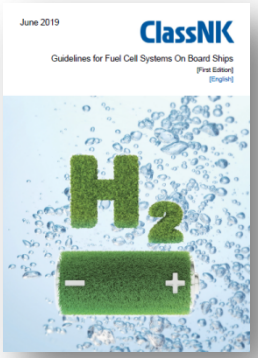
Liquefied Hydrogen Carrier Pilot Project in Japan

H2@Port
Wednesday, September 11, 2019
ClassNK

NIPPON KAIJI KYOKAI (ClassNK or NK)

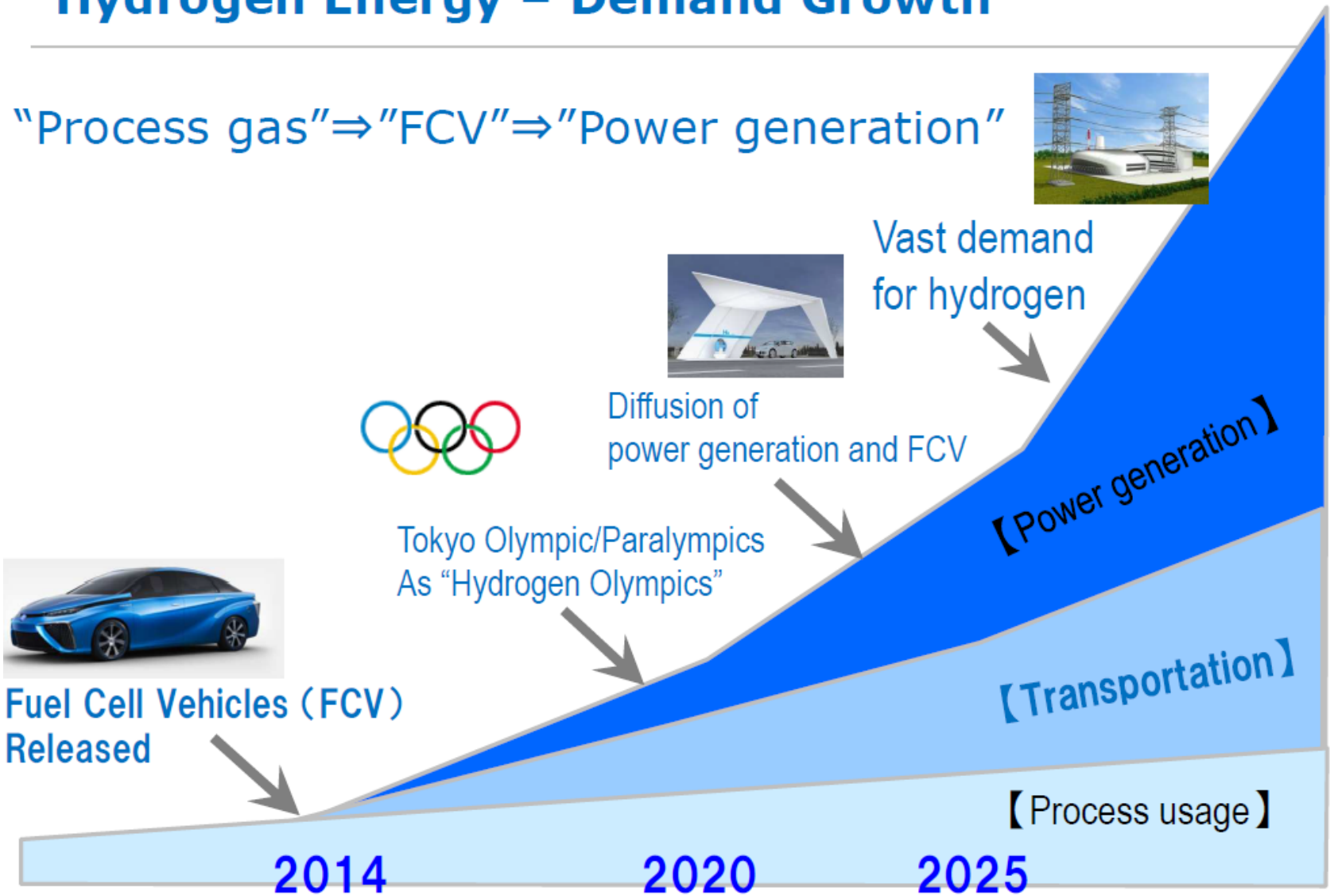
- International classification society in Japan established in 1899
- Abt. 20% share of classification of world cargo vessels in Gross Tonnage
- Head Office : Tokyo, Japan
- Abt.130 sites in the world for ship survey
- Offices in U.S. : New York, Charleston, Houston, Los Angeles, Miami, New Orleans, Norfolk, Seattle



ClassNK activities relating to hydrogen / fuel cell

- Guidelines providing additional safety requirements for design and construction of the vessels have been issued based on the results of R&D and IMO discussions.
  - ① **Guidelines for Liquefied Hydrogen Carriers (March 2017)**
  - ② **Guidelines for Fuel Cell Systems On Board Ships (First Edition) (June 2019)**
- Design approval and surveys for construction of LH2C for the pilot project in Japan applying the above Guidelines ①.

