.1.2.3:	5	1		same as for HTFC, see item 1.1.2.3:	-	-	-	-
	same as for HTFC, see item 1.1.2.3: too slow reaction to high load fluctuation	will be covered by redundancies in buffer system (design)	1	failure in buffer system	2.1.2.3-2	buffer system design to cope with slow power dynamics PMS buffer system design requires sufficient redundancies -> to be investigated	5	1		Redundancy requirements for buffer system to be investigated	1	3	1	
	same as for HTFC, see item 1.1.2.3 electrical load sharing failures in decentralized grid	Reverse power from the grid	3	failure of power management system	2.1.2.3-3	Power management system	4	1		Consideration to be given to electrical reveres power	3	3	1	
2.1.2.4 - Fuel Cell control system														
process control	same as for HTFC; see item 1.1.2.4: General	The Fuel Cell control system shall be designed in a way, that the fuel cell power system will be automatically set in a safe state in case of an unsafe situation	-	-	2.1.2.4-1	The Fuel Cell control system shall be designed in a way, that the fuel cell power system will be automatically set in a safe state in case of an unsafe situation	-	-	-	The Fuel Cell control system shall be designed in a way, that the fuel cell power system will be automatically set in a safe state in case of an unsafe situation	-	-	-	-
	same as for HTFC; see item 1.1.2.4: external communication failure with ship automation	temporary over- or underproduction; following the net	3	loss of communication link to ship automation	2.1.2.4-2	FC system has internal process control (follow the net) (system must maintain safe state or bring itself into a safe state) no-communication alarm	4	1		develop re-connection procedure to reconnect to the ship automation	3	3	1	
	same as for HTFC; see item 1.1.2.4 mismatch of fuel, water and energy production	overrun of safety relevant parameter limits, safety control system takes over, hard shut down will be initiated	3	e.g. internal communication failure or sensor failure	2.1.2.4-2	certified safety system shut down of the system to a safe state	3	1		the safe state of the fuel cell power installation has to be defined for all possible modes of shut down	-	-	-	-
	same as for HTFC; see item 1.1.2.4 loss of control system	overrun of safety relevant parameter limits, safety control system takes over, hard shut down will be initiated	3	e.g. internal communication failure or sensor failure	2.1.2.4-3	certified safety system shut down of the system to a safe state	3	1		the safe state of the fuel cell power installation has to be defined for all possible modes of shut down	-	-	-	-
2.1.2.5 - Fuel Cell safety control system														
Control of Fuel Cell safety system	same as for HTFC; see item 1.1.2.6: General	safety control system required acc. to IGF Code and established rules and regulations	-	-	2.1.2.5-1	safety control system required acc. to IGF Code and established rules and regulations	-	-	-	Safety control system required acc. to IGF Code and established rules and regulations	-	-	-	-
2.1.3 - Ventilation system for ESD protected fuel cell spaces														
Transport of possible leaking gases out of the ESD protected fuel cell space to a safe location	same as for HTFC; see item 1.1.3: failure of ventilation	loss of one safety barrier, controlled shut down initiated: complete loss of ventilation not expected due to redundancy requirements	3	electrical failure, mechanical damage	2.1.3-1	monitor functioning of ventilation system redundancy requirements of the IGF-Code	2	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
2.1.4 - Ventilation system for gas safe fuel cell spaces														
no requirements on ventilation of gas safe fuel cell space but for the gas interbarrier space	same as for HTFC; see item 1.1.4: loss of ventilation	loss of one safety barrier, controlled shut down initiated: complete loss of ventilation not expected due to redundancy requirements	3	electrical failure, mechanical damage	2.1.4-1	gas interbarrier space needs to be monitored redundancy requirements of the IGF-Code	2	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
2.1.5 - Onboard energy buffer														
Backup power in case of shut down of the whole fuel cell power plant	same as for HTFC; see item 1.1.5: Loss of fuel cell power output	same as for HTFC see item 1.1.5	3	same as for HTFC see item 1.1.5	2.1.5-1	same as for HTFC see item 1.1.5	3	1		Redundancy requirements for buffer system to be investigated	-	-	-	
	same as for HTFC; see item 1.1.5: thermal runaway, fire	same as for HTFC see item 1.1.5	4	same as for HTFC see item 1.1.5	2.1.5-2	same as for HTFC see item 1.1.5	3	1		Functional safety requirements for battery installation to be considered as e.g. defined in DNV GL guideline for large maritime battery systems	3	3	1	
Accommodate for load fluctuations	see net integration failure ID 1.1.2.3-2	-	-	-	-	-	-	-	-	-	-	-	-	-
