Value chain analysis of liquefied hydrogen, ammonia and pipeline for long distance hydrogen transport

The Institute of Applied Energy

SINTEF

Yuki Ishimoto (The Institute of Applied Energy)

Mari Voldsund, Petter Nekså, Simon Roussanaly, David Berstad and Stefania Osk Gardarsdottir (SINTEF)

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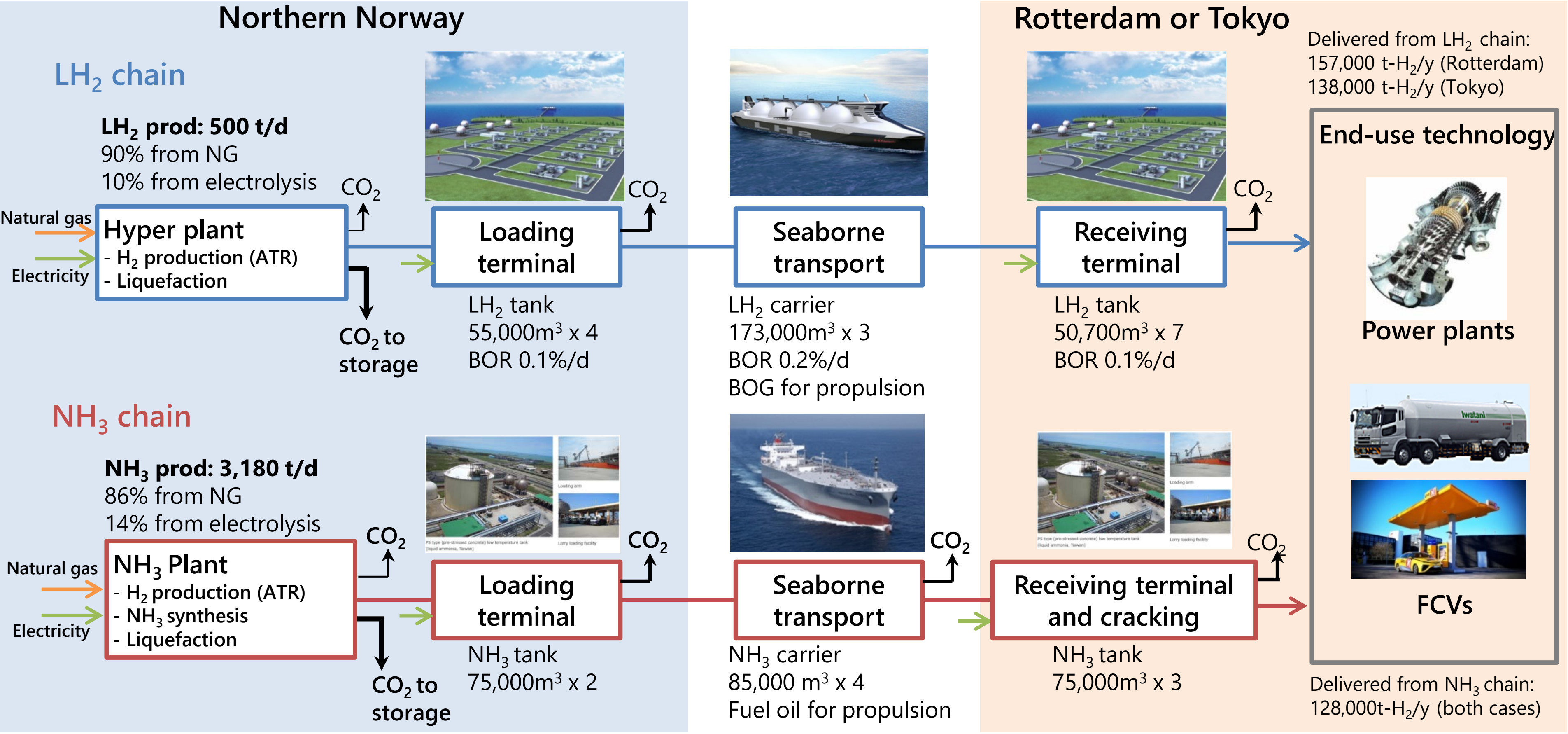
Agenda

- Scope and objectives
- Long distance transportation using LH_2 and ammonia
  - Assumptions
  - Highlights (efficiency, CO_2 emissions and cost)
- Pipeline option for a short distance alternative
  - Assumptions
  - Highlights (efficiency, CO_2 emission and cost)
- Comparison of transport options
- Summary

Scope and Objectives

- Scope
  - The whole value chain from hydrogen production to the receiving terminal including the “Hyper concept”.
- Objectives
  - To obtain quantitative results of efficiency, CO_2 emission and cost
  - To identify important elements for improving the values chain performances
- Methodologies
  - High level analysis (mainly based on aggregated energy intensities of facilities and cost from literature)
  - Uncertainty: no existing commercial value chain for utility scale today

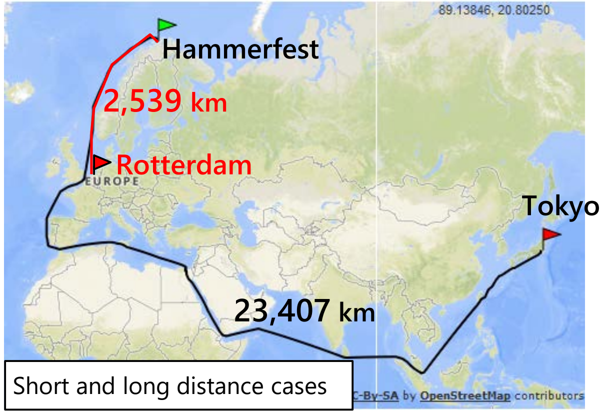
Schematic diagram of the chains for long distance transport



