



Norwegian University of
Science and Technology



Air Liquide

Identification and prioritisation of hazards for LH2 transfer operations

ELVHYS Dissemination Conference

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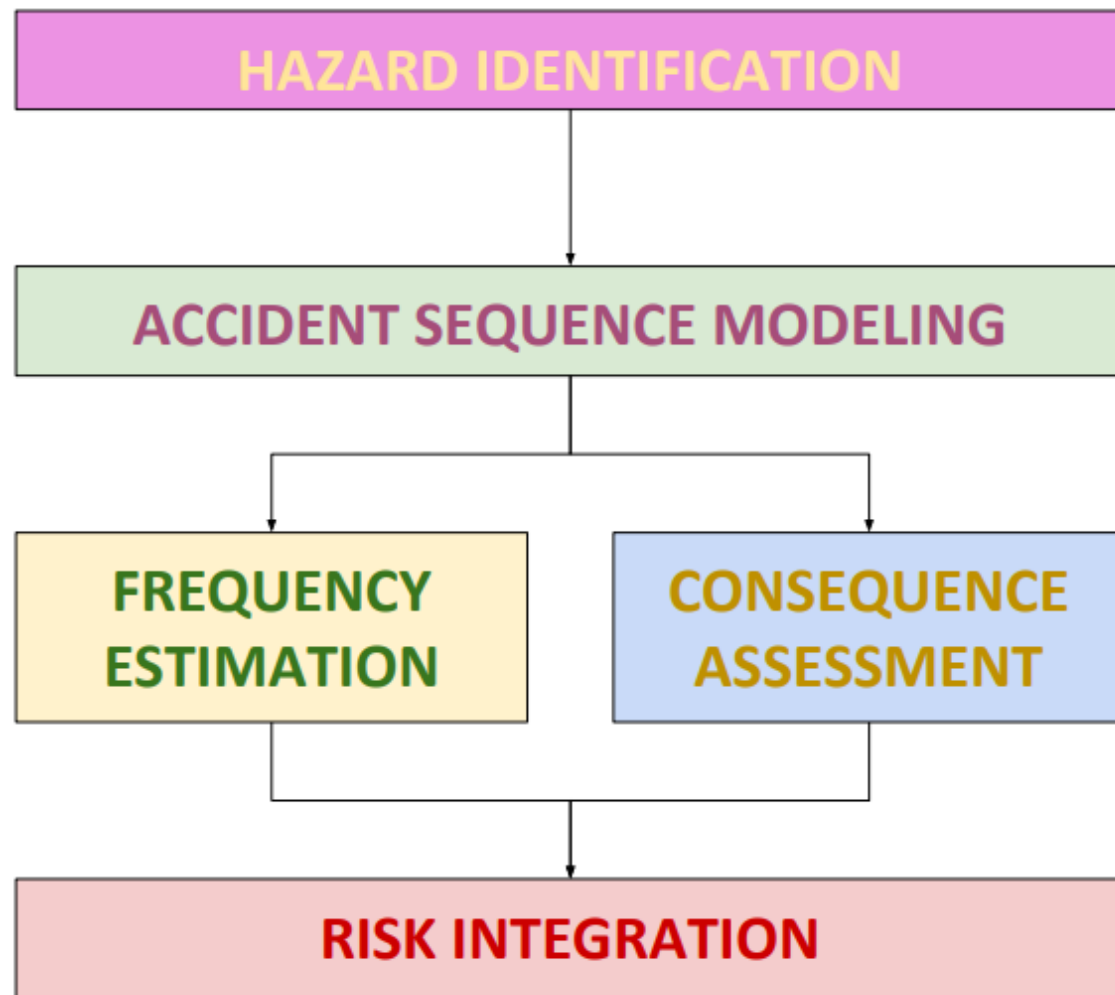


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OUTLINE

- Introduction
- Major Steps for QRA
- Hazard Identification
- Case Study: Liquid Hydrogen Bunkering
- Conclusions

MAJOR STEPS FOR QRA



WHAT CAN GO WRONG?