Active purging system - not applicable for this technology														

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	category	Recommended Action	Sr	Or	Dr	category
2.1.6 - Inertgas system														
Inerting of FC Power System	same as for HTFC; see item 1.1.6: no inert gas	same as for HTFC see item 1.1.6:	4	same as for HTFC see item 1.1.6:	2.1.6-1	same as for HTFC see item 1.1.6:	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
2.1.7 - External events														
External events acting on the Fuel and / or Fuel Cell Power Installation	same as for HTFC; see item 1.1.7: Fire in FC power installation place	fire will be contained in space (active and passive fire protection), automatic shut down of fuel cell by safety system and shut down of fuel system to affected space	3	fuel self ignition, reverse power	2.1.7-1	active and passive fire protection systems acc. to IGF Code requirements safety system with ESD function	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: black-out	FC system designed to be fail safe; black-out recovery will be considered in ship design	3	e.g. electrical net failure	2.1.7-2	Black-out recovery	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: **LGC specific:** ESD of cargo system	ESD during cargo transfer, loss of fuel if fuel used from the cargo for auxiliary power supply by FC during port stay	3	e.g. activation of ERC jetty	2.1.7-3	Separation of ESD system of primary fuel and cargo system	4	1		-	-	-	-	-
	same as for HTFC; see item 1.1.7: flooding	short circuits (nothing specific to FC technology), FC system will be shut down by the safety system, electrical power supply by other power system (redundancy)	3	e.g. collision	2.1.7-4	same requirements than for conventional engine spaces redundancy requirements of the IGF-Code decentralised power supply	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: blockage of exhaust	loss of performance and shut down of fuel cells due to deviation of process parameters	3	blockage of exhaust pipe	2.1.7-5	T monitoring of after burner monitoring of fuel cell process parameter	3	1		Exhaust gas outlet shall be designed in a way, that blockage by e. g. particles is avoided.	-	-	-	-
	same as for HTFC; see item 1.1.7: out of range ambient T (low T)	freezing at out of range T could cause damage - no safety relevant failures expected	-	-	-	-	-	-	-	-	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire in Tank hold space: containment issue not directly fuel cell related	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire in adjacent rooms to tank hold space	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire in fuel preparation room	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire adjacent to fuel preparation room	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire in the vicinity of distribution line (LNG)	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire in the vicinity of distribution line (NG)	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: **RoPax specific:** Fire on car deck or open deck structural fire protection acc. to SOLAS and IGF	Covered by requirements of the IGF Code	-	-	2.1.7-6	Fuel piping routed through the RoRo deck must be protected against possible fire	-	-	-	Fuel piping routed through the RoRo deck must be protected against possible fire	-	-	-	-
	same as for HTFC; see item 1.1.7: Ship / Ship collision	Damage of outer shell, damage of adjacent systems possible	3	human error	2.1.7-7	distance requirements for fuel piping shall be also applied to fuel cell stacks	3	1		Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (reduce collision effects)	-	-	-	-

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	cate-gory	Recommended Action	Sr	Or	Dr	cate-gory
	same as for HTFC; see item 1.1.7: Shore / Ship collision	Damage of outer shell, damage of adjacent systems possible	3	human error	2.1.7-8	distance requirements for fuel piping shall be also applied to fuel cell stacks	3	1		Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (reduce collision effects)	-	-	-	-
	same as for HTFC; see item 1.1.7: RoPax specific: vehicle crash	Damage of shell, damage of adjacent systems possible	4	human error	2.1.7-9		3	1		Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (reduce collision effects) Shells of space facing the car deck where parts of the Fuel Cell Power Installation and related fuel storage, distribution and storage systems are installed must be protected against possible impact of vehicles or cargo Fuel piping routed through the RoRo deck must be protected against possible impacts by vehicles or cargo	3	3	1	
2.2 - Bunkering LNG, NG														
