World Energy Outlook 2018

Chapter 3: Delivery infrastructure for hydrogen-based fuels

H2 considered in the WEO under NPS, for…

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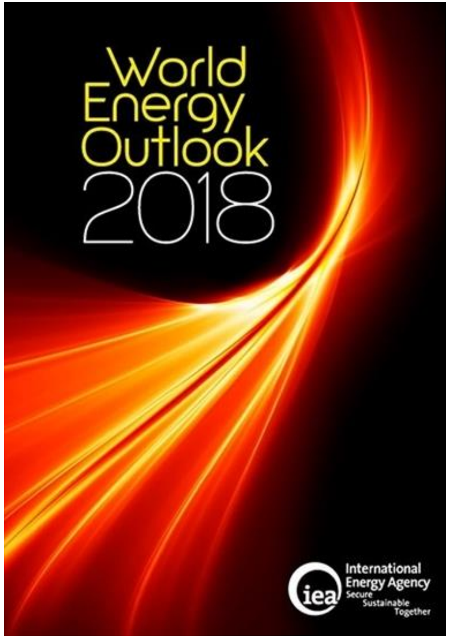
- **Reducing emissions from largest consumers of H2 today:**
  - ***Ammonia*** *(33.4 Mt, 53% of merchant H2) consumption: 450 Mt CO_2 in 2017*
  - ***Oil Refining****: 35 Mt of H2 today (20% of merchant H2) → 39 Mt H2 in 2040 = 360 Mt CO2 from SMR, 30% of total refining CO2 emissions*
  - *Other sectors, including: iron and steel, glass, electronics, chemicals and bulk chemicals*

