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ACCIDENTAL SPILL OF LIQUID HYDROGEN AND RISK OF RAPID PHASE TRANSITION

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Outline

- Why liquid hydrogen (LH2)?
- Safety aspects
- Rapid phase transition (RPT)
- Risk of LH2 RPT
- Potential consequence of LH2 RPT

Why liquid hydrogen?

- Hydrogen is potentially a zero-emission energy carrier
- Distribution: small quanta → compressed gas

  large quanta → liquid form
- Heavy-duty transportation foreseen to run on LH2

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Safety aspects

- "New" fuels are under the microscope
- Various safety aspects must be investigated

Safety aspects investigated in the SH2IFT* project

Gaseous hydrogen	Liquid hydrogen
• Jet fires	• Boiling liquid expanding vapor explosion (BLEVE) • Rapid phase transition (RPT)

*sintef.no/projectweb/sh2ift

Rapid phase transition

- Sudden and explosive phase transition
- Known from liquified natural gas: LNG on water may lead to RPT
- Q: will LH2 on water lead to RPT in the same way?

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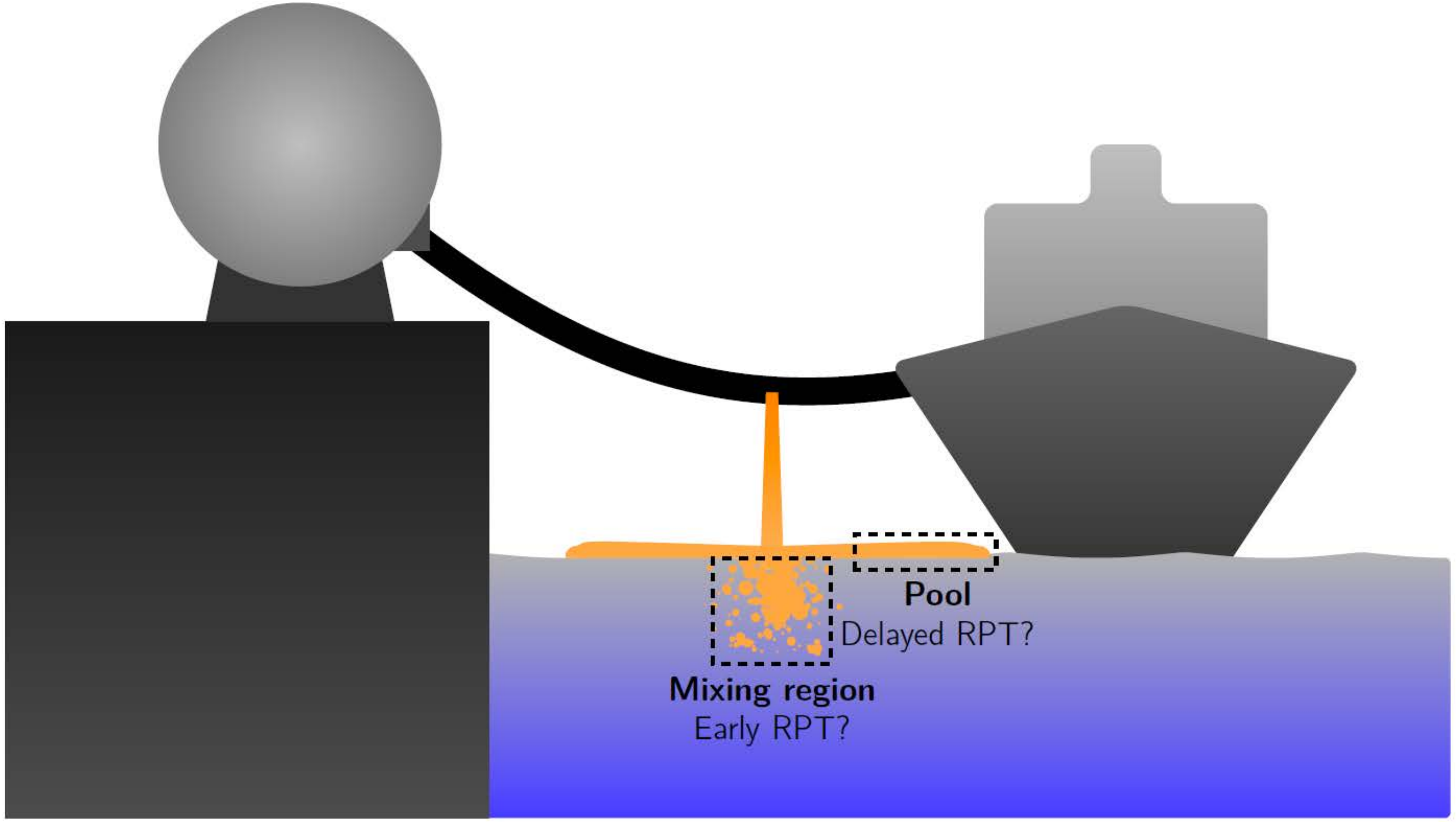
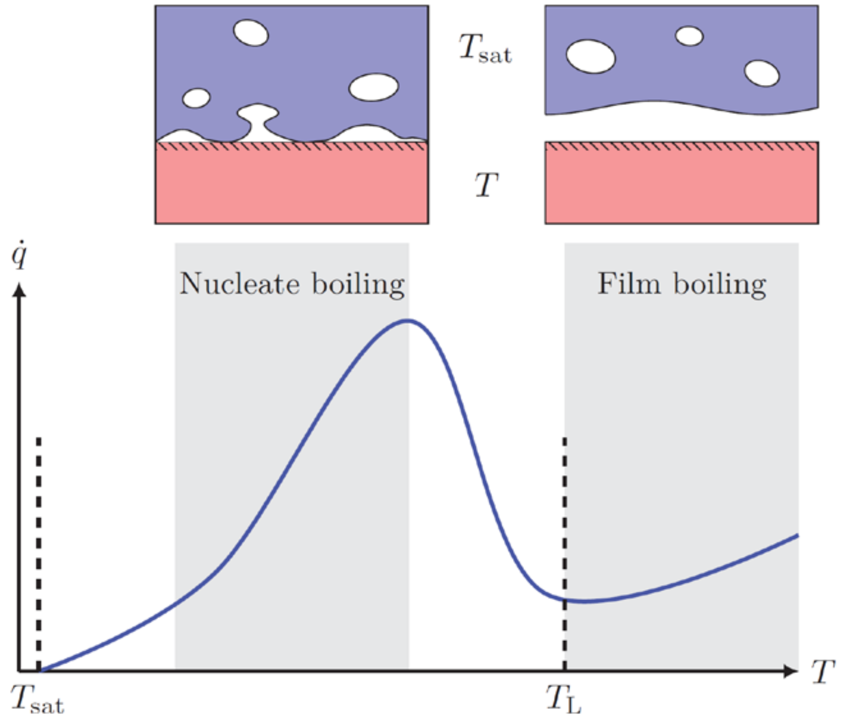
Rapid phase transition