Transport of LNG or NG in liquid or compressed form from a bunker source to the ships	IGF Code requirements for bunker station locations and hazardous zone definition to be considered. Additional functional requirements for bunkering LNG or NG are ISO TS 18683 and DNV GL recommended practice, for this study an analysis for bunkering Hydrogen as fuel will be done	-	-	-	2.2-1	IGF Code requirements for bunker station locations and hazardous zone definition to be considered. Additional functional requirements for bunkering LNG or NG are ISO TS 18683 and DNV GL recommended practice, for this study an analysis for bunkering Hydrogen as fuel will be done	-	-	-	Hazardous Areas, safety and security zones are to be aligned according to the behaviour and dispersion characteristics of Methanol (different to Natural Gas) Toxicity of Methanol to be considered **For RoPax vessels** special attention to possible impact on Passengers and vehicle traffic during bunkering shall be payed. Safety and security zones are to be established. Most credible release scenarios are to be analysed according to possible influence on passengers, crew and ship; especially for this ship type influences on balconies, cabins, open passenger decks, open roro-and cargo decks, passenger bridges as well as passenger ways and vehicle routes on terminal side shall be taken into account. **For LGC** special attention shall be payed to the primary fuel if it is different from the cargo. In this case additional means for bunkering the primary fuels are necessary which differ from the normal cargo transfer. Additional gas detection systems, safety and security zones (e.g. in case of truck to Ship bunkering), training and instruction may be necessary	-	-	-	-
					58	with failure ID								
					16	without failure ID								
					74	Total								
					23	from 74 not ranked (with and without ID)								
					51	from 74 ranked								

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	category	Recommended Action	Sr	Or	Dr	category
3 - Scenario "Low Temperature PEM Fuel Cell (LT PEMFC) on-board RoPax ferry and LGC"														
3.1 - Normal operation with Methanol as fuel														
3.1.1 - Fuel System														
3.1.1.1 - Fuel Tank System														
Storage of Liquefied Hydrogen (vacuum insulated type C-tank assumed, proper design of the tank supports assumed)	loss of integrity (inner tank)	Release of Hydrogen to the interbarrier space of the tank, loss of vacuum, increase of boil off, venting possible	3	material, welding failure	3.1.1.1-1	vacuum monitoring same design parameters for the inner and outer shell of the fuel containment system shall be considered pressure relief device for interbarrier space	3	1		consideration to be given to diffusion effects / embrittlement of hydrogen through materials	-	-	-	-
	loss of integrity	release of hydrogen to the hold space of the tank, fire and explosion possible	5	Collision (including collision with vehicles on-board)	3.1.1.1-2	reinforced ship structure collision protection with respect to vehicle operation on-board	2	1		distance between tank and ship side has to be clarified to reach the same safety level as a conventional fuelled vessel / LNG fuelled vessel detail assessment of hydrogen release scenarios in respect to ignition, dispersion to be done storage of hydrogen tanks below accommodation should be evaluated location of tank should be evaluated with respect to collision probability	-	-	-	-
	overpressure in tank	release of hydrogen out of the vent mast	3	mechanical damage	3.1.1.1-3	tank safety valves	4	1		Hazardous area definition and vent mast outlet distances to be analysed due to the behaviour and dispersion characteristics of hydrogen (low and high-pressure release)	-	-	-	-
Storage of compressed Hydrogen	rupture of the tank / fuel containment system	damage of the ship structure possible	5	mechanical damage	3.1.1.1-4	suitable pressure relief system for the hold space of the tank, cp. IGF-Code 6.7.11	2	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
3.1.1.2 - Distribution line between LH2 tank and fuel preparation (liquid)														
Transport of LH2 from tank to fuel preparation (cold box principle assumed)	External leakage	Leakage into the cold box, gas detection and shut down of the system	3	material, welding failure	3.1.1.2-1	redundancy requirements of the IGF Code liquid piping as short as possible secondary barrier principle (cold box design)	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
3.1.1.3 - Fuel preparation (Liquefied Hydrogen)														
vaporize to Hydrogen, supply of fuel with the needed temperature and pressure (cold box principle assumed, no liquid lines through the vessel)	leakage into the cold box	release of liquid hydrogen into the col box	3	material or welding failure	3.1.1.3-1	materials for the cold box shall be suitable to withstand pressure and cryogenic effects of liquid hydrogen gas detection systems temperature detection creation of ignitable mixtures will be avoid by ventilation or inerting the cold box automatically operated main tank valve	3	1		Consideration shall be given to the different properties of Hydrogen in comparison to LNG in respect to ignition and dispersion mechanism Consideration shall be given to possible ventilation or inerting of the cold box in case of leakage into space not normally to be entered (due to the behaviour of hydrogen)	-	-	-	-
