CO2-FREE HYDROGEN SUPPLY CHAIN PROJECT AND RISK ASSESSMENT FOR THE SAFETY DESIGN

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Kawasaki Heavy Industries, Ltd.
Suguru Oyama

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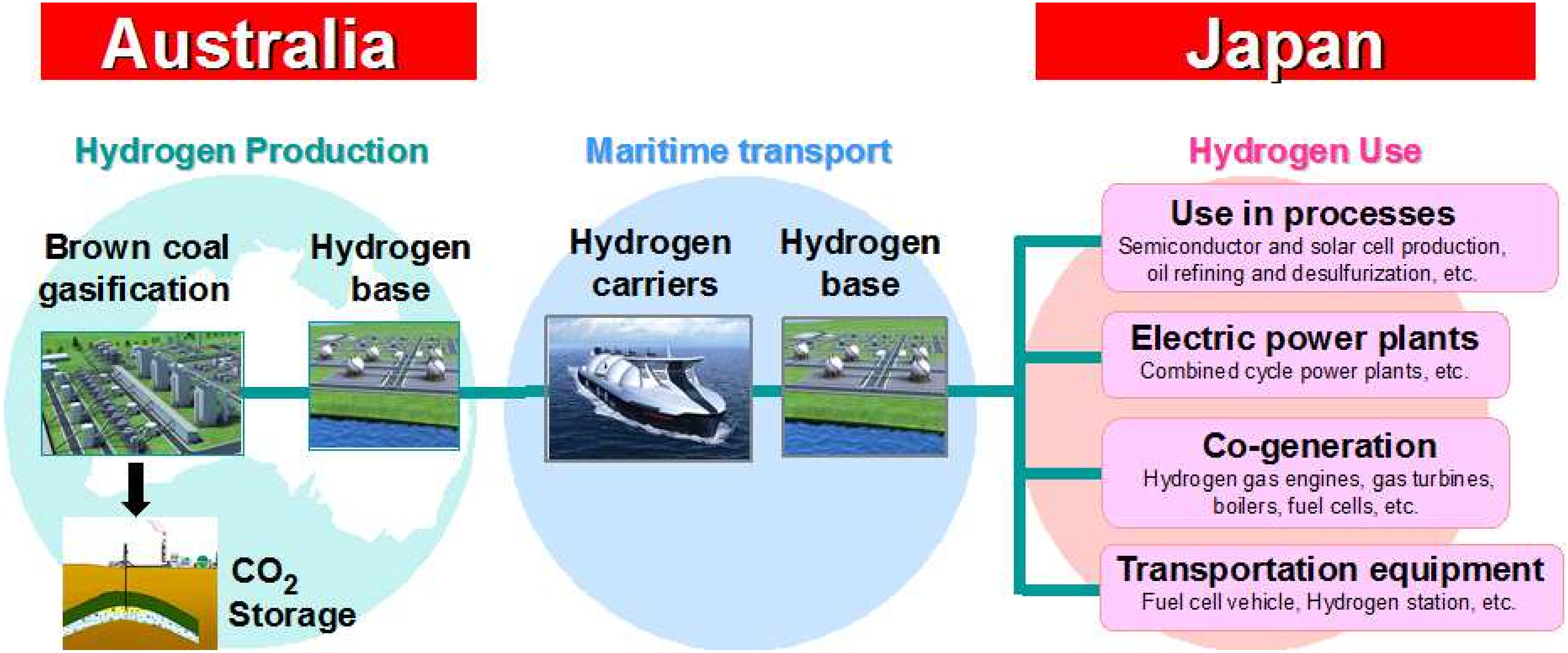
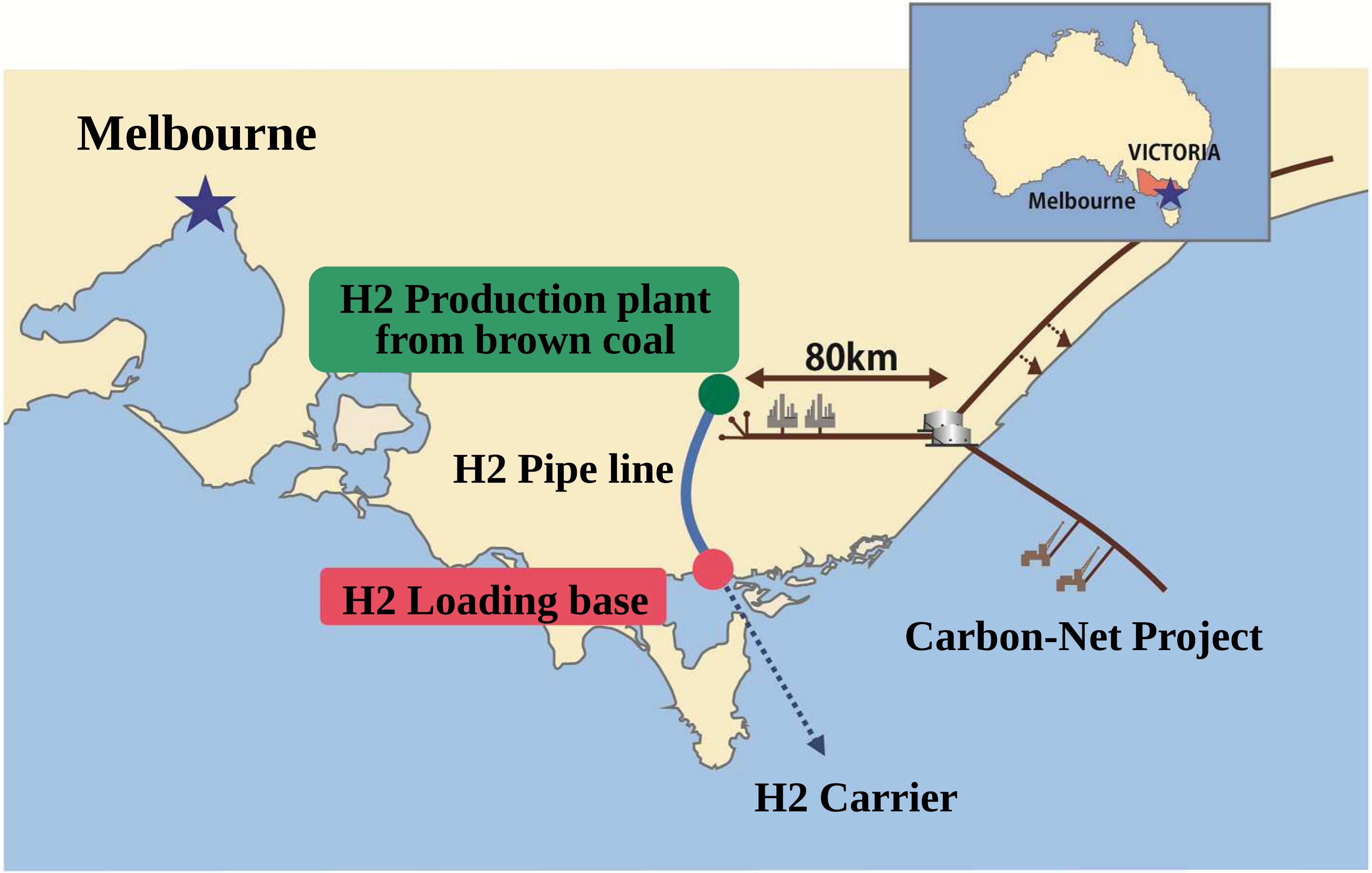
1.CO2-Free Hydrogen Supply Chain