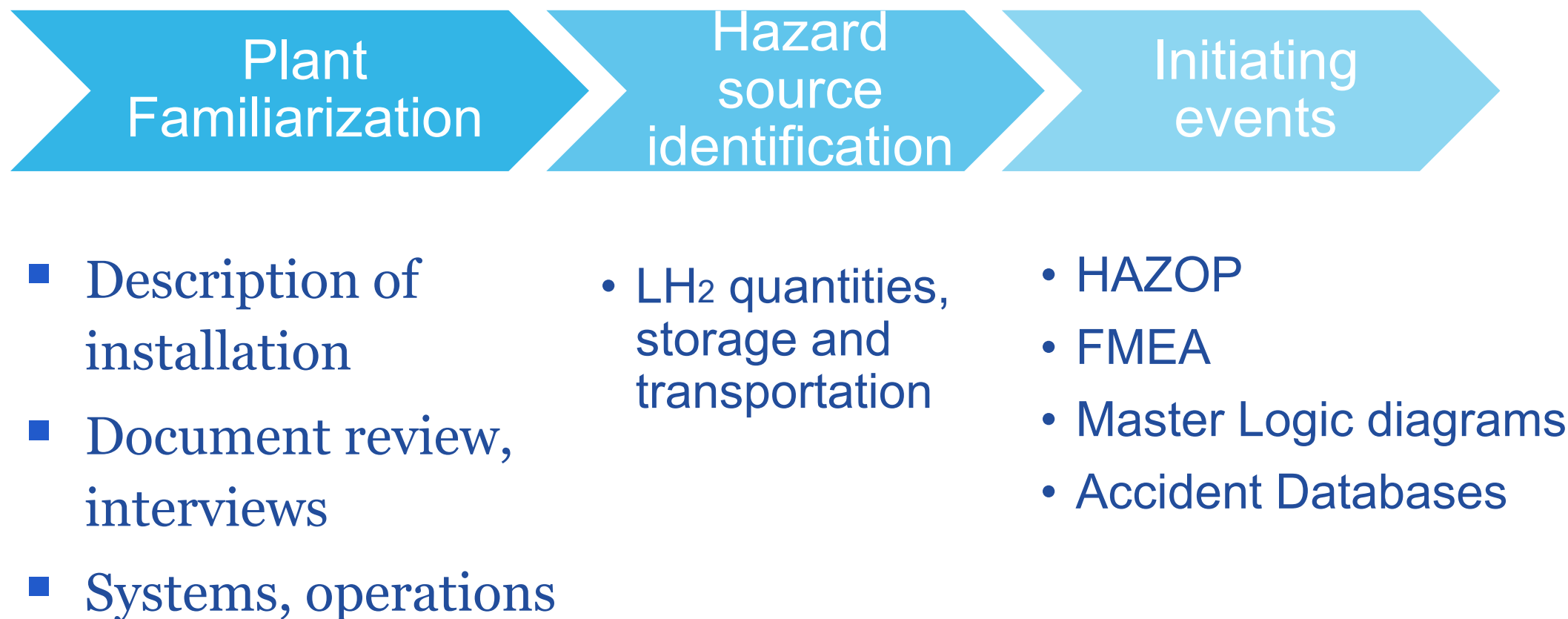
WHAT ARE THE POSSIBLE CONSEQUENCES?

HOW OFTEN THIS CAN HAPPEN?

HOW FREQUENT ARE THESE CONSEQUENCES?