	failure of conditioning system	Fuel conditions deviate from specification needed	3	failure of heating media supply	3.1.1.3-2	evaporator shall be designed suitable for hydrogen application Temperature detection and shut down when reaching defined limits cell voltage monitoring	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	Internal leakages of heating device	Hydrogen entering in the heating media, gas detection and shut down of the system	3	material, welding failure	3.1.1.3-3	hydrogen sensor to be installed in heating media dispension vessel	3	1		consideration shall be given to the different properties of Hydrogen in comparison to LNG in respect to lower temperature diffusion of hydrogen shall be considered according to ISO 15916, chapter 4.1.3.3	-	-	-	-

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	category	Recommended Action	Sr	Or	Dr	category
3.1.1.4 - Distribution line between H2 tank and fuel preparation (gaseous)														
Transportation of gaseous Hydrogen from tank to fuel preparation (secondary barrier principal)	External leakage	leakage of hydrogen in the secondary barrier space, gas detection and shut down of the system, hydrogen will be ventilated in a safe location	3	material or welding failure	3.1.1.4-1	secondary barrier principle hydrogen pipes between tank and fuel preparation design as short as possible redundancy requirements of the IGF Code	3	1		Consideration shall be given to possible ventilation or inerting of the secondary barrier space in case of leakage into space not normally to be entered (due to the behaviour of hydrogen) diffusion of hydrogen shall be considered according to ISO 15916, chapter 4.1.3.3	-	-	-	-
3.1.1.5 - Fuel preparation (gaseous)														
Reduction of hydrogen pressure	no or unsufficient pressure reduction	possible damage of downstream components to be considered	4	failure of gas pressure reducer	3.1.1.5-1	pressure relief device to be installed to protect systems in case of failure of the pressure reducer	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
Heating of hydrogen	see internal leakage of heating device failure ID '3.1.1.3-3	-	-	-	-	-	-	-	-	-	-	-	-	-
3.1.1.6 - Distribution line to fuel cell power system (primary fuel, gaseous)														
Transportation of gaseous Hydrogen as fuel	External leakage	see distribution line between H2 tank and fuel preparation (gaseous), failure ID 3.1.1.4-1	-	-	-	-	-	-	-	-	-	-	-	-
3.1.2 - Fuel Cell Power Installation														
3.1.2.1 - Fuel Cell Power System														
3.1.2.1.1 - Fuel Reforming														
not applicable for this technology														
3.1.2.1.2 - LT Fuel Cell FC Module														
Provision of electrical energy for propulsion and other consumers	wrong qualification of the fuel	unlikely: pure hydrogen as fuel	-	-	-	-	-	-	-	-	-	-	-	-
	external leakage	same as for HTFC, see Failure ID 1.1.2.1.4-2	4	same as for HTFC, see Failure ID 1.1.2.1.4-2	3.1.2.1.2-1	same as for HTFC, see Failure ID 1.1.2.1.4-2	3	1		Detail assessment of hydrogen rich gas release scenarios in respect to (self-) ignition and dispersion to be done Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (reduce collision effects)	3	3	1	
	internal leakage	same as for HTFC, see Failure ID 1.1.2.1.4-3	4	same as for HTFC, see Failure ID 1.1.2.1.4-3	3.1.2.1.2.-2	same as for HTFC, see Failure ID 1.1.2.1.4-3	4	1		amount of fuel in the fuel cell space and the corresponding consequences shall be evaluated. Safety devices are designed to handle max. credible release scenario. Combustible material in fuel cell modules are to be minimized	3	4	1	
	load jumps: not considered to cause an hazardous event, energy buffer systems installed (e.g. battery system)	same as for HTFC, see Failure ID 1.1.2.1.4-4	1	same as for HTFC, see Failure ID 1.1.2.1.4-4	3.1.2.1.2-3	same as for HTFC, see Failure ID 1.1.2.1.4-4	5	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	short circuit	same as for HTFC, see Failure ID 1.1.2.1.4-5	3	same as for HTFC, see Failure ID 1.1.2.1.4-5	3.1.2.1.2-4	same as for HTFC, see Failure ID 1.1.2.1.4-5	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	uncomplete oxidation	same as for HTFC, see Failure ID 1.1.2.1.4-6	2	same as for HTFC, see Failure ID 1.1.2.1.4-6	3.1.2.1.2-5	same as for HTFC, see Failure ID 1.1.2.1.4-6	4	2		The after burner should be designed to process 100% fuel in the exhaust line Exhaust gas temperature behind the afterburner should be monitored and shut down to be initiated in case of reaching limiting values	2	4	1	
	high temperature exhaust	not applicable	-	-	-	-	-	-	-	-	-	-	-	-