Overview of commercial-scale HESC



Hydrogen Production Plant

Brown coal:	**14,200 t/day**	**4,700,000 t/year**
Hydrogen:	**770 t/day**	**246,000 t/year**
CO_2 :	**13,300 t/day**	**4,400,000 t/year**

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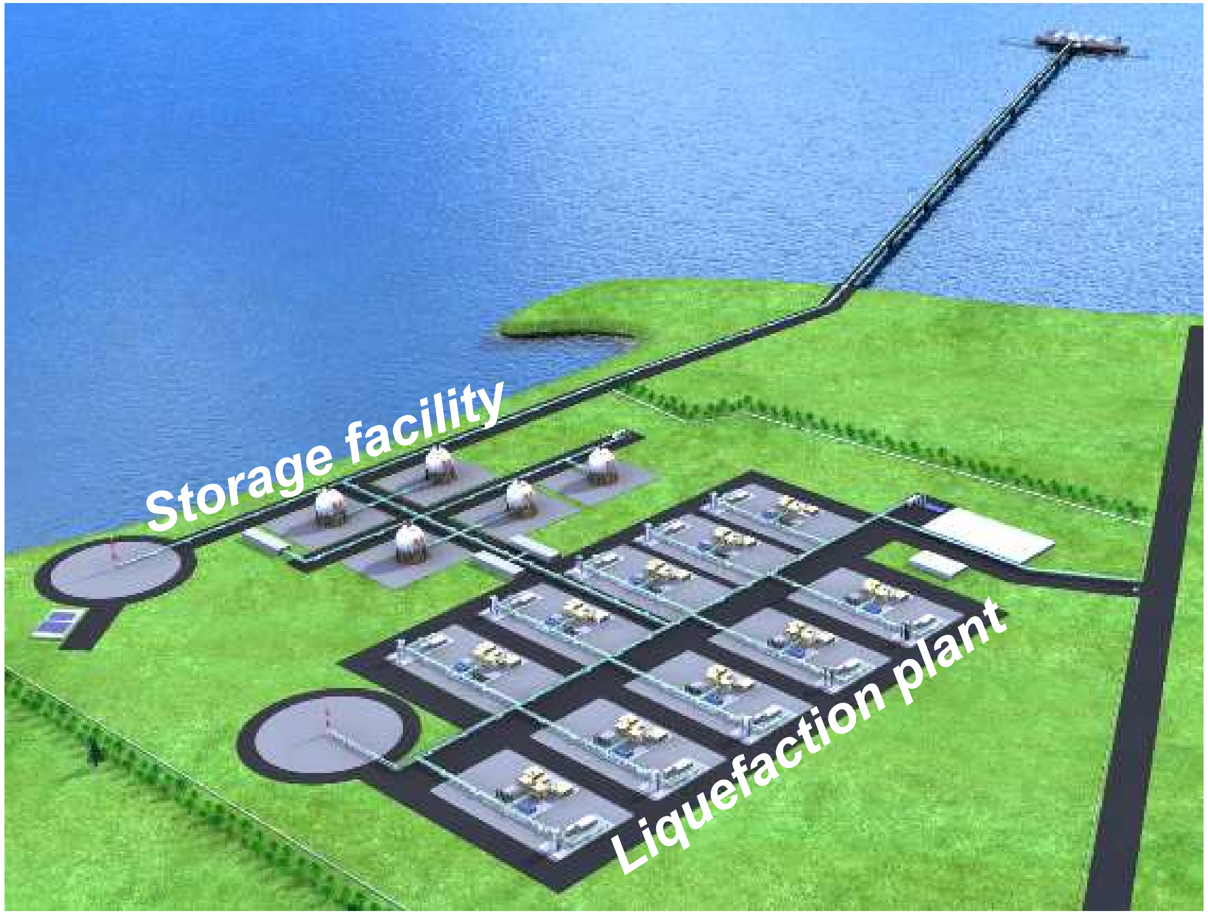
Hydrogen Loading Base



Hydrogen liquefaction: Capacity:770 t/day

Hydrogen storage facility: 50,000 m^3 x 5 tanks

Liquefied Hydrogen Carrier

Length:	315 m
Width:	56 m
Depth:	28 m
Required sea depth:	11 m

Ship type: Pressure built-up
Numbers of ship: 2
H2 carrier size: 160,000 m^3/ship
Boil off Rate (BOR): 0.2% / day

Annual delivery Qty: 238,500 ton/year-H_2
Service speed: 16 kts
Voyage days: 12.6 days/one way

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Delivered hydrogen cost (CIF Japan)

CIF cost
≒ **30 yen/Nm^3**

Carrier	9%
Loading base	11%
Liquefaction	33%
Production	29%
CO_2 storage	10%
Brown coal	8%