RPT triggering

- What is (likely) the fundamental cause of LNG RPT?
  Superheating of LNG due to large heat transfer
- Why does RPT normally NOT happen?
  Limited heat transfer due to stable film boiling
- Why does RPT suddenly happen?
  Film boiling instability and breakdown (?)



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RPT triggering for LNG

- Leidenfrost temperature determines risk of triggering

$$T_L > T_w$$

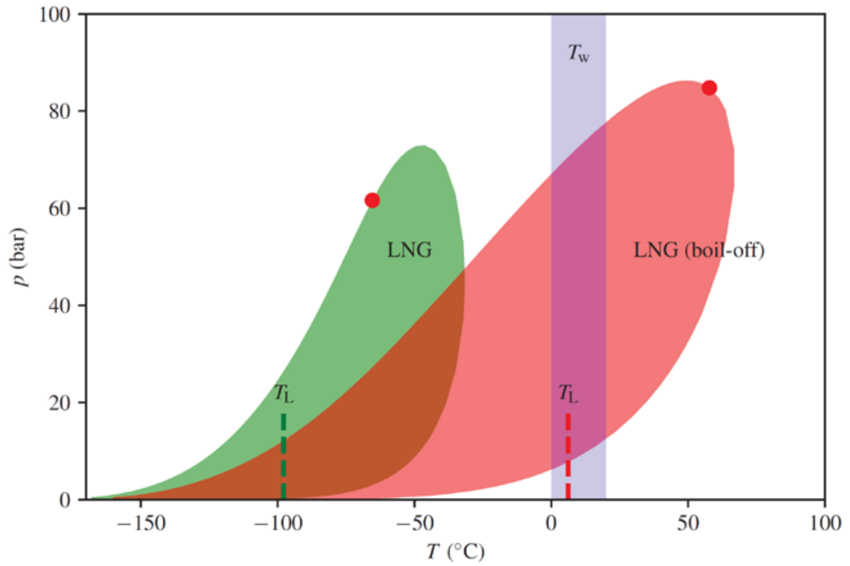
- Estimate of LNG Leidenfrost temperature:

$$T_{\mathrm{L}} = \frac{27}{32} T_{\mathrm{crit}} = -102°\mathrm{C} \;\; \mathrm{vs} \;\; T_{\mathrm{water}} \approx 0°\mathrm{C}$$

- When 30-50mol% methane concentration is reached:

$$T_{\mathrm{L}} = T_{\mathrm{water}}$$

- LNG becomes enriched on heavier components as it boils
- Triggering! But only 10-20% of original LNG remains



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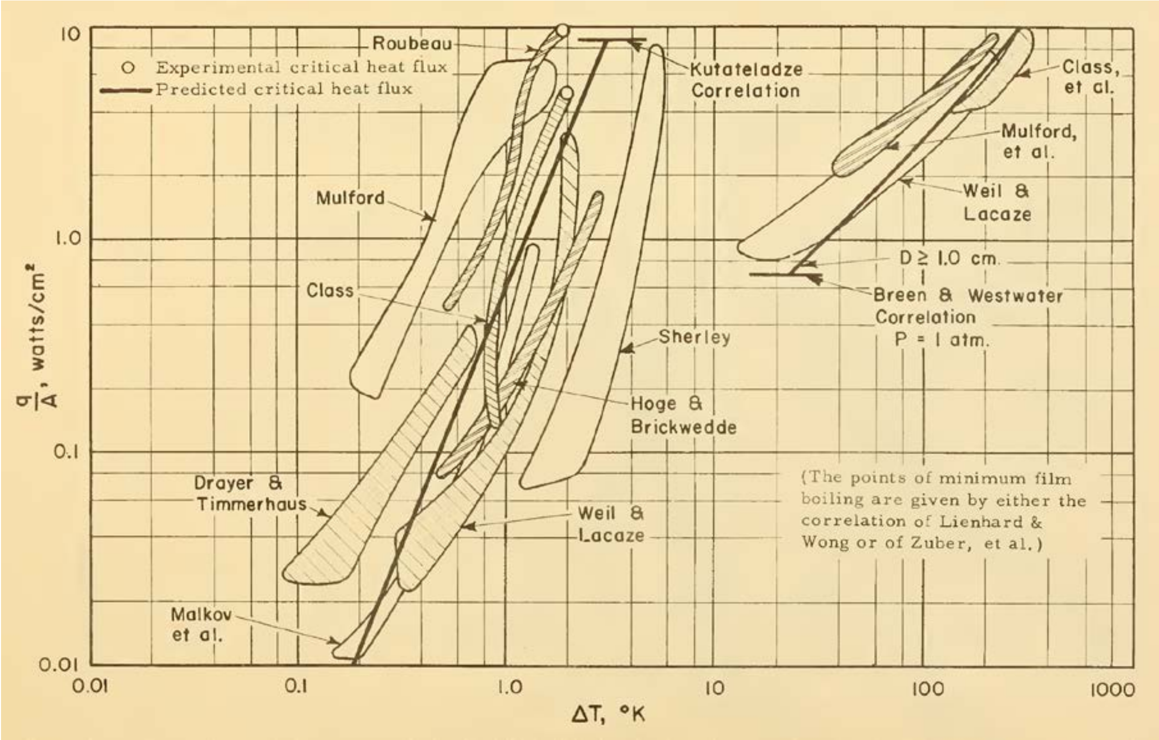
RPT triggering LH2: Triggering condition