3.1.2.1.3 - Process Air														
Provide oxygen for the FC process	Loss of Process Air	same as for HTFC, see failure ID 1.1.2.1.5-1	3	same as for HTFC, see failure ID 1.1.2.1.5-1	3.1.2.1.3-1	same as for HTFC, see failure ID 1.1.2.1.5-1	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	category	Recommended Action	Sr	Or	Dr	category
3.1.2.1.4 - Afterburner														
use of the heat from the exhaust, burn remaining fuel in the exhaust	no oxygen	same as for HTFC, see failure ID 1.1.2.1.6-1	3	same as for HTFC, see failure ID 1.1.2.1.6-1	3.1.2.1.4-1	same as for HTFC, see failure ID 1.1.2.1.6-1	4	2		Exhaust gas temperature behind the afterburner should be monitored and shut down to be initiated in case of reaching limiting values	3	4	1	
	mechanical damage	see external leakage for piping and fuel cell	-	-	-	-	-	-	-	-	-	-	-	-
	more than 100 % fuel (excluded at least 2 failures have to occur)	-	-	-	-	-	-	-	-	-	-	-	-	-
3.1.2.1.5 - heat (energy) recovery - not applicable due to low temperature														
3.1.2.1.6 - exhaust gas line (overpressure)														
transport of exhaust gas	external leakage	same as for HTFC, see failure ID 1.1.2.1.8-1	1	same as for HTFC, see failure ID 1.1.2.1.8-1	3.1.2.1.6-1	same as for HTFC, see failure ID 1.1.2.1.8-1	4	2		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	external leakage of exhaust gas with flammable content	same as for HTFC, see failure ID 1.1.2.1.8-2	3	same as for HTFC, see failure ID 1.1.2.1.8-2	3.1.2.1.6-2	same as for HTFC, see failure ID 1.1.2.1.8-2	2	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
3.1.2.2 - electrical power output conditioning - same as for HTFC														
Conditioning of electrical output of the FC power system for onboard net integration; Protection of Fuel Cell Power System against reverse power; Galvanic isolation from the grid	same as for HTFC see item 1.1.2.2 Short circuit (input side)	same as for HTFC see item 1.1.2.2	3	same as for HTFC see item 1.1.2.2	3.1.2.2-1	same as for HTFC see item 1.1.2.2	4	1		same as for HTFC see item 1.1.2.2	-	-	-	-
	same as for HTFC see item 1.1.2.2 Short circuit (internal)	same as for HTFC see item 1.1.2.2	4	same as for HTFC see item 1.1.2.2	3.1.2.2-2	same as for HTFC see item 1.1.2.2	3	1		Consideration to be given to electrical reverse power	3	3	1	
	same as for HTFC see item 1.1.2.2 Short circuit (output side)	same as for HTFC see item 1.1.2.2	3	same as for HTFC see item 1.1.2.2	3.1.2.2-3	same as for HTFC see item 1.1.2.2	3	1		same as for HTFC see item 1.1.2.2	-	-	-	-
	same as for HTFC see item 1.1.2.2 wrong conversion, e.g. faulty frequency	same as for HTFC see item 1.1.2.2	4	same as for HTFC see item 1.1.2.2	3.1.2.2-4	same as for HTFC see item 1.1.2.2	3	1		decentralised grids are to be designed for load fluctua-tions	-	-	-	-
Protection of Fuel Cell Power System against reverse power	same as for HTFC see item 1.1.2.2: covered in above	-	-	-	-	-	-	-	-	-	-	-	-	-
Galvanic isolation from the grid	same as for HTFC see item 1.1.2.2: covered in above	-	-	-	-	-	-	-	-	-	-	-	-	-
3.1.2.3 - Net integration - same as for HTFC														
Providing required electrical power from FC power system to the electrical board net	same as for HTFC, see item 1.1.2.3: overproduction / underproduc-tion	same as for HTFC, see item 1.1.2.3:	1	same as for HTFC, see item 1.1.2.3:	3.1.2.3-1	same as for HTFC, see item 1.1.2.3:	5	1		same as for HTFC, see item 1.1.2.3:	-	-	-	-
	same as for HTFC, see item 1.1.2.3: too slow reaction to high load fluctuation	will be covered by redundancies in buffer system (design)	1	failure in buffer system	3.1.2.3-2	buffer system design to cope with slow power dynamics PMS buffer system design requires sufficient redundancies -> to be investigated	5	1		Redundancy requirements for buffer system to be inves-tigated	1	3	1	
	same as for HTFC, see item 1.1.2.3 electrical load sharing failures in decentralized grid	Reverse power from the grid	3	failure of power management system	3.1.2.3-3	Power management system	4	1		Consideration to be given to electrical reveres power	3	3	1	

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	category	Recommended Action	Sr	Or	Dr	category
3.1.2.4 - Fuel Cell control system - same as for HTFC														
process control	same as for HTFC; see item 1.1.2.4: General	The Fuel Cell control system shall be designed in a way, that the fuel cell power system will be automatically set in a safe state in case of an unsafe situation	-	-	3.1.2.4-1	The Fuel Cell control system shall be designed in a way, that the fuel cell power system will be automatically set in a safe state in case of an unsafe situation	-	-	-	The Fuel Cell control system shall be designed in a way, that the fuel cell power system will be automatically set in a safe state in case of an unsafe situation	-	-	-	-
