Comparing Powertrains for Heavy-Duty Long-Haul Trucks and Their Implications for Liquid Hydrogen

Dr. Zhenbiao Zhou
Research Fellow – Clean Energy & Clean Transport
Mechanical Engineering, University of Melbourne

Overview

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2 Methodology
- Vehicle models
- Financial model

3 Powertrain comparison
- Efficiency
- Financial

4 Role of LH2
- Compressed gas vs LH2
- LH2 Safety

5 Our Work on LH2

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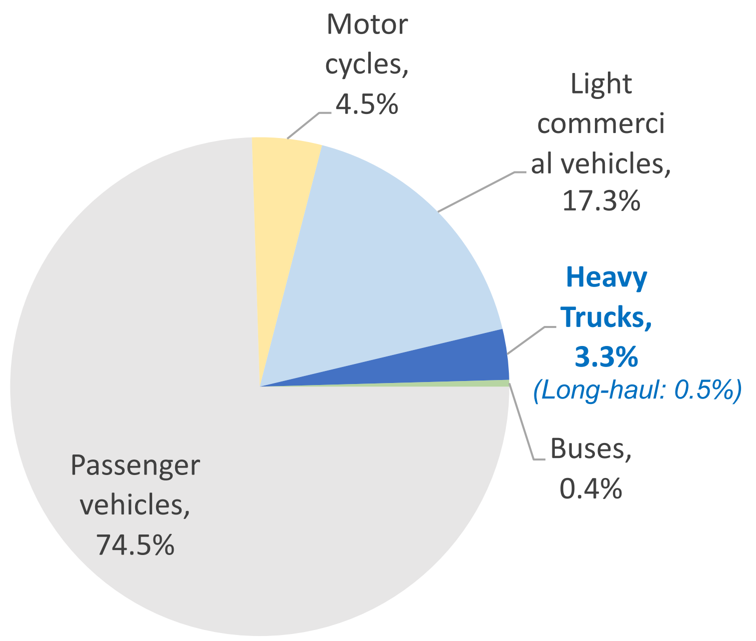
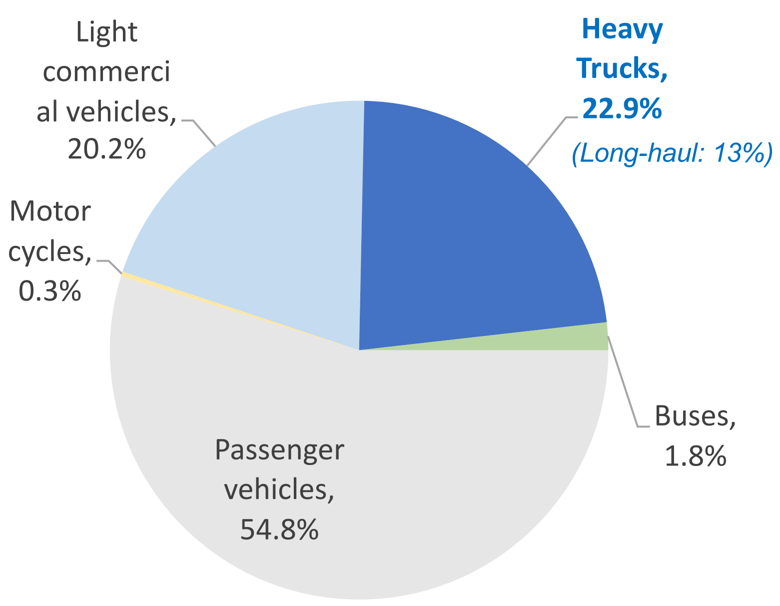
1. Introduction of Heavy-Duty Trucks

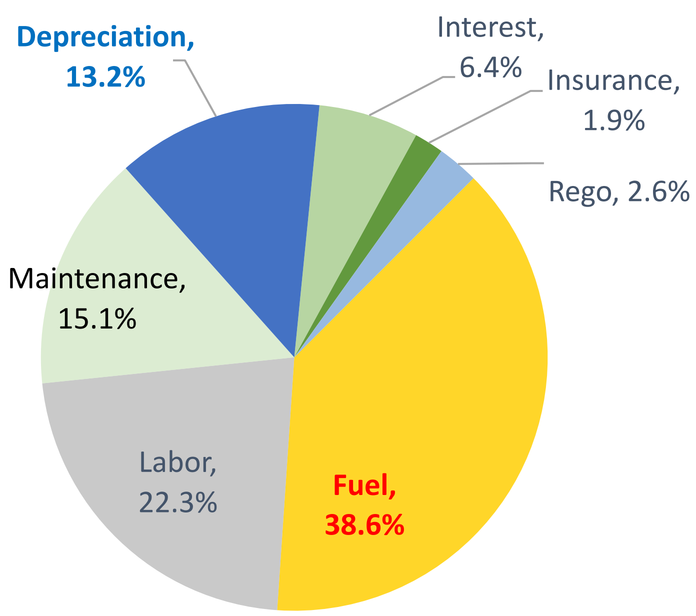
Vehicle Volume[1]



Fuel Consumption [1]



Operating Cost [2]



Heavy-duty trucks: a niche market consuming significant amount of fuel.