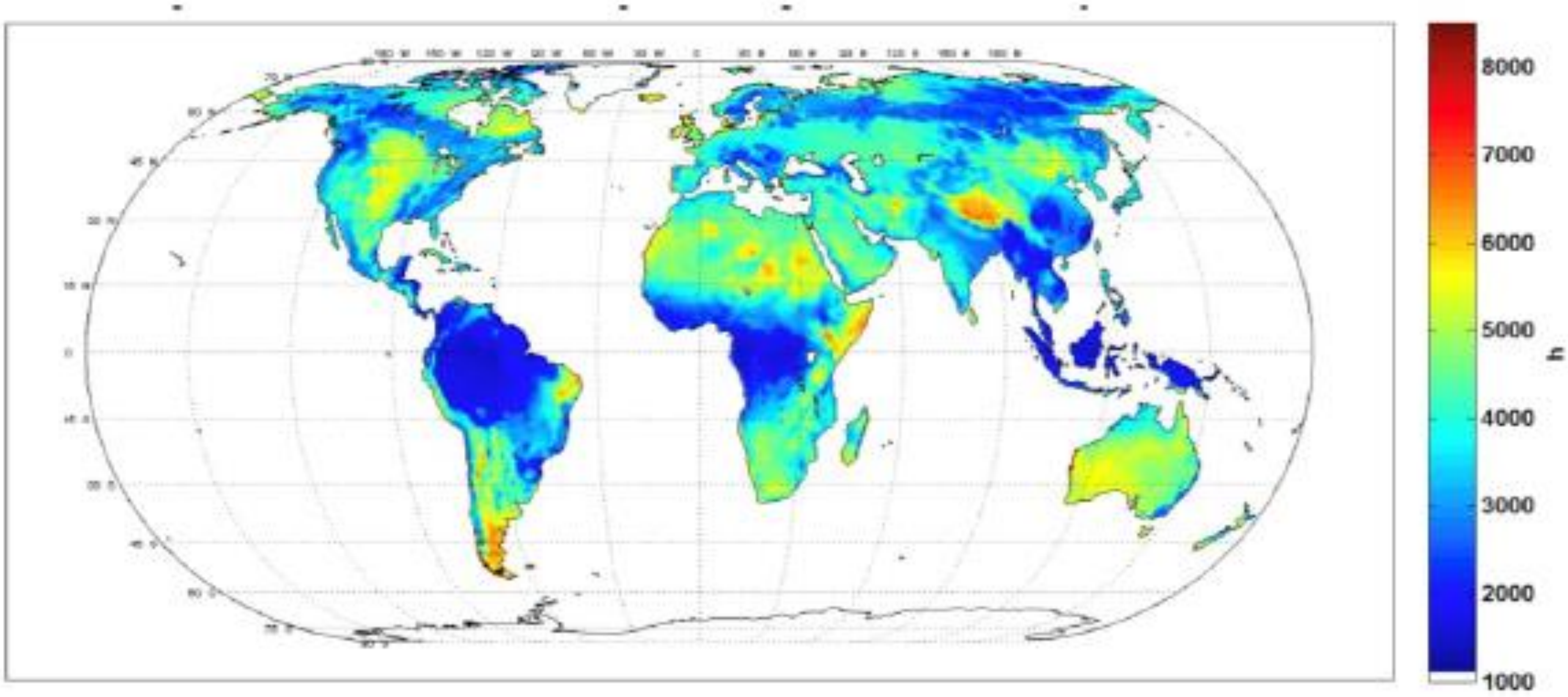


- **Shipping sector : IMO target to reduce CO2 emissions by 50% by 2050**

- **H2 as an energy carrier:**
  - *Review of cost of H2 production from main options*

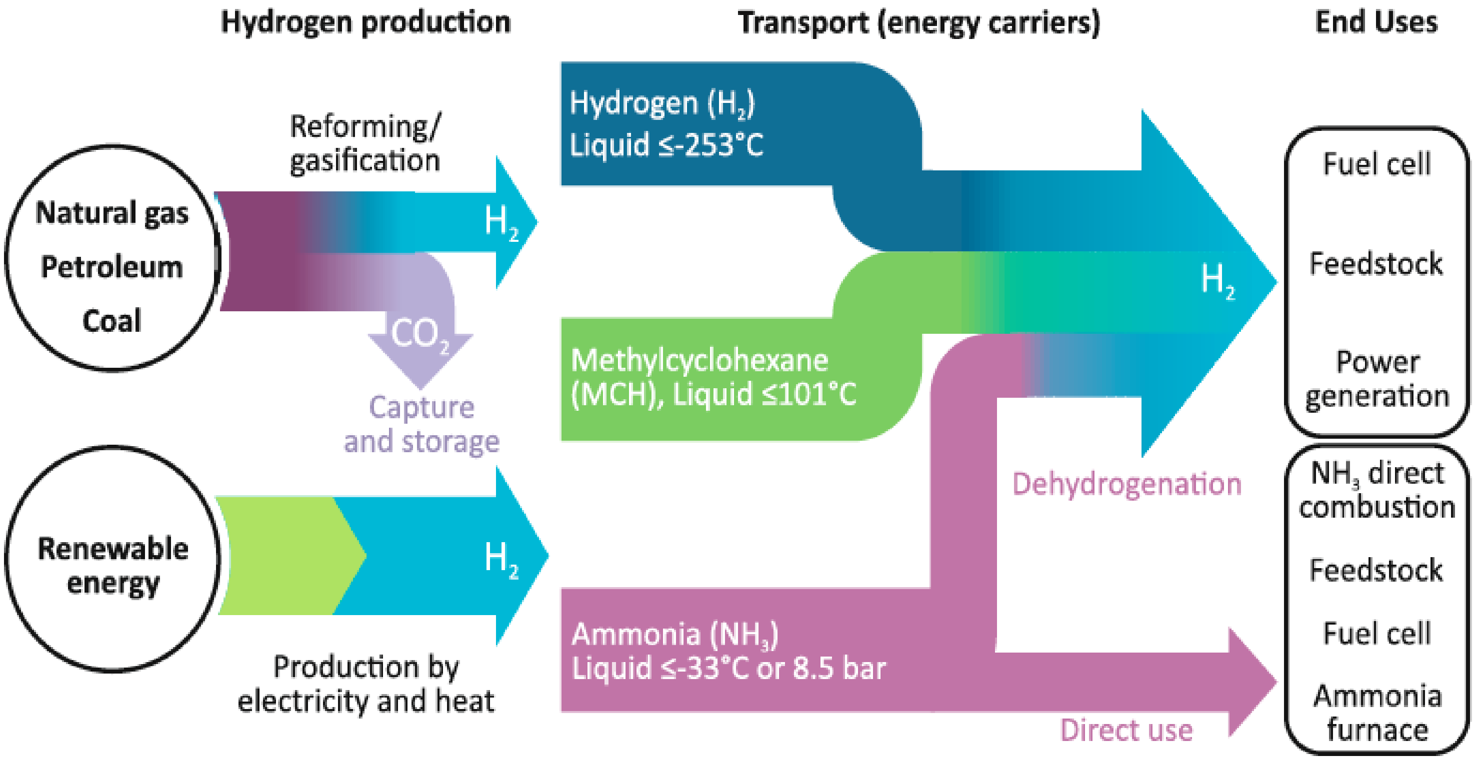
Note: NPS = New Policies Scenario (other scenarios: Current Policy Scenario, Sustainable Development Scenario)

Hybrid solar and wind full load hours adjusted for overlap