Note: Terminal and ship data are for the Tokyo case

Common assumptions

- Seaborne transportation
  - Origin: Hammerfest
  - Destination
    - Rotterdam: Short distance case
    - Tokyo: Long distance case and Northern Sea Route (NSR) case
- Carbon intensity of grid electricity
  - Supply side (Norway): 16 kg-CO_2/MWh_{el}
    - 98% from renewable
  - Demand side (Continental Europe and Japan): 367 kg-CO_2/MWh_{el}
    - NGCC (conversion efficiency 55%)
- Utilization factor: 90%
- Methodology for the analysis
  - Hyper plants: Process simulation models
  - NH_3 synthesis: Literature based specific natural gas consumption
  - Seaborne transportation:
    - Analysis duration: 1 year
    - Analysis time resolution: 1 hour
  - Cost data: based on literature

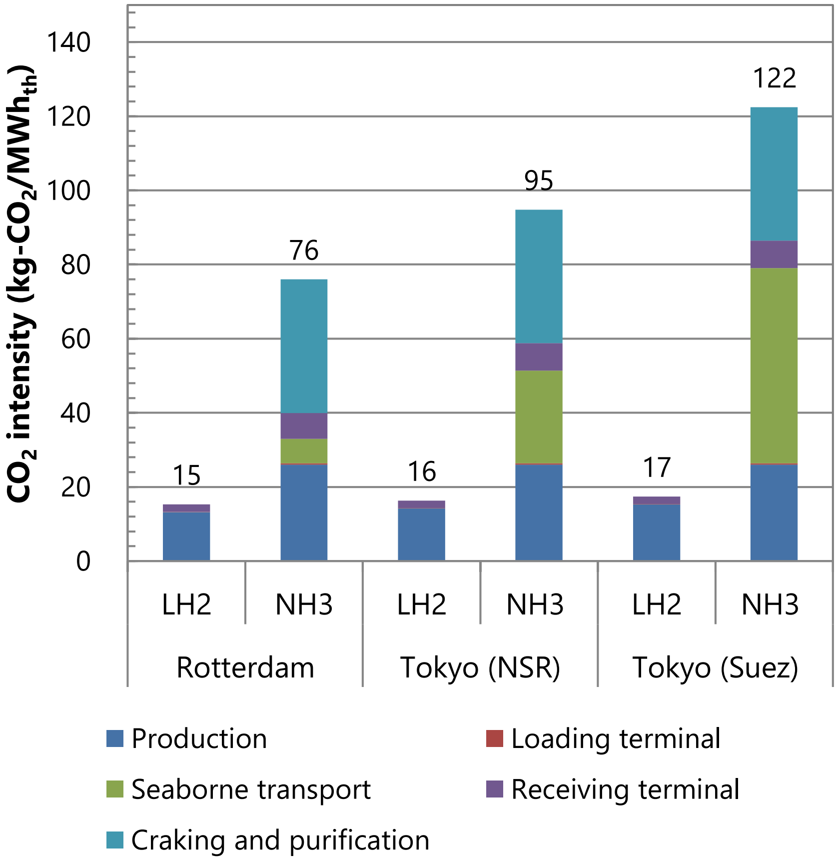


Short and long distance cases

https://www.vesseltracker.com/en/Routing.html

Northern sea route (NSR) case

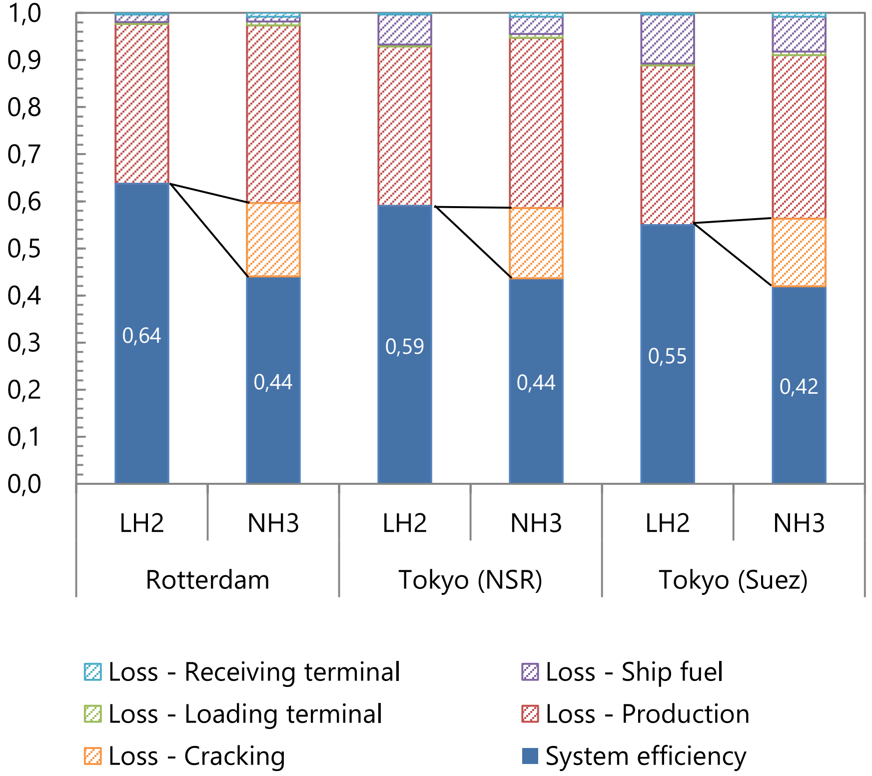
CO_2 emissions



- CO_2 emissions of the LH_2 chain are <20 kg-CO_2/MWh_{th} (CO_2 capture rate: 94□)
- Several measures *may partly* reduce emission from the NH_3 chain:
  - Transport via the NSR route can reduce CO_2 from ship fuel
  - Transport with NH_3 used as ship fuel
  - Renewable electricity in the cracking process
  - Direct use of NH_3 by end user – no cracking