[1] Survey of Motor Vehicle Use 2022, Australian Bureau of Statistics. [2] Vic Forestry Contractors – Rates & Costs Schedule 2021-2022

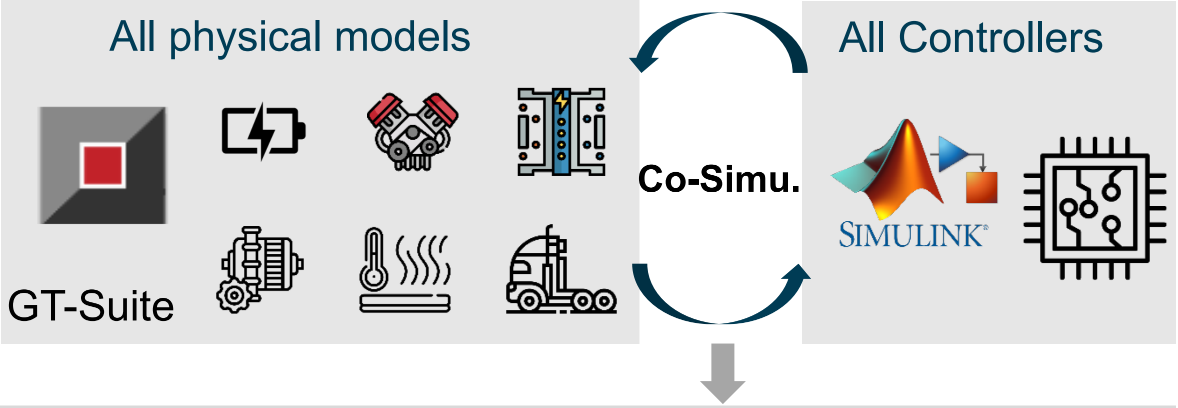
2. Methodology

Vehicle and Powertrains

Gross weight (ton)	49
Net Payload (ton)	32
Aero drag	0.37

	LNG	Diesel	H2-hybrid	BEV	FCV
Energy Source	13L Internal combustion engine			Battery	Fuel cell
Max. Eff.	46%	51%	51%	98%	60%
Range	1000+ km			500km	1000+km

Vehicle Modelling



1.Component Sizing 2.Optimized efficiency 3.Performance

Financial Modelling

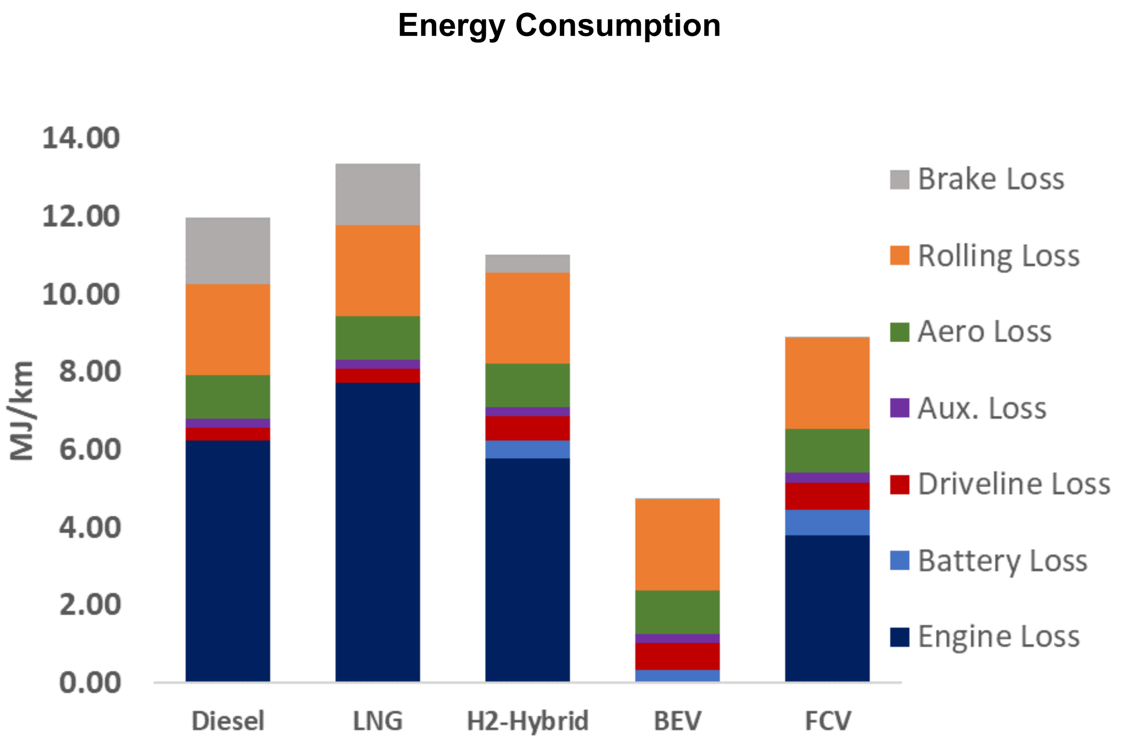
Bottom-up approach:

