HORIZON EUROPE PROGRAM
Topic HORIZON–JTI–CLEANH2–2024–04–01

GA No. 101192169

RESCUE

Reliable and Efficient Dual Fuel System for Civil Protection during Natural Disasters using HT–PEM Technology

RESCUE

Deliverable report

D2.1 – Safety Management

Clean Hydrogen Partnership
Co-funded by the European Union

WP	2	System Requirements
Deliverable No.	D2.1	Safety Management

Dissemination level	PU	**Due delivery date**	December 2025
Deliverable Type	Safety Plan	**Actual delivery date**	December 31st, 2025

Lead beneficiary	(ProAct Consultants)
Contributing beneficiaries	all

Document history

DATE	VERSION	CHANGES MADE / REASON FOR THIS ISSUE	AUTHOR / PARTNER
01/12/2025	0.1	Cabinet design	ProAct Consultants
06/01/2026	0.2	Minor changes	ProAct Consultants

Dissemination level: PU = Public, SEN= Sensitive, limited under the conditions of the Grant Agreement.

Project RESCUE with Grant Agreement number 101192169
The project is supported by the Clean Hydrogen Partnership and its members. Co-funded by the European Union.

Project details

PROJECT TITLE	
PROJECT NUMBER	101192169
PROJECT ACRONYM	RESCUE
PROJECT NAME	Reliable and Efficient Dual Fuel System for Civil Protection during Natural Disasters using HT–PEM Technology
CALL	HORIZON–JTI–CLEANH2–2024
TOPIC	HORIZON–JTI–CLEANH2–2024–04–01
STARTING DATE OF THE PROJECT	01–01–2025
PROJECT DURATION	48 months

Summary/Abstract:

This safety plan outlines the safety framework for the RESCUE project, which aims to develop a dual-fuel (hydrogen and methanol) high-temperature PEM fuel cell system for civil protection applications. The safety planning addresses the safe design, operation, and emergency response related to fuel cell technology. It includes identification of chemical hazards (methanol, hydrogen, oil), applicable safety standards, regulatory frameworks (e.g., ATEX, CLP, PED), and risk assessment methodologies such as HAZID and HAZOP.

Dedicated safety teams have been established to conduct hazard evaluations, ensure regulatory compliance, oversee incident reporting, and manage training programs. Key areas include emergency planning, personnel training, signage, and protective equipment protocols. Emphasis is placed on inherently safe design, proactive mitigation strategies, system monitoring, and continuous safety improvement through the management of change process. The plan adopts European Hydrogen Safety Panel guidance and integrates both technical and organizational safety responsibilities across the project's lifecycle. It also details how risks will be assessed, documented, and communicated, ensuring safety remains central as the system evolves from lab testing to field deployment.

Key Words (optional): Hydrogen, Methanol, Fuel Cells, HT–PEMFC, Safety Plan

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List of Abbreviations

- **API:** American Petroleum Institute
- **ACGIH:** American Conference of Governmental Industrial Hygienists
- **ATEX:** Atmosphères Explosibles
- **BCGA:** British Compressed Gases Association
- **CAS:** Chemical Abstracts Service
- **CERTH:** Centre for Research and Technology Hellas
- **DDT:** Deflagration to Detonation Transition
- **DLR:** Deutsches Zentrum für Luft– und Raumfahrt e. V.
- **DTU:** Technical University of Denmark
- **EC:** European Commission
- **ECHA:** European Chemicals Agency
- **EHSP:** European Hydrogen Safety Panel
- **EI:** Energy Institute
- **EN:** European Norm
- **ENSOSP**: French National Fire Officers Academy
- **EPL**: Equipment Protection Level
- **ERPG**: Emergency Response Planning Guidelines
- **EU:** European Union
- **HAZID:** Hazard Identification
- **HAZOP:** Hazard and Operability
- **HELLEN:** Hydrogen Event and Lessons Learned Database
- **HIAD:** Hydrogen Incidents and Accidents Database
- **HSE:** Health and Safety Executive
- **HT–PEM:** High Temperature – Proton Exchange Membrane
- **IEC:** International Electrotechnical Commission
- **IP:** Ingress Protection
- **IDLH:** Immediately Dangerous to Life or Health
- **ISO:** International Organization for Standardization
- **ISV:** Identification of Safety Vulnerabilities
- **LFL:** Lower Flammability Limit
- **LOHC:** Liquid Organic Hydrogen Carriers
- **MOC**: Management of Change
- **NE:** Negligible Extent
- **NFPA:** National Fire Protection Association
- **OSHA:** Occupational Safety and Health Administration
- **PED:** Pressure Equipment Directive
- **PEMFC:** Proton Exchange Membrane Fuel Cell
- **PID (P&ID):** Piping and Instrumentation Diagram
- **RAM:** Risk Assessment Matrix
- **RP:** Recommended Practice
- **SDS:** Safety Data Sheet
- **SIMOPS:** Simultaneous Operations
- **STEL:** Short Term Exposure Limit
- **THW:** Bundesanstalt Technisches Hilfswerk
- **TPED:** Transportable Pressure Equipment Directive
- **TR:** Technical Report
- **TWA:** Time Weighted Average
- **UFL:** Upper Flammability Limit

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- **WP:** Work Package

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1. Safety Plan

A comprehensive safety plan is a vital component of the RESCUE project, requiring careful and deliberate attention to identifying and analysing potential safety vulnerabilities, managing or eliminating hazards, and mitigating associated risks. The safety plan functions as "living document", adapting to the specific tasks involved, acknowledging human error, accounting for equipment lifecycle, and evolving alongside changes in project development, design, implementation, operation, and maintenance.

The project safety plan aim is to develop technical and organisational activities to:

- Ensure that RESCUE provides an adequate level of safety and follows or even improves the state-of-the-art
- Identify and address essential for the project success knowledge gaps and technological bottlenecks
- Formulate activities providing a high level of technical and organisational safety activities in the project delivery.

The preparation of the project safety plan involves all partners to a different extent as needed. Two project safety teams have been formed in the context of the safety plan, that consist of representatives of all partners. The technical safety team under guidance of PROACT is responsible for solving challenging H_2 safety issues by developing mitigation solutions, preparing the HAZID and HAZOP studies, identifying safety critical equipment and tasks with the Bowtie methodology (mainly PROACT), performing H_2 safety research (ADV, CERTH), identifying, categorising, and ranking hazards (mainly PROACT), developing job safety analysis (mainly PROACT), formulating potential incident scenarios (ADV, CERTH under support of PROACT), assessing consequences of identified incident scenarios to people (ALL), property and environment and reporting results, performing system audits during laboratory testing and field testing and demonstration (organised by DLR, THW), performing regular safety audits, updating the safety plan and managing changes (PROACT). Members of the RESCUE technical safety team are the following:

- Elsa Georgiza, Proact Consultants
- Panagiotis – Vasileios Evdaimon, Proact Consultants
- Christina Karagianni, Proact Consultants
- Stavros Katsiaounis, Advent Technologies
- Nies Reininghaus, DLR
- Arash Nemati, DTU
- Alexios – Spyridon Kyriakides, CERTH

The management safety team (led by PROACT) is responsible for planning, monitoring and reporting on arrangements of safety based on established general safety procedures available at each organisation involved in the project and for each WP. Members of the RESCUE management safety team are the following:

- Vasileios Peppas, Proact Consultants
- Dana Schonvogel, DLR
- Nies Reininghaus, DLR
- Stavros Katsiaounis, Advent Technologies
- Alexios – Spyridon Kyriakides, CERTH

The initial safety plan was delivered at the beginning of WP2. The present version has been developed at the end of WP2. It will be subsequently updated at conclusion of each work package to reflect advancements in hydrogen safety measures throughout the project's implementation and in its outcomes, whether systems, processes, or infrastructure components. It will be also updated, if required by the management of change procedure. Each update of the safety plan is subject to approval by the management safety team, who is also responsible for communicating the revisions to all relevant stakeholders.

The tables that follow present the safety plan of the RESCUE project. Its purpose is to ensure that identified hazards are systematically assessed and reduced through appropriate design decisions and safety measures. This stage focuses on translating safety principles into technical requirements, defining safeguards, and verifying compliance with applicable standards, in order to minimise risks throughout the system lifecycle. The format of the safety plan follows the recommendations of the European Hydrogen Safety Panel.

Table 1 – Project Brief.

No	TOPIC	EXPLANATION	INPUT
1a.	General Information	Title of project:	Reliable and Efficient Dual Fuel System for Civil Protection during Natural Disasters using High Temperature – Proton Exchange Membrane (HT–PEM) Technology
		Term (duration):	01/2025 to 01/2027
		Funding:	This project is supported by the Clean Hydrogen Partnership and its members. Co–funded by the European Union.
		Coordinator (Person, Institution):	Dr. Dana Schonvogel Deutsches Zentrum für Luft– und Raumfahrt e. V. (DLR) German Aerospace Center Institute of Engineering Thermodynamics, Electrochemical Energy Technology
1b.	Consortium	Give name list of partners and highlight those with hydrogen safety specific experience	• DLR • Advent Technologies • Centre for Research and Technology Hellas (CERTH) • Technical University of Denmark (DTU) • Bundesanstalt Technisches Hilfswerk (THW) • PROACT Consultants
1c.	Safety Responsible Person	Give name and contact data of person responsible for safety of the	Name: Vasileios Peppas Position: Industrial Safety Director, PROACT Address: 42 Ipirou Street, Haidari, GR–12461, Greece Telephone: + 30 210 220 8492 E–mail: peppas@proact.gr

