HySchool Webinar

Trondheim, 05.05.2023

COMPARATIVE SAFETY ASSESSMENT OF HYDROGEN STORAGE TANKS FOR HYDROGEN-POWERED BUSES

Alice Schiaroli

Department of Mechanical and Industrial Engineering

Outline

1. Hydrogen mobility
2. On board storage
3. Safety concerns
4. Safety assessment: methodology
5. Case study
6. Results
7. Conclusions
8. What’s next?

Hydrogen mobility

The **transportation** sector is one of the major contributor to GHG emissions.

The deployment of hydrogen-powered vehicles is part of decarbonization strategies aimed at meeting the target of carbon neutrality within the next decades.

Many demonstration projects worldwide are focused on **hydrogen-powered buses**.

Clean fuels

+

Public transport →

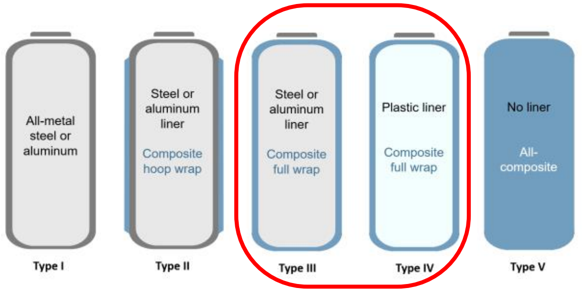
+

Electrification

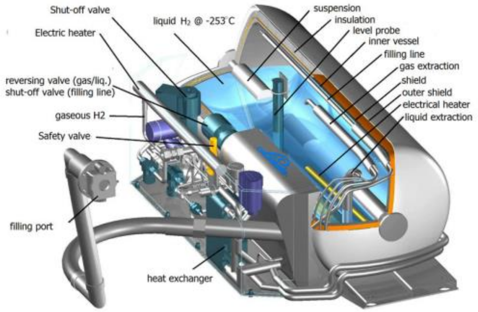
On board storage

Hydrogen is currently stored on board of hydogen-powered buses as:

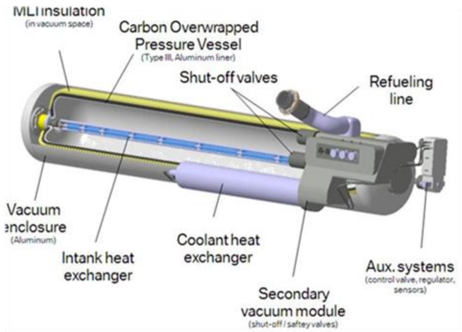
- **Compressed gas** (CH2): stored at 350-700 bar in Type III and Type IV high-pressure vessels



- **Cryogenic liquid** (LH2): stored at cryogenic temperatures (～20 K) in super insulated cryogenic tanks



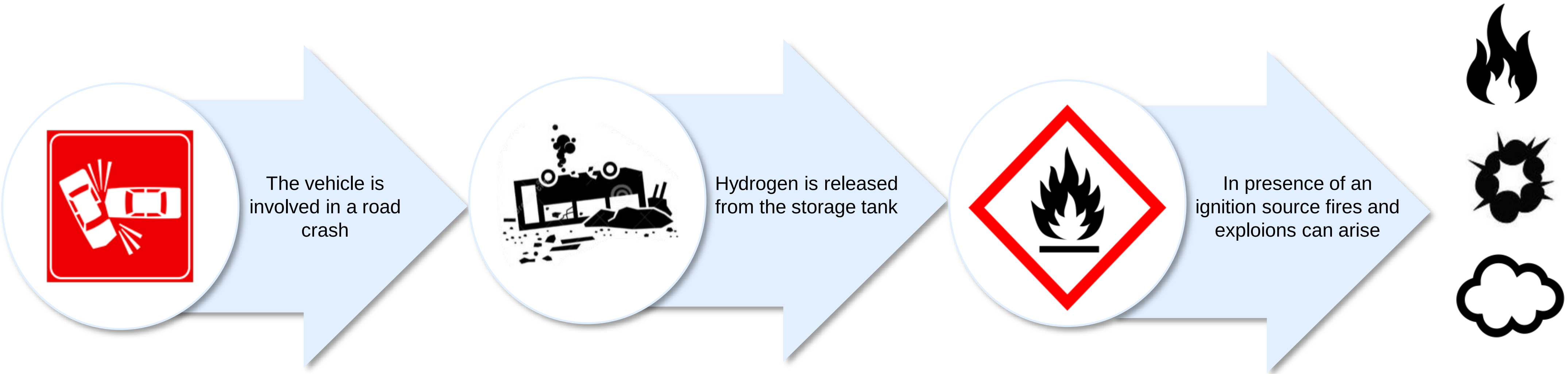
- **Cryo-compressed gas or liquid** (CcH2): stored at cryogenic temperatures and high pressure in super insultaed high-pressure cylinders