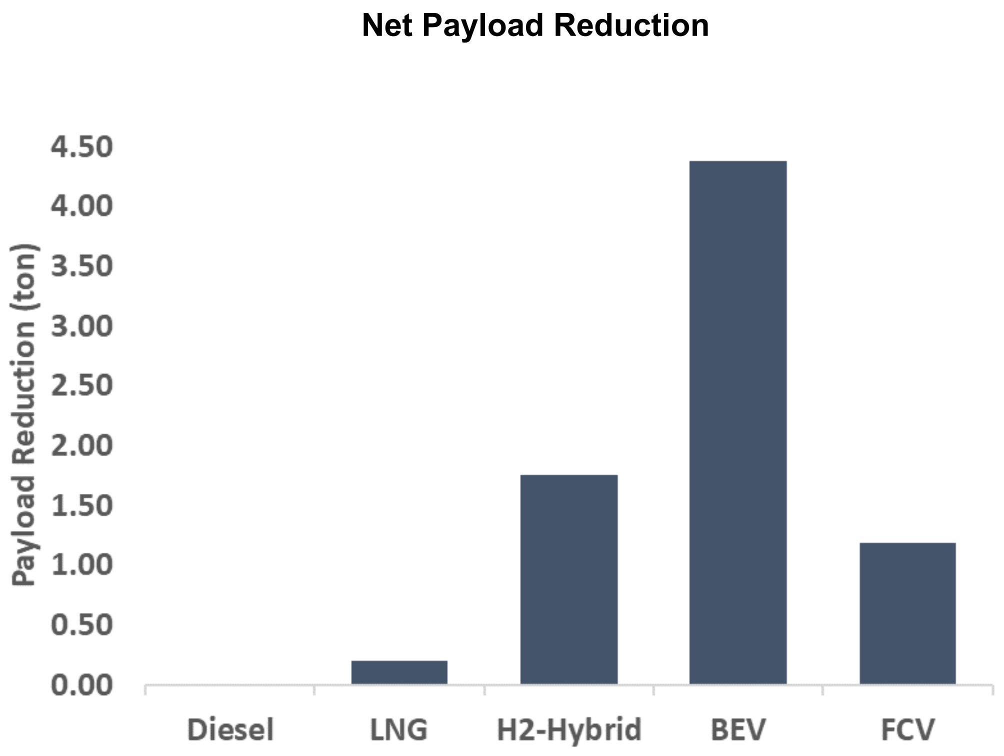
$$TCO = \sum_i \frac{(Initial + Loan + Fuel + Service + Insurance + Labor + Rego)_i}{(1 + Discount\ Factor)^i}$$

$$Freight\ Rate = \frac{TCO}{Total\ distance \times Net\ Payload} \quad in \quad [\frac{\$}{km} \cdot ton]$$

Detailed vehicle simulation and financial modelling of various powertrains for a fair comparison.

3-1.Energy Efficiency





BEV and H2-trucks use less energy but suffer reduced payload capacity.