	same as for HTFC; see item 1.1.2.4: external communication failure with ship automation	temporary over- or underproduction; following the net	3	loss of communi-cation link to ship automation	3.1.2.4-2	FC system has internal process control (follow the net) (system must maintain safe state or bring itself into a safe state) no-communication alarm	4	1		develop re-connection procedure to reconnect to the ship automation	3	3	1	
	same as for HTFC; see item 1.1.2.4 loss of control system	overrun of safety relevant parameter limits, safe-ty control system takes over, hard shut down will be initiated	3	e.g. internal com-munication failure or sensor failure	3.1.2.4-3	certified safety system shut down of the system to a safe state	3	1		the safe state of the fuel cell power installation has to be defined for all possible modes of shut down	-	-	-	-
3.1.2.5 - Fuel Cell safety control system - same as for HTFC														
Control of Fuel Cell safe-ty system	same as for HTFC; see item 1.1.2.6: General	safety control system required acc. to IGF Code and established rules and regulations	-	-	3.1.2.5-1	safety control system required acc. to IGF Code and established rules and regulations	-	-	-	Safety control system required acc. to IGF Code and established rules and regulations	-	-	-	-
3.1.3 - Ventilation system for ESD protected fuel cell spaces - same as for HTFC														
Transport of possible leaking gases out of the ESD protected fuel cell space to a safe location	same as for HTFC; see item 1.1.3: failure of ventilation	loss of one safety barrier, controlled shut down initiated: complete loss of ventilation not ex-pected due to redundancy requirements	3	electrical failure, me-chanical damage	3.1.3-1	monitor functioning of ventilation system redundancy requirements of the IGF-Code	2	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
3.1.4 - Ventilation system for gas safe fuel cell spaces - same as for HTFC														
no requirements on ven-tilation of gas safe fuel cell space but for the gas interbarrier space	same as for HTFC; see item 1.1.4: loss of ventilation	loss of one safety barrier, controlled shut down initiated: complete loss of ventilation not ex-pected due to redundancy requirements	3	electrical failure, me-chanical damage	3.1.4-1	gas interbarrier space needs to be moni-tored redundancy requirements of the IGF-Code	2	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
3.1.5 - On-board energy buffer - same as for HTFC														
Backup power in case of shut down of the whole fuel cell power plant	same as for HTFC; see item 1.1.5: Loss of fuel cell power output	same as for HTFC see item 1.1.5	3	same as for HTFC see item 1.1.5	3.1.5-1	same as for HTFC see item 1.1.5	3	1		Redundancy requirements for buffer system to be inves-tigated	-	-	-	
	same as for HTFC; see item 1.1.5: Thermal runaway, fire	same as for HTFC see item 1.1.5	4	same as for HTFC see item 1.1.5	3.1.5-2	same as for HTFC see item 1.1.5	3	1		Functional safety requirements for battery installation to be considered as e.g. defined in DNV GL guideline for large maritime battery systems	3	3	1	
Accommodate for load fluctuations	see net integration failure ID 1.1.2.3-2	-	-	-	-	-	-	-	-	-	-	-	-	-
3.1.6 - active purging system and inertgas system														
active for removal of liquid water from Anode side of the FC	blockage of purging line before FC	purging not possible (performance issue)	3	failure of purgin system	3.1.6-1		3	1		Second purge connection for manual operated purging to be provided in case of failure of the active purging system	-	-	-	-
	blockage of purging line (after FC)	purging not possible (performance issue)	3	failure of purgin system	3.1.6-2		3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.6: release of H2	same as for HTFC see item 1.1.6:	-	same as for HTFC see item 1.1.6:	3.1.6-3	same as for HTFC see item 1.1.6:	-	-		-	-	-	-	-
Inerting of FC Power System	same as for HTFC; see item 1.1.6: no inert gas	same as for HTFC see item 1.1.6:	4	same as for HTFC see item 1.1.6:	3.1.6-4	same as for HTFC see item 1.1.6:	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	category	Recommended Action	Sr	Or	Dr	category
3.1.7 - External events - same as for HTFC														
External events acting on the Fuel and / or Fuel Cell Power Installation	same as for HTFC; see item 1.1.7: Fire in FC power installation place	fire will be contained in space (active and passive fire protection), automatic shut down of fuel cell by safety system and shut down of fuel system to affected space	3	fuel self ignition, reverse power	3.1.7-1	active and passive fire protection systems acc. to IGF Code requirements safety system with ESD function	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: black-out	FC system designed to be fail safe; black-out recovery will be considered in ship design	3	e.g. electrical net failure	3.1.7-2	Black-out recovery	4	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: **LGC specific:** ESD of cargo system	ESD during cargo transfer, loss of fuel if fuel used from the cargo for auxiliary power supply by FC during port stay	3	e.g. activation of ERC jetty	3.1.7-3	Separation of ESD system of primary fuel and cargo system	4	1		-	-	-	-	-