Loading quantity: 238,500 t/year

Delivered hydrogen quantity
225,400 t/year

FCV (Fuel Cell Vehicle) : 3 million

Hydrogen power plant : 650 MW

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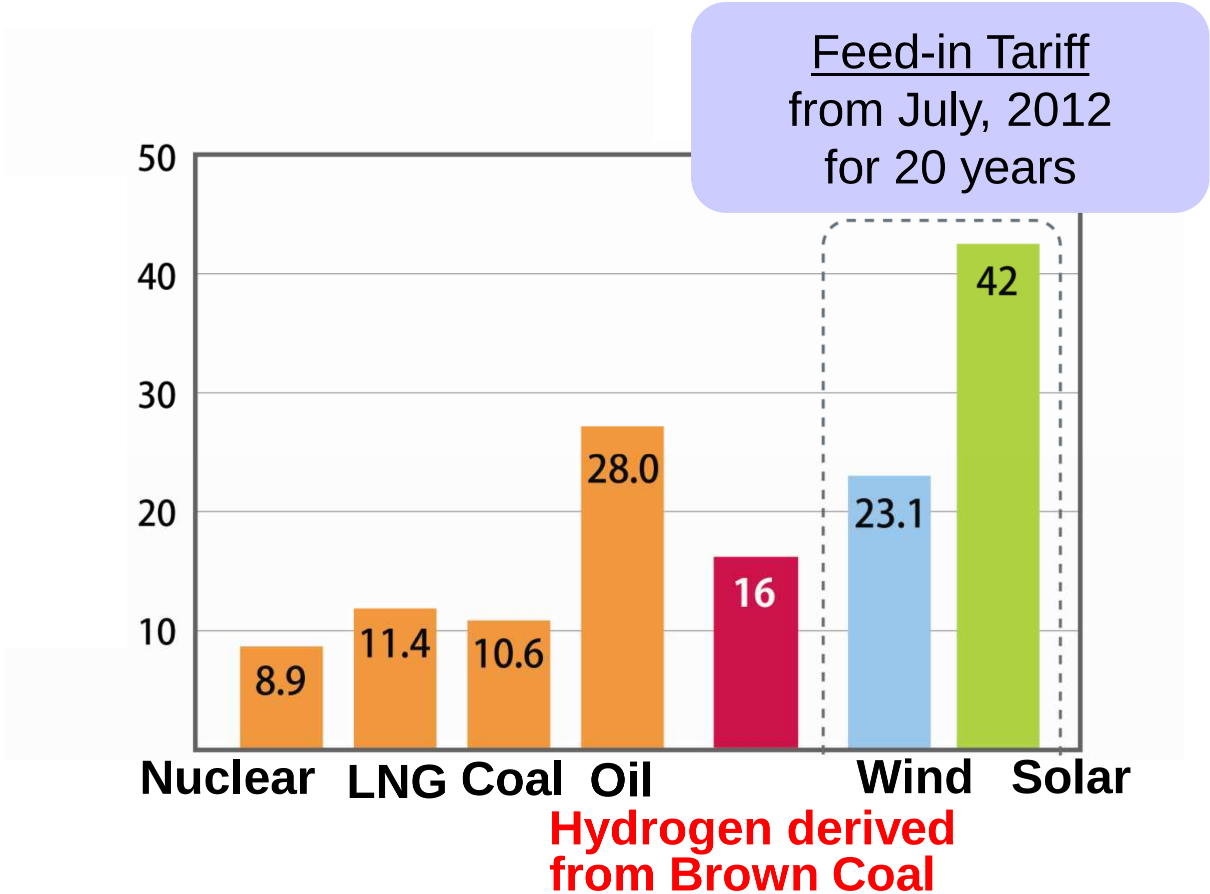
Evaluation of power generation use in Japan

Power generation cost [yen/kWh]



Result cost is more competitive than wind and solar.

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The Next Stage

- It was found that commercial-scale HESC is **technically and economically feasible** and will deliver **significant benefits both to Australia and Japan**.
- However, before commercialization, technical demonstration, safety verification and demonstration of stable operation to potential investors are necessary with pilot-scale HESC.

↓

Then as a next stage, **conceptual design of pilot-scale HESC with preliminary costs has been conducted**.

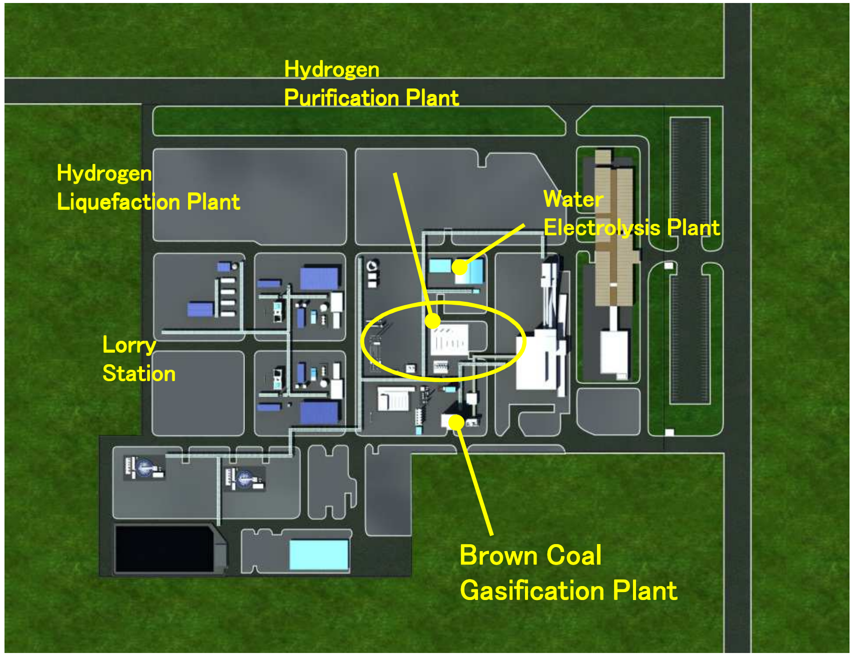
＊HESC：Hydrogen Energy Supply Chain

Pilot Scale Chain Main Specifications

PLANT SYSTEM	CAPACITY	NUMBER	REFERENCE
Brown coal Gasification Plant and Hydrogen Refining Plant	5.5t/d-H2	1set	Annual Hydrogen Production Capacity 2,660 ton
Electrytic Hydrogen Production Plant	2.9t/d-H2	1set	
Hydrogen Liquefaction Plant	4.2t/d-H2	1set	
Hydrogen Gas Turbine Generation Plant	4.2t/d-H2	1set	-
Hydrogen Storage Facility	3,400m3	1set	Annual Cargo Capacity 873 ton
Hydrogen Carrier	2,500 m3	1set	