3-2. Cost Analysis: Mid-Term 2025-2030

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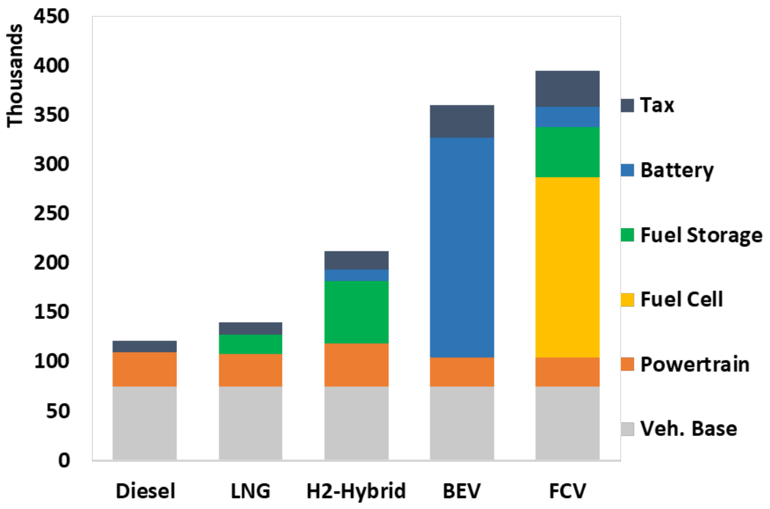
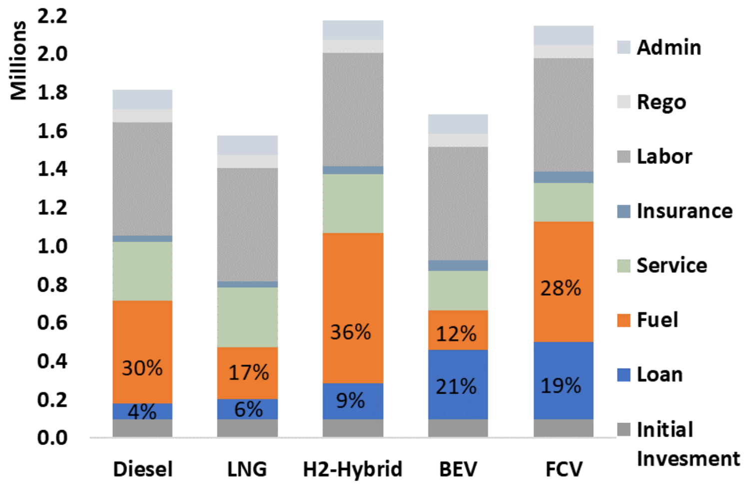
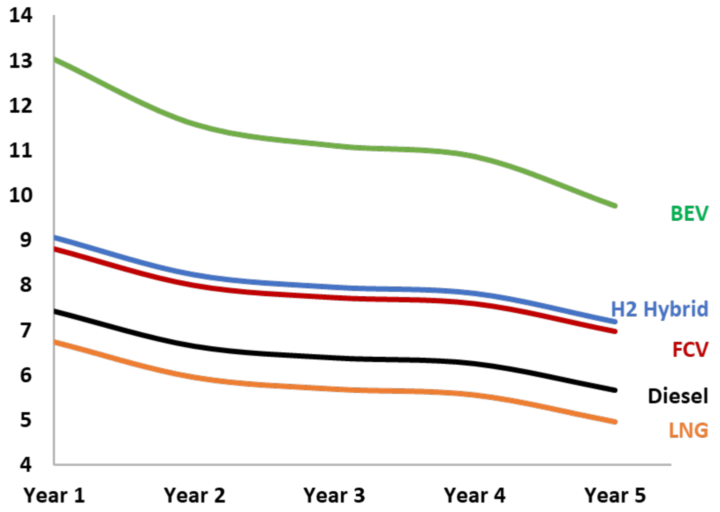
Vehicle Cost (A$ 000s)



TCO (A$ Millions)



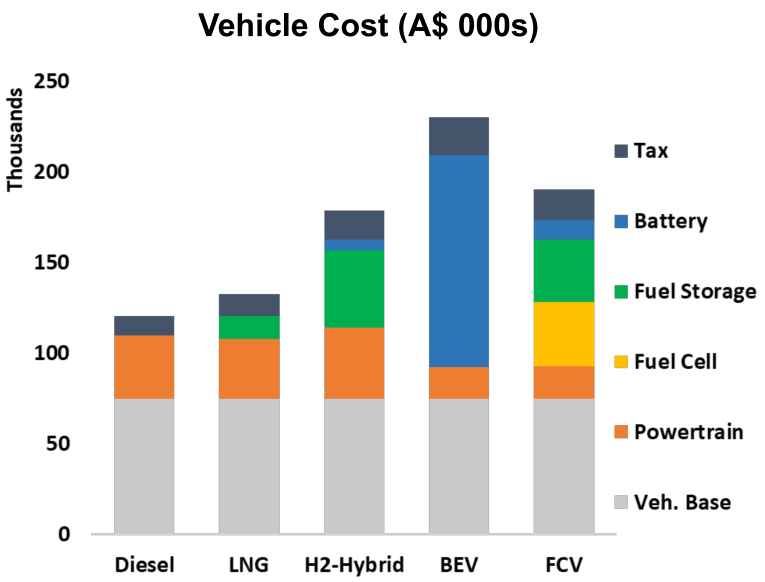
Freight Rate (cents/km·ton)