TASK 5.1.1

HAZARD IDENTIFICATION

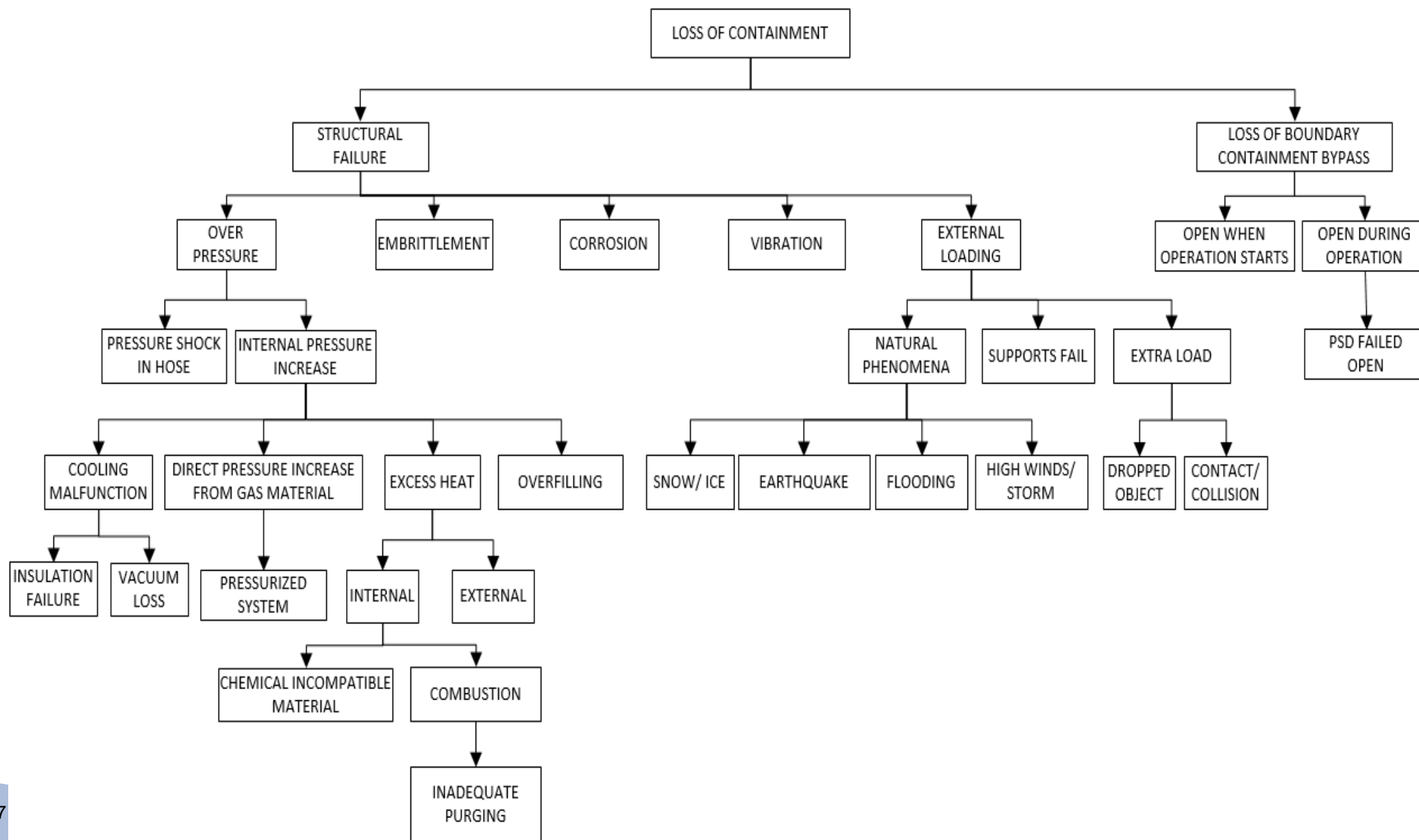


MASTER LOGIC DIAGRAM FOR HAZARD IDENTIFICATION



- It is a Logic Diagram and starts with a Top Event, considered undesirable.
- The top event is the “Loss of Containment”
- It continues decomposing into simpler events until events challenging safety systems are identified
- These are the initiating events

MLD FOR LOSS OF CONTAINMENT OF LH₂ SYSTEMS



HAZOP study

HazOp analysis (EN 61882:2016) was applied as support hazard identification phase for the specific systems and operations of concern for ELVHyS Project.