- Estimate of LH2 Leidenfrost temperature:

$$T_{\mathrm{L}} = \frac{27}{32} T_{\mathrm{crit}} = -245°\mathrm{C} \ \text{ vs } \ T_{\mathrm{water}} \approx 0°\mathrm{C}$$

- No LH2 RPT through known pathways. Must be experimentally verified
- To this point RPT from LH2 spilled on water has not been observed (see e.g. Verfondern & Dienhart 1997)
- Experiments being performed right now within the SH2IFT project

Brentari et. al (1965)



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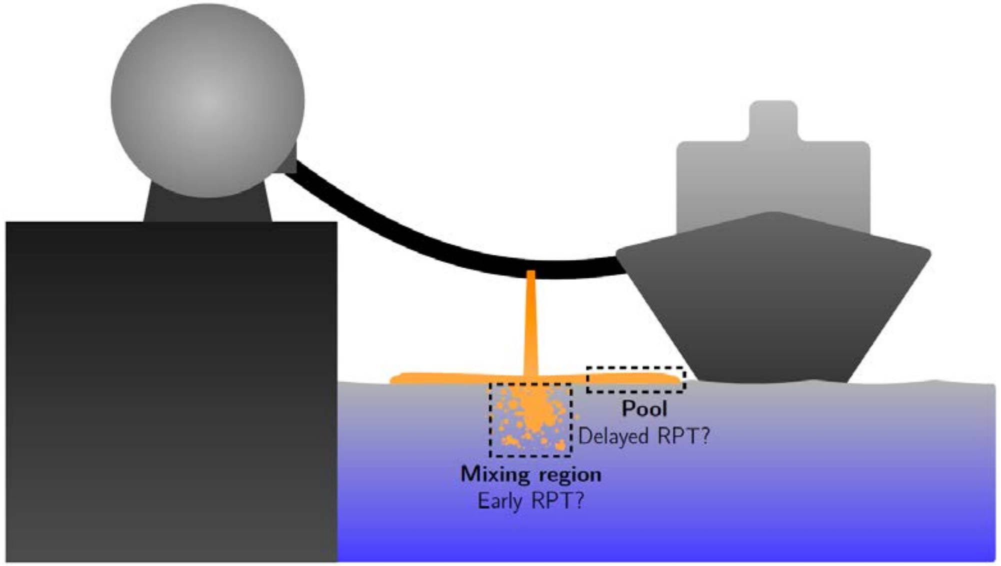
What about early RPT?

- RPT in the mixing zone
- Film boiling stability for high impact and high pressure?
- Unlikely due to
  - Extremely low density of liquid hydrogen (70 kg/m3)
  - Stable film-boiling (low Leidenfrost temperature)
- Potential triggering mechanisms
  - External forces
  - Ice formation