Safety concerns

Hydrogen application in transports rises **safety concerns** because of its hazardous properties.

Severe consequences can arise from an accidental **loss of integrity** of the storage tank.



Safety assessment: methodology

Definition of the **Storage Unit** (SU)

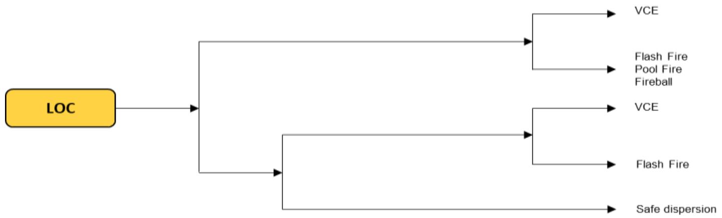
- Storage tank volume
- Hydrogen mass inventory
- Operating conditions (temperature and pressure)

Assignment of **Loss of Containment** events (LOCs)

Catastrophic rutpure of the storage tank

Leak from a hole in a connection pipe

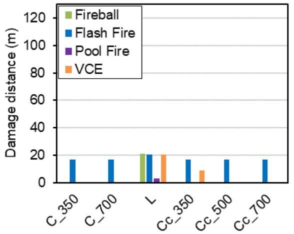
Definition of the **event tree**

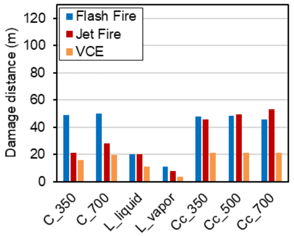


Definition of **threshold** values

Final event	Threshold value
Fireball, Jet Fire, Pool Fire	7 kW/m^2
Flash Fire	½ LFL
Vapor Cloud Explosion (VCE)	14 kPa

Calculation of **damage distances**





Case study (1)

Definition of the Storage Unit (SU)

Tank ID	Physical state	Storage pressure (bar)	Storage temperature (K)
C_350	Gaseous	350	293
C_700	Gaseous	700	293
L	Liquid	2.13	23
Cc_350	Gaseous	350	66
Cc_500	Gaseous	500	72
Cc_700	Gaseous	700	78

Damage distances are calculated under the following assumptions:

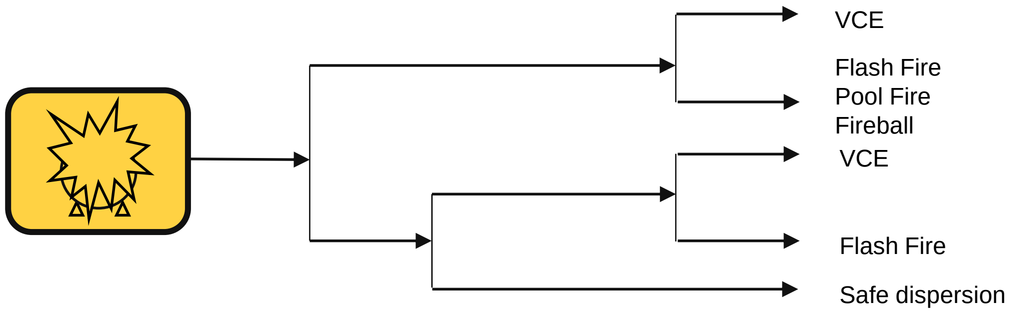
- Vessels have the **same volume** (RV);
- Vessels have the **same hydorgen content** (RM);
- Vessels have **commercial characteristics** (RC).