Pilot Scale Chain

Hydrogen Production Plant
Hydrogen Loading Base
Liquefied Hydrogen Carrier



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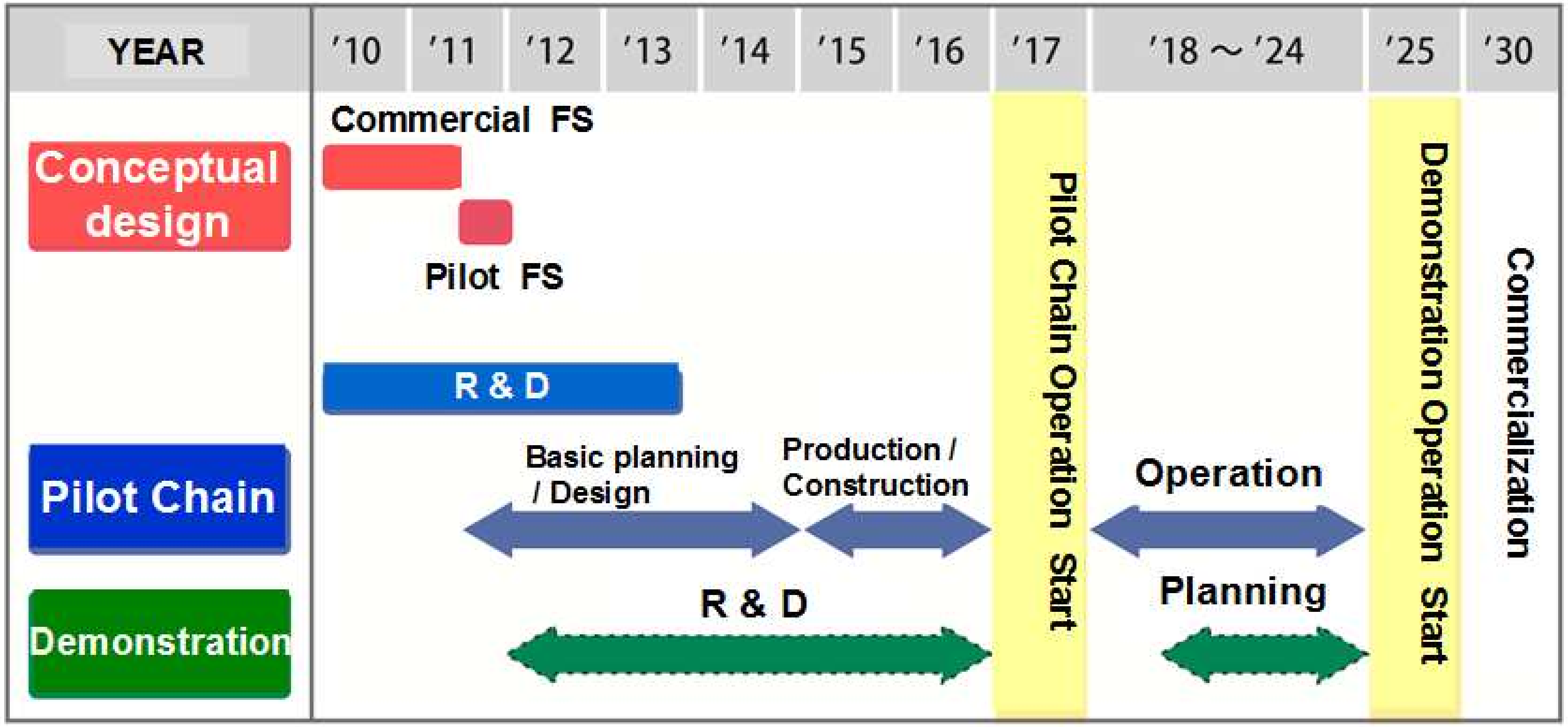
Schedule of Development



1) 2030 Commercialization
2) 2025 Demonstration Operation Start
3) 2017 Pilot Chain Operation Start
4) ~2013 Establishment of Technology, Funding and Consortium

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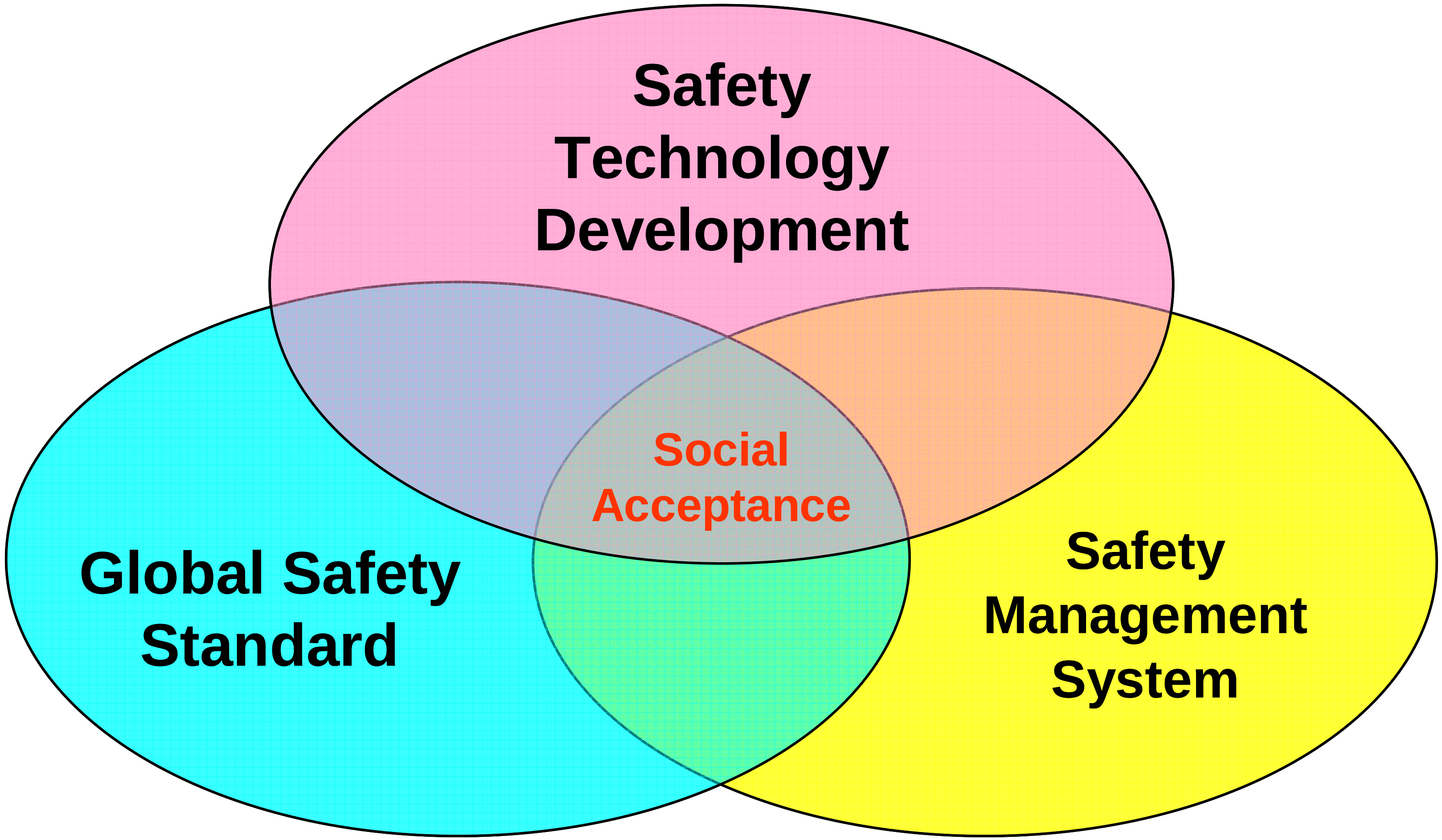
2. Establishment of Hydrogen Safety System



Establishment of International Safety Standards
(Liquefied Hydrogen Carrier)