- **The LH_2 chain will in any case have less CO_2 emissions than the NH_3 chain**

System efficiency and breakdown of losses

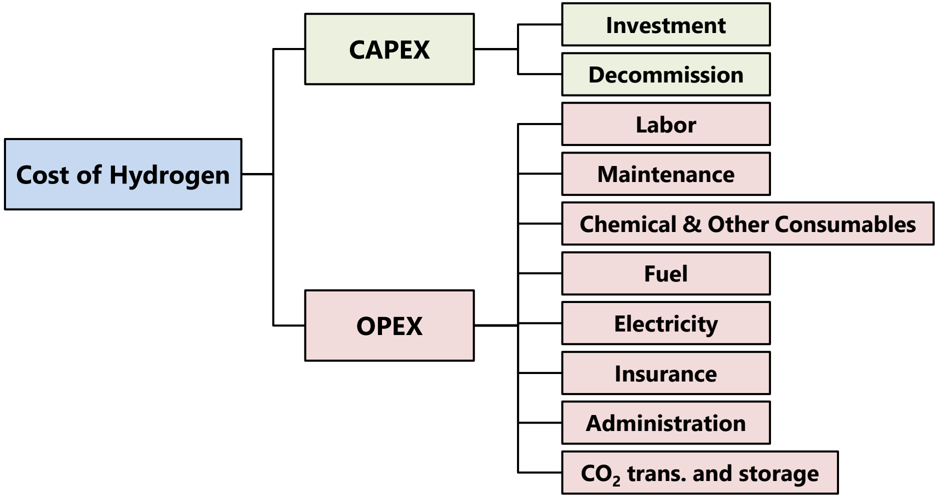


- Power and fuel consumption in hydrogen production makes up the largest loss in both the LH_2 and NH_3 chains.
- Cracking accounts for the second largest loss in the NH_3 chain.
- In the Tokyo case, ship fuel makes up a considerable efficiency loss for both chains.
- Transport via the NSR can improve system efficiency due to the shorter distance.

- The LH_2 value chain is significantly more efficient than the NH_3 chain if NH_3 cracking is required.
- The results are comparable if NH_3 cracking is not required.

Costing of value chains: Assumptions

- Cost of hydrogen = Total cost / Delivered hydrogen



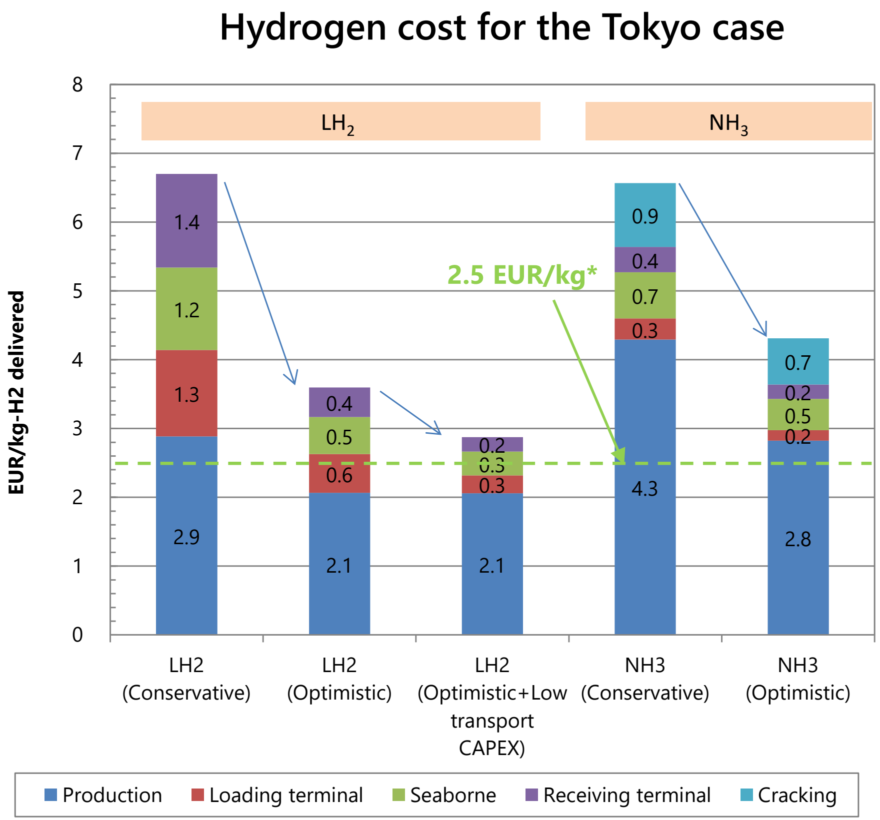
- Delivery (t-H_2 delivered/y)
  - LH_2 Rotterdam: 157,000
  - LH_2 Tokyo: 138,000
  - NH_3 both cases: 128,000
- Natural gas price: 4.5 EUR/GJ
- Electricity price: 38 EUR/MWh_{el}
- 25-year lifetime
- 3-year construction
- 90 % utilization

Total investment (Mil EUR_{2015}) is estimated based mainly on literature.

		Production	Loading terminal	Seaborne transport	Receiving terminal	Cracking	Total
LH_2	Rotterdam	1,846	1,068 (391)	275 (178)	1,473 (540)		4,662
	Tokyo	1,846	1,380 (506)	1,318 (851)	1,479 (542)		6,023
NH_3	Rotterdam	2,616	286	102	294	430	3,728
	Tokyo	2,616	286	409	294	430	4,035

Numbers in brackets are Low CAPEX case.