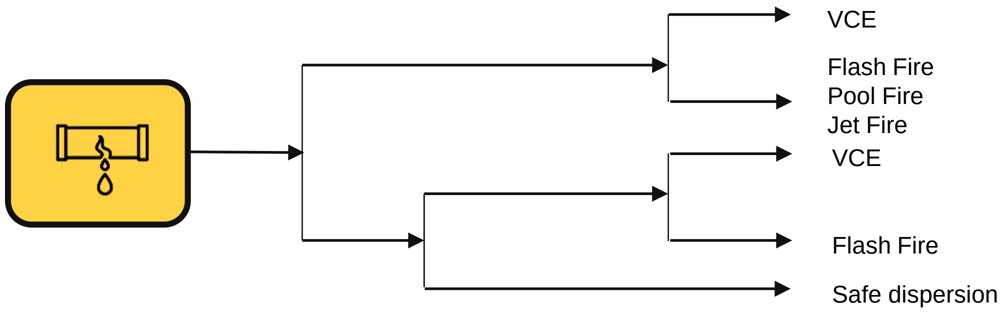
Case study (2)

Assignment of LOCs

- Catastrophic rupture of the storage tank → **LOC 1**
- Continuous leak from a 10 mm hole in a connection pipe ($d = 25\ mm$) → **LOC 2**
- Continuous leak from the full-bore rutpure of a connection pipe ($d = 25\ mm$) → **LOC 3**

Definition of the event tree





Case study (3)

Definition of threshold values

Final event	Threshold value
Fireball, Jet Fire, Pool Fire	7 kW/m^2
Flash Fire	½ LFL
Vapor Cloud Explosion (VCE)	14 kPa

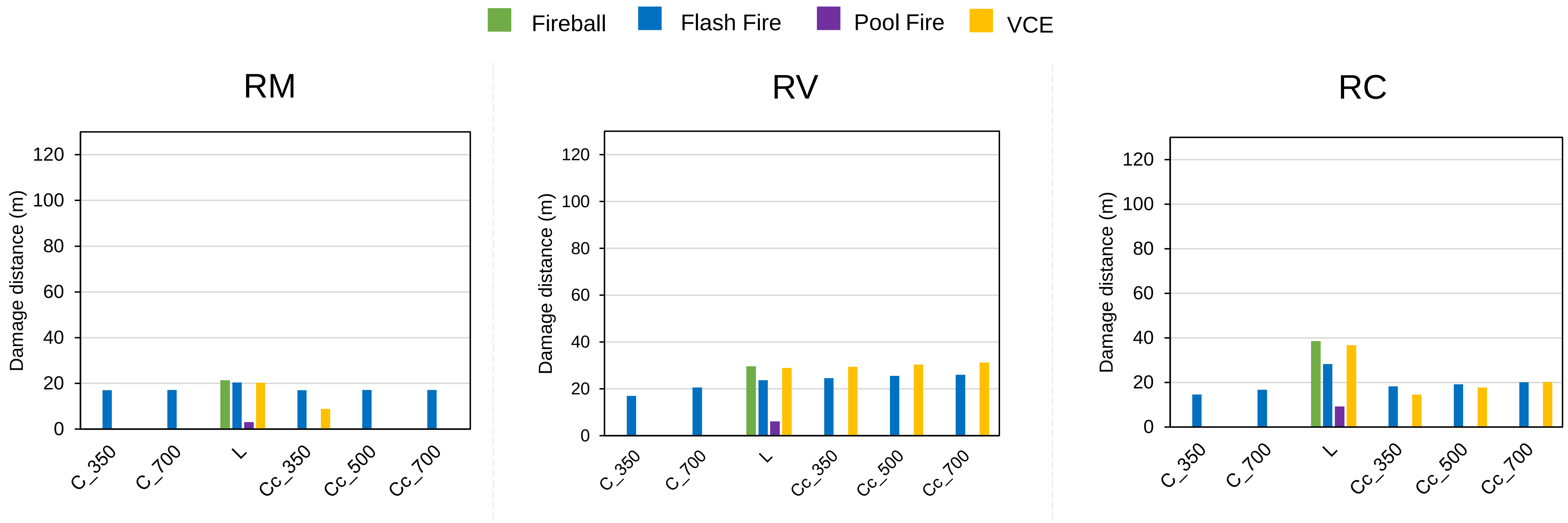
From TNO «Purple Book»