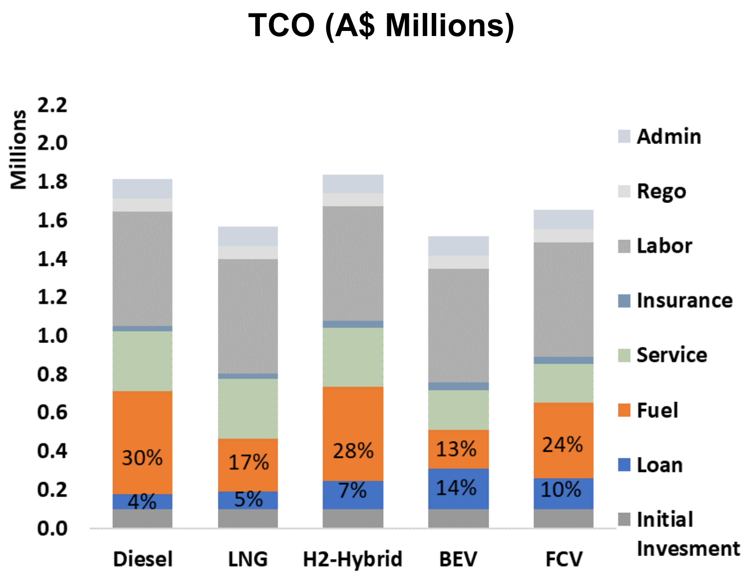


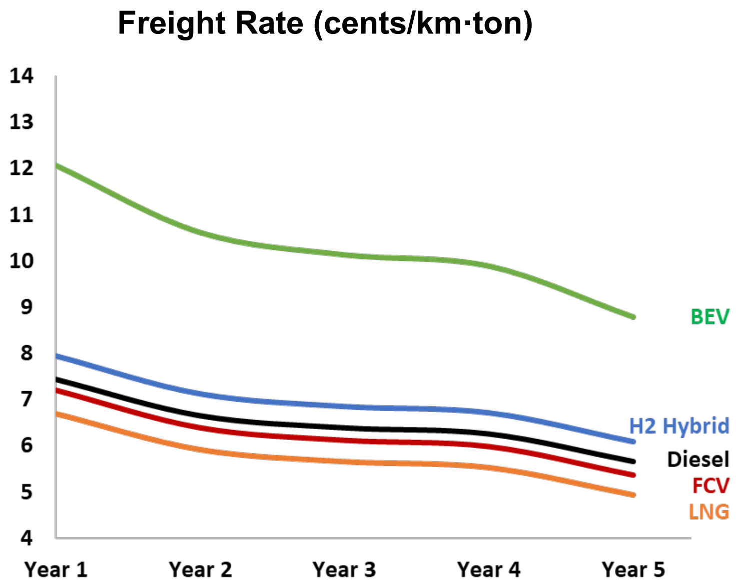
- Zero-Emission trucks: 2-3x pricier than a diesel truck due to the expensive H2 tank (Type IV), battery and fuel cell system.
- BEV: low TCO but extremely high freight rate due to the limited range and payload capacity.
- H2-powered trucks: similar cost but 25% more than a diesel due to high H2 price (A$8.5/kg) and vehicle cost.

In mid-term：Zero-Emission trucks run at a higher cost and BEV shows no advantage in heavy-duty long-haul application.

3-2. Cost Analysis: Long-Term 2030+







- H2-powered trucks still ~50% more expensive than diesel as H2 tank being the most expensive component.
- FCV cost is on par with diesel with low H2 price (A$5.3/kg) and reduced fuel cell price.
- BEV: lowest TCO but highest freight rate due to the limited range and payload capacity.

In long-term：Zero-Emission trucks can be achieved with cost saving when H2 and fuel cell price targets are met.

4-1. The Role of LH2: Advantages

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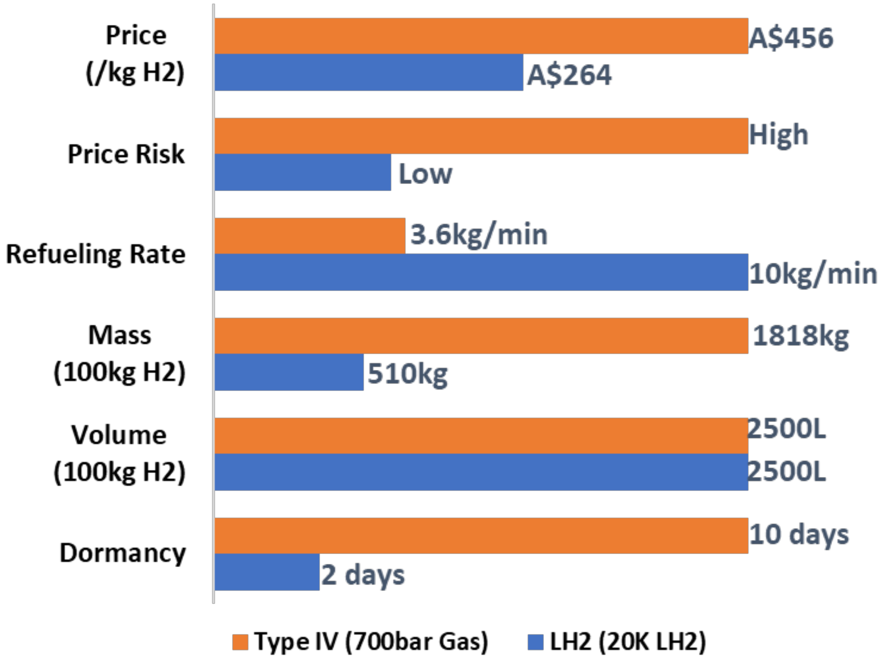
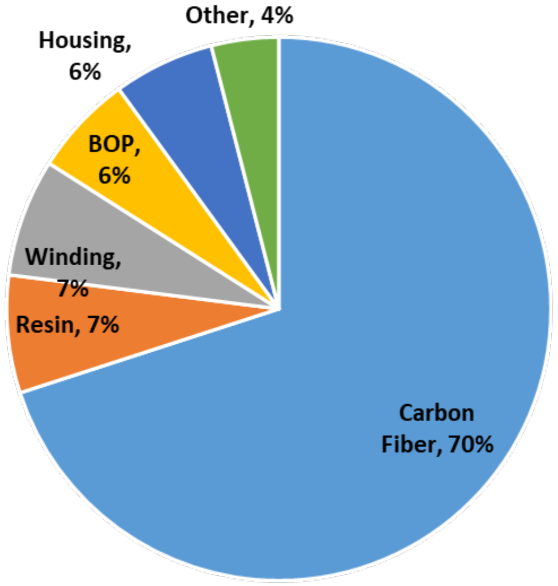
Comparison of H2 Storage