<table>
<tr><th>No</th><th>TOPIC</th><th>EXPLANATION</th><th colspan="2">INPUT</th></tr>
<tr><td></td><td></td><td>project "safety officer" (better one than many, and usually the author of this document)</td><td colspan="2"></td></tr>
<tr><td>1d.</td><td>Type of Work</td><td>Describe the specific nature of the work</td><td colspan="2">☐ laboratory–scale research
☐ bench–scale testing
☐ engineering development
☐ safety engineering
✓ prototype operation
☐ demonstration
✓ commercial application
☐ other:</td></tr>
<tr><td>1e.</td><td>Description of Work</td><td>Short summary of the Description of Activities (maybe copy the short summary of the contract)</td><td colspan="2">Development and demonstration of a fuel cell system which allows the operation using 100 % of hydrogen and additionally using methanol and assures 50 kW of electrical power, with peak power of up to 100 kW. The containerised and modular design in combination with the dual fuel approach leads to an application flexibility for various important facilities during natural disasters like the civil protection with different energy requirements. The HT–PEM technology is characterised by increased operating temperature of around 160 °C and enables a simplified cell design and operation regarding water management, heat rejection and direct use of reformates.</td></tr>
<tr><td>1f.</td><td>Project Phases (origin of change)</td><td>What is done in which phase of the project (free text input)</td><td colspan="2">System requirements have been developed during Work Package 2 (WP2). Afterwards, the fuel cell module equipped with the fuelling possibilities will be constructed and tested in laboratory environment (WP3). After fuel cell and fuel container constructions (WP4), the system integration (WP5) considering safety and transport certification requirements (WP2/9), demonstration using defined load profiles and conditions with performing grid integration is planned (WP6). Testing for at least 2,000 hours on site of a civil protection organisation shows the system capabilities and completes the project (WP7). State–of–Health against the criterium of system efficiency and fuel flexibility on system and on fuel cell level is analysed and accompanies the whole project duration (WP8). Dissemination and exploitation are mandatory in this project (WP10).</td></tr>
<tr><td rowspan="5">1g.</td><td rowspan="5">Hydrogen Inventory</td><td rowspan="5">Type of hydrogen storage and maximum inventory of hydrogen physically stored on site(s) per storage type</td><td>☐ p < 2 bar</td><td></td></tr>
<tr><td>☐ p < 20 bar</td><td></td></tr>
<tr><td>☐ p <= 200 bar</td><td></td></tr>
<tr><td>✓ p > 200 bar</td><td>One (1) compressed hydrogen bundle with twelve (12) cylinders.
Water volume per cylinder: ~50 L.
Total hydrogen mass: ~14 kg @ 300 bar</td></tr>
<tr><td>☐ liquid (cryogenic)</td><td></td></tr>
</table>

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No	TOPIC	EXPLANATION	INPUT	
			☐ solid storage (metal hydride)	
			✓ other (e.g. LOHC):	Methanol as hydrogen carrier transferred and stored in a certified iso tank container. Total methanol mass: ~ 6336 kg
1h.	Location	Where is your activity, respectively hydrogen located (industrial, public, colocation with other technologies and hazards, etc)	✓ specially controlled area ☐ industrial environment ☐ research lab ☐ public ☐ co–located with other hazardous materials, fuels etc.:	

Table 2 – Project Safety.

No	TOPIC	EXPLANATION	INPUT	RESPONSIBLE, IF NOT "SAFETY OFFICER"
2a.	Relevant regulation, codes, standards and safety policies	List all relevant regulation and applied codes and standards for your project	See Chapter 2 of the present safety plan.	
2b.	Hazard Identification and Risk Assessment	Provide a chronological list of hazard identification procedures and risk assessments done (or planned) and summarize key results or provide full documentation in attachments	1. Hazard Identification (HAZID) study during initial design stage (see "HAZID_Initial Design_V0.1.xlsx" attached in "Safety Plan_Initial Design_V1.1.docx") 2. HAZID study at the end of WP2 (see attached "HAZID_V0.1.xlsx") 3. Hazard and Operability (HAZOP) study at the end of WP2 (see attached "HAZOP_V0.1.xlsx") 4. Hazardous area classification (ATEX zones) at the end of WP2 (see Chapter 8 of the Safety Plan) 5. Bowtie analysis at the end of WP2 (see attached "Bowtie Diagrams_V0.1.pdf") 6. Explosion protection document before commissioning **Note**: All studies shall be reviewed, and if necessary revised, before	

No	TOPIC	EXPLANATION	INPUT	RESPONSIBLE, IF NOT "SAFETY OFFICER"
			hardware installations and before operations.	
2c.	Prevention and mitigation	List all prevention strategies and installed mitigation technology used (e.g. ventilation, water sprays, sensors…). Follow the first 8 safety principles, (potential outcome of 2b)	• See attached "HAZID_V0.1.xlsx" • See attached "HAZOP_V0.1.xlsx" • See attached "Bowtie Diagrams_V0.1.pdf"	

Table 3 – Operations Management.

No	TOPIC	EXPLANATION	INPUT	RESPONSIBLE, IF NOT "SAFETY OFFICER"
3a.	Nominal and limit values of critical process parameters	Provide a list of controlled or easy to check process parameters, like filling status of a liquid, pressure and or temperature and there corresponding design and limit values (potential outcome of 2b)	The following indicative parameters will be continuously monitored during operation: • Methanol pressure • Methanol level in manifold tank • Reformer burner temperature • Reformer gas outlet sensor • Ventilation airflow • Reformer inlet temperature • Reformer middle temperature • Reformer outer temperature • Voltage drops • Hydrogen concentration in cabinet • Methanol solution pressure • Fuel cell stack inlet temperature • Fuel cell stack inlet pressure • Cathode inlet pressure • Cathode outlet pressure • Anode waste gas pressure • Cabinet temperature • Liquid spills in cabinet • Condenser exhaust temperature • Fuel cell stack outlet temperature • Oil heater temperature • Oil radiator outlet temperature If any of the above parameters fall outside the safe operating envelope, the system will	Advent Technologies

No	TOPIC	EXPLANATION	INPUT	RESPONSIBLE, IF NOT “SAFETY OFFICER”
			automatically transition to a safe state. **Note**: For a full list of sensors see attached “P&ID_V0.1.pdf”	
3b.	Procedures for operation	Refer to checklists for start or/ and shut–down, operation instructions (potential outcome of 2b and possibly attached in 4)	The following shall be part of the RESCUE safety management system, as a minimum, and shall be prepared by the technical safety team: • Laboratory testing • Container transfer • Fuel receipt • Calibration and testing • Commissioning • Safe operating envelope • Startup checklist • Shut down checklist • Operations manual • Alarm management including Cause and Effect matrix • Decommissioning • Management of change (MOC) • Maintenance manual The above shall incorporate the safeguards identified in HAZID. HAZOP and all safety studies. The management safety team shall review all procedures and shall provide feedback for improvements and clarity	
3c.	Emergency alarm, evacuation and response plans	(maybe just attach them in 4 and indicate this here)	See Chapter 10 of the present safety plan.	
3d.	Personnel education and training	Describe or list all measures where involved persons (operators, first responders….) are participating in courses and explain how this is documented	See Chapter 11 of the present safety plan.	
3e.	Monitoring and Periodic Reviews	Describe the procedures and periodicity of checking whether everything above is in place and known by all relevant people	Safety reviews shall be conducted at various times during the project by the technical safety team, and records shall be kept as part of system documentation. At least the following safety reviews shall be performed to verify that safety-related procedures and practices are being followed throughout the life of the project:	

No	TOPIC	EXPLANATION	INPUT	RESPONSIBLE, IF NOT "SAFETY OFFICER"
			• in the context of the HAZOP study • before the commencement of each relevant task • after finalising each relevant task • before laboratory testing • before field testing • in the context of MOC • a pre-start-up safety review to ensure the system is installed as designed, all identified safety features, including engineering and administrative controls are in place, training has been implemented, equipment has been inspected and tested	
3f.	Reporting of safety events and lessons learned in HELLEN and HIAD	Describe plans for sharing safety critical information	See Chapter 12 of the present safety plan.	

Table 4 – Checklists and other helpful documents.

No	TOPIC	AVAILABLE	WHERE (LINK, LIBRARY, ROOM…)
4a.	Block flow diagram (PID) or simplified process flow diagram	☒	Attached in Appendix (P&ID_V0.1.pdf)
4b.	ATEX zones	☒	Chapter 8
4c.	Process chemistry	☐	
4d.	Material of construction	☒	Attached in Appendix (P&ID_V0.1.pdf)
4e.	Safety data sheets	☒	Attached in Appendix
4f.	Material and energy balances	☐	
4g.	Electrical classification	☒	Chapter 9
4h.	Pressure relief system design	☐	
4i.	Ventilations system design	☐	
4j.	Technical documentation of further safety / mitigation equipment	☐	
4k.	Checklists before or after start	☐	
4l.	Results of ISV before or at project start	☒	Attached in Appendix
4m.	Results of ISV or risk assessment before hardware installation	☐	
4n.	Results of ISV or risk assessment before operations	☐	

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2. Applicable Regulations, Codes and Standards

Below is a list of applicable regulations, codes and standards that will be implemented throughout the duration of the project in order to enhance operational reliability and safety. The list will be revised with each revision of the safety plan, whenever the need to apply additional regulations, codes and standards is identified.

2.1. Regulations

1.1. Directive 1999/92/EC of the European Parliament and of the Council of 16 December 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres (ATEX Workplace Directive).

1.2. Directive 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (ATEX Equipment Directive).

1.3. Directive 2014/68/EU of the European Parliament and of the Council of 15 May 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment (Pressure Equipment Directive, PED).

1.4. Directive 2010/35/EU of the European Parliament and of the Council of 16 June 2010 on transportable pressure equipment (Transportable Pressure Equipment Directive, TPED).

1.5. Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery (Machinery Directive).

1.6. Directive 2014/35/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits (Low Voltage Directive).

1.7. Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (Electromagnetic Compatibility Directive).

1.8. Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC (Seveso III).

1.9. Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives

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67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (CLP).

1.10. United Nations Economic Commission for Europe. European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR): Volume I & II. United Nations.

2.2. Standards

2.1. API RP 505:2025. Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1 and Zone 2.

2.2. EN 60204–1:2018. Safety of machinery – Electrical equipment of machines – Part 1: General requirements.

2.3. EN 1127–1:2019. Explosive atmospheres – Explosion prevention and protection – Part 1: Basic concepts and methodology.

2.4. IEC 62282–2–100:2020. Fuel cell technologies – Part 2–100: Fuel cell modules – Safety.

2.5. IEC 62282–3–300:2012. Fuel cell technologies – Part 3–300: Stationary fuel cell power systems – Installation.

2.6. IEC 60079–10–1:2020. Explosive atmospheres – Part 10–1: Classification of areas – Explosive gas atmospheres.

2.7. IEC 60079–14:2024. Explosive atmospheres – Part 14: Electrical installation design, selection and installation of equipment, including initial inspection.

2.8. IEC 60079–17:2023. Explosive atmospheres – Part 17: Electrical installations inspection and maintenance.

2.9. IEC 60079–19:2019. Explosive atmospheres – Part 19: Equipment repair, overhaul and reclamation.

2.10. IEC 61882:2016. Hazard and operability studies (HAZOP studies) – Application guide.

2.11. ISO/IEC 80079–20–1:2019. Explosive atmospheres – Part 20–1: Material characteristics for gas and vapour classification – Test methods and data.

2.12. IEC TS 60079-32-1:2013. Explosive atmospheres – Part 32-1: Electrostatic hazards, guidance.

2.13. IEC 60529:1989+AMD1:1999+AMD2:2013. Degrees of protection provided by enclosures (IP Code).

2.14. ISO 26142:2010. Hydrogen detection apparatus. Stationary applications.

2.15. ISO 14687:2025. Hydrogen fuel quality – Product specification.

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2.16. ISO/TR 15916:2015. Basic considerations for the safety of hydrogen systems.