Costing of value chains: Results

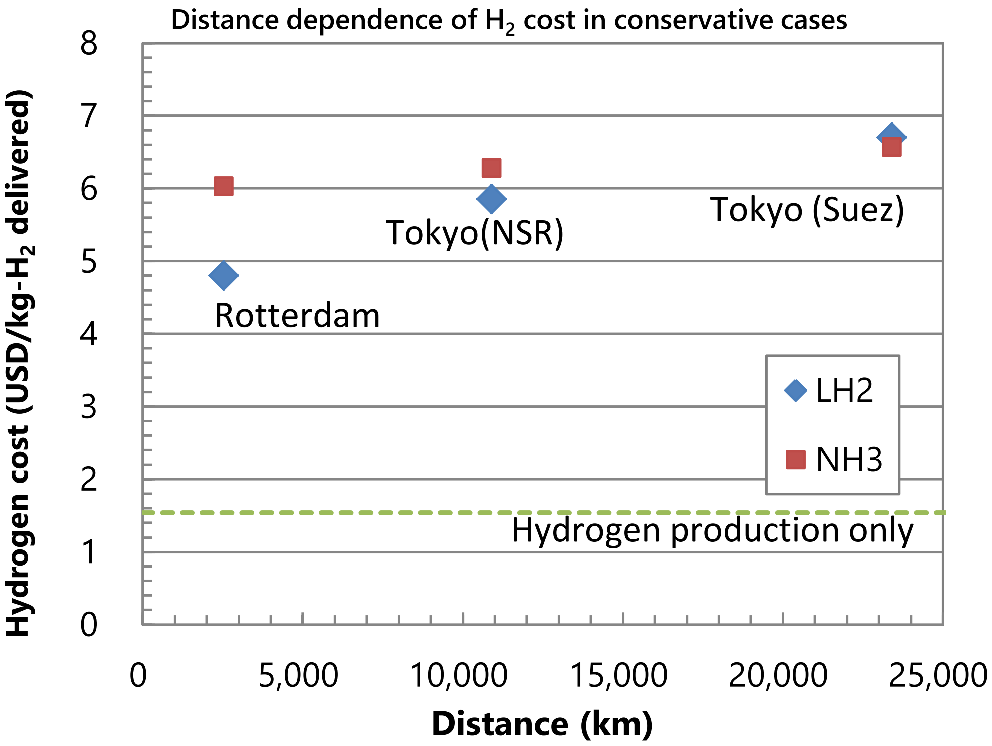


- Low cost case
  - Change production site to Southern area: Location factor 1.3 –> 1.0
  - Financial support for introduction phase: Discount rate 7.5 % -> 1.35 %
  - Capacity in the receiving terminal is reduced to 200,000 m^3 (~ 25 days).
  - Utilization rate 90->95%
- Low CAPEX case: Further LH_2 transport CAPEX reduction based on similarity with LNG technologies.

- The cost of both chains are in similar range in the conservative case.
- LH2 related facility cost should be reduced by R&D for transport facility.

* The target is in JPY. Value in EUR/kg may change depending on the exchange rate.

Distance dependence of hydrogen cost



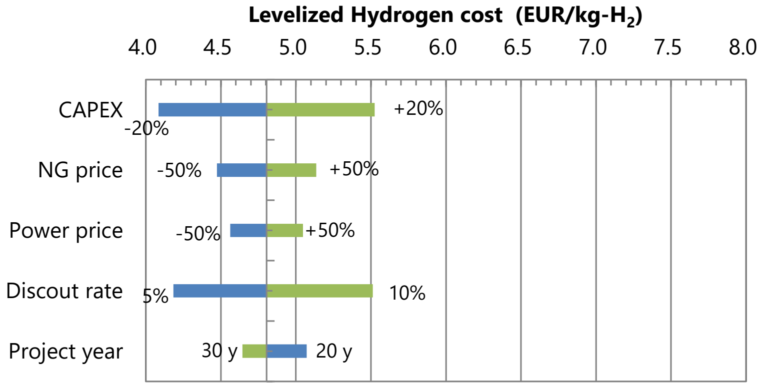
- LH_2: Shorter distance can reduce transport cost
  - Reduction of CAPEX
  - Reduction of BOG leads to increase of delivered hydrogen amount
  - Using NSR can reduce the transport cost of LH_2
- NH_3: Weaker sensitivity to distance than LH_2
  - Production cost is dominant in the total cost