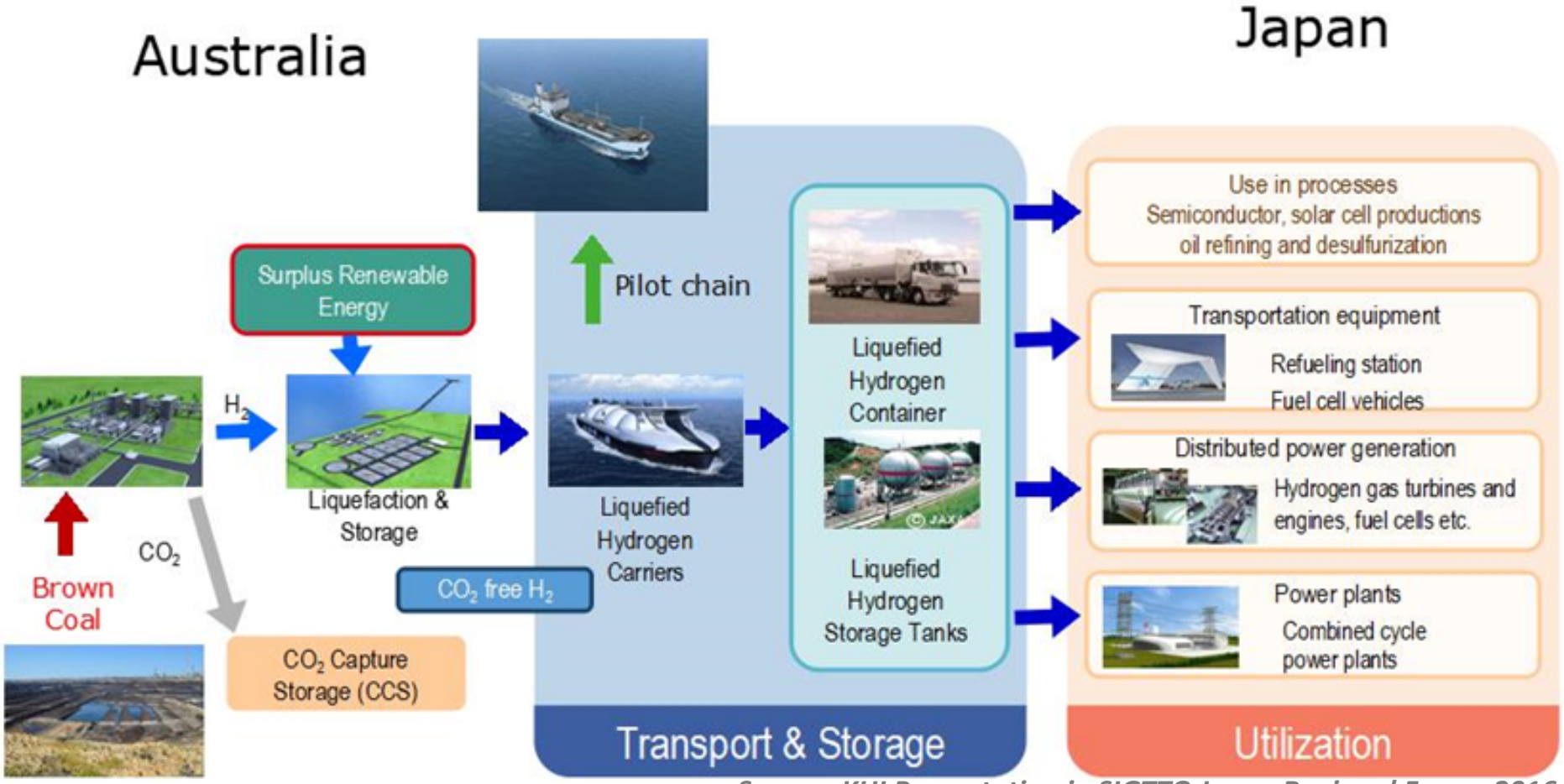
Hydrogen Energy – Demand Growth



KHI "Introduction to a Liquefied Hydrogen Carrier for a Pilot Hydrogen Energy Supply Chain (HESC) project in Japan", Gastech 2017

Pilot Hydrogen Energy Supply Chain project run by HySTRA*

*) HySTRA: CO2-free Hydrogen energy Supply-chain Technology Research Association composed of Kawasaki Heavy Industries, Shell, Iwatani Corporation, J-Power