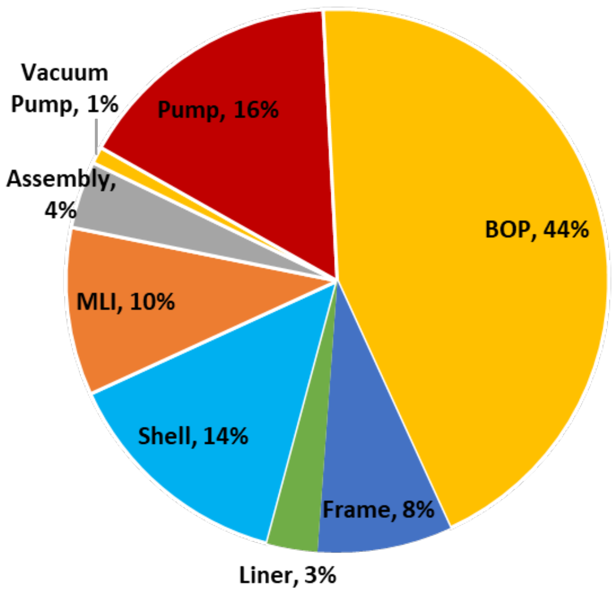


Type IV Tank Cost (700bar gas)



High risk of carbon fiber cost down.

Stainless Steel Dewar Cost (Cryogenic LH2)



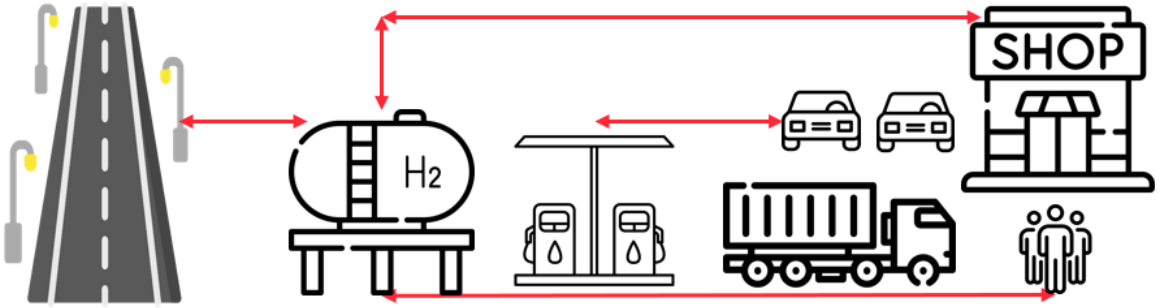
Low risk of meeting cost target.

LH2: more suitable for HD trucks (lighter, cheaper, faster refuelling, and acceptable dormancy).

Open Questions: the total energy consumption/cost including liquefaction and boil-off as compared to high-pressure gas storage?

4-2. The Role of LH2: Safety

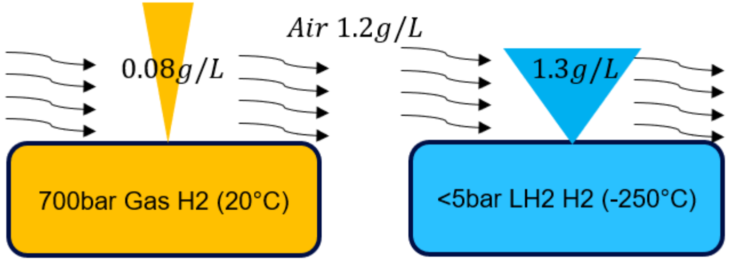
Safety requirements set the footprint of H2 fueling stations.



Cryogenic LH2 has different characteristics for safety evaluation.

Leak Example[3]:

Buoyancy difference*



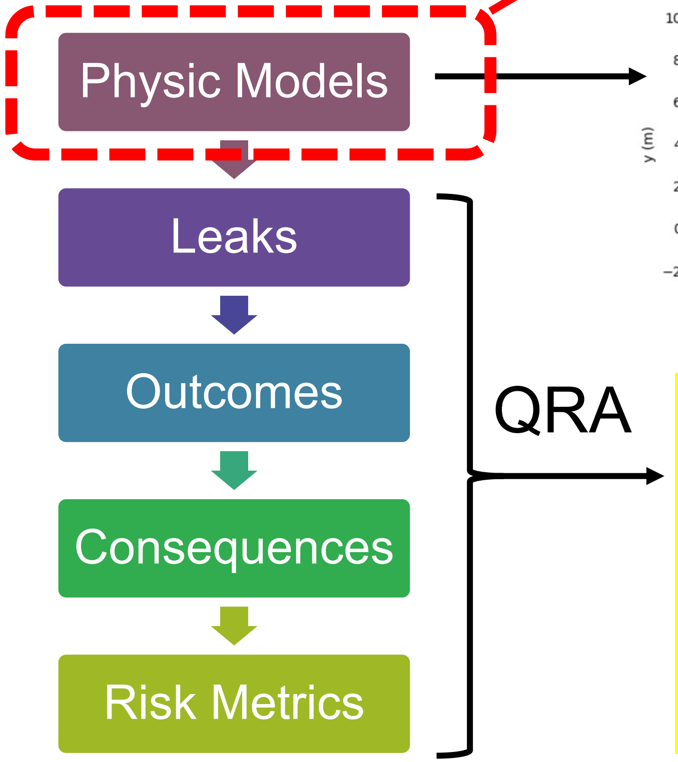
NFPA2 electrical distance req.	**4.6m**	**7.6m**