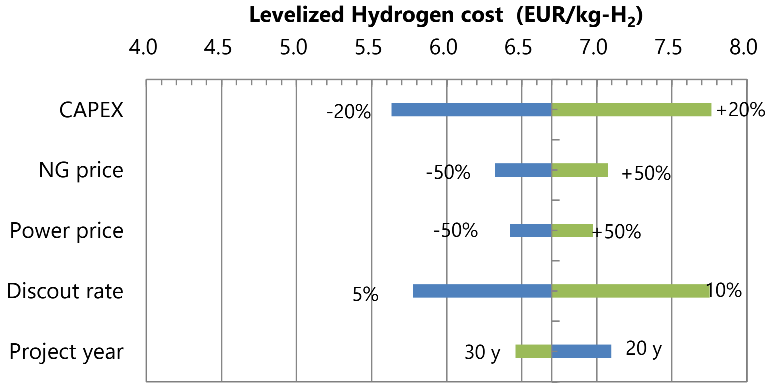
Sensitivity analysis of hydrogen cost

Rotterdam case

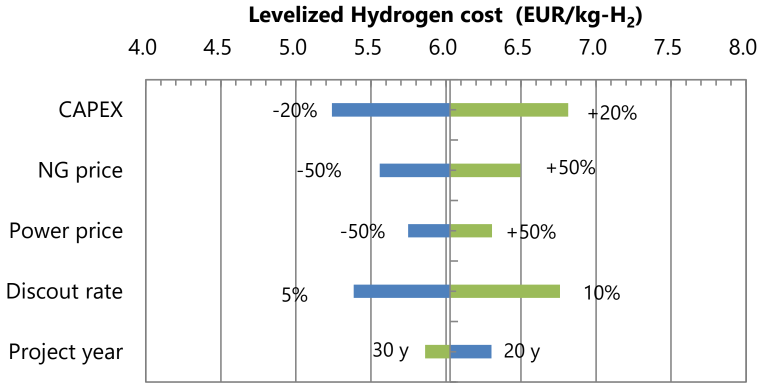
Tokyo case

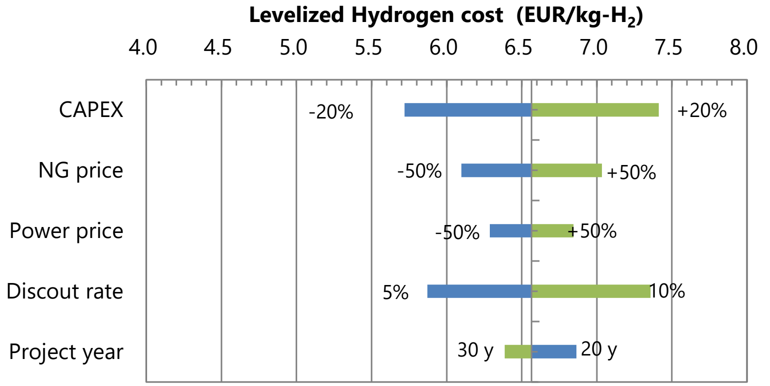
LH_2





NH_3

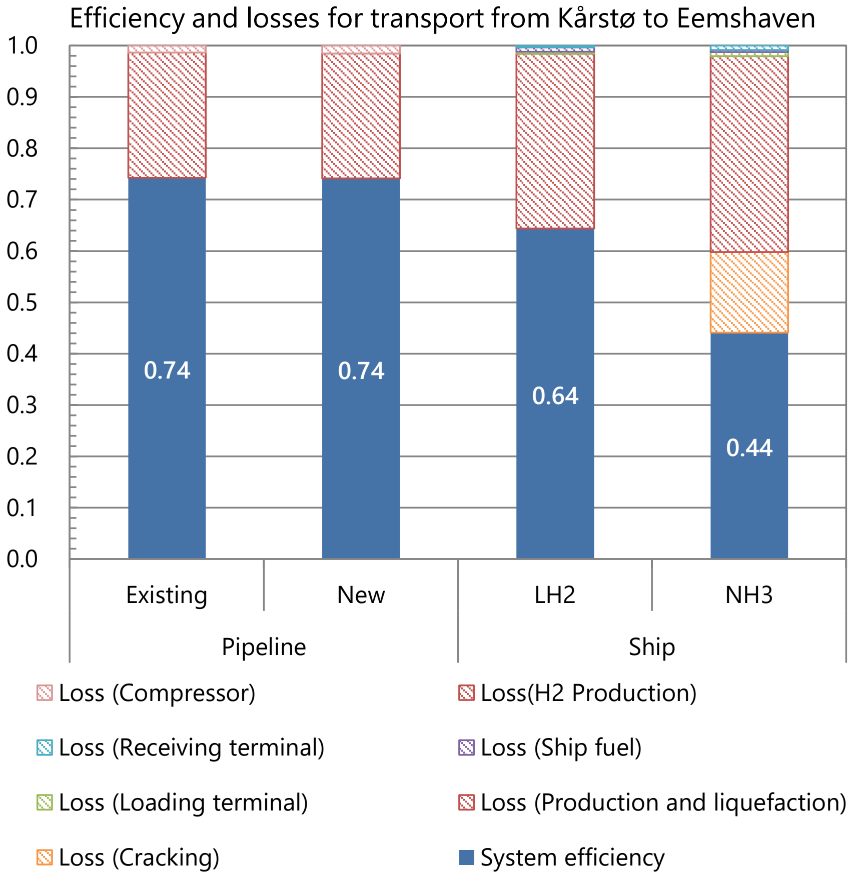




Short distance pipeline transport

- Kårstø to Eemshaven
- Flow rate: 500 t/d
- Outlet pressure 30 bar
- Compressor(s) at Kårstø
  - Draupner contains risers and platforms but does not contain any compressor.
- Route 1 (Existing pipeline)
  - 948 km (228 + 620 (subsea) + 60 (onshore and subsea))
    - Existing:Statpipe (28") + Europipe (40")
      - Inlet pressure of Europipe 83 bar at maximum
      - New bypass at Draupner
    - New onshore and subsea pipelines
      - 50 km and 10 km
      - 12"
- Route 2 (New pipeline)
  - 660 km, 18"
  - Direct path from Kårstø to Eemshaven