Source: KHI Presentation in SIGTTO Japan Regional Forum 2016

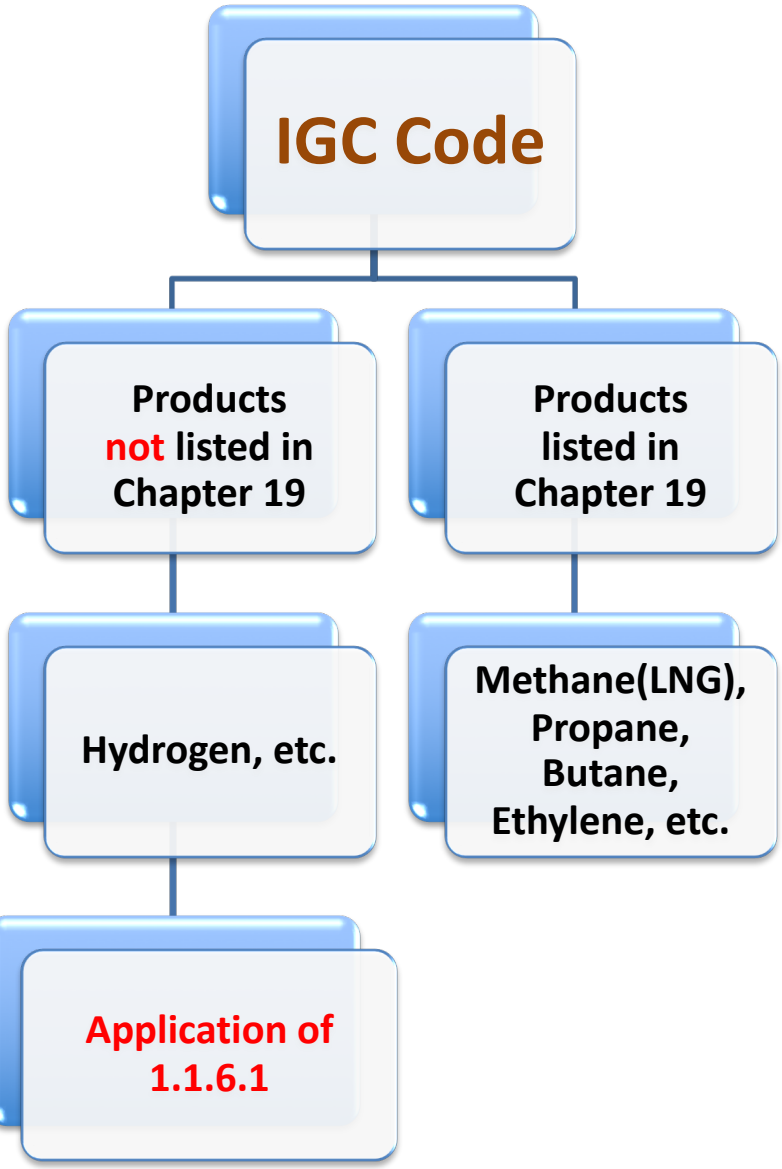
LH2 carrier pilot project in Japan

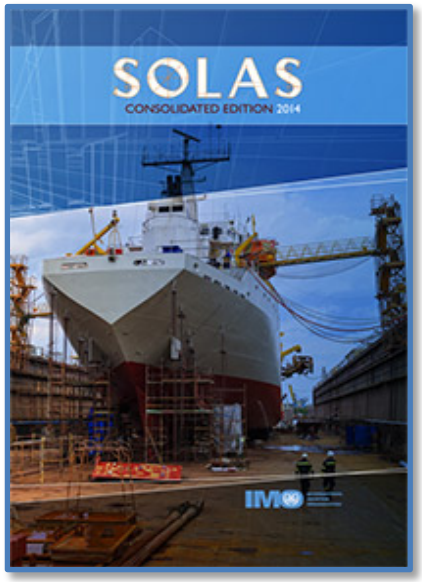
1250m3 Liquefied Hydrogen Carrier

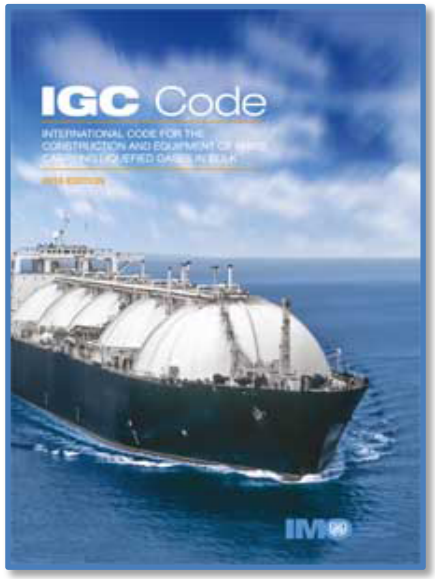
Liquefied Hydrogen Carrier	
Shipyard	Kawasaki Heavy Industries
Dimensions (L_{pp} x B x D)	ab.110m x ab.20 m x ab.11m
Gross tonnage	ab. 8,000 tons
Propulsion System	Diesel Electric
Speed	ab. 13.0 knots
Flag State/Class	Japan / ClassNK

LH2 Cargo Containment System	
Manufacturer	Kawasaki Heavy Industries
Total Capacity	Ab. 1,250 m3 x 1 tank
Tank Type	IMO Independent tank type C
Design Press. x Temp.	0.4 MPaG x -253 degC (20K)
Insulation System	Vacuum Multi-layer Insulation + Supplementary Kawasaki Panel Insulation System
BOG Management	Pressure Accumulation