This required:

- Definition of reference P&IDs (Piping and Instrumentation Diagrams) and Operative Procedures for cases of interest
- Application of the HazOp technique to each stage of the operative procedure

Overall results:

- List of top events and causes
- List of effective safeguards in place

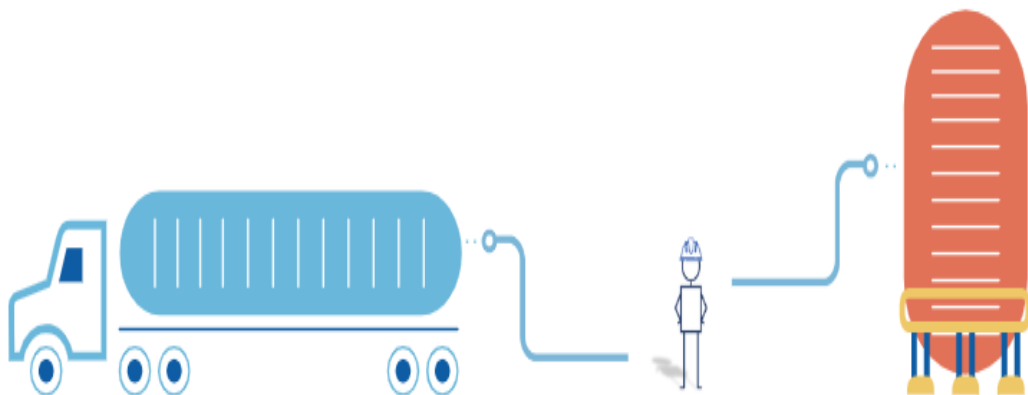
PAST ACCIDENTS FROM DATABASES

- Material defect, e.g embrittlement, corrosion, material incompatibility
- External fire in the vicinity of a tank or truck
- Safety disc failures
- Air in system owing to inadequate purging
- Loss of vacuum (insulation failure)
- Leakage from valves, welds, isolation and sealing failures, during disconnection of loadings arms or connection during transfer of hydrogen
- Operator errors related to containment by-pass (valves left open or closed)
- Overpressure created in tank and malfunction of PSVs (left open)
- Overpressure in pipes owing to inadequate emptying of pipes
- Natural phenomena (e.g snow, heavy rain)
- External load (collision, vibration, e.t.c)
- Plugged LH2 tank, owing to vent failure
- Hydrogen accumulation in pipes

CASE STUDY: Tank Filling from Trailer



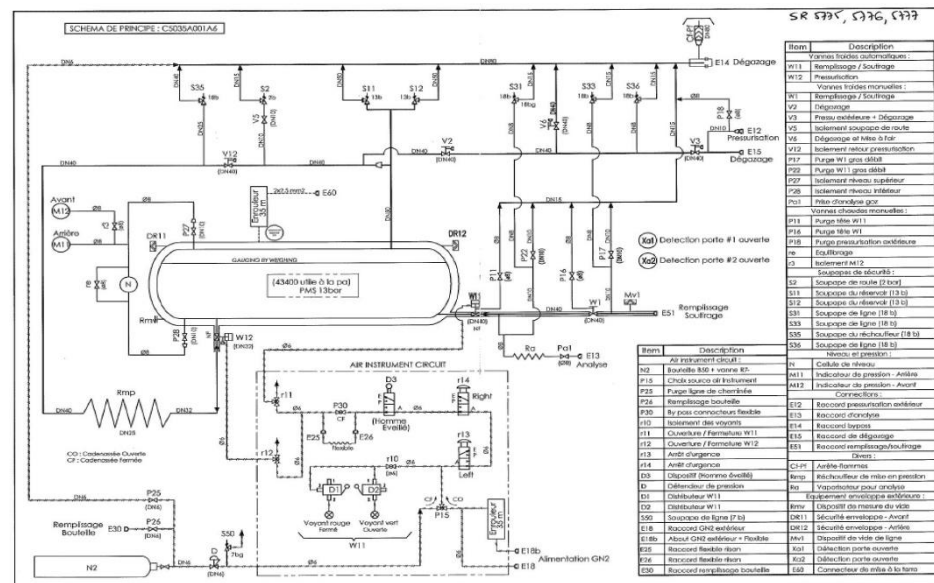
CONVENTIONAL LH₂ delivery for STATIONARY tank