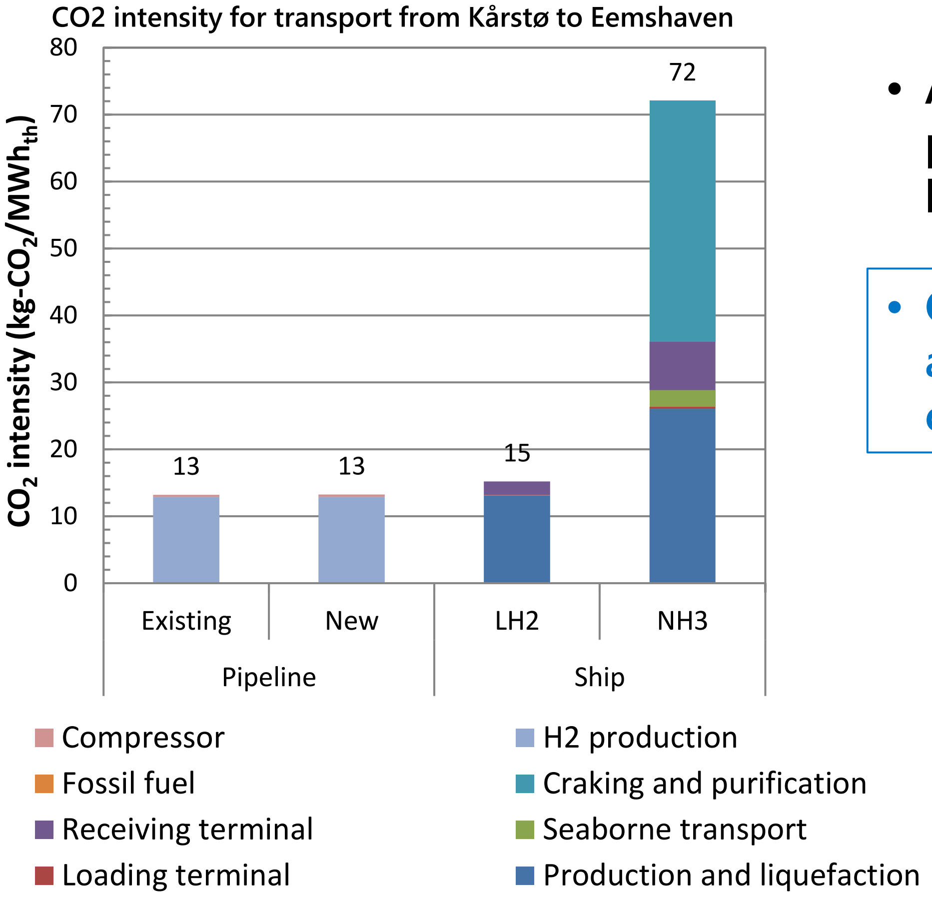
Energy efficiency of the pipeline and short distance ship



- **The system efficiencies of pipeline cases are almost the same (74%) because compressor power difference is almost negligible.**
- **The difference between pipeline and ship cases is the liquefier power consumption.**

- The system efficiency of the pipeline is higher than ship cases for short distance transport (ca. 1,000 km).
- At longer distances, pipeline efficiency might be reduced due to higher inlet pressure.

CO_2 emissions of the pipeline and short distance ship

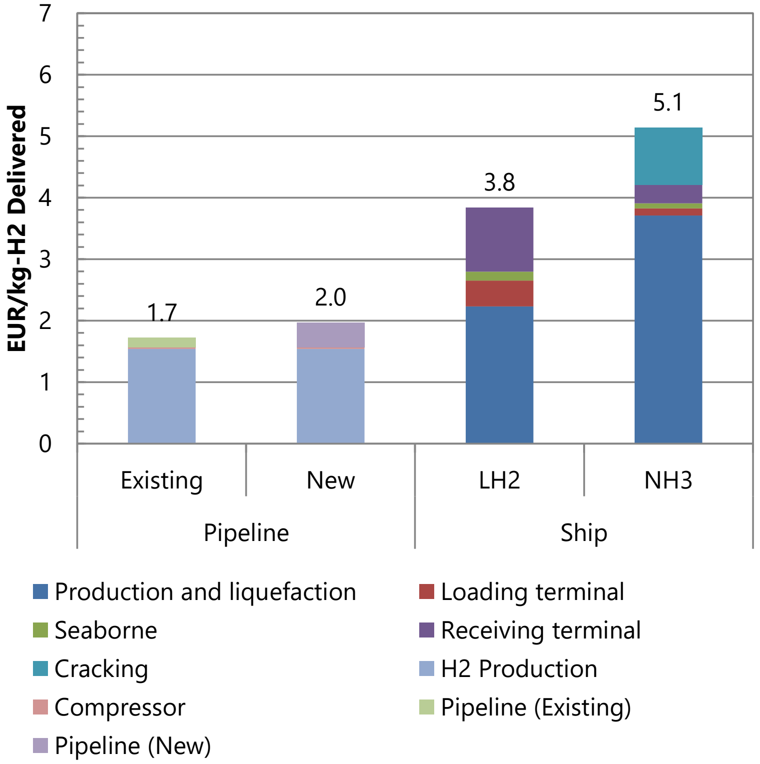


- Almost all CO_2 emissions of the pipeline value chain comes from the hydrogen production plant.

- CO_2 emissions from pipeline system are comparable with ones from LH_2 cases.

Cost breakdown of the pipeline and short distance ship

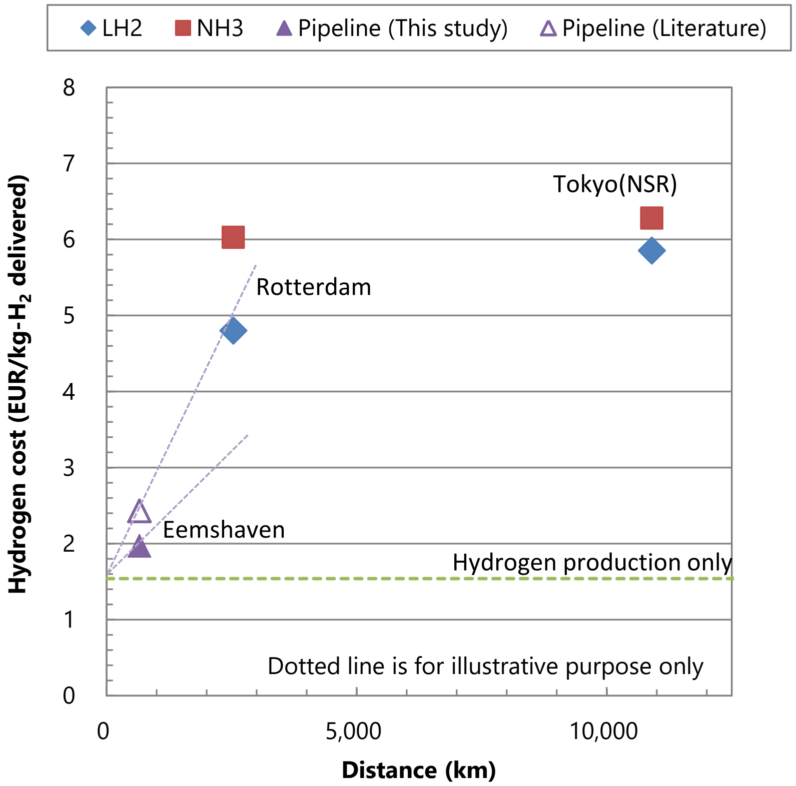
Delivered hydrogen cost of transport from Kårstø to Eemshaven