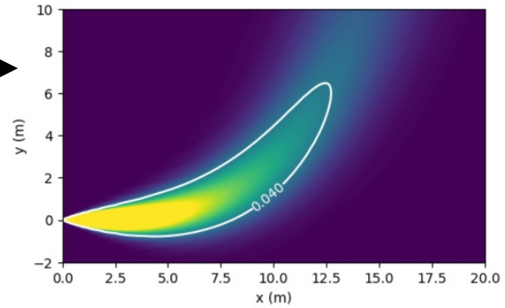
**Actual buoyancy effect is much more complex than this example.*
NFPA: National Fire Protection Association (USA)

Quantitative Risk Assessment (QRA) Tool[4]

HyRAM+
Hydrogen Plus Other Alternative Fuels Risk Assessment Models

Need more experiments to refine (especially condensation)



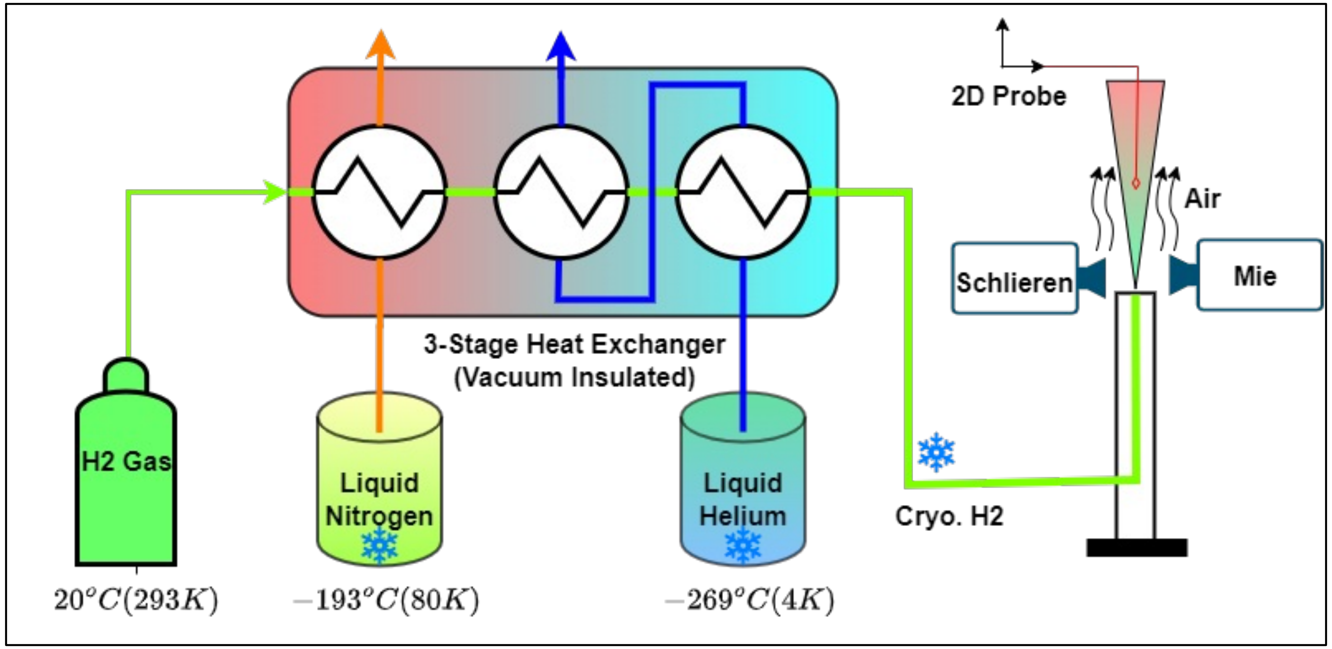


- Failures &Leaks
- Ignition Probabilities
- Physical Harm
- Fatality Probability
- Potential Loss of Life
- Fatal Accident Rate
- Individual Risk
- …

[3] Handbook of H2 Safety – Chap 2 LH2. [4] Brian Ehrhart et.at., Hyram+ Ver 5.0. Sandia National Lab

5-1. Our LH2 Work: Cryogenic H2 System

Simplified Diagram of Cryogenic System



System Specs	
Release Pressure	1-10 bar
Release Temperature	25K(-251 °C) – Room T
Max H2 Rate	1 g/s
Release Size	0.5 – 3mm
Air RH	3 – 100%
2D Sampling	X: 0-150mm, Y: 0-1.5m
Optical Measurements	Schlieren: flow geometry Mie Scattering: liquid phase
Imaging Speed	Up to 20,000 frames/sec.