LIQUID TRAILER

OPERATOR

LIQUID STORAGE



Trailer arrival



Trailer departure



Trailer connections

Hose Prefill

Delivery Pressure Management

Transfilling

Pressure Management

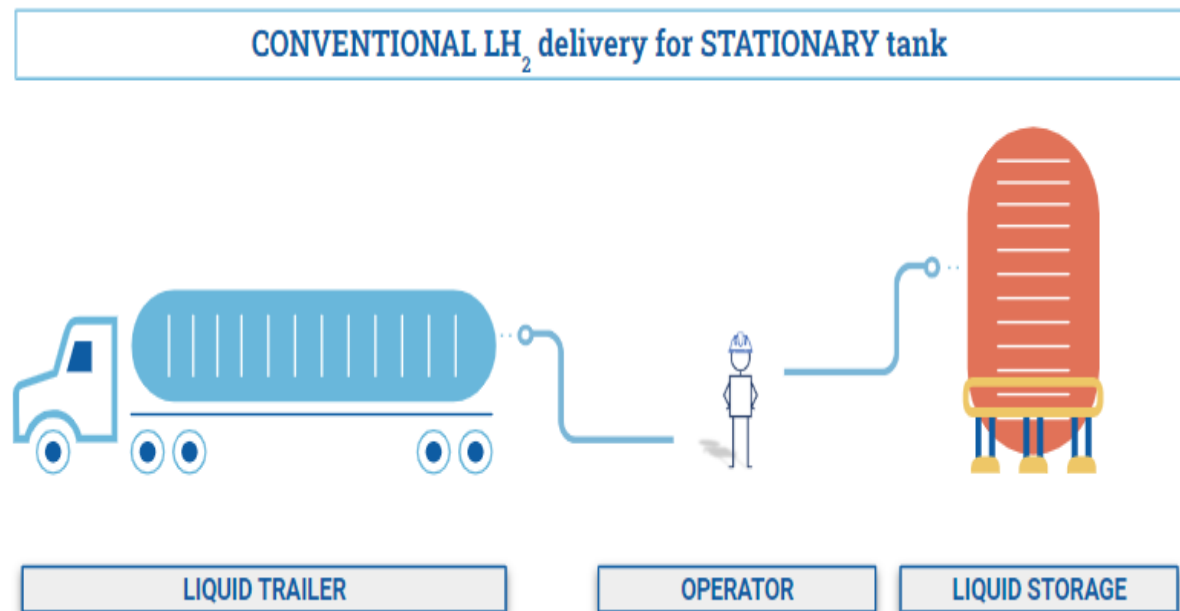
Post Fill before disconnection

Trailer venting

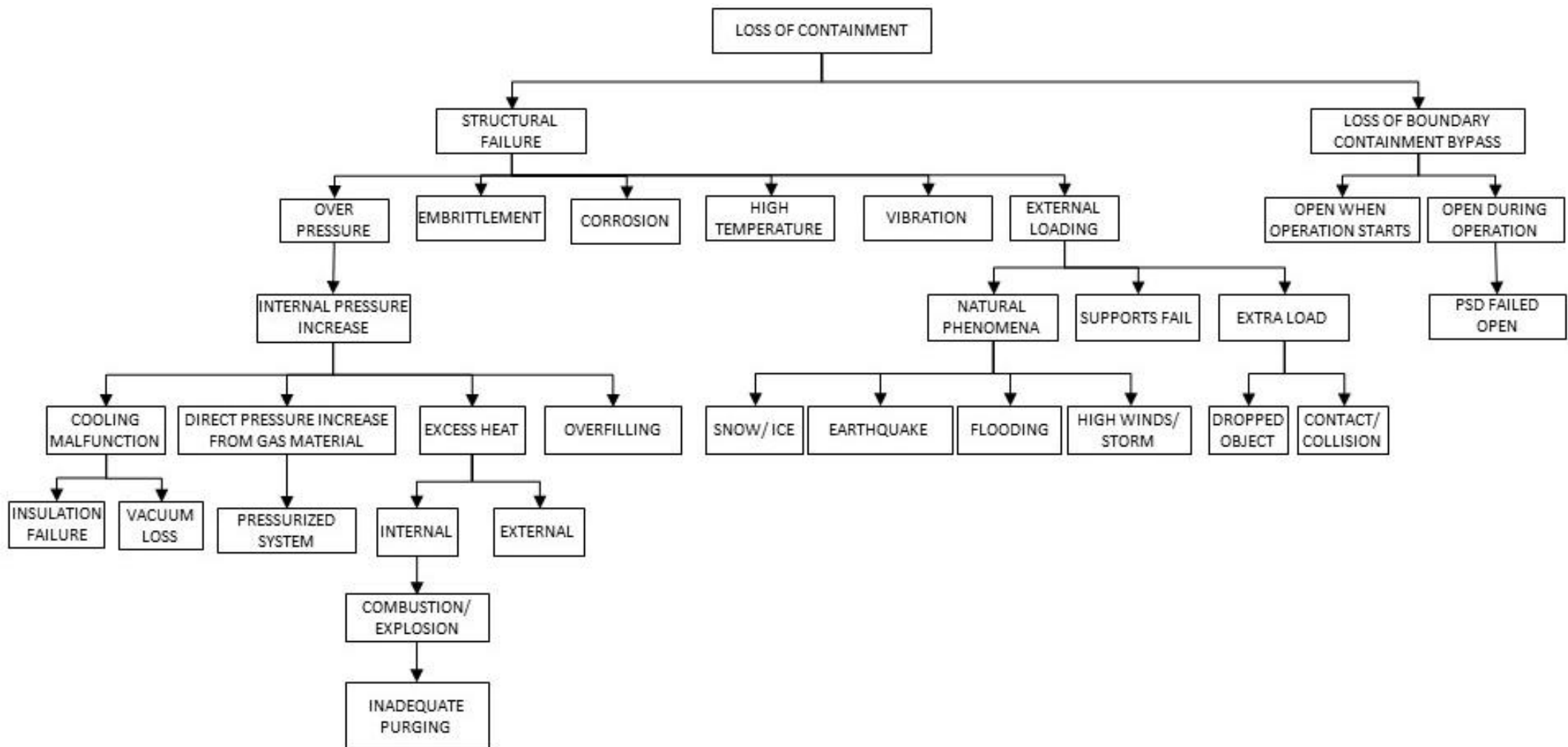
Identification of critical areas



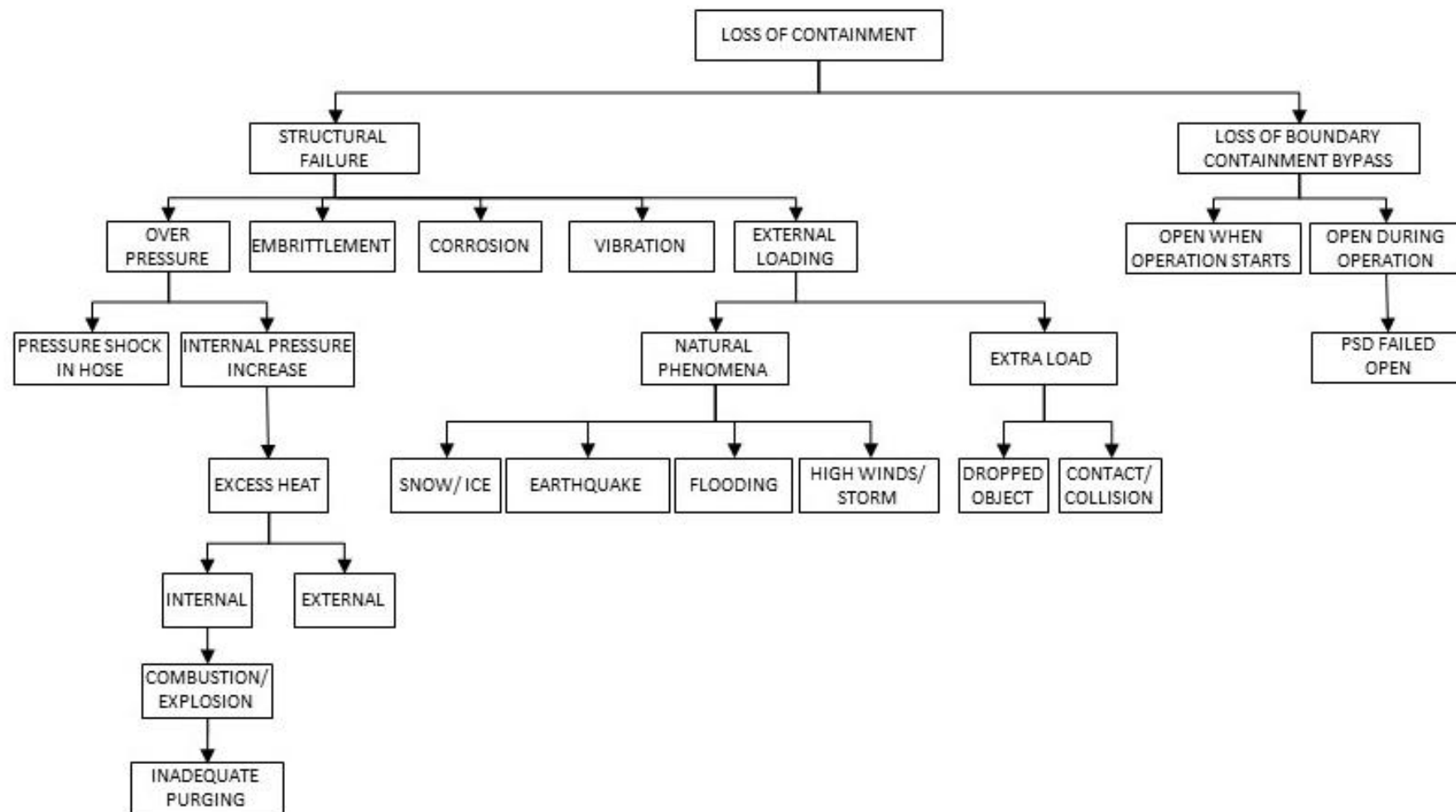
- a) Trailer area with capacity up to $57 \text{ m}^3 \text{ LH}_2$
- b) The transfer hose from the trailer to the tank (Rate 50 Kg/min)
- c) Storage tank section. It comprises the containment tank with capacity up to $80 \text{ m}^3 \text{ LH}_2$ together with the vent stack.



CASE STUDY: MLD of LH₂ storage tank



CASE STUDY: MLD of LH₂ hose during unloading



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HAZOP study – Results