Calculation of damage distances

Damage distances are calculated with the software **PHAST 8.4** by DNV under the following assumptions:

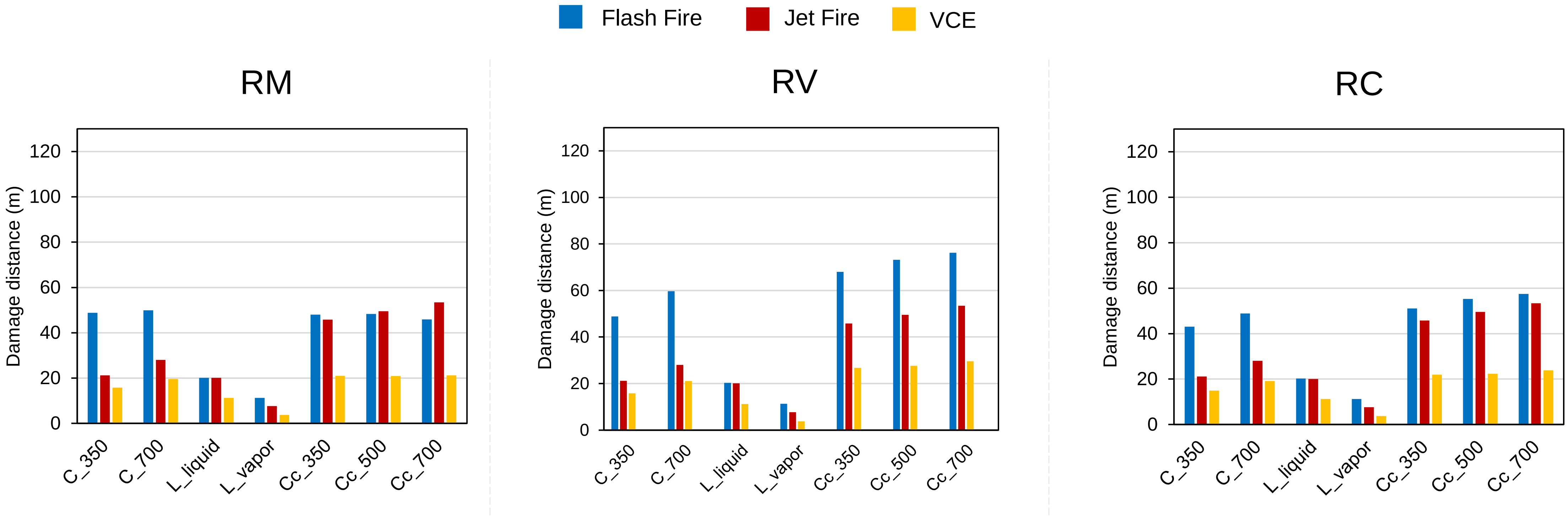
- Stable atmosphere (Pasquill's **class F**);
- Wind speed **1.5 m/s**;
- Release height **1 m**;
- Continuous leaks are simulated as holes directly in the tank.

Results: LOC 1



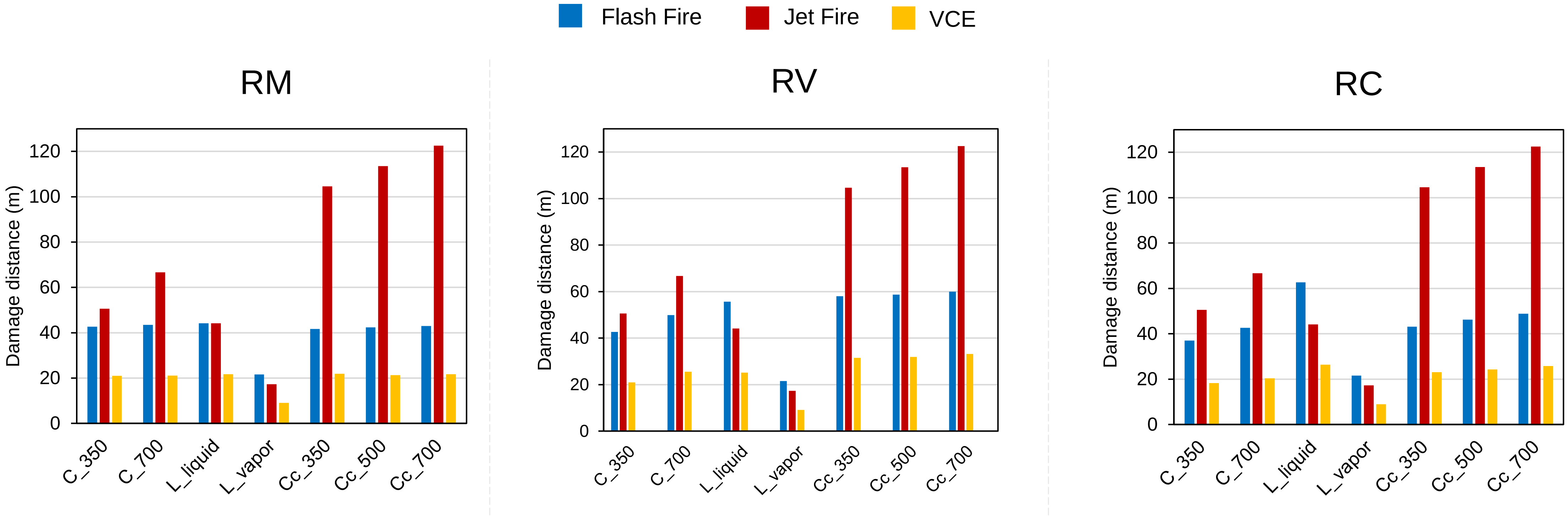
- **Fireball** from the LH2 tank gives the largest damage distances, regardless of the reference set;
- For CH2 and CcH2 the highest distances (~ 20 m) are calculated for the **flash fire** in RM and RC;
- In **RV** LH2 and CcH2 are comparable in terms of maximum distance.

Results: LOC 2



- **Flash fire** is critical for high-pressure hydrogen;
- Distances for **jet fire** for CcH2 are twice the ones for CH2 with the same pressure level;
- **LH2** is the safest storage solution;
- Liquid releases are more critical than gaseous leaks from LH2 tanks.

Results: LOC 3



- **Jet fire** is critical for high-pressure hydrogen; distances for CcH2 (>100 m) are twice the ones for CH2 with the same pressure level;
- The performance of **LH2** is similar to LOC 2.

Conclusions

The present study highlights that:

- Cryo-compression is the **most critical solution** from a safety standpoint¨because of the large damage distances of jet fires;

- The effects of the catastrophic rutpure (LOC 1) vanish at the **shortest distances**, while the highest values are calculated in case of full-bore rupture of the connection pipe (LOC 3);

- Cryogenic liquid hydrogen is appears to be a **valid alternative** to compressed hydrogen that allows to reduce the storage space on board without a significant increase in the level of hazardousness.

What’s next?

The present analysis can be extended with:

- A **sensitivity analysis** to assess the robustness of the results;
- A **comparison** between hydrogen storage technologies and storage solutions currently used for conventional fuels (i.e. diesel, LNG or CNG);
- An evaluation of the **risk** relative to hydrogen storage technologies.

NTNU

Norwegian University of Science and Technology

THANK YOU FOR YOUR ATTENTION!

alicesc@ntnu.no