Incorporation of selective countermeasures

Basic Design of Liquid Hydrogen Carrier

Hazard identification and risk assessment, using HAZID and FMEA method

Safety Evaluation of Hydrogen Carrier

Minimum/Special Requirements of IGC Code

Amendment of minimum/special requirements in IGC Code

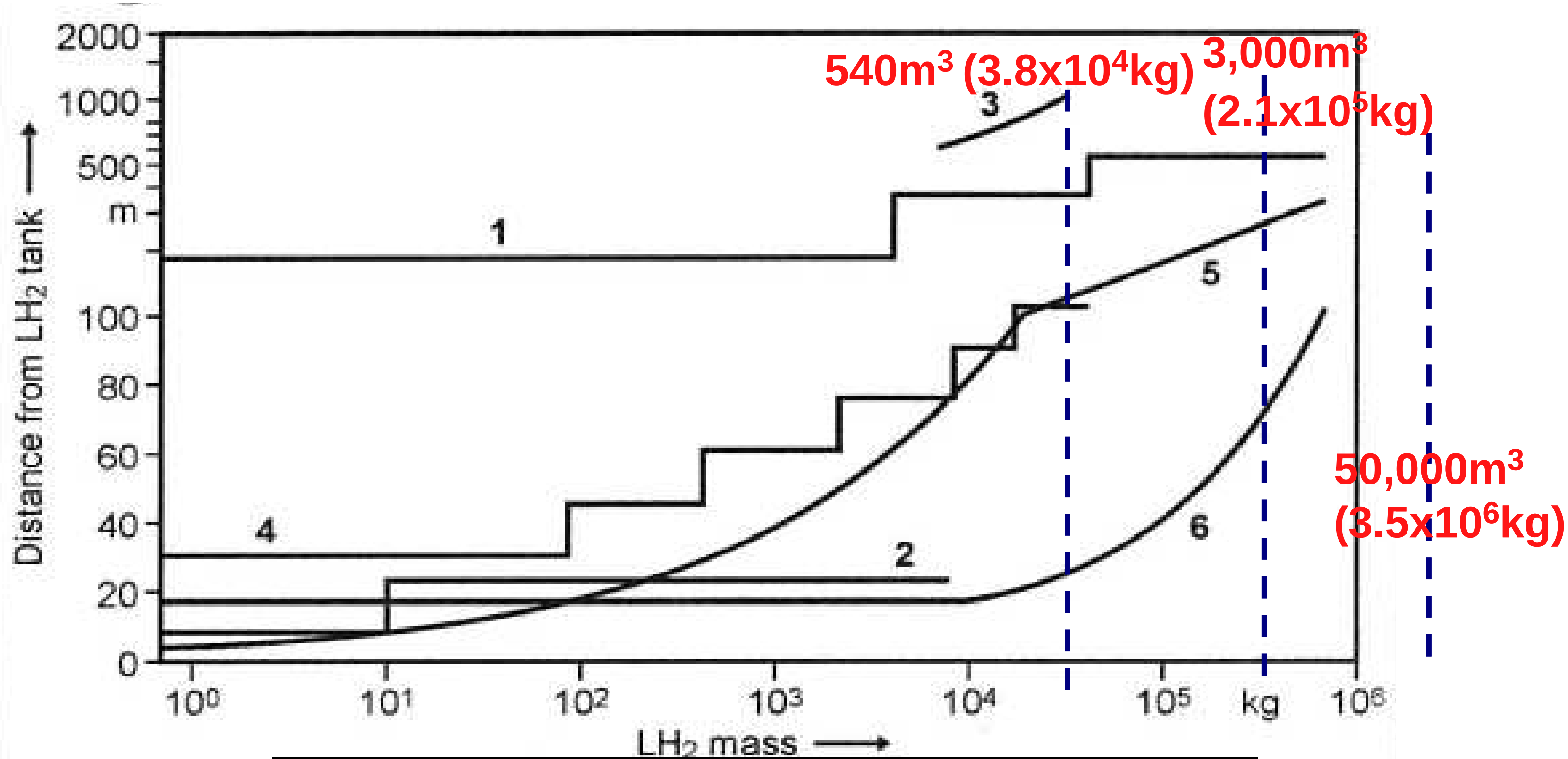
Proposal for IGC Code and International standard

Conclusion of bilateral agreement between Japan and Australia, Certification of IMO

＊HAZID : HAZard Identification

＊FMEA : Failure Modes and Effects Analysis

Safety Distance from LH2 Tank



1 US Dep. Defense Instruction No. 4145.21 (1964)
2 National Fire Protection Association (NFPA), Boston (1973)
3 US Army Material Command Safety Manual No. 385-224 (1964)
4 Burean of Mines, Pittsburgh (1961)
5 German Fed. Ministry of the Interior, Bonn (1974) (nuclear power plants) for liquefied gases
6 High-Pressure Gas Control Legislation, Japan (category I)

Reference: K. Verfondern, Figure 6-5 Safety Distances, Safety Considerations on Liquid Hydrogen, p53-54, 2008.

Development of Hydrogen Safety Technologies

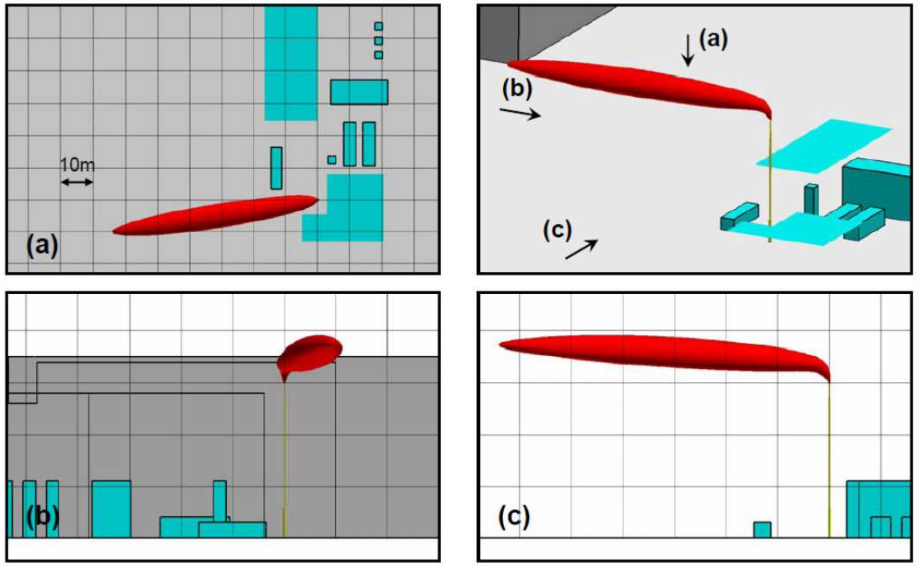
"NEXT H2" Program
(Non-EXplosion Technology for H2" Program)

We,KAWASAKI is developing the indispensable hydrogen technologies to realize "CO2 Free Hydrogen Utilization Society".
Through the best "explosion proof technologies for hydrogen" in the world, we give you the safety and security in Hydrogen Utilization Society.

STEP 1	We appreciate the hydrogen properties concerning safety through acquisition of the fundamental data resulted from hydrogen leakage, ignition, explosion experiments.
STEP 2	We analyze the hydrogen leakage, ignition, explosion phenomena for safety thoroughly with computer simulation.
STEP 3	We never cause a hydrogen explosion accident due to equipment failure, human error through thorough evaluations of system safety and reliability.
STEP 4	We develop and produce the highly safe and reliable explosion proof devices and systems for hydrogen.