	same as for HTFC; see item 1.1.7: flooding	short circuits (nothing specific to FC technology), FC system will be shut down by the safety system, electrical power supply by other power system (redundancy)	3	e.g. collision	3.1.7-4	same requirements than for conventional engine spaces redundancy requirements of the IGF-Code decentralised power supply	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: blockage of exhaust	loss of performance and shut down of fuel cells due to deviation of process parameters	3	blockage of exhaust pipe	3.1.7-5	T monitoring of after burner monitoring of fuel cell process parameter	3	1		Exhaust gas outlet shall be designed in a way, that blockage by e.g. particles is avoided.	-	-	-	-
	same as for HTFC; see item 1.1.7: out of range ambient T (low T)	freezing at out of range T could cause damage - no safety relevant failures expected	-	-	-	-	-	-	-	-	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire in Tank hold space: containment issue not directly fuel cell related	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire in adjacent rooms to tank hold space	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire in fuel preparation room	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire adjacent to fuel preparation room	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire in the vicinity of distribution line (LNG)	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: Fire in the vicinity of distribution line (NG)	Covered by requirements of the IGF Code	-	-	-	-	-	-	-	No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	same as for HTFC; see item 1.1.7: **RoPax specific:** Fire on car deck or open deck structural fire protection acc. to SOLAS and IGF	Covered by requirements of the IGF Code	-	-	3.1.7-6	Fuel piping routed through the RoRo deck must be protected against possible fire	-	-	-	Fuel piping routed through the RoRo deck must be protected against possible fire	-	-	-	-
	same as for HTFC; see item 1.1.7: Ship / Ship collision	Damage of outer shell, damage of adjacent systems possible	3	human error	3.1.7-7	distance requirements for fuel piping shall be also applied to fuel cell stacks	3	1		Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (reduce collision effects)	-	-	-	-
	same as for HTFC; see item 1.1.7: Shore / Ship collision	Damage of outer shell, damage of adjacent systems possible	3	human error	3.1.7-8	distance requirements for fuel piping shall be also applied to fuel cell stacks	3	1		Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (reduce collision effects)	-	-	-	-

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	category	Recommended Action	Sr	Or	Dr	category
	same as for HTFC; see item 1.1.7: **RoPax specific:** vehicle crash	Damage of shell, damage of adjacent systems possible	4	human error	3.1.7-9		3	1		Distance requirements to the outer shell for fuel piping shall be also applied to fuel cell stacks (reduce collision effects) Shells of space facing the car deck where parts of the Fuel Cell Power Installation and related fuel storage, distribution and storage systems are installed must be protected against possible impact of vehicles or cargo Fuel piping routed through the RoRo deck must be protected against possible impacts by vehicles or cargo	3	3	1	
	blockage of vent mast outlet (by weather conditions)	rain water entering the vent mast, icing possible, no (or limited) venting possible	3	e.g. rain	3.1.7-10	rain cap and water drainage system for the vent mast	3	1		The vent mast outlet shall be designed in a way, that blockage by particles and entering rainwater is avoided. In case of high pressure release these design solutions must still **ensure an upturned release** out of the vent mast outlet	-	-	-	-
3.2 - Bunkering LH2														
Transport of LNG or NG in liquid or compressed form from a bunker source to the ships	Delivery pressure to high	High pressure detection and shut down of the bunker line on-board of the vessel, shut down of supply pump	3	supply pump failure of bunker source (ship, truck, shore)	3.2-1	bunker line inlet pressure monitoring shut off valves in bunker line communication link between bunker source and receiving vessel to be provided	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	External leakage at bunker source	gas detection and shut down of the bunker process	5	material or welding failure, untight connections	3.2-2	communication link between bunker source and receiving vessel to be provided	3	1		Hazardous Areas, safety and security zones are to be established and aligned according to the behaviour, dispersion and ignition characteristics / mechanism of Hydrogen (different