2.17. ISO 12100:2010. Safety of machinery – General principles for design – Risk assessment and risk reduction.

2.18. ISO 13849–1:2023. Safety of machinery – Safety–related parts of control systems – Part 1: General principles for design.

2.19. ISO 13849–2:2012. Safety of machinery – Safety-related parts of control systems – Part 2: Validation.

2.20. ISO 20607:2019. Safety of machinery – Instruction handbook – General drafting principles.

2.21. ISO 14118:2017. Safety of machinery – Prevention of unexpected start–up.

2.22. ISO 80079–36:2016. Explosive atmospheres – Part 36: Non-electrical equipment for explosive atmospheres – Basic method and requirements.

2.23. NFPA 2:2023. Hydrogen Technologies Code.

2.24. NFPA 853:2025. Standard for the Installation of Stationary Fuel Cell Power Systems.

2.25. NFPA 30:2024. Flammable and Combustible Liquids Code.

2.26. NFPA 400:2025. Hazardous Materials Code.

2.27. NFPA 704:2022. Standard System for the Identification of the Hazards of Materials for Emergency Response.

2.3. Guidelines and Codes of Practice

3.1. British Compressed Gases Association. 2020. Code of Practice 4 – Gas Supply and Distribution Systems.

3.2. British Compressed Gases Association. 2021. Guidance Note 13 – DSEAR Risk Assessment Guidance for Compressed Gases.

3.3. British Compressed Gases Association. 2022. Code of Practice 44 – The Storage of Gas Cylinders.

3.4. Center for Hydrogen Safety / Hydrogen Safety Panel. 2022. Hydrogen Incident Recovery Guide.

3.5. Energy Institute. 2024. Model Code of Safe Practice Part 15: Area Classification for Installations Handling Flammable Fluids.

3.6. European Hydrogen Safety Panel. 2023. Safety Planning and Management in Hydrogen and Fuel Cells Projects – Guidance Document.

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3.7. European Hydrogen Safety Panel. 2023. EHSP Guidance on Hydrogen Safety Engineering – Guidance Document.

3.8. European Hydrogen Safety Panel. 2021. Statistics, lessons learnt and recommendations from the analysis of the Hydrogen Incidents and Accidents Database (HIAD 2.0).

3.9. Health and Safety Executive, 2015, The storage of flammable liquids in tanks.

3.10. Health and Safety Executive, 2015, Storage of flammable liquids in containers.

3.11. Hydrogen Safety Panel. 2020. Example Safety Plan for Hydrogen and Fuel Cell Projects.

3.12. Hydrogen Safety Panel. 2020. Hydrogen Incident Examples.

3.13. Hydrogen Safety Panel. 2020. Safety Planning for Hydrogen and Fuel Cell Projects.

3.14. Hydrogen Safety Panel. 2021. Simplified Safety Planning for Low Volume Hydrogen and Fuel Cell Projects.

3.15. ENSOSP. 2022. European Emergency Response Guide.

3.16. European Industrial Gases Association. 2021. Gaseous Hydrogen Installations.

3.17. Methanol Institute, Methanol Small Quantities Bulletin.

3.18. Methanol Institute, Methanol Safe Handling Manual, 5th edition.

3.19. Methanol Institute, Precautions for Loading, Unloading, Transporting & Storing Methanol.

3.20. Methanol Institute, Crisis Communications Guidebook, 1st Edition, 2008.

3.21. Methanol Institute, Atmospheric Above Ground Tank Storage of Methanol.

2.4. Papers and Books

4.1. Meiling Dou, Ming Hou, Dong Liang, Qiang Shen, Huabing Zhang, Wangting Lu, Zhigang Shao, Baolian Yi, Behaviors of proton exchange membrane fuel cells under oxidant starvation, Journal of Power Sources, Volume 196, Issue 5, 2011, Pages 2759-2762, ISSN 0378-7753.

4.2. Michael Whiteley, Sarah Dunnett, Lisa Jackson, Failure Mode and Effect Analysis, and Fault Tree Analysis of Polymer Electrolyte Membrane Fuel Cells, International Journal of Hydrogen Energy, Volume 41, Issue 2, 2016, Pages 1187-1202, ISSN 0360-3199.

4.3. Marko Gerbec, Vladimir Jovan, Janko Petrovčič, Operational and safety analyses of a commercial PEMFC system, International Journal of

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Hydrogen Energy, Volume 33, Issue 15, 2008, Pages 4147-4160, ISSN 0360-3199.

4.4. Joachim Grüne, Mike Kuznetsov, Alexander Lelyakin and Thomas Jordan, Spontaneous Ignition Processes Due to High-Pressure Hydrogen Release in Air, International Conference on Hydrogen Safety, 2011.

4.5. Zhixiang Liu, Lizhai Yang, Zongqiang Mao, Weilin Zhuge, Yangjun Zhang, Lisheng Wang, Behavior of PEMFC in starvation, Journal of Power Sources, Volume 157, Issue 1, 2006, Pages 166-176, ISSN 0378-7753.

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3. Methanol and Methanol Solutions Properties and Hazards

3.1. Physical and Chemical Properties

The pure liquid methanol shall arrive on site in a certified iso tank container. It will be mixed with water from the fuel cell cathode by an automated system in order to produce a 60% v/v methanol solution, which will be supplied to the reformer.

Methanol (CH_3OH) is a colourless hygroscopic and completely miscible with water liquid. It is a good solvent, but very toxic and extremely flammable. This simple single-carbon alcohol is a volatile solvent and a light fuel. Four overriding considerations are important when storing and handling methanol:

1. Methanol is a flammable, easily ignited liquid that burns and, under certain circumstances, may explode in the air.
2. Since the density of methanol vapor is only slightly higher than that of air, the vapor can follow the air movements. However, if the methanol is warmer than the ambient air it may rise, and if it is colder it may migrate near the ground and collect in confined spaces and low-lying areas. It is expected that methanol vapor, being near neutral buoyancy, will dissipate readily from ventilated locations, but not from non-ventilated locations such as sewers and enclosed spaces. If ignited, methanol vapor can flash back to its source.
3. Methanol is a toxin; ingestion of a small amount (approximately 10 to 30 mL, or less than a 1/4 cup) may cause death; lesser amounts are known to cause irreversible blindness. Persons shall not swallow methanol liquid, shall not breathe methanol vapor, shall not walk in pooled liquid, and shall not allow vapor or liquid to contact skin. Methanol absorbs through the skin and other tissues directly into the blood stream.
4. Methanol is totally miscible in water and retains its flammability even at very high concentrations of water. A 75% water and 25% v/v methanol solution is considered to be a flammable liquid. This has important consequences for firefighting. Methanol is a chemical solvent, which has important implications for materials selection and also firefighting.

The physical and chemical properties of methanol and methanol solution are described below:

- Melting point: -98° C (methanol) / -50° C (methanol solution
- Boiling point: 64.7° C
- Vapour pressure: 169 hPa @ 25° C (methanol) / 128 hPa @ 20° C (methanol solution)
- Density: 0.79 g/cm³
- Solubility: Complete soluble in water
- Lower Flammability Limit (LFL): 5.5% vol
- Upper Flammability Limit (UFL): 44% vol
- Flash point: 9.7° C (methanol) / 23° C (methanol

solution)
- Auto ignition temperature: 440° C (as per EN ISO/IEC 80079-20-1)
- Viscosity: 0.544-0.59 mm^2/s

Aluminium, lead, magnesium and alkali metals are considered incompatible with methanol, whereas aluminium, lead, zinc and polystyrene are unsuitable for methanol containers. An explosive reaction with chloroform, sodium methoxide and diethyl zinc is possible. Methanol reacts violently and uncontrollably with strong reducing agents and dilute solutions of alkyl aluminium salts, diethyl zinc, acetyl bromide, cyanuric chloride. Methanol is incompatible with beryllium dihydride and reacts violently with the ether containing hydride. Reaction with alkali metals (sodium, potassium, magnesium) is vigorous and often subject to a lengthy induction period. Mixtures with powdered MG or Al are capable of powerful detonation. Reaction with K may lead to an explosion. Methanol reacts violently with strong oxidizers (calcium hypochlorite, barium, perchlorates, peroxides, permanganates, chlorates), strong acids, (nitric, hydrochloric, sulfuric), halogen gases (bromine, chlorine, fluorine, and iodine) and liquid phosphorus (III) oxide above 24° C. It also reacts vigorously and dangerously with oxidizing materials. Methylene chloride may become flammable in the presence of small amounts of methanol, whereas reaction of liquid methanol with solid potassium tert-Butoxide causes ignition after 2 minutes. The above-mentioned chemicals shall not be kept on site unless appropriate measures have been defined after a risk assessment.

3.2. Toxicity

According to the SDS, methanol and methanol solution are classified under CLP Regulation as toxic if swallowed, in contact with skin or if inhaled (H301 + H311 + H331). They also cause damage to eyes and the central nervous system (H370).

In general, methanol has a faintly sweet alcohol odour but does not make its presence known until a concentration of 2000 ppm or above is reached, which is ten times higher than the safe limit for human exposure of 200 ppm. This value is based on an 8-hour time weighted average (TWA) exposure, set by both the American Conference of Governmental Industrial Hygienists (ACGIH) and the Occupational Safety and Health Administration (OSHA) to protect workers against the health effects of exposure to methanol. The ACGIH short-term exposure limit for methanol is 250 ppm and it contains a skin notation which serves as a warning that skin absorption should be prevented in order to avoid exceeding the absorbed dose received by inhalation at the 200-ppm level.

Methanol's primary routes of entry into the body are by inhalation, absorption through the skin as a result of contact, eye contact, and ingestion by either eating or drinking or smoking. Regardless of the route of exposure, the toxicity of methanol is the same. Signs of systemic toxic effects may be delayed between 8 and 36 hours after initial exposure. Methanol is irritating to the eyes, the skin, and the respiratory tract. It also strips the natural oils and fat from the skin, causing skin to become dry and cracked. It can cause permanent damage to the optic nerve and central and peripheral nervous system with just a single acute exposure. Other signs and symptoms of methanol poisoning include headache, dizziness, vomiting, severe abdominal pain, back pain, difficulty breathing, cold extremities, lethargy, and lack of coordination. Eye exposure can also cause a burning sensation accompanied by tearing, redness, and swelling. Direct contact with the liquid may cause conjunctivitis and corneal burns. High exposures may result in blindness, organ failure and death.

The characteristics of methanol, in terms of toxicity, are summarized in the table below:

Table 5 – Toxicological characteristics of methanol.