STEP1 Hydrogen Leakage Experiments

STE2 Computer Simulation



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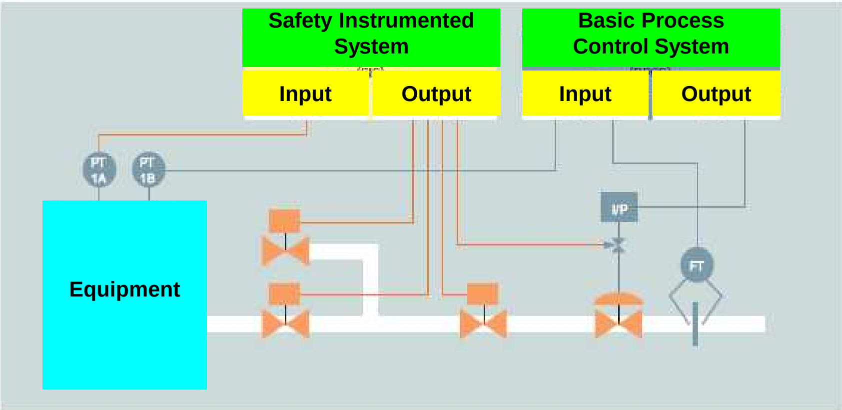
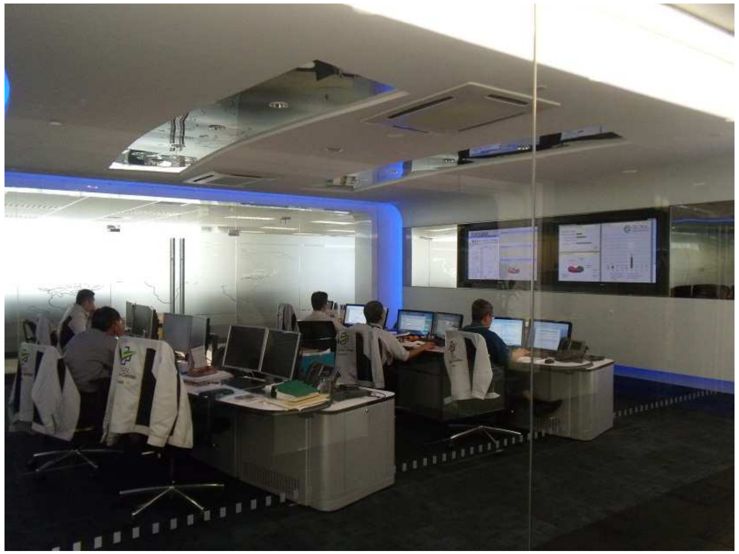
STEP3
Safety System and Operator Support System



Safety System for Plants

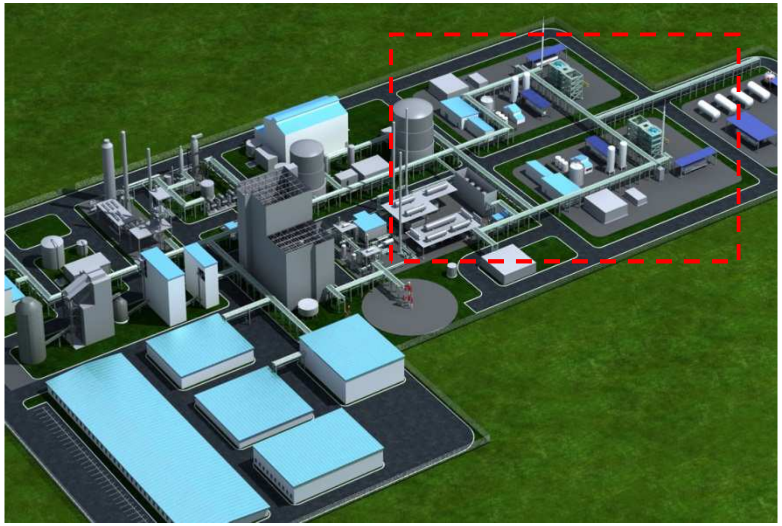


Operator Support System for Plants

STEP4
The highly Safe and Reliable Explosion proof Systems

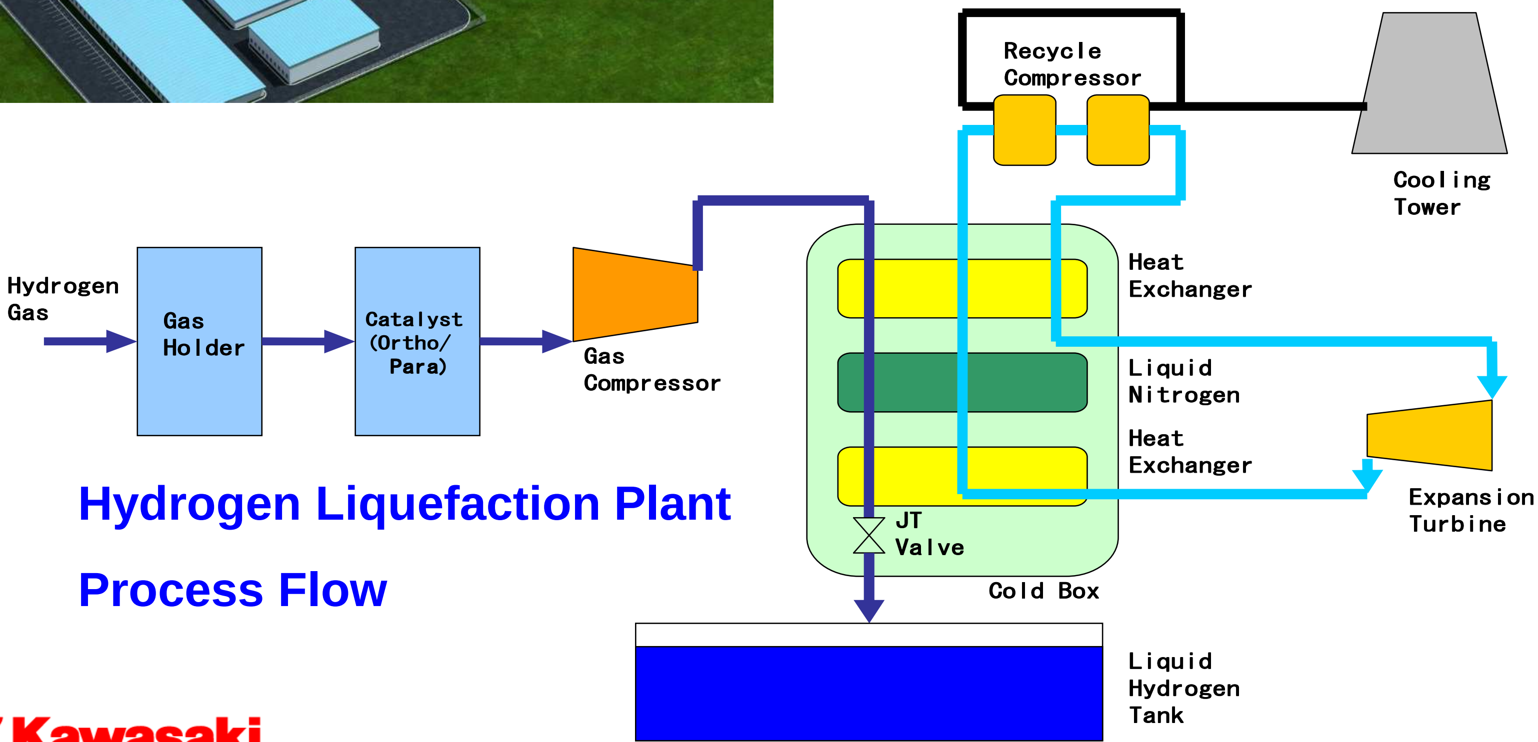
Explosion Proof
for Liquid Hydrogen Carrier
Propulsion System