to Natural Gas) **For RoPax vessels** special attention to possible impact on Passengers and vehicle traffic during bunkering shall be payed. Safety and security zones are to be established. Most credible release scenarios are to be analysed according to possible influence on passengers, crew and ship; especially for this ship type influences on balconies, cabins, open passenger decks, open roro-and cargo decks, passenger bridges as well as passenger ways and vehicle routes on terminal side shall be taken into account. **For LGC** special attention shall be payed to the primary fuel if it is different from the cargo. In this case additional means for bunkering the primary fuels are necessary which differ from the normal cargo transfer. Additional gas detection systems, safety and security zones (e.g. in case of truck to Ship bunkering), training and instruction may be necessary	4	3	1	-
	External leakage at transfer system	Release of Hydrogen out of the transfer system, detection by loss of supply pressure, shut down of the bunker process	5	material or welding failure, untight connections	3.2-3	surroundings of the bunker station shall be designed for the max. credible leakage scenario Hazardous zones are to be defined acc. to IEC 60079 Safety and security zones are to be established around the whole bunker arrangement (compare ISO TS 18683 and DNV GL recommended practice) Measures are to be provided to avoid cryogenic effects due to spraying LH2 bunker line inlet pressure monitoring	3	1		Hazardous Areas, safety and security zones are to be established and aligned according to the behaviour, dispersion and ignition characteristics / mechanism of Hydrogen (different to Natural Gas) **For RoPax vessels** special attention to possible impact on Passengers and vehicle traffic during bunkering shall be payed. Safety and security zones are to be established. Most credible release scenarios are to be analysed according to possible influence on passengers, crew and ship; especially for this ship type influences on balconies, cabins, open passenger decks, open roro-and cargo decks, passenger bridges as well as passenger ways and vehicle routes on terminal side shall be taken into account. **For LGC** special attention shall be payed to the primary fuel if it is different from the cargo. In this case additional means for bunkering the primary fuels are necessary which differ from the normal cargo transfer. Additional gas detection systems, safety and security zones (e.g. in case of truck to Ship bunkering), training and instruction may be necessary	4	3	1	

Function	Failure	Effect	Si	Cause	Failure ID	Control	Oi	Di	category	Recommended Action	Sr	Or	Dr	category
	External leakage in bunker station	Leakage of LH2 into the bunker station	5	material or welding failure, untight connections	3.2-4	Measures are to be provided to avoid cryogenic effects due to spraying LH2 bunker line inlet pressure monitoring Ensure sufficient ventilation to dilute possible explosive gas clouds	3	1		Hazardous Areas, safety and security zones are to be established and aligned according to the behaviour, dispersion and ignition characteristics / mechanism of Hydrogen (different to Natural Gas) **For RoPax vessels** special attention to possible impact on Passengers and vehicle traffic during bunkering shall be payed. Safety and security zones are to be established. Most credible release scenarios are to be analysed according to possible influence on passengers, crew and ship; especially for this ship type influences on balconies, cabins, open passenger decks, open roro-and cargo decks, passenger bridges as well as passenger ways and vehicle routes on terminal side shall be taken into account. **For LGC** special attention shall be payed to the primary fuel if it is different from the cargo. In this case additional means for bunkering the primary fuels are necessary which differ from the normal cargo transfer. Additional gas detection systems, safety and security zones (e.g. in case of truck to Ship bunkering), training and instruction may be necessary	4	3	1	
	Blackout	automatic shut down of the bunker process	3	failure in ship grid	3.2-5	Valves are fail safe closed communication link between bunker source and receiving vessel to be provided	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
	excessive tensile forces acting on transfer system	stretching of transfer system, activation of Emergency release coupling, activation of ESD	3	wind loads acting on the ship	3.2-6	Means are to be provided that the bunker source holds its position during transfer Dry break coupling with ESD function	3	1		No further recommended actions related to Fuel Cell applications identified	-	-	-	-
					53	with failure ID								
					16	without failure ID								
					69	Total								
					20	from 69 not ranked (with and without ID)								
					49	from 74 ranked								