- Main cost difference between existing and new pipelines is due to CAPEX
- Main reasons for cost difference from the ship case
  - Hydrogen amount delivered: no H_2 loss assumed for the pipeline cases
  - Liquefaction: liquefiers and NH_3 synthesis plant
  - Transport: terminals and ships

- Hydrogen transport costs using existing and new pipelines are cheaper than using ship in the case of a short distance if destination is fixed.

Flexibility and breakeven range between ship and pipeline



- **Breakeven range seems to be around a few thousand km.**
- **The optimum transport technology depends on range and flexibility requirement.**

	Pros	Cons
Ship	• Relatively weak sensitivity to distance • Flexible destination	• Initial investment required even for short distance
Pipeline	• Cheap for short distance	• Cost sensitive to distance • Fixed destination

Note: the location factor of production plant and loading terminal in Eemshaven case is lower than other cases because hydrogen production plant is located in Kårstø (Southern area).

Pipeline cost literature: M. J. Kaiser, Marine Policy, 2017, 147-166

Summary

- We studied value chain analysis of long-distance hydrogen transport using LH_2 and NH_3 for both regional and global markets.
- The LH_2 chain is more energy efficient than the NH_3 chain.
- The LH_2 chain is greener than the NH_3 chain in terms of CO_2 emission from the chain.
- The hydrogen costs of both chains are similar for transport to Tokyo.
- It is cheaper to deliver LH_2 to Rotterdam compared to NH_3.
- Hydrogen transport cost using pipeline is cheaper than using ship in the case of a short distance if destination is fixed.
- The optimum transport technology (pipeline vs ship) depends on range and flexibility requirement.

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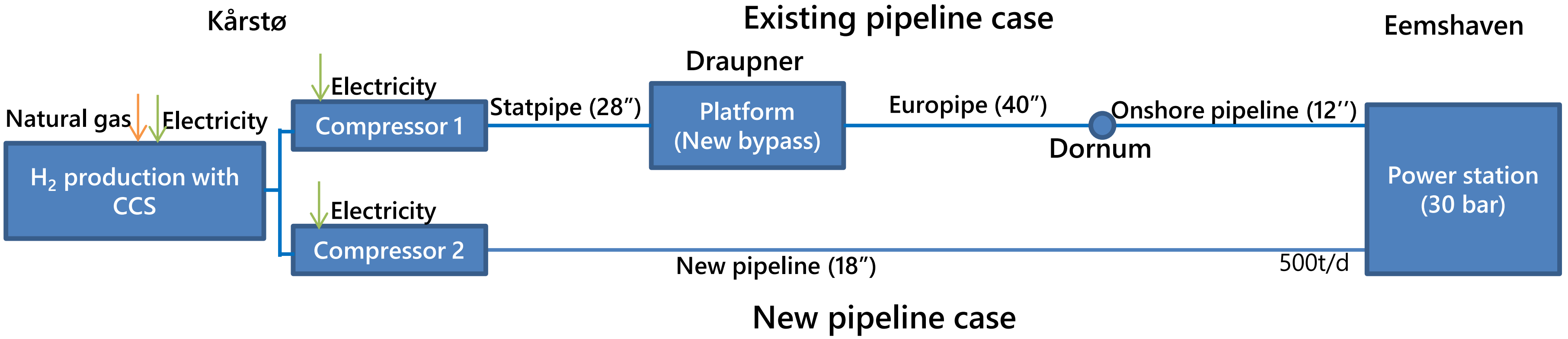
Backup slides