CONCENTRATION (ppm)	EFFECT
200	European Chemicals Agency (ECHA), Occupational Safety and Health Administration (OSHA) and American Conference of Governmental Industrial Hygienists (ACGIH) exposure limit averaged over an eight-hour workday. The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odour (ERPG-1).
250	Short Term Exposure Limit (STEL) during any 15-minute period in the day. No worker should be exposed to more than that amount over any 15-minute period (ACGIH).
1000	The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action (ERPG-2).
2000	Odour threshold.
5000	The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects (ERPG-3).
6000	Methanol 30-minute dose that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere (Immediately Dangerous to Life or Health, IDLH).

3.3. Flammability

Methanol and methanol solutions have a wide flammability range, as indicated by Lower and Upper Flammability Limit (LFL, UFL). The extent of the flammability range means that methanol vapor can be ignited throughout a wide range of concentrations in air. The flammability of a fuel depends on this tendency to release vapor in combination with its flammability limits; these define the concentration range where the vapor can burn in air. Below the LFL, sustained combustion will not take place as the fuel air mixture is too lean. Above the UFL, the mixture is too rich, and combustion is quenched.

The LFL in combination with the tendency to release vapor can be translated to the temperature at which sufficient vapor is generated above the liquid to enable ignition. This temperature is referred to as the flash point. A more specific definition of flash point is the lowest temperature at which the application of an ignition source causes the vapor of a test portion to ignite and the flame to propagate across the surface of the liquid under the specified conditions of the test. Pure methanol has a low flash point of 9.7° C. However, the flash point of the methanol solution to be stored and handled on site is 23° C, thus slightly decreasing the risk of ignition. Methanol burns with a clear blue-coloured, non-luminous flame that may be difficult to see in bright sunlight. Methanol may be on fire and an individual may not be able to discern the hazard of a fire by looking for a flame.

3.4. Classifications

Methanol is classified as follows according to various relevant codes, standards and regulations:

Table 6 – Classification of methanol.

CODE, STANDARD OR REGULATION	CLASSIFICATION
CLP	H225: Flammable liquids, Hazard Category 2. H301 + H311 + H331: Acute toxicity (oral, dermal, inhalation), Hazard Category 3. H370: Specific target organ toxicity — single exposure, Hazard Category 1 (Eyes, Central nervous system).
EI 15	C: A flammable liquid, not in categories A or B, but which can, on release, be at a temperature above its flash point, or form a flammable mist or spray.
HSE	Category 2: flashpoint <23° C and initial boiling point >35° C.
NFPA 30	IB: Any liquid that has a flash point below 22.8° C and a boiling point at or above 37.8° C.
NFPA 704	Flammability: 3 – Liquids that can be ignited under almost all ambient temperature conditions. Health: 1 – Materials that, under emergency conditions, can cause significant irritation. Instability: 0 – Materials that in themselves are normally stable, even under fire conditions.
ADR	UN Number: 1230 UN Proper Shipping Name: Flammable Liquid, Toxic, N.O.S. (Methanol Solution) Transport Hazard Class(es): 3 + (6.1) Packing Group: II Environmental Hazards – MP: No, F-E, S-E Other Information: LQ: 1 L. Tunnel: D/E

The methanol solution 60% vol is classified as follows according to various relevant codes, standards and regulations:

Table 7 – Classification of methanol solution.

CODE, STANDARD OR REGULATION	CLASSIFICATION
CLP	H226: Flammable liquids, Hazard Category 3. H301 + H311 + H331: Acute toxicity (oral, dermal, inhalation), Hazard Category 3. H370: Specific target organ toxicity — single exposure, Hazard Category 1 (Eyes, Central nervous system).

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CODE, STANDARD OR REGULATION	CLASSIFICATION
EI 15	C: A flammable liquid, not in categories A or B, but which can, on release, be at a temperature above its flash point, or form a flammable mist or spray.
HSE	Category 3 flammable liquids (under CLP) flashpoint ≥23° C and ≤60° C.
NFPA 30	IC: Any liquid that has a flash point at or above 22.8° C, but below 37.8° C
ADR	UN Number: 1230 UN Proper Shipping Name: Flammable Liquid, Toxic, N.O.S. (Methanol Solution) Transport Hazard Class(es): 3 + (6.1) Packing Group: II Environmental Hazards – MP: No, F-E, S-E Other Information: LQ: 1 L. Tunnel: D/E

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4. Gaseous Hydrogen Properties and Hazards

4.1. Physical and Chemical Properties

Gaseous hydrogen (H_2), with a CAS number of 1333-74-0, is flammable, non-toxic, and non-corrosive. It is colourless, odourless, tasteless, and does not support life (asphyxiant). It is classified under the CLP Regulation as an "extremely flammable gas", while its containers are labeled as "contains gas under pressure, may explode if heated."

Under normal temperature and pressure conditions, hydrogen has a density of 0.0838 kg/m^3 and a specific gravity of 0.0696 (air = 1). It forms the smallest, lightest molecule of any gas (about 14 times lighter than air). As a result, gaseous hydrogen better permeates through materials, passes through smaller leak paths, diffuses more rapidly in surrounding media, and has greater buoyancy than other gases. The consequences arising from these properties are that released hydrogen has a tendency to rise and diffuse, but if confined, it can accumulate in high spots and reach ignition sources located there (e.g. ceiling lights).

The physical and chemical properties of gaseous hydrogen are described below:

- Melting point: -259^o C
- Boiling point: -253^o C
- Density: 0.08 kg/m^3
- Solubility: 1.62 mg/L
- Lower Flammability Limit (LFL): 4% vol
- Upper Flammability Limit (UFL): 77% vol
- Auto ignition temperature: 560^o C

4.2. Flammability and Combustion Properties

In the case of gaseous hydrogen leaks, the effects of fluid dynamics (such as wind, momentum, or buoyancy controlled flows) can dominate molecular diffusion. The buoyancy of hydrogen when it is allowed to rise will create convection currents. As a consequence of these properties, hydrogen gas has a tendency to disperse and diffuse and form ignitable mixtures with air. In an unconfined atmosphere, these mixtures ultimately dilute to a level below the LFL. But it should not be taken for granted that this will necessarily happen very quickly; boundary conditions can have a strong effect.

The low viscosity of hydrogen, an effect of the small size of the molecule, causes a comparatively high flow rate if the gas leaks through porous materials, fittings, or seals. This negative effect is to a certain extent offset by the low energy density of the gas in comparison with methane or other hydrocarbon gases.

On a molar basis, the heat capacity of hydrogen is similar to that of other diatomic gases despite its low molecular mass. The thermal conductivity of hydrogen is significantly higher than that of other gases. In a Joule-Thomson process (isenthalpic expansion) starting at ambient temperature, the temperature of hydrogen will not drop but rise. This temperature rise, however, is not sufficient to cause ignition.

The most easily ignitable mixture for hydrogen can be found in the range between 22% and 26%. Over the flammability range (a given pressure and temperature) of hydrogen/air mixtures, the ignition energy varies by almost three orders of magnitude and can be as low as 0.017 mJ for the most easily ignitable mixture (minimum ignition energy).

In contrast to hydrocarbon fuels, such as gasoline, which generate most of their radiation as visible light and heat, the hydrogen flame radiates less heat and is practically invisible in broad daylight. Most of the emission is around 311 nm. Chemiluminescence around 350 nm has also been measured. This radiation is just outside the visible range near ultraviolet spectrum. Light passing through the thermal gradients in the flame or hot products flow sometimes casts a flickering light/dark pattern. For the human senses, these characteristics make detection of small hydrogen flames difficult compared to hydrocarbon flames. Thus, without suitable detection equipment, the first indication of a small flame is likely to be the hissing noise of the gas leak and perhaps the intermittent shadows from the thermal gradients of the flame.

If a fire occurs in a sealed region, a pressure rise will occur. Combustion occurs in three different physical processes, namely:

a) as a non-premixed flame;
b) as a premixed flame propagating as a deflagration wave (a subsonic process);
c) as a premixed flame coupled with a shock wave propagating as a detonation wave (a supersonic process).

A deflagration wave is a subsonic process where the pressure change across the flame is negligible. A detonation is a supersonic process, which has very significant pressure rise across the front (10 times or more). Deflagration waves propagate by the diffusion of heat and chemical radicals in front of the wave to ignite the mixture whereas detonations propagate by adiabatic shock heating. Under suitable fluid dynamic conditions, a deflagration wave can accelerate to near the speed of sound and can even transition to a detonation wave (known as a deflagration to detonation transition, or DDT). In these cases, a fast deflagration wave can create a spherically propagating audible sound wave similar to that created by a detonation wave.

4.3. Classifications

Gaseous hydrogen is classified as follows according to various relevant codes, standards and regulations:

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Table 8 – Classification of gaseous hydrogen.

CODE, STANDARD OR REGULATION	CLASSIFICATION
CLP	H220: Flammable gases, Hazard Category 1. H280: Gases under pressure: Compressed gas.
EI 15	Pure gaseous hydrogen
NFPA 704	Flammability: 4 – Materials that rapidly or completely vaporize at atmospheric pressure and normal ambient temperature or that are readily dispersed in air and burn readily. Health: 0 – Materials that, under emergency conditions, would offer no hazard beyond that of ordinary combustible materials. Instability: 0 – Materials that in themselves are normally stable, even under fire conditions.
ADR	UN Number: 1049 UN Proper Shipping Name: Hydrogen Compressed Transport Hazard Class: 2 Packing Group: - Environmental Hazards – MP: Not applicable Tunnel: B/D

5. MultiTherm 503® Heat Transfer Fluid

5.1. Physical and Chemical Properties

MultiTherm 503® is an odorless and colorless liquid, that will be recirculated in the fuel cell cabinet. It is a mixture that contains dec-1-ene (CAS number 68649-11-6) and hydrogenated dimerization products of 1-decene and 1-dodecene (CAS number 151006-58-5). The product is stable under normal circumstances can be used in standard low pressure fluid heating systems. It has low vapor pressure and high flashpoint. Due to its lubricity, it reduces wear on moving parts and protects surfaces from corrosion. It is chemically inert, therefore it will not attack gaskets and seals

The physical and chemical properties of MultiTherm 503® are described below:

- Pour point: -65° C
- Boiling point: 267° C
- Vapour pressure: <0.013 kPa @ 20° C
- Density: 0.79 g/cm^3
- Solubility: Negligible in water
- Flash Point: 154° C
- Auto ignition temperature: 324° C
- Viscosity: 0.051 cm^2/s @ 40° C

5.2. Classifications

MultiTherm 503® is classified as follows according to various relevant codes, standards and regulations:

Table 9 – Classification of MultiTherm 503®.