Establishment of Safety Management System (Hydrogen Liquefaction Pilot Plant)



Specification of Hydrogen Liquefaction Plant

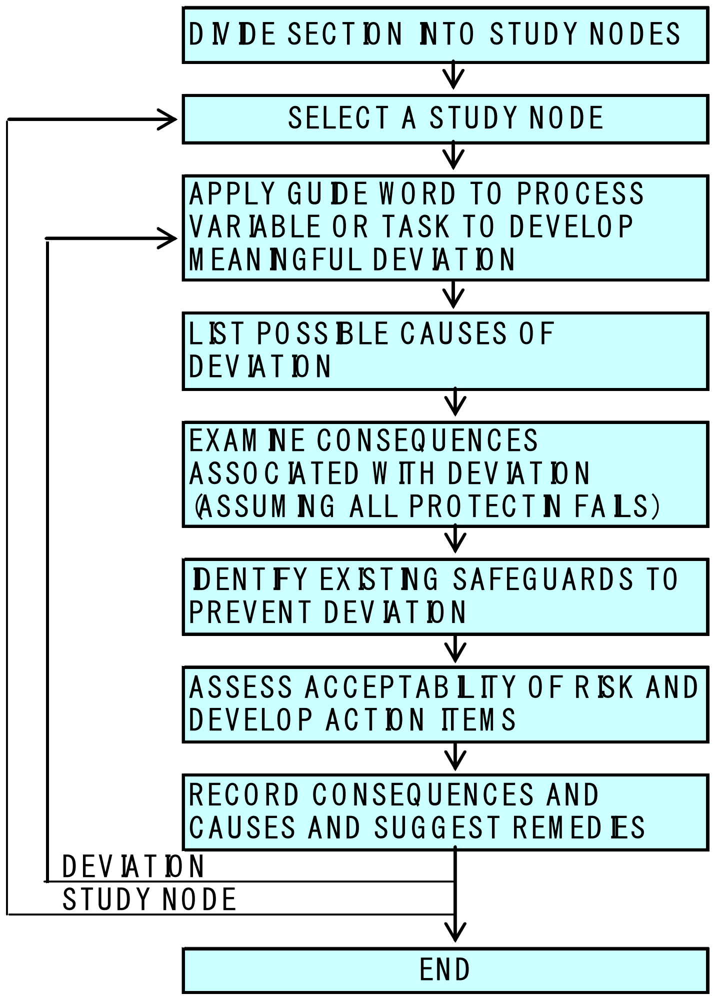
Numbers	2 units
Liquefaction Process	Hydrogen Claude Cycle
Liquefaction Capacity	5 tons/day/unit
Inlet Hydrogen Purity	＞99.999 Vol %
Inlet Pressure	2.0 MPaG
Inlet Temperature	ambient temperature



Hydrogen Liquefaction Plant Process Flow

Safety Design with HAZOP
(Hazard and Operability Studies)

HAZOP Basic Procedure



Example: Deviation and Cause on HAZOP

Parameter	Deviation	Cause
Flow	no flow	control valve fails closed, pump fails suspension
	more flow	contorol valve fails open, control valve bypass full open
	less flow	partial blockage of filter
	reverse flow	backpressure high, down stream pressure high
Pressure	high pressure	control valve fails closed, manual valve misoperation closed
	low pressure	pressure control valve fails open, upstream piping blockage
Temperature	high temperature	heating furnace abnormal combustion, cooling water no flow
	low temperature	heating furnace suspension, loss of heat medium
Level	higher level	level control valve fails closed
	lower level	level control valve fails open, less feed flow, discharge line open
Composition	changes	feed material change, quantitative increase of ingredient material
	impurities	generation of reaction byproduct, filter fenestration

SIL Evaluation based on AIChE CCPS

INDEPENDENT PROTECTION LAYERS

IPL8	Community Emergency Response
IPL7	Plant Emergency Response
IPL6	Post-Release Physical Protection (e.g. Bunding)
IPL5	Physical Protection (e.g. Relief Devices)
IPL4	Safety Instrumented System prevention action
IPL3	Critical Alarms and Operator Intervention
IPL2	Basic Process Control System, Operating Discipline/Supervision
IPL1	PROCESS DESIGN

HAZARD LEVELING

Risk Parameter		Classification	
Hazardous event Severity	C1	Minor	Minor injury
	C2	Serious	One death or permanent injury to one or more persons
	C3	Extensive	Several deaths
Event Likelihood	W1	Very Slight	$<10^{-4}$/year
	W2	Slight	$10^{-4}\sim10^{-2}$/year
	W3	Relatively High	$\geqq 10^{-2}$/year

Total Number of Independent Safety-Related systems

MINOR (C1)

Total Number of Independent Safety-Related systems	LOW (W1)	MED (W2)	HIGH (W3)
3	SIS: not required	SIS: not required	SIS: not required
2	SIS NR	SIS NR	SIL1
1	SIS NR	SIL1	SIL2

EVENT LIKELIHOOD

SERIOUS (C2)

Total Number of Independent Safety-Related systems	LOW (W1)	MED (W2)	HIGH (W3)
3	SIS: not required	SIS: not required	SIS: not required
2	SIS NR	SIL1	SIL2
1	SIL1	SIL2	SIL3

EVENT LIKELIHOOD

EXTENSIVE (C3)

Total Number of Independent Safety-Related systems	LOW (W1)	MED (W2)	HIGH (W3)
3	SIS NR	SIL1	SIL1
2	SIL1	SIL2	SIL3
1	SIL3	SIL3	SIL3