Rule requirements for LH2 carrier







IGC Code 1.1.6.1

*Where it is proposed to carry products that may be considered to come within the scope of this Code that are not at present designated in chapter 19, **the Administration and the port Administrations involved in such carriage shall establish a Tripartite Agreement** based on a provisional assessment and lay down preliminary suitable conditions of carriage based on the principles of the Code.*

Rule requirements for LH2 carrier

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MSC 94 Dec 2014 — Approval to develop Interim recommendations for carriage of liquefied hydrogen in bulk proposed by Australia and Japan

CCC 2 Sep 2015 — Start discussion of draft Interim recommendations

CG CCC 2 to 3 — Members: Australia, China, France, Germany, Greece, Japan, Liberia, Marshall Islands, Norway, Korea, Spain, Sweden, UK, USA, ICS, IACS, OCIMF, SIGTTO

CCC 3 Sep 2016 — The draft interim recommendations endorsed

MSC 97 Nov 2016 — Adoption of IMO Res. MSC.420(97) "INTERIM RECOMMENDATIONS FOR CARRIAGE OF LIQUEFIED HYDROGEN IN BULK"

Jan 2017 →

Application of the Interim Recommendation to the pilot LH2C was agreed by Australia and Japan

Rule requirements for LH2 carrier

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Table 1: Interim Recommendations for carriage of liquefied hydrogen in bulk

Product name	*Ship type*	*Independent tank type C required*	*Control of vapour space within cargo tanks*	*Vapour detection*	*Gauging*	*Special requirements*
Hydrogen	2G	-	-	Flammable	Closed	See Table 2

Table 2: Special Requirements carriage of liquefied hydrogen in bulk (Total 29 Special Requirements)

No.	*Special Requirement*	*Related hazard*
6	At places where contact with hydrogen is anticipated, suitable materials should be used to prevent any deterioration owing to hydrogen embrittlement, as necessary.	Hydrogen embrittlement (see 4.3)

Ref to IMO Res. MSC.420(97)

Design Basis for Pilot LH2C

- IGC Code + Interim Recommendations(IMO Res. MSC.420(97))
- Hydrogen specific standards / guidelines:
  - ✓ ISO/TR 15916 : *Basic Considerations for the Safety of Hydrogen Systems*
  - ✓ AIAA G-095-2004 : *Guide to Safety of Hydrogen and Hydrogen Systems*
  - ✓ NFPA 2 : *Hydrogen Technologies Code*
  - ✓ NFPA 55 : *Compressed Gases and Cryogenic Fluids Code*
  - ✓ CGA G 5.4 : *Standard for Hydrogen Piping Systems At User Locations*
  - ✓ CGA G 5.5 : *Hydrogen Vent Systems*
  - ✓ ASME B31.12-2011 : *Hydrogen Piping and Pipelines*
  - ✓ IEC 60078-10-1 : *Explosive atmospheres - Part 10.1 Classification of areas - Explosive gas atmospheres*
  - ✓ IEC 60079-29-2 : *Explosive atmospheres - Part 29.2 Gas detectors - Selection, installation, use and maintenance of detectors for flammable gases and oxygen*
- Safety Risk Assessment (HAZID, HAZOP, FMEA, QRA, etc.)

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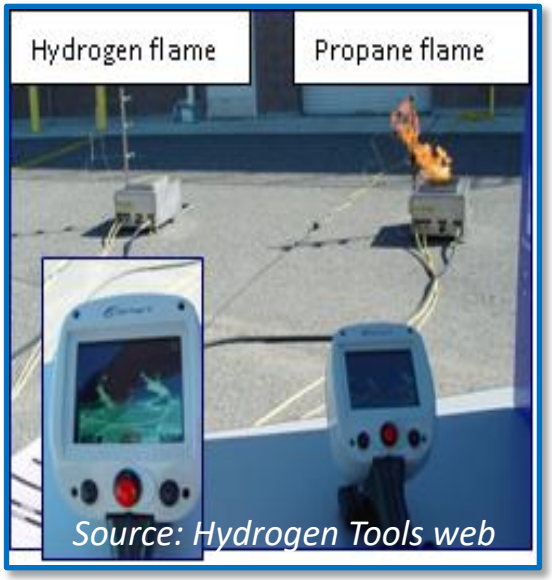
Hazards related to Hydrogen