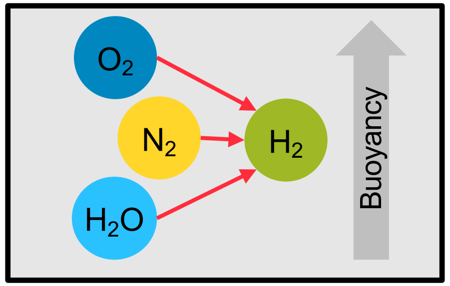
A Cryogenic system has been developed for experimenting cryogenic H2 release → Refine current leak models

5-2. Our LH2 Work: Current Progress

Condensation Process in Cryo. H2 Release

H2	**Release T=~20K**	**Cp=~12kJ/kg_H2**

Air@20C, RH60%	Condense T (K)	Enthalpy of vaporization(kJ/kg_air)
Water	285	22
Oxygen	77	52
Nitrogen	75	153

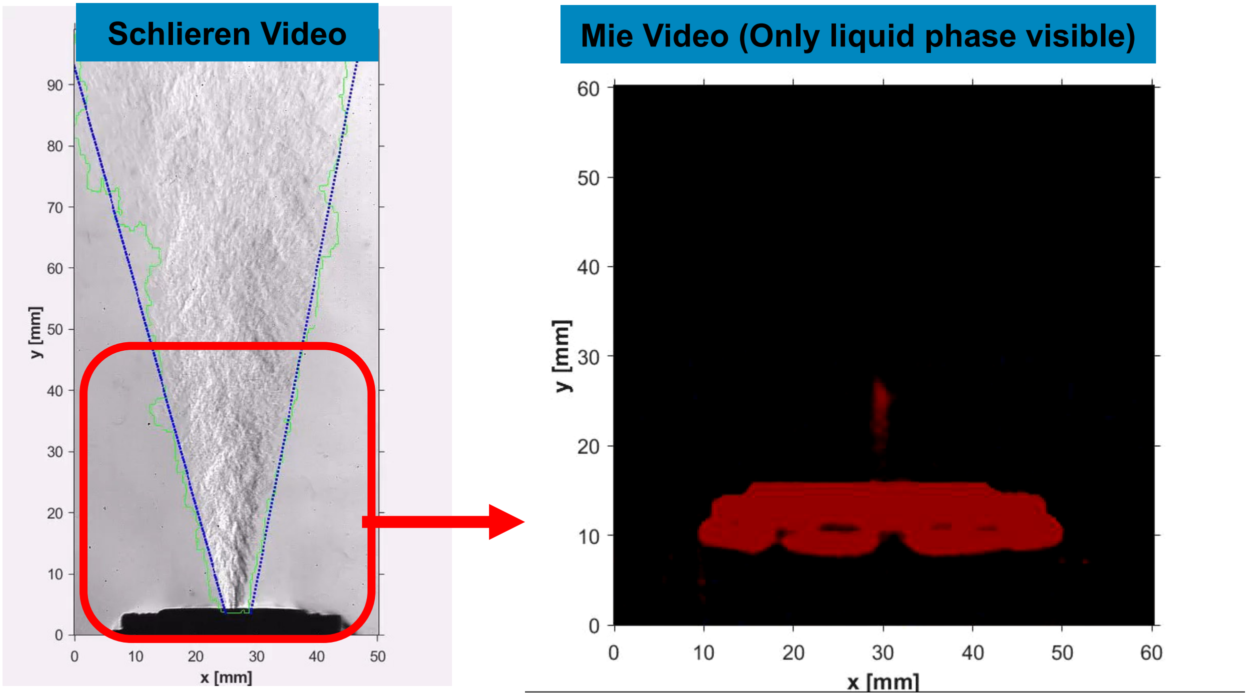


- Heating ↑
- Buoyancy ↑
- Vertical dispersion ↑
- Separation distance ↓

Missing in current QRA model!

Current Experiment Results

H2 release: 36K (-197°C, 2.2bar, 0.3g/s, 1mm orifice, dry air)



(1) Condensation process affects H2 dispersion. (2) The condensation is captured in the near-release region.

6. Summary

1. **BEV**: highest efficiency and lowest energy cost but not suitable for HD long-haul application.
2. **H2-Powered trucks**: similar cost of ICE and FCV in the mid-term.
3. **FCV**: financially on par with diesel trucks in the long-term if FC cost and H2 price targets are met.
4. **Onboard H2 storage**: LH2 is a promising solution than high-P gas storage.
5. **LH2 safety**: LH2 has different characteristics than other forms of storage due its low T.
6. **Our research**: preliminary exp. results show air condensation near release point.

Thank you.

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Dr. Zhenbiao Zhou
Research Fellow – Clean Energy and Clean Transport
zhenbiao@unimelb.edu.au