Schematic diagram of the Pipeline model

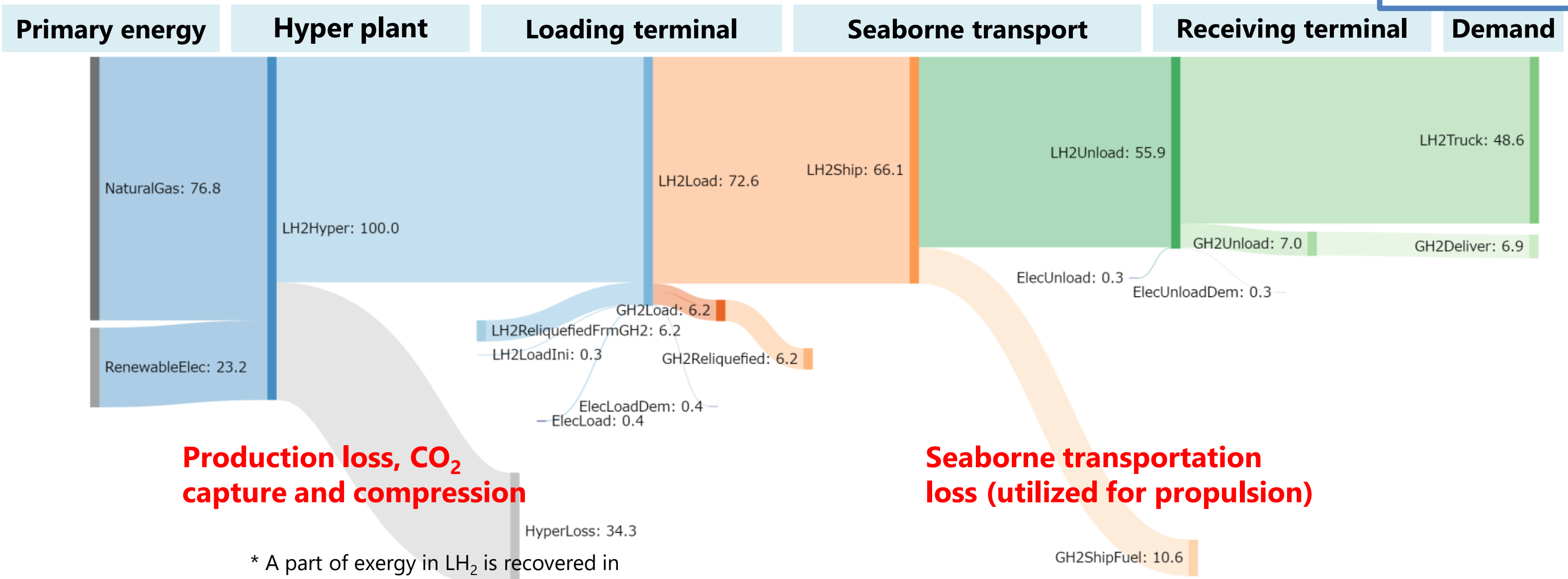


- H_2 production
  - Liquefiers removed from Hyper adv plant (electricity and CAPEX)
- Compressor
  - Reciprocating, from 20 bar to pipeline inlet pressure
- Pipeline
  - Existing pipeline: 61.2 bar (12”)
  - New pipeline: 73.7 bar (18”)
  - No H_2 loss (leak) during transport
- Platform at Draupner
  - New by-pass is installed.

Energy balance of LH_2 chain for power plant

Input to Hyper adv plant = 100

Note: the values are the total of flows into the node.



* A part of exergy in LH_2 is recovered in H_2 compression in HRS.

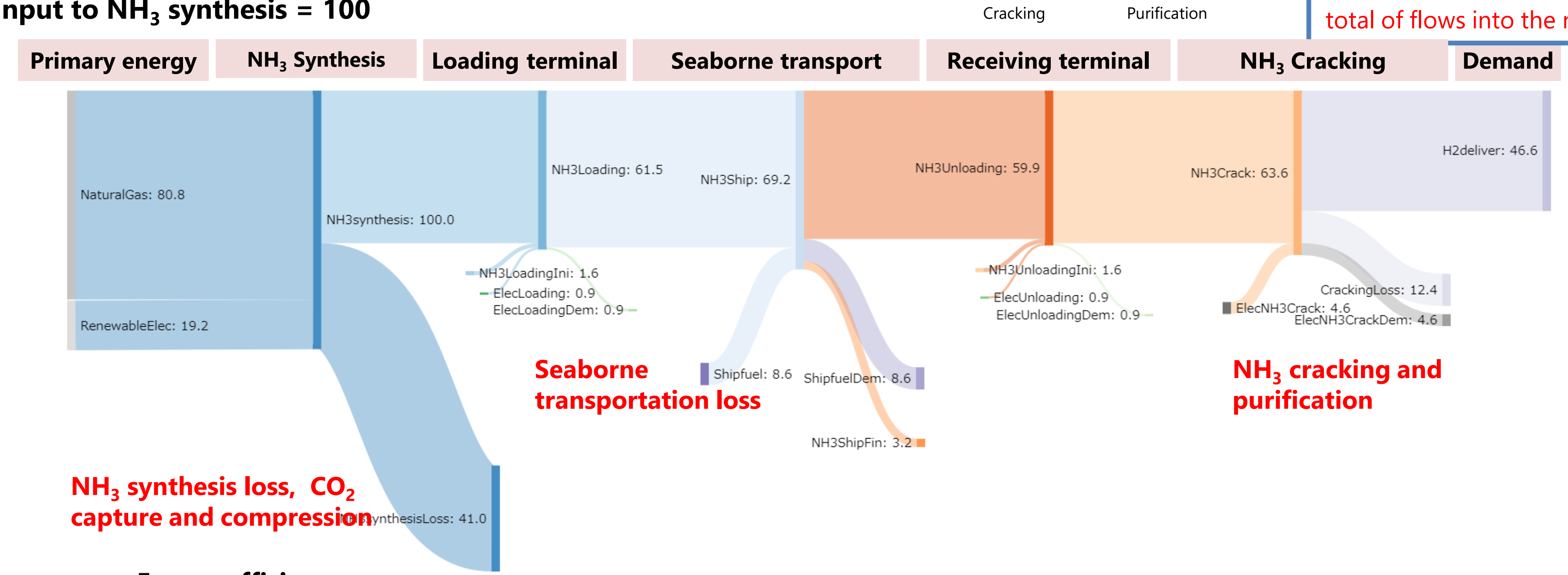
Shipfuel 2.7 in Rotterdam case

- **Energy efficiency**
  - **= (Output hydrogen + final stock)/ (Input resources + electricity + Initial stock)**
  - **Rotterdam 0.64, Tokyo 0.55**
- **Major energy loss**
  - **Production and liquefaction 34%**
  - **Seaborne transport 11% (Tokyo case)**

Energy balance of NH_3 chain for power plant

Input to NH_3 synthesis = 100

Note: the values are the total of flows into the node.



- **Energy efficiency**
  - **= (Output hydrogen + final stock)/ (Input resources + electricity + Initial stock)**
  - **Rotterdam 0.44, Tokyo 0.42**
- **Major energy loss**
  - **NH3 synthesis 41%**
  - **NH3 cracking, purification 12%**
  - **Seaborne transport 9%**