■ HazOp tables

ID	Parameter	Guideword	Cause	Consequence	Detection	Safeguards
S03	Level (in storage tank)	More	W11 and W1 do not open	No transfer	LI on the tank	
			No flow in node 2	No transfer		
			W12 and V12 close	No transfer	LI on the tank	
			Less pressure	No transfer	LI on the tank	
		Less	Leakage	Loss of containment	LI on the tank	
			External impact	Loss of containment	LI on the tank	
			More pressure	NA	LI on the tank	
			W1 fails to open	- Overpressure in L03, L04 and tank and potential for equipment damage - More level - No flow	P11 and P12	
	Pressure (in tank/pipe)	More				Requirement for opening valve; PSV: S31 and S11-14

■ List of top-events, causes and safeguards (and sizing criteria for safeguards)

Top event	Initiating event	Safety function
Loss of containment from truck	- Leakage★ - External impact ★ - Spurious opening of W11 and W1 if the hose is not connected or X100 is not connected to X101★	- Requirement for opening valves - X100 connection
Overpressure in truck tank or pipes	Spurious opening of W12 in steps 1, 2, 5, and 6 of the procedure.	- Requirement for opening valves - PSV: S35 and S11-14
Overpressure in the hydrogen transfer hose		

In e.g. case study 1 top events fall into the following categories:

- **Loss of containment**
- **Vent release of gas or liquid H₂**
- **Damage of equipment (by overpressure)**

PSV	Sizing scenarios
S11-14	- Failure of insulation system. - External fire. - Spurious opening of W12
S31 and S33	- Thermal expansion of LH2 in L04, L05, .. - Hose decoupling during step 3.
...	...