CODE, STANDARD OR REGULATION	CLASSIFICATION
CLP	H304: May be fatal if swallowed and enters airways; Aspiration hazard, Hazard Category 1. H332: Harmful if inhaled; Acute toxicity (inhal.), Hazard Category 4.
EI 15	Unclassified (2): Liquids that have flash points above 100° C, handled at or above flash point.
HSE	Combustible liquids with a flashpoint above 60° C.
NFPA 30	Class IIIB Liquid: Any liquid that has a flash point at or above 93° C.
NFPA 704	Flammability: 1 – Materials that must be preheated before ignition can occur. Health: 1 – Materials that, under emergency conditions, can cause significant irritation. Instability: 0 – Materials that in themselves are normally stable, even under fire conditions.
ADR	N/A

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6. Identification of Safety Vulnerabilities, Hazards and Risk Assessment

Identification of safety vulnerabilities (ISV), hazards and risk assessment has been carried out using the established and standardised industry methods of Hazard Identification (HAZID) as well as the Hazard and Operability (HAZOP) and the Open-PHA software by Kenexis.

6.1. Hazard Identification (HAZID)

HAZID is a team based brainstorming analysis used to identify process and non-process hazards. HAZID can be broad in scope and has wide applicability. It is typically used early in a project to focus on inherently safe design and to direct future risk reduction activities. The HAZID process is at a higher level compared to HAZOP study or What If and is typically conducted at a unit or system level with less documentation. The purpose of HAZID is to:

- Identify and assess potential hazards relevant to the operation or stage of the project.
- Identify and assess the potential consequences of the hazards.
- Support application of inherently safe design.
- Identify safeguards that shall be in place to provide hazard prevention or mitigation.
- Provide a list of hazards for inclusion in hazard and risk registers and for further evaluation and risk reduction.

During the initial stage, RESCUE was broken down into four nodes, i.e. clearly defined sections of a process where the analysis is focused. Nodes serve as logical points for examining potential deviations in process conditions that could lead to hazards or operational problems. Each node should be small enough to allow thorough analysis, but large enough to avoid redundancy. Subsequently, the technical safety team was gathered in order to examine the system node by node during a HAZID session, guided by the engineers of PROACT.

The safety vulnerabilities and hazards, i.e. deviations, that were identified during the session by the Team are presented in the following Table:

Table 10 – Identified safety vulnerabilities and hazards per RESCUE node in the HAZID study during the initial design stage.

RESCUE NODE	SAFETY VULNERABILITIES AND HAZARDS (DEVIATIONS)
1. Methanol Storage Tank and Cabinet Feeding Equipment (outside cabinet)	1.1. High temperature 1.2. Low temperature 1.3. Contamination 1.4. Loss of containment 1.5. High pressure 1.6. High level 1.7. Low level

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RESCUE NODE	SAFETY VULNERABILITIES AND HAZARDS (DEVIATIONS)
	1.8. Domino effects 1.9. Emergencies 1.10. Fire and explosion hazards 1.11. Natural and environmental hazards 1.12. Security 1.13. Simultaneous Operations (SIMOPS) 1.14. Health hazards
2. Hydrogen Bundle and Cabinet Feeding Equipment (outside cabinet)	2.1. High temperature 2.2. Contamination 2.3. Loss of containment 2.4. High pressure 2.5. Low pressure 2.6. Domino effects 2.7. Emergencies 2.8. Fire and explosion hazards 2.9. Natural and environmental hazards 2.10. Security 2.11. Simultaneous Operations (SIMOPS)
3. Cabinet (Methanol Operation)	3.1. Loss of coolant / Low coolant effectiveness 3.2. Reformer failure 3.3. Reformer evaporator failure 3.4. Burner failure 3.5. Oxidant starvation 3.6. Fuel starvation 3.7. High temperature 3.8. Low temperature 3.9. Loss of containment 3.10. Startup hazards 3.11. High pressure 3.12. Low pressure 3.13. High level 3.14. Low level 3.15. Domino effects 3.16. Emergencies 3.17. Fire and explosion hazards 3.18. Chemical reaction hazards 3.19. Air emissions 3.20. Waste disposal 3.21. Maintenance hazards 3.22. Natural and environmental hazards 3.23. Security 3.24. Simultaneous Operations (SIMOPS) 3.25. Health hazards 3.26. Contamination 3.27. Cell reversal
4. Cabinet (Hydrogen Operation)	4.1. Loss of coolant / Low coolant effectiveness 4.2. Oxidant starvation 4.3. Fuel starvation 4.4. High temperature 4.5. Low temperature 4.6. Loss of containment 4.7. Startup hazards 4.8. High pressure 4.9. Low pressure 4.10. Domino effects

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RESCUE NODE	SAFETY VULNERABILITIES AND HAZARDS (DEVIATIONS)
	4.11. Emergencies 4.12. Fire and explosion hazards 4.13. Chemical reaction hazards 4.14. Air emissions 4.15. Waste disposal 4.16. Maintenance hazards 4.17. Natural and environmental hazards 4.18. Security 4.19. Simultaneous Operations (SIMOPS) 4.20. Health hazards 4.21. Contamination 4.22. Cell reversal

At the end of WP2, the system in the context of the HAZID study was divided into fewer nodes, as the primary objective was to identify high-level hazards and critical interfaces, whereas the methodology was kept the same. A more detailed and granular node definition was subsequently developed and analysed during the HAZOP study. To avoid duplication of analyses and repetition of findings, the present HAZID therefore focuses on fewer nodes, while detailed hazard evaluation is addressed in HAZOP.

The HAZID study is provided as an excel file in the Appendix of the present safety plan.

Table 11 – Identified safety vulnerabilities and hazards per RESCUE node in the HAZID study at the end of WP2.

RESCUE NODE	SAFETY VULNERABILITIES AND HAZARDS (DEVIATIONS)
1. Methanol storage tank and cabinet feeding equipment	1.1. High temperature 1.2. Low temperature 1.3. Contamination 1.4. Loss of containment 1.5. High pressure 1.6. High level 1.7. Low level 1.8. Domino effects 1.9. Emergencies 1.10. Fire and explosion hazards 1.11. Natural and environmental hazards 1.12. Security 1.13. Simultaneous Operations (SIMOPS) 1.14. Health hazards 1.15. Emptying / Filling
2. Hydrogen bundle and cabinet feeding equipment	2.1. High temperature 2.2. Contamination 2.3. Loss of containment 2.4. High pressure 2.5. Low pressure 2.6. Domino effects 2.7. Emergencies 2.8. Fire and explosion hazards 2.9. Natural and environmental hazards 2.10. Security

RESCUE NODE	SAFETY VULNERABILITIES AND HAZARDS (DEVIATIONS)
	2.11. Simultaneous Operations (SIMOPS)
3. Cabinet	3.1. High temperature 3.2. Loss of containment 3.3. Domino effects 3.4. Emergencies 3.5. Fire and explosion hazards 3.6. Chemical reaction hazards 3.7. Air emissions 3.8. Waste disposal 3.9. Maintenance hazards 3.10. Natural and environmental hazards 3.11. Security 3.12. Simultaneous Operations (SIMOPS) 3.13. Health hazards 3.14. Loss of services

6.2. Hazard and Operability (HAZOP)

As mentioned in IEC 61882, a HAZOP study is a detailed hazard and operability problem identification process, carried out by a team. When compared to HAZID, HAZOP is a distinct and complementary activity that is typically conducted at later project stages as design details and documentation are progressively developed. HAZOP deals with the identification of potential deviations from the design intent, examination of their possible causes and assessment of their consequences.

Key features of HAZOP examination include the following:

- The examination is a creative process. The examination proceeds by systematically using a series of guide words to identify potential deviations from the design intent and employing these deviations as "triggering devices" to stimulate team members to envisage how the deviation might occur and what might be the consequences.
- The examination is carried out under the guidance of a trained and experienced study leader (PROACT), who has to ensure comprehensive coverage of the system under study, using logical, analytical thinking. The study leader is preferably assisted by a recorder who records identified hazards and/or operational disturbances for further evaluation and resolution.
- The examination relies on specialists from various disciplines with appropriate skills and experience who display intuition and good judgement.
- The examination should be carried out in a climate of positive thinking and frank discussion. When a problem is identified, it is recorded for subsequent assessment and resolution.

A fundamental prerequisite for conducting a HAZOP study is the availability of a Piping and Instrumentation Diagram (P&ID). The P&ID is divided into nodes, which

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represent clearly defined sections of the process. For each node, relevant process parameters, such as flow, temperature, pressure, level, etc., are selected.

The HAZOP analysis then examines the effects of deviations from the design intent for each parameter. To systematically identify potential deviations, a predefined list of guidewords is used. The applicable guidewords for the RESCUE system along with their meaning are as follows:

- No: None of the design intent is achieved
- More: Quantitative increase in a parameter
- Less: Quantitative decrease in a parameter
- As well as: An additional activity occurs
- Part of: Only some of the design intention is achieved
- Other than: Complete substitution—another activity takes place or an unusual activity occurs or uncommon condition exists

Taking into account the above mentioned approach, the safety vulnerabilities and hazards, i.e. deviations, that were identified during the HAZOP sessions by the Team are presented in the following Table, whereas the complete HAZOP study, together with the system P&ID in which the nodes are highlighted using different colours, is provided as an excel file in the Appendix of the present safety plan:

Table 12 – Identified safety vulnerabilities and hazards per RESCUE node in the HAZOP study.