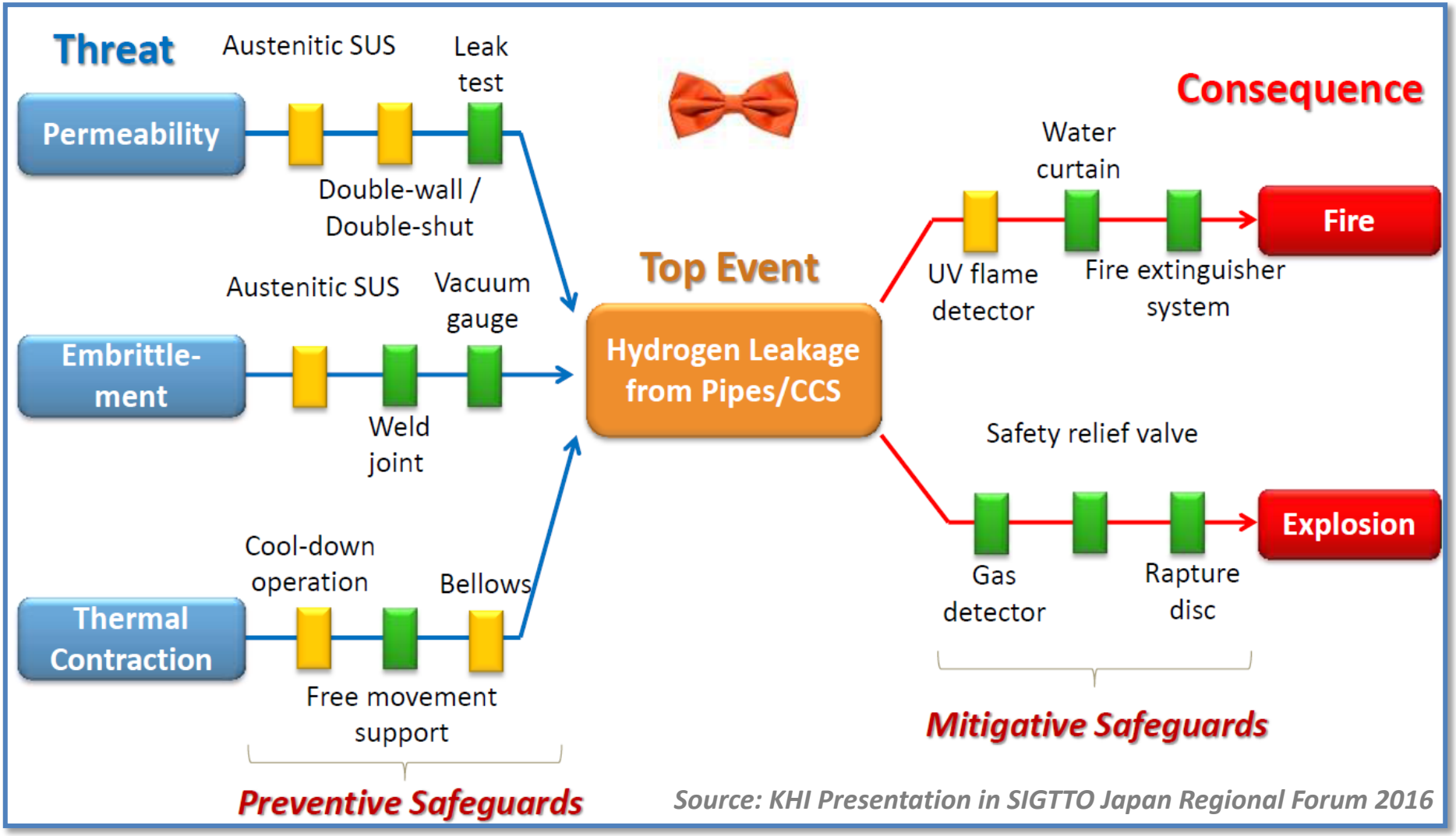
- Low temperature hazard
- Hydrogen embrittlement
- Permeability
- Low density & High diffusivity
- Ignitability
- High pressure hazard
- Health hazard
- Wide range of flammable limits

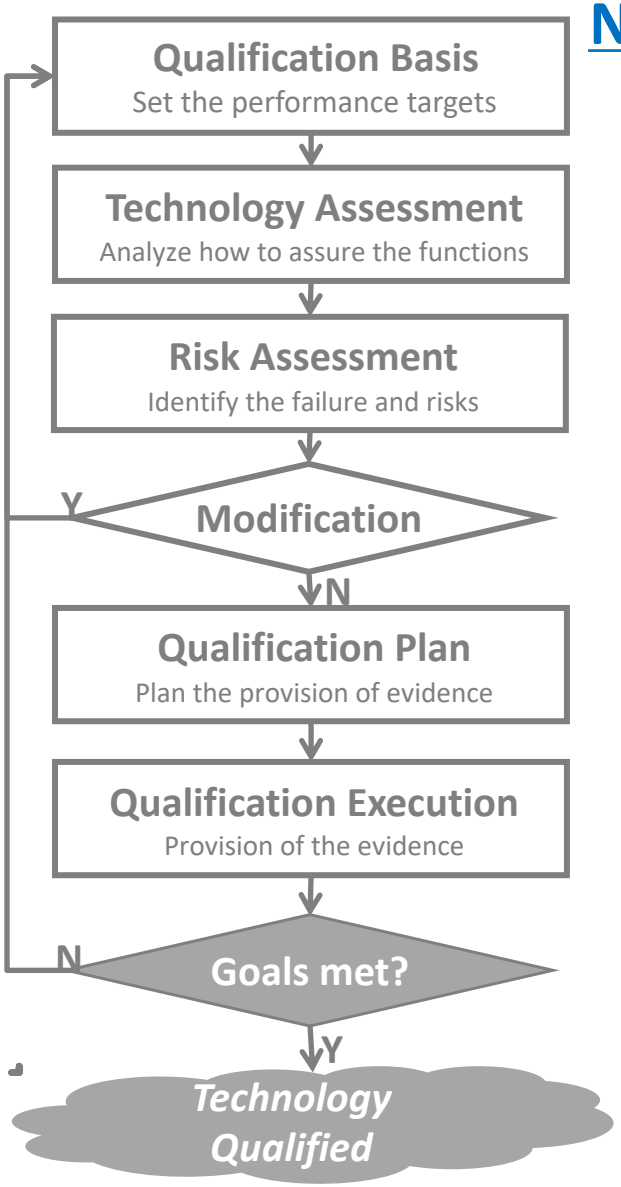


Source: Hydrogen Tools web

	Hydrogen	Methane
Boiling temp (K)	20.3 (-253 ℃)	111.7 (-161.5℃)
Gas density at standard cod. (273K & 1atm (kg/m^3)	0.09	0.72
Gas density at boiling point (kg/m^3)	1.34	1.82
Liquid density (kg/m^3)	70.8	422.5
Evaporation Latent heat (kJ/L)	31.6	215.8
Flammability range (% vol)	4 - 75	5 - 17
Min. Ignition Energy (mJ)	0.017	0.274
Diffusion Coefficient in air (cm^2/s)	0.61	0.16

HAZID study / Accidental Scenario on Hydrogen Leakage



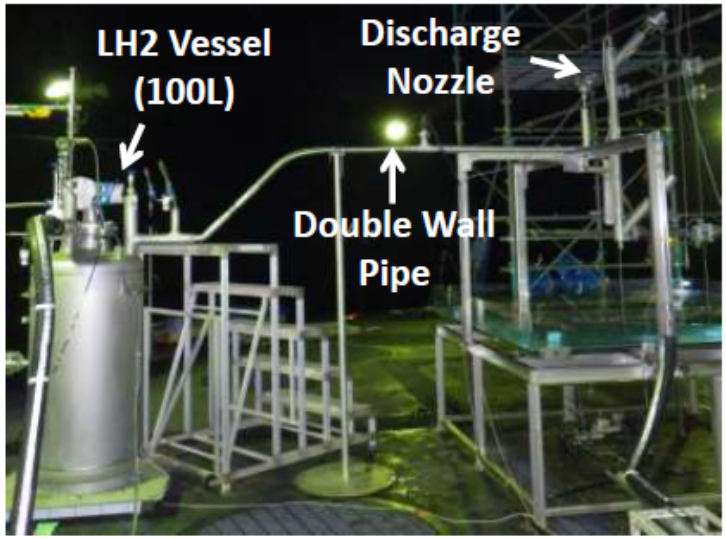


Novel Technologies Qualification

Application (Safety Critical System & Equipment)	
Cargo containment system	Hazardous area classification
Vacuum insulated piping	Ship / shore bonding philosophy
Cargo compressor	Flange management philosophy
Cargo pumps	Cargo venting philosophy
Cargo vaporizer / heater	Cargo jettisoning
Gas Combustion Unit	Cargo hold LIN/LOX protection philosophy
Level measurement/TPS	Ventilation System
Relief valves, bellows, gaskets etc.	Gas detection
Instrumentation (Pressure, Temp., Vacuume press., plugs, sensor)	Fire detection
Cargo vent mast	Firefighting philosophy
Cargo manifold	Purging and sampling philosophy
Marine loading arm & connection piece	

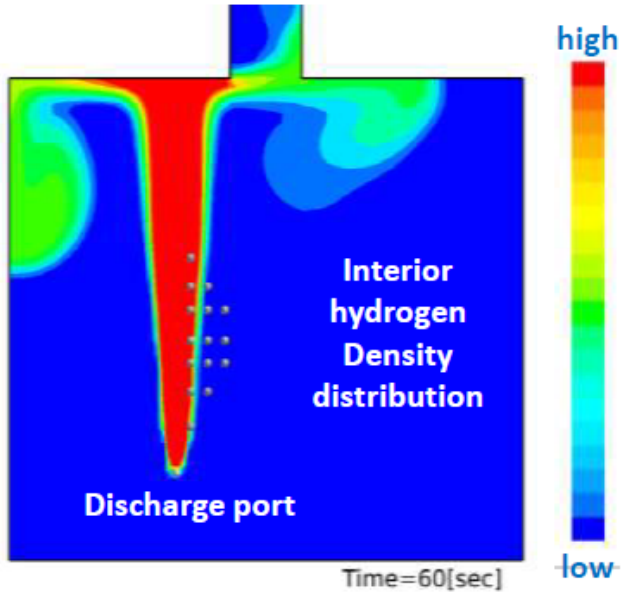
Verification Experiment

- ✓ Verification and validation of physical effects modelling software for liquefied hydrogen