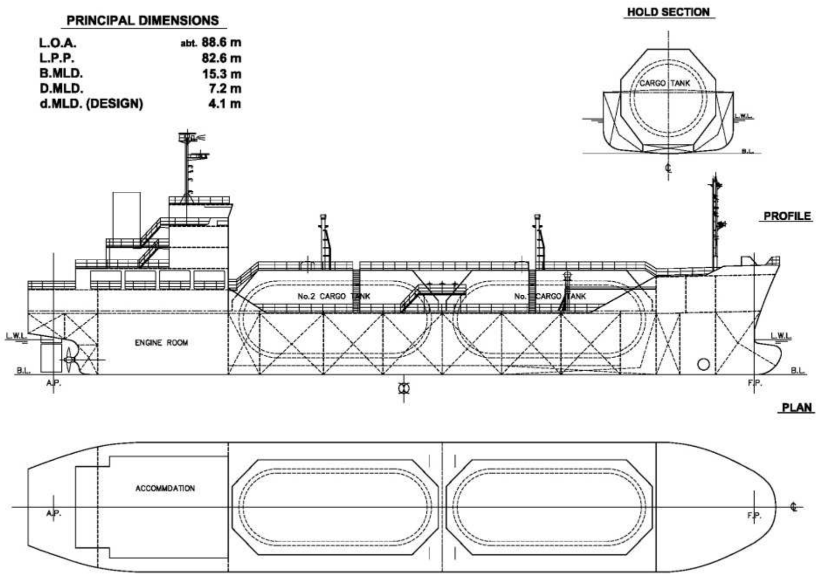
EVENT LIKELIHOOD

* SIL : System Integrity Level

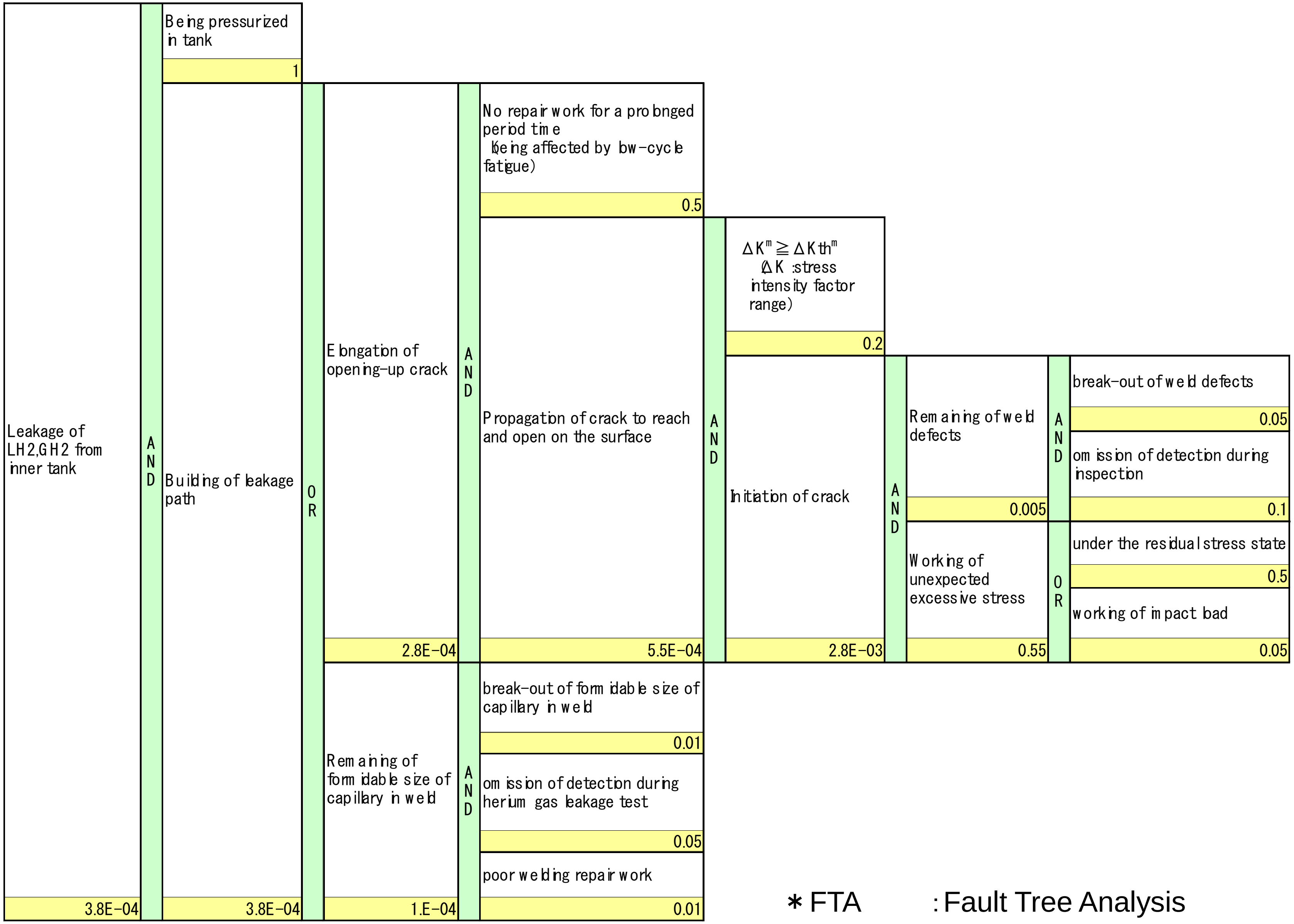
* AIChE : American Institute of Chemical Engineering

* CCPS : Center of Chemical Process Safety

Liquid Hydrogen Carrier Safety Design



Example1 : FTA (Inner Tank Leakage)



＊FTA　　:Fault Tree Analysis

Example2 : FTA (Inner Tank Breakdown)

＊FTA　　:Fault Tree Analysis

- **Breakdown of inner tank** — 0.001 — OR
  - Insufficient structural strength — 0.001
  - High pressure exceeding the structural strength of tank — 6.4E-06 — AND
    - Pressure rising of BOG in tank — 0.064 — AND
      - Continuous and/or rapid pressure rising of BOG — 0.400 — OR
        - Sluggish increase of heat flux due to gradual degradation of vacuume degree — 0.25 — AND
          - Diffusion of H2 gas in vacuume chamber derived from extraction of absorbed gas or leakage from capillary — 0.5
          - Incompetency of vacuume pump — 0.5
        - Rapid increase of heat flux due to hasty degradation of vacuume degree — 3.8E-04 — OR
          - Diffusion of H2 gas in vacuume chamber due to leakage from through wall crack of inner tank — 3.8E-04
          - Diffusion of N2 gas in vacuume chamber due to leakage from through wall crack of outer tank — 3.5E-10
        - Building of evaporation layer on the LH2 surface (Stratification) due to extension of long period detention — 0.15 — OR
          - Stranding — 0.05
          - Long period anchorage — 0.1
      - Incompetency of H2 incinaretor — 0.160 — OR
        - Malfunction of pressure sensor — 0.01
        - Malfunction of CPU — 0.0001
        - Malfunction of flow control valve — 0.05
        - Malfunction of incinerator body — 0.1
    - Incompetency of No.1 pressure relief valve — 0.01
    - Incompetency of No.2 pressure relief valve — 0.01

Thank you for your attention !