RESCUE NODE	GUIDEWORD	PARAMETER	SAFETY VULNERABILITIES AND HAZARDS (DEVIATIONS)
1. Pure methanol feed in cabinet	More	Flow	1.1. More Flow
	Less / No	Flow	1.2. Less Flow / No Flow
	Other than	Flow	1.3. Misdirected Flow
	As well as	Flow	1.4. Contamination
	More	Level	1.5. High Level
	Less	Level	1.6. Low Level
	Less	Temperature	1.7. Low Temperature
	More	Pressure	1.8. High Pressure
	Less	Pressure	1.9. Low Pressure
2. Reformer	More	Flow	2.1. More Flow
	Less / No	Flow	2.2. Less Flow / No Flow
	Part of	Flow	2.3. Wrong Ratio
	As well as	Flow	2.4. Contamination
	Less / No	Reaction	2.5. Low Reaction / No Reaction
	More	Pressure	2.6. High Pressure
	Less	Pressure	2.7. Low Pressure
	More	Temperature	2.8. High Temperature
	Less	Temperature	2.9. Low Temperature
3. Fuel cell stack	More	Flow	3.1. More Flow
	Less / No	Flow	3.2. Less Flow / No Flow
	Other than	Flow	3.3. Misdirected Flow
	As well as	Flow	3.4. Contamination

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RESCUE NODE	GUIDEWORD	PARAMETER	SAFETY VULNERABILITIES AND HAZARDS (DEVIATIONS)
	Less / No	Reaction	3.5. Low Reaction / No Reaction
	More	Pressure	3.6. High Pressure
	Less	Pressure	3.7. Low Pressure
	More	Temperature	3.8. High Temperature
	Less	Temperature	3.9. Low Temperature
4. Hydrogen feed in cabinet	Less / No	Flow	4.1. Less Flow / No Flow
	Other than	Flow	4.2. Misdirected Flow
	More	Pressure	4.3. High Pressure
	Less	Pressure	4.4. Low Pressure
5. Water line	More	Flow	5.1. More Flow
	Less / No	Flow	5.2. Less Flow / No Flow
	Other than	Flow	5.3. Misdirected Flow
	As well as	Flow	5.4. Contamination
	More	Temperature	5.5. High Temperature
	Less	Temperature	5.6. Low Temperature
	More	Level	5.7. High Level
	More	Pressure	5.8. High Pressure
	Less	Pressure	5.9. Low Pressure
6. Oil recirculation during normal operation	More	Flow	6.1. More Flow
	Less / No	Flow	6.2. Less Flow / No Flow
	As well as	Flow	6.3. Contamination
	More	Level	6.4. High Level
	Less	Level	6.5. Low Level
	More	Temperature	6.6. High Temperature
	Less	Temperature	6.7. Low Temperature
	More	Pressure	6.8. High Pressure
	Less	Pressure	6.9. Low Pressure
7. Start up mode	More	Flow	7.1. More Flow
	Less / No	Flow	7.2. Less Flow / No Flow
	As well as	Flow	7.3. Contamination
	More	Temperature	7.4. High Temperature
	Less	Temperature	7.5. Low Temperature
	More	Level	7.6. High Level
	Less	Level	7.7. Low Level
	More	Pressure	7.8. High Pressure
	Less	Pressure	7.9. Low Pressure

6.3. Risk Assessment

For each deviation identified in HAZID and HAZOP studies, one or more causes were identified, each of which was associated with one or more consequences. The relevant safeguards, both preventive and protective, were also documented. The inherent risk assessment that followed was based on a qualitative evaluation of the unmitigated likelihood of the deviation occurring in relation to the unmitigated severity of the potential consequences, according to the risk assessment matrix below:

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RESCUE Risk Assessment Matrix		Likelihood				
		1	2	3	4	5
Consequence	5	5	10	15	20	25
	4	4+	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5

Figure 1 – Qualitative risk assessment matrix for RESCUE. Field colour green: Low Risk, yellow: Medium Risk, red: High Risk (Modified from the deliverable of IDEALHY project).

The chosen likelihood categories are:

1. Extremely Unlikely (about 10^{-9} per year)
2. Unlikely (about 10^{-7} per year)
3. Possible (about 10^{-5} per year)
4. Very Possible (about 10^{-3} per year)
5. Probable (about 10^{-1} per year)

and the consequence categories:

1. Slight Effect (slight injury or health effect, no damage)
2. Minor Injury (minor injury or health effect, minor damage)
3. Major Injury (major injury or health effect, moderate damage)
4. Fatality (or permanent disability, major damage)
5. Multiple fatalities (or massive damage)

Based on the results of the inherent risk assessment, additional safeguards are recommended, as referenced in applicable regulations, codes and standards and according to the team's experience, in order to reduce or maintain the risk at acceptable levels, namely, within the green area of the risk assessment matrix.

Recommendations included in the safety plan are identified as follows:

- "Shall": Indicates a mandatory requirement for compliance with the Safety Plan.
- "Should": Indicates a preferred requirement but is not mandatory for compliance with the Safety Plan.

Safeguards and recommendations, which concern both the design phase and the overall project, are ultimately categorized according to the list of basic safety principles/strategies, as referenced in [3.5] and as presented in the Table below:

Table 13 – Basic safety principles/strategies.

No.	SAFETY STRATEGY
1	Proper design and material selection
2	Limit hydrogen inventories especially indoors, to what is strictly necessary by technology
3	Avoid or limit the formation of a flammable mixture
4	Carry out ATEX zoning analysis. Avoid ignition sources by the use of proper materials or installations in the different ATEX zones
5	Combine leak detection and countermeasures
6	Avoid congestion, reduce turbulence promoting flow obstacles in the respective ATEX zone
7	Avoid confinement, promote openings for natural or mechanical ventilation or explosion vents
8	Prefer passive barriers to active barriers
9	Train and educate staff
10	Report near misses and incidents
11	Perform periodic maintenance and audit

The residual risk, i.e. the risk after implementing the recommendations, is also presented in each HAZID and HAZOP spreadsheet.

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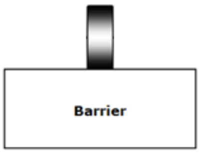
7. Bowtie Analysis

The higher-risk scenarios identified during the HAZOP and HAZID studies are selected for visualisation and further analysis through Bowtie analysis using the BowTieXP software by Wolters Kluwer. The Bowtie method provides a specific structure to systematically analyse a hazard and increases risk communication and awareness by essentially combining the logic of Fault Tree Analysis, Event Tree Analysis and the Swiss Cheese Model of risk management. The following table introduces the elements that make up a bowtie diagram. Building a bowtie happens in the same order.

Table 14 – Elements of bowtie diagrams.

Step	IDENTIFICATION OF	EXPLANATION
1		A bowtie starts with a hazard to analyse. In the bowtie method, hazards are part of normal operation and are often necessary for a system to run. What makes a hazard special is that this part of the system introduces the possibility for harm to occur. Most hazards are introduced into a system for good reasons, otherwise they could simply be eliminated and no harm would be possible. As long as hazards are under control, they will not cause harm, but they introduce the potential for harm. Examples of hazards for the RESCUE system are "Hydrogen Rich Gas Production", "Power Output of Fuel Cell" etc.
2		When control over a hazard is lost, it is usually possible to identify the moment when a normal situation changes to an abnormal situation. That point is called the top event in bowtie and is the centre event of the diagram. The top event is not a catastrophe yet, but the system is now exposed to the potential harm of the hazard. It should be possible for the system to bring the situation under control again. If control is regained after the top event has occurred, it will be thought of as a narrow escape that could have led to more serious unwanted events. Examples of top events are "Loss of Containment", "Low Flow /No Flow to Reformer" etc. The top events chosen in the analysis are, in most cases, the "deviations" with the highest risk, as these are identified during HAZOP and HAZID sessions.
3		There are often several factors that could cause the top event. These are called threats in the bowtie. Threats lead directly to the top event and should be able to cause the top event independently. Examples of threats are "pipe rupture", "external impact" etc. The threats identified in the analysis are the causes of each high risk deviation of the HAZOP and HAZID study.
4		When a top event has occurred, it can lead to certain consequences. Consequences are unwanted scenarios that could be caused by the top event. They should be realistic and specific. Consequences are mainly unwanted because they will lead to loss or damage. Examples of consequences are "Reformer overheating", "Fuel starvation in fuel cell stack". The consequences identified in the analysis are the "consequences" of the selected "causes" of the HAZOP and HAZID study.

Step	IDENTIFICATION OF	EXPLANATION
5		Risk management is about controlling risks. This is done by implementing barriers to prevent certain events form happening. A barrier can be any measure taken that acts against some undesirable force or intention, in order to maintain a desired state. Barriers are placed on both sides of the top event. Preventive barriers on the left side of the bowtie prevent the top event from happening. Recovery barriers on the right side of the bowtie can either prevent the top event from resulting in unwanted consequences or mitigate further consequences. The barriers identified in the analysis are the "safeguards" of the selected "causes" and "consequences" of the HAZOP and HAZID study.

The bowtie diagrams for the high-risk hazards of the RESCUE system are provided as a separate report in the Appendix of the Safety Plan.

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8. Hazardous Area Classification

8.1. Theory of Hazardous Area Classification

The aim of hazardous area classification is to avoid ignition of those releases that may occur from time to time in the operation of facilities producing, storing and handling flammable materials. The approach is to reduce to an acceptable level the probability of coincidence of a flammable atmosphere and an electrical or other source of ignition.

As prescribed by the International Electrotechnical Council (see IEC 60079-10-1), it is not the aim of hazardous area classification to guard against the ignition of major releases of flammable materials under the catastrophic failure of plant, e.g. the rupture of a pressure vessel, or the cold failure of a tank which, in properly run facilities, has a very low probability of occurrence. The incidence of such releases must be kept within acceptable limits by correct design, construction, maintenance and operation of facilities.

A hazardous area is defined as a three-dimensional space in which a flammable atmosphere may be expected to be present at such frequencies as to require special precautions for the design and construction of equipment, and the control of other potential ignition sources. Areas are subdivided into zones based on the likelihood of the occurrence and duration of a flammable atmosphere, as follows:

- **Zone 0**: Area in which an explosive gas atmosphere is present continuously, or for long periods, or frequently.
- **Zone 1**: Area in which an explosive gas atmosphere is likely to occur occasionally in normal operation.
- **Zone 2**: Area in which an explosive gas atmosphere is not likely to occur in normal operation, but, if it does occur, will exist for a short period only.
- **Zone NE**: Zone of negligible extent such that if ignition did occur it would have negligible consequences.

The second step in the identification and assessment of the explosion risks caused by the formation of explosive atmospheres is the identification of release sources. For the purpose of hazardous area classification, a source of release is defined as a point from which a flammable gas, vapour or liquid may be released into the atmosphere. All process equipment, pipes, valves or elements with flammable substances susceptible to releases during normal operation are considered potential release sources.

Three grades of release are defined in terms of their likelihood, frequency and duration:

- **Continuous** grade of release: A release that is continuous or nearly so, or that occurs frequently and for short periods.

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- **Primary** grade of release: A release that is likely to occur periodically or occasionally in normal operation i.e. a release which in operating procedures, is anticipated to occur.
- **Secondary** grade of release: A release that is unlikely to occur in normal operation and, in any event, will do so only infrequently and for short periods i.e. a release which, in operating procedures, is not anticipated to occur. Such releases may be of known size e.g. fracture of a drain, or unknown size e.g. corrosion hole.

The grade of release is dependent solely on the frequency and duration of the release. It is completely independent of the rate and quantity of the release, the degree of ventilation, or the characteristics of the fluid, although these factors determine the extent of vapour travel and, in consequence, the dimensional limits of the hazardous area.

In order to be able to estimate the type of a zone, especially in an enclosed area such as the fuel cell cabinet, two more factors are required: degree of dilution and availability of ventilation.