Experimental Apparatus

LH2 Leakage from 3.0mm Nozzle



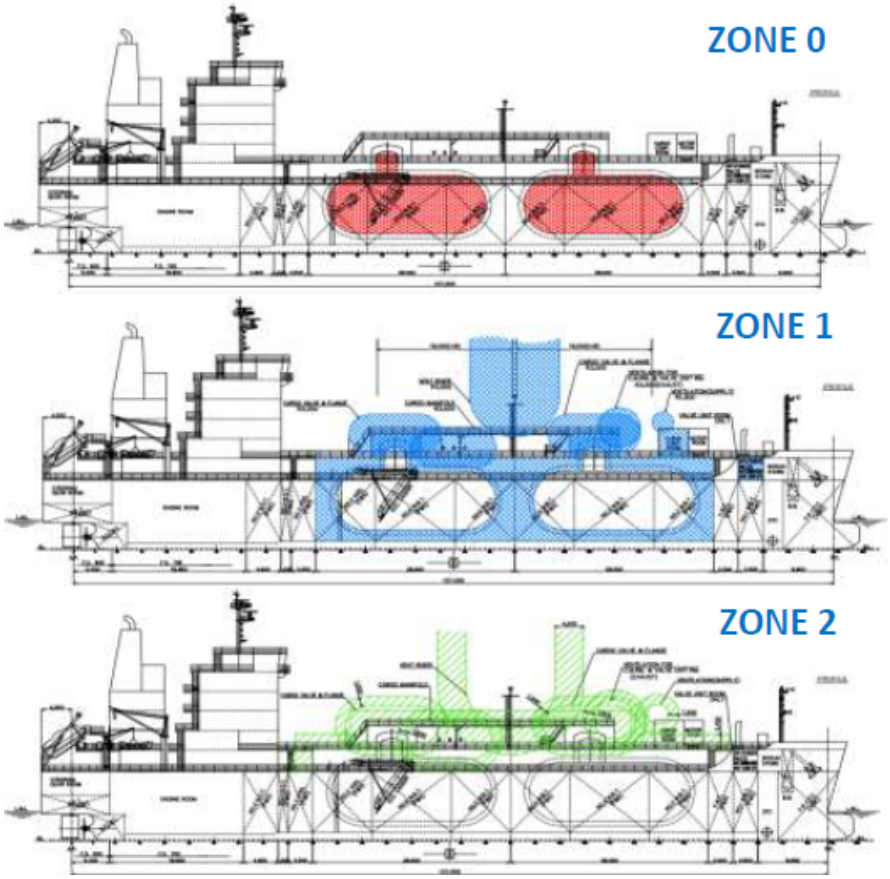
CFD Results

Co-developed with KHI, Iwatani Corporation, K-Line, ClassNK

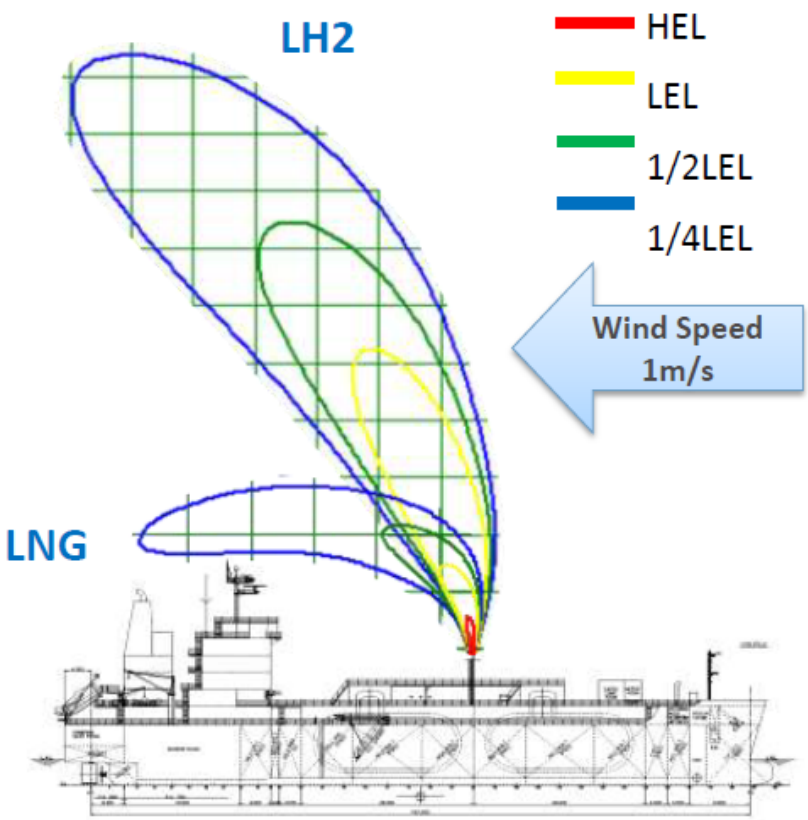
Source: KHI Presentation in SIGTTO Japan Regional Forum 2016

Dispersion Analysis Study

✓ Extended hazardous area in accordance with IEC 60079-10-1



Hazardous area classification

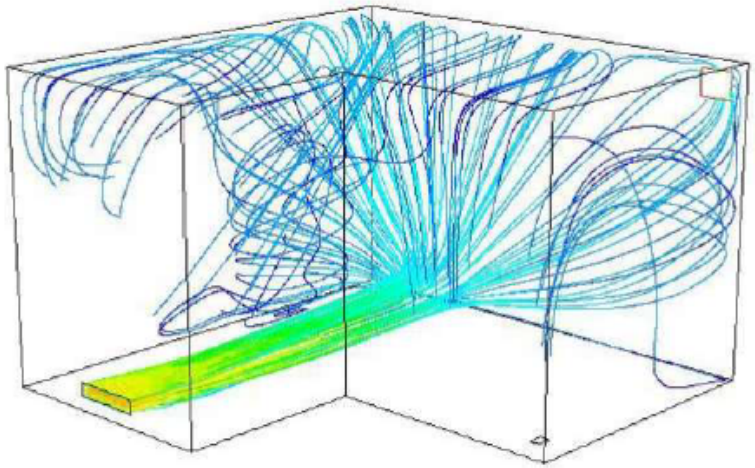


Vent dispersion analysis

Source: KHI Presentation in SIGTTO Japan Regional Forum 2016

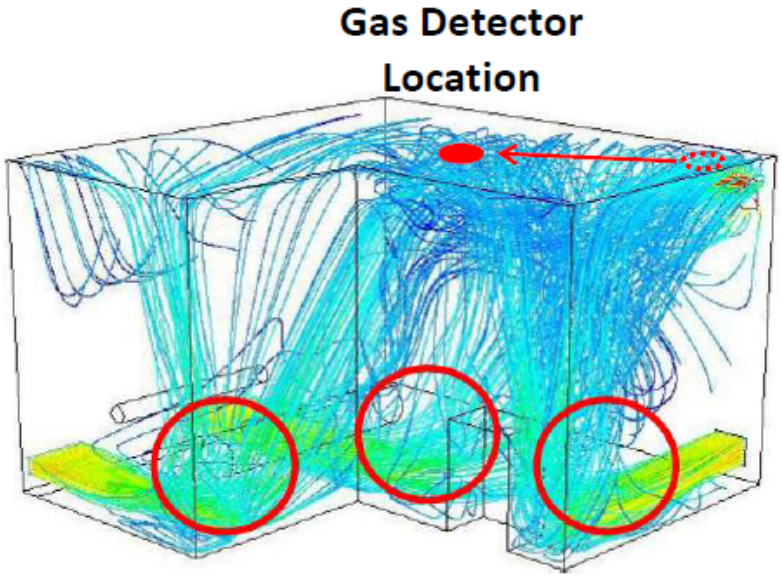
Airflow Analysis Study

- ✓ Improve the airflow within cargo compressor room by optimizing ventilation change rate, inlet/outlet location
- ✓ Effective gas detector location



Initial Design

Optimize



Improvement
of airflow

Source: KHI Presentation in SIGTTO Japan Regional Forum 2016

ClassNK "Guidelines for Liquefied Hydrogen Carriers"

- ✓ Guidelines for the design and construction of LH2C
- ✓ Re-structuring and partly supplementing the interim guidelines with additional requirements

free download fm www.classnk.or.jp

e.g. **Special Requirements in Interim Recommendations: No. 25 "Risk Assessment"**

ClassNK Guidelines "Items to be considered in the assessments"

- Predicting venting scenario and safer venting procedures including prevention and mitigation measures for vent fire to explosion and flashback
- Accuracy verification for applied CFD tools to series of dispersion analysis
- Ergonomic evaluation for access routes to LH2 related equipment from safety perspective
- Prevention measures against BLEVE of the CCS
- Influences of small leaked LH2/GH2 in case of ERS activation
- Chain repercussion due to single failure of VMI system for CCS and VIP
- Possibility of negative pressure by Cryo-pumping effect of CCS
- Isolation philosophy and comprehensive hydrogen fire control
- Safety measures in case of blackout of the ship, etc.

Conclusion

- The LH2C for pilot project in Japan has been designed, constructed and operated based on the requirements of IGC Code, Interim Recommendations issued by IMO, relevant hydrogen specific standards / guidelines, and various risk based approach (HAZID, HAZOP, FMEA etc.).
- Safe operation of the pilot LH2C will be verified in trials/tests phase for several months duration after delivery of the ship in 2020.
- The results of these studies would contribute to further development of commercial LH2C and consideration of amendment to IGC code and IGF code to include safety requirements intended for commercial hydrogen carriers and also use of hydrogen as ship fuel.
- ClassNK will update “Guidelines for Hydrogen Carriers” and “Guidelines for Fuel Cell On Board Ships” taking into account both the experience and technical developments.

for your kind attention