CASE STUDY: Initiating events to be quantified



LH₂ trailer

Trailer insulation failure or vacuum loss
 Excess external heat owing to nearby external fire
 High temperature, leading to BLEVE of trailer
 High pressure, owing to vaporizer malfunction or not stopped

LH₂ hoses

Excess external heat owing to nearby external fire
 Pressure shock in pipelines (Inadvertent valve closure during unloading)
 Inadequate purging or cooling of hoses
 Containment bypass during loading (e.g. premature disconnection of hose)

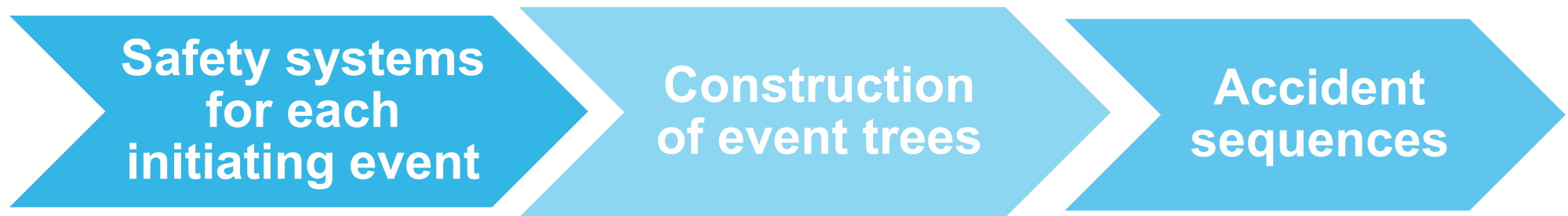
LH₂ storage tank

Tank insulation failure or vacuum loss
 Excess external heat owing to nearby external fire
 High temperature, leading to BLEVE of tank
 High pressure, owing to vaporizer malfunction or not stopped
 High level in tank due to overfilling

IEs corresponding to trailer and tank

Extra loads; e.g. a) heavy objects drop on truck, b) truck collides with other vehicle or equipment, c) truck leaves with hose still connected
 PSD valve failed open during unloading

DAMAGE STATES: ACCIDENT SEQUENCE MODELLING





CASE STUDY: Safety systems and success criteria



FRONTLINE SYSTEMS	SUCCESS CRITERIA
LH₂ Tank	
Vent (PSV)	1 out of 2
Bursting disks	1 out of 2
Stack	
High Pressure Control System	
Manual pressure reduction through blow down valve	1 out of 2 pressure indicators
High Level System	1 level indicator
Manual system (Level indicator, Operator)	Operating Procedures
Procedures for corrosion protection	Successful application of procedures and checks
Procedures for Containment bypass protection	Successful application of procedures for venting
Fire protection system	
Sprinklers	
Collision and extra load protection (external impact)	
Restricted vehicle traffic	
Tow-away interlock safety system	
LH₂ Hoses	
Overpressure protection: follow procedures for cooling and emptying lines	Successful application of procedures
PSV	Successful operation of PSVs
Collision and extra load protection (external impact protection)	
Restricted vehicle traffic	
Tow-away interlock safety system	
Boundary containment by-passing protection (e.g. inadvertent disconnection)	Leak test before LH ₂ transfer



CASE STUDY: ACCIDENT SEQUENCE MODELING



SAFETY SYSTEMS FOR INITIATING EVENT: External fire (*near tank*):

- Fire Fighting System
- Pressure Safety Valves (PSV)

External fire near tank	Fire fighting system	Pressure safety valve		SEQUENCES
IE	FFS	PSV		
			1	SAFE
			2	RELEASE FROM PSV
			3	TANK RUPTURE

DAMAGE STATE

CASE STUDY: Damage states to be quantified

- ✓ Trailer rupture
- ✓ Hose rupture
- ✓ Tank rupture

CONCLUSIONS

- MLD has been used for Hazard Identification of Liquid Hydrogen systems
- HAZOP has also been used for LH₂ transfer case studies
- Safety of transfer operations is depicted by the accident sequences developed during the first Qualitative phase of Risk assessment



Thank you for your attention

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