The following three degrees of dilution are normally recognized:

- **High** dilution: The concentration near the source of release reduces quickly and there will be virtually no persistence after the release has stopped.
- **Medium** dilution: The concentration is controlled resulting in a stable zone boundary, whilst the release is in progress and the explosive gas atmosphere does not persist unduly after the release has stopped.
- **Low** dilution: There is significant concentration whilst release is in progress and/or significant persistence of an explosive gas atmosphere after the release has stopped.

The availability of ventilation has an influence on the presence or formation of an explosive gas atmosphere. Thus, the availability (as well as the effectiveness) of ventilation needs to be taken into consideration when determining the type of zone. Three levels of availability of the ventilation should be considered:

- **Good**: Ventilation is present virtually continuously.
- **Fair**: Ventilation is expected to be present during normal operation. Discontinuities are permitted provided they occur infrequently and for short periods.
- **Poor**: Ventilation which does not meet the standard of fair or good, but discontinuities are not expected to occur for long periods.

8.2. Hazardous Area Classification for the RESCUE System

A leak occurring inside the cabinet is classified as a secondary grade of release, as it is unlikely to occur during normal operation and, if it does occur, the system automation and interlocks will detect it and initiate a shutdown at approximately 40% of the Lower Flammable Limit (LFL), thereby limiting its duration to a short period. The degree of dilution is considered high, since the air change rate within the cabinet will be sufficient to ensure that any potential release is maintained below the LFL. In addition, the availability of ventilation is considered good, as ventilation is continuously operating, remains active in the event of a leak, and is equipped with a flow sensor hardwired to the safety circuit.

Consequently, and taking into account the theoretical background analysed in the previous paragraph, the interior of the cabinet is classified as **Zone 2 NE**, and therefore ATEX-certified equipment is not required, with the exception of sensors, the ventilation fan, and the pumps (see the following chapter).

With regard to the hazardous area classification for the methanol storage tank and cabinet feeding equipment, the direct example approach of the Energy Institute Model Code of Safe Practice, Part 15 has been followed. The ullage space of the methanol tanks is classified as a **Zone 0** hazardous area, as methanol vapours are continuously present. The area extending 1.5 m in all directions from the external tank breathing point is classified as **Zone 1**, since the point is considered a primary grade of release. Taking API RP 505 into consideration as well, **Zone 2** is also applicable within a 3 m radius from the tank breathing point. The connection points around the tanks, the road tanker and the cabinets are also considered primary grade sources of release; therefore, the area within a 1 m radius around each connection point is classified as **Zone 1**. In the case where a dry disconnect coupling is used, the hazardous area may be downgraded to Zone 2, as any minor releases expected during coupling and decoupling are anticipated to be minimal. The external methanol pump may give rise to fugitive emissions, which should be regarded as primary grade release sources associated with a **Zone 1** hazard radius of 0.3 m. Furthermore, a **Zone 2** hazardous area with a radius of 3 m is defined around the pump, to account for the potential of secondary grade releases.

As far as the hydrogen bundle and cabinet feeding equipment is concerned, the British Compressed Gases Association (BCGA) has estimated the extend of the **Zone 2** hazardous area as follows, using gas dispersion modelling:

- Horizontal release, 640 mm horizontally with a width of 60 mm.
- Vertical release, 260 mm vertical with a width of 15 mm with a maximum horizontal hazardous area of 130 mm.

The above mentioned Zone 2 covers secondary releases from the following potential leak paths

- on a gas cylinder, where experience has shown that, typically, a leak path will originate from the valve to cylinder neck joint, the valve gland or the valve outlet (where it does not close correctly after use)
- connections in small bore pipework systems

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- pigtails or coupling hoses, which connect the gas supply to the pipework system
- flexible hose couplings, through wear and tear

To cover any fugitive emissions that may occur, a **Zone 1** of nominal 1 m radius shall be placed around the end of any discharge point of the hydrogen pressure relief valves. The extent of the required **Zone 2** around the relief valves as well as the hazardous area classification for the hydrogen purge line will be determined based on the design flow rate.

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9. Equipment Selection in Hazardous Areas

9.1. Mechanical Equipment

According to standard ISO 80079.36 and taking into account the requirements of 2014/34/EU directive, mechanical equipment (non-electrical) for potentially explosive atmospheres from flammable liquids, gases and dusts is divided in three categories in the same manner as for electrical equipment:

Table 15 – Requirements for non-electrical equipment in hazardous areas..

CATEGORY / EPL	DESCRIPTION
Category 1 Equipment Protection Level, EPL a	Equipment in which formation of ignition sources is prevented during normal operation, during expected malfunction but also in cases of rare malfunction as well. Equipment of that category is suitable for use in areas where the presence of an explosive atmosphere is continuous, i.e. Zone 0
Category 2 Equipment Protection Level, EPL b	Equipment in which formation of ignition sources is prevented during normal operation, during expected malfunction but not in cases of rare malfunction. Equipment of that category is suitable for Zone 1.
Category 3 Equipment Protection Level, EPL c	Equipment in which formation of ignition sources is prevented only during normal operation but not in cases of malfunctions (either expected or rare). Equipment of that category is suitable for Zone 2.

9.2. Electrical Equipment

Even at low voltages, electrical sparking and hot surfaces may occur as sources of ignition in electrical apparatus (e.g. on making and breaking circuits and as a result of stray electric currents). Electrical equipment may therefore be used in hazardous places only if it complies with Annex II of Directive 1999/92/EC. In all hazardous classified areas, equipment must be selected on the basis of the categories set out in Directive 2014/34/EU.

The equipment for use in hazardous areas, as these are described in the previous chapter, shall have the following marking in accordance with Directive 2014/34/EU:

CE Ex II 1-3 G Ex* IIA-IIC T1-T6

Below is an explanation of the symbols in the above order:

- CE means that the equipment can be sold, circulated and used within the European Union
- Ex means that the equipment is manufactured for use in explosive atmospheres
- The **II** sign means that equipment is of group II for use in above ground installations other than mines (while group I equipment is suitable for use in mines susceptible to firedamp)

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- The numbers **1-3** indicate the category of protection that equipment has. Category 1 equipment can be used in all Zones (0, 1, 2), Category 2 equipment can be used in Zones 1 and 2 and Category 3 equipment can only be used in Zone 2 hazardous area
- The **G** sign indicates that the equipment has been manufactured for use in explosive atmospheres formed by gases or vapours (G: Gas), while the D sign indicates that the equipment has been manufactured for use in explosive atmospheres formed by combustible dusts (D: Dust). In some cases, equipment manufacturers include both symbols (G/D)
- The **Ex** sign indicates that the equipment has been manufactured following the latest standards on explosion protection. The ***** sign is substituted by a series of codifications regarding the type of protections with which the equipment has been manufactured
- **IIA-IIC** denotes the equipment subgroup. As far as gases are concerned there are three equipment subgroups: IIA, IIB, IIC that reflect different minimum ignition energies. The equipment subgroup requirements become progressively more stringent from Group IIA to Group IIB and then to Group IIC. IIC subgroup apparatus may be used in place of subgroup IIA apparatus and subgroup IIC can be used in place of apparatus for both subgroups IIA and IIB, but the converse is not true
- The **T1-T6** sign indicates the temperature class of equipment. The temperature class specifies the maximum permitted surface temperature of equipment to prevent ignition of the surrounding explosive atmosphere. Temperature classes range from T1 to T6, with T1 allowing a maximum surface temperature of 450° C and T6 limiting it to 85° C. The selected temperature class must always be lower than the ignition temperature of the flammable gas or vapour present, providing protection against ignition due to hot surfaces.

Considering all of the above, the marking of the ATEX certified equipment of the RESCUE system shall be the following:

CE Ex II 2 G Ex* IIC T2

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10. Emergencies

The following sections present the basic emergency guidelines in case the system operates outside the safe operating limits. The emergency plan will be further developed with detailed emergency scenarios as more details are added to the system design, such as equipment characteristics and safety devices, as well as by taking into account the results of the consequence modelling.

Considerations that emergency procedures will address are the following:

- procedures to be followed by employees who remain to operate critical systems before they evacuate;
- procedures to account for all personnel after an emergency evacuation has been completed;
- rescue and medical duties for those employees who are to perform them;
- the preferred means of reporting fires and other emergencies;
- names and regular job titles of persons responsible for providing further information or explanation of duties under the emergency plan;
- actions to be taken by the initial-response personnel;
- appropriate fire-suppression response;
- establishing and maintaining communications;
- appropriate medical response;
- requesting outside assistance;
- possible media coverage;
- salvage and restoration operations;
- establishing a command post with a pre-designated line of authority;
- hazardous material inventory.

Emergency procedures should be reviewed periodically to ensure that the procedures are relevant and up to date.

10.1. Safety Signage and Equipment

Operating personnel shall ensure that all warning signs and placards are in their appropriate place and clearly displayed. Methanol solution and hydrogen SDS in local language, as provided by the supplier, shall be always readily available to operating personnel on site. Safety signage shall include as a minimum:

Table 16 – Minimum safety signage.

DESCRIPTION	SAFETY SIGNAGE
CLP hazard pictograms for methanol	  
CLP hazard pictograms for hydrogen	 
CLP hazard and precautionary	H225: Highly flammable liquid and vapor. H301 + H311 + H331: Toxic if swallowed, in contact with skin or if inhaled. H370: Causes damage to organs (Eyes, Central nervous system).

DESCRIPTION	SAFETY SIGNAGE		
statements for methanol	P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking. P233: Keep container tightly closed. P240: Ground/bond container and receiving equipment. P241: Use explosion-proof electrical/ ventilating/ lighting/ equipment. P242: Use only non-sparking tools. P243: Take precautionary measures against static discharge. P260: Do not breathe dust/ fume/ gas/ mist/ vapors/ spray. P264: Wash skin thoroughly after handling. P270: Do not eat, drink or smoke when using this product. P271: Use only outdoors or in a well-ventilated area. P280: Wear protective gloves/ eye protection/ face protection. P301 + P310 + P330: IF SWALLOWED: Immediately call a POISON CENTER/doctor. Rinse mouth. P303 + P361 + P353: IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/ shower. P304 + P340 + P311: IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER/ doctor. P307 + P311: IF exposed: Call a POISON CENTER or doctor/ physician. P362: Take off contaminated clothing and wash before reuse. P370 + P378: In case of fire: Use dry sand, dry chemical or alcohol-resistant foam to extinguish. P403 + P233: Store in a well-ventilated place. Keep container tightly closed. P403 + P235: Store in a well-ventilated place. Keep cool. P405: Store locked up. P501: Dispose of contents/ container to an approved waste disposal plant.		
CLP hazard and precautionary statements for hydrogen	H220: Extremely flammable gas. H280: Contains gas under pressure; may explode if heated. P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking. P377: Leaking gas fire: Do not extinguish, unless leak can be stopped safely. P381: In case of leakage, eliminate all ignition sources. P403: Store in a well-ventilated place.		
Minimum prohibition signs			

The following shall be readily available on site in case of an emergency:

1. A complete spill kit that shall include:

- Various types and sizes of sorbent materials (vermiculite or activated carbon, sorbent pads).
- Non-sparking shovel to disperse the sorbent materials.
- Yellow caution tape or other barrier devices to isolate the area.
- Drum or container to hold the collected waste material.