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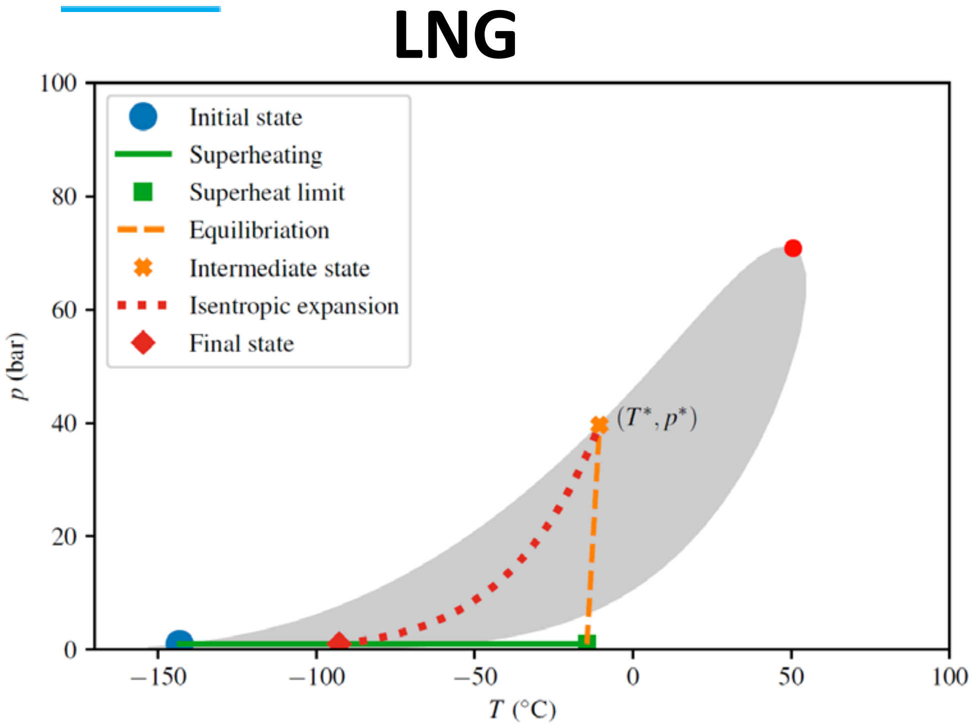
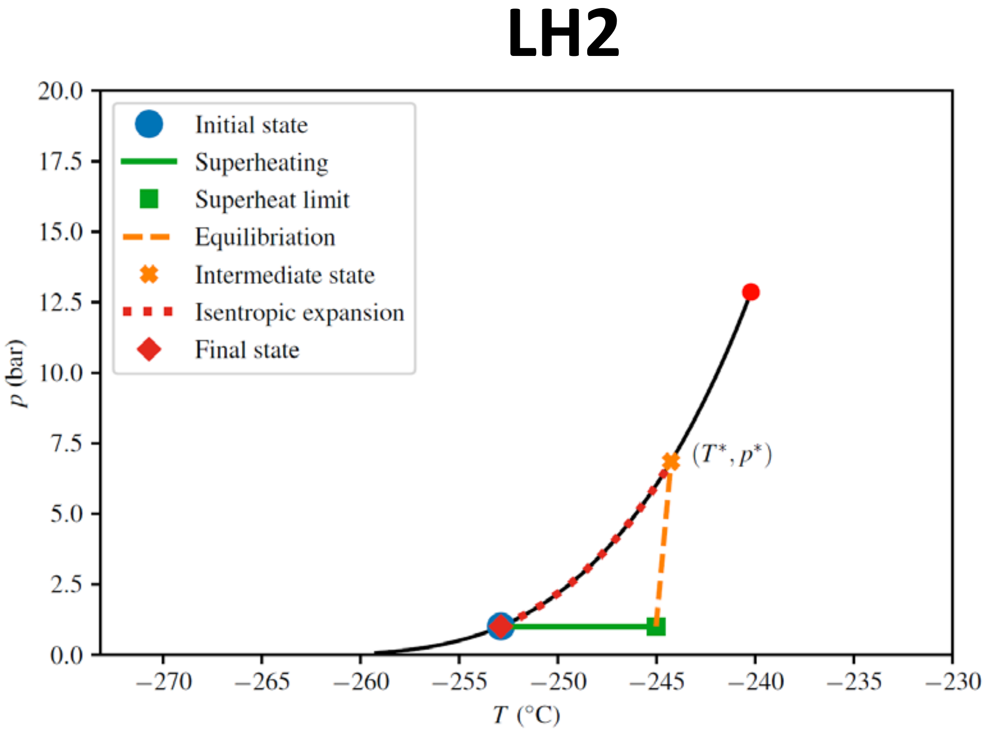
Explosive yields, LNG and LH2





Consequence	LH_2	LNG
Peak pressure, p^* (bar)	7	40
Energy yield, E (kJ kg^{-1})	40	68
Energy yield, E (MJ m^{-3})	2	39

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Conclusion

- The probability of an explosive LH2 RPT event for a LH2-on-water scenario seems low
- This is supported by the fact that no RPT events have been reported from real spills
- In the hypothetical case of an LH2 RPT the predicted peak pressure is 17% of that from LNG RPT
- The predicted explosive energy yield is 60% by mass (or 5% by volume) compared to LNG RPT

[Odsæter et.al. (2021): https://doi.org/10.3390/en14164789]

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