2. Industrial first aid kit

3. An infrared temperature detector should be available to detect flames

4. Hydrogen leak detector

5. Methanol leak detector

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6. Emergency personal protective equipment

- Fire retardant and antistatic clothing and boots
- Antistatic protective gloves
- Goggles giving complete protection to the eyes
- Respiratory protection with recommended filter type of AX

All PPE shall be CE-marked and certified according to European standards. The supplier shall verify that they are suitable for methanol. They must be inspected and maintained in accordance with the equipment manufacturer's instructions. They shall be easily accessed by all personnel and not be locked up. PPE should be replaced at first signs of wear.

10.2. Basic Principles in Case of an Emergency

- NEVER PUT YOURSELF IN DANGER
- In case of fire, immediately call the fire department.
- Wear proper emergency PPE.
- Use the infrared temperature detector to detect invisible flames.
- The first indication of a small hydrogen flame is likely to be the hissing noise of the gas leak and perhaps the intermittent shadows from the thermal gradients of the flame.
- Due to the high pressure needed for storage (350-700 bar), a gaseous hydrogen leak produces a noise that can reach 130-140 dB. (ear damage can occur above 90 dB and pain can be experienced from 120 dB).
- Stop or reduce methanol solution or hydrogen release rate at the point of release if it can be done safely. Normally, a hydrogen fire should not be extinguished until the hydrogen source has been isolated, because of the danger of ignition of a large combustible premixed cloud that could develop from unburnt hydrogen.
- Isolate (pressure, gas supply, electricity) fuel cell and storages (each one from the others).
- Eliminate all sources of ignition to a safe standoff distance from the point of release and nearby methanol solution pooling. Do not try to light any appliance. Do not touch any electrical switches.
- Evacuate all persons not wearing protective equipment from the area of the spill or leak.
- If possible, system components around a flame may be cooled with water to prevent mechanical failure due to decreased strength at elevated temperatures.
- Do not walk through spilled methanol solution. Avoid skin contact and inhalation.
- Stay upwind of point of release.
- ALWAYS stay away from tanks and cylinders engulfed in fire.

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- Containers may explode when heated.
- Ruptured cylinders may rocket.
- Spontaneous ignition of a sudden hydrogen release is possible.
- Prevent methanol solution entry into waterways, sewers, basements or confined areas.
- Clean up methanol solution spill with the appropriate equipment in the spill kit.
- Ensure that medical personnel are aware of the material(s) involved and take precautions to protect themselves.
- Move victim to fresh air if it can be done safely.
- Do not perform mouth-to-mouth resuscitation if the victim ingested or inhaled methanol; wash face and mouth before giving artificial respiration. Use a pocket mask equipped with a one-way valve or other proper respiratory medical device.
- Administer oxygen if breathing is difficult.
- Remove and isolate the contaminated with methanol clothing and shoes.
- In case of contact with methanol, immediately flush skin or eyes with running water for at least 20 minutes.
- Wash skin with soap and water.
- In case of burns, immediately cool affected skin for as long as possible with cold water. Do not remove clothing if adhering to skin.
- To reach safely a casualty, it is necessary to verify that he's not submitted to an electrical current.
- Keep victim calm and warm.
- Effects of exposure (inhalation, ingestion or skin contact) to methanol solution may be delayed.

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11. Training Plan

This Chapter describes the activities that will be performed throughout RESCUE project lifecycle to ensure proper personnel education and training.

11.1. Responsibilities

The partner responsible for the preparation and implementation of the training plan and revising it, when required, is PROACT. Training records will be maintained by the management safety team according to the form provided in the Appendix. The members of the management safety team are also responsible for distributing the training material to the involved personnel of each partner.

11.2. Description

All involved personnel will undergo safety training on all identified hazards that pertain to each WP prior to beginning work. This training will be conducted as follows:

1. General training on:

- system hazards
- fuel hazards
- pressurised cylinder handling
- fire incident
- small and large spillages
- first response
- emergency plan
- response to alarms
- stop work
- personal protective equipment
- safety data sheets
- lessons learnt from HIAD

This training is conducted:

- in the beginning of WP2 by PROACT for all partners
- immediately upon a new hire and prior to the start of work
- once a year as refresher training by PROACT for all partners

This course will include relevant training material from the HyFacts project.

2. Project specific training on:

- system operation
- calibration
- maintenance
- alarms

- interlocks
- safety plan
- written procedures

Refresher project specific training shall be conducted once a year.

3. Emergency specific training shall be provided towards the end of the project for personnel who will respond to an incident. The training topics will include, in addition to general training subjects, at a minimum the following:

- arrival on scene
- rescue
- exposure protection
- incident treatment
- incident recovery

This course will be based on relevant training material from the Center of Hydrogen Safety, as well as from the HyResponder project.

4. ISV-specific training will be conducted during the first session of each safety study (e.g., HAZID, HAZOP, Bowtie), to ensure that all members of the technical safety team are familiar with the purpose, methodology, and specific terminology of each study

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12. Reporting of Safety Events and Lessons Learnt

By learning about likelihood, severity, causal factors, setting, and relevant circumstances regarding safety events, teams are better equipped to prevent similar, perhaps more serious, events in the future. To be effective, this process requires a thorough investigation, a comprehensive report, and a great deal of information sharing as openly and thoroughly as possible.

An INCIDENT is an event that results in:

- A lost-time accident and/or injury to personnel
- Damage to project equipment, facilities or property
- Impact on the public or environment
- An emergency response or should have resulted in an emergency response

A NEAR MISS is an event that, under slightly different circumstances, could have become an incident.

The investigation of an incident will be initiated by the technical safety team as promptly as possible. This includes first placing the site in a safe condition, securing evidence and producing a formal event report. The event report will include:

- Date of incident
- Country that the incident has occurred
- Date investigation began
- Release type
- Release substance
- A description of the incident including actions before the incident, progress of the incident
- The physical consequences
- Interviews with involved personnel
- Photographic evidence
- The causes of the incident, as identified through the use of the Tripod Theory of Incident Causation or Tripod Beta method
- The factors that contributed to the incident
- Emergency actions
- Lessons learnt from the incident
- Any recommendations resulting from the investigation
- Implementation action plan for the proposed measures

The event report will be reviewed with all affected personnel whose job tasks are relevant to the incident findings and then it will be approved by the management safety team.

The technical safety team will promptly address and resolve the incident report findings and recommendations. Resolutions and corrective actions will be documented.

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When required by contract or law, the management safety team will report to the appropriate authority within required timeframes. Records will be kept pursuant to legal requirements.

All communications to the public will occur through the management safety team.

The management safety team is also responsible for creating a leaflet in order to pass along the lessons learnt from the incident and other necessary information to employees. If deemed necessary, additional training will be provided for the staff.

In addition, any safety-related event that may occur during execution of the project will be reported by the management safety team to the European Commission's Joint Research Center dedicated mailbox (JRC-PTT-H2SAFETY@ec.europa.eu), which manages the European hydrogen safety reference database, HIAD and the Hydrogen Event and Lessons Learned Database, HELLEN. For reporting in HELLEN, the input form provided in the following link will be used:

https://ec.europa.eu/eusurvey/runner/CleanH2_HELLEN

13. Management of Change (MOC)

In the context of the Management of Change (MOC) procedure, a 'change' refers to any modification in materials, technology, equipment, procedures, personnel, or system operations. All modifications that are not replaced "in kind" will be reviewed for their effect on safety vulnerabilities and to ensure that they do not create any unintended detrimental consequences.

Anyone involved in the project may identify and propose a change to the technical safety team, in accordance with the current procedure. The technical safety team will then fill in the form "MOC", that is attached in the Appendix of the present safety plan, in order to document:

- the title of the proposed change
- the estimated cost
- the name of the proposer
- proposed start date
- the area of the proposed change
- the type of implementation (permanent or temporary)
- the maximum duration for the implementation of the temporary change
- the purpose of the proposed change, including any relevant background or similar historical cases
- the significant risks involved during and after the implementation of the change
- the necessary actions for risk control in collaboration with responsible parties, adhering to established timelines
- means of effective communication with all stakeholders impacted by the change
- the expected benefits of the change in terms of safety, efficiency, cost reduction, etc.

The management safety team:

- approves the MOC form
- ensures that the necessary resources and approvals for the change are secured
- confirms that all individuals affected by the change have been informed
- reviews and approves the action plan
- reviews and approves the proposed duration of temporary changes
- verifies the restoration of temporary changes to their original state and ensures they have not become permanent
- completes and maintains the form "Change Register", that is attached in the Appendix of the present safety plan.

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14. Conclusions

The hydrogen safety planning detailed in this deliverable provides a foundational framework that directly supports the RESCUE project's overarching objectives: the safe development and deployment of a dual-fuel HT–PEM fuel cell system for civil protection applications. Through the identification of hazards, risk assessment via HAZID, HAZOP and Bowtie methodology, and the definition of mitigation strategies, the safety plan ensures that critical safety requirements are embedded from the earliest design phases. These results contribute to achieving regulatory compliance, minimizing operational risks, and enhancing system resilience. Furthermore, the outcomes of this planning effort will inform and guide the subsequent design (WP3–WP5), integration, testing (WP6–WP7), and training activities (WP8), ensuring consistency and safety throughout the system's lifecycle. Regular updates will ensure adaptability to design advancements and real-world findings, fostering a continuous improvement approach. Ultimately, this deliverable enables a harmonized and proactive safety culture across all project partners, feeding into dissemination (WP10) and setting a robust precedent for future hydrogen-based emergency response systems.

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15. Appendix

List of Attached Documentation

1. "H2_SDS.pdf"
2. "Methanol_SDS.pdf"
3. "Methanol Solution_SDS.pdf"
4. "MultiTherm 503_SDS.pdf"
5. "P&ID_V0.1.pdf"
6. "P&ID_Nodes 1-6_V0.1.pdf"
7. "P&ID_Node 7_V0.1.pdf"
8. "HAZID_V0.1.xlsx"
9. "HAZOP_V0.1.xlsx"
10. "Bowtie Diagrams_V0.1.pdf"
11. "Training Record_V1.1.docx"
12. "Completed Training Records.pdf"
13. "Change Register_V0.1.docx"
14. "MOC_V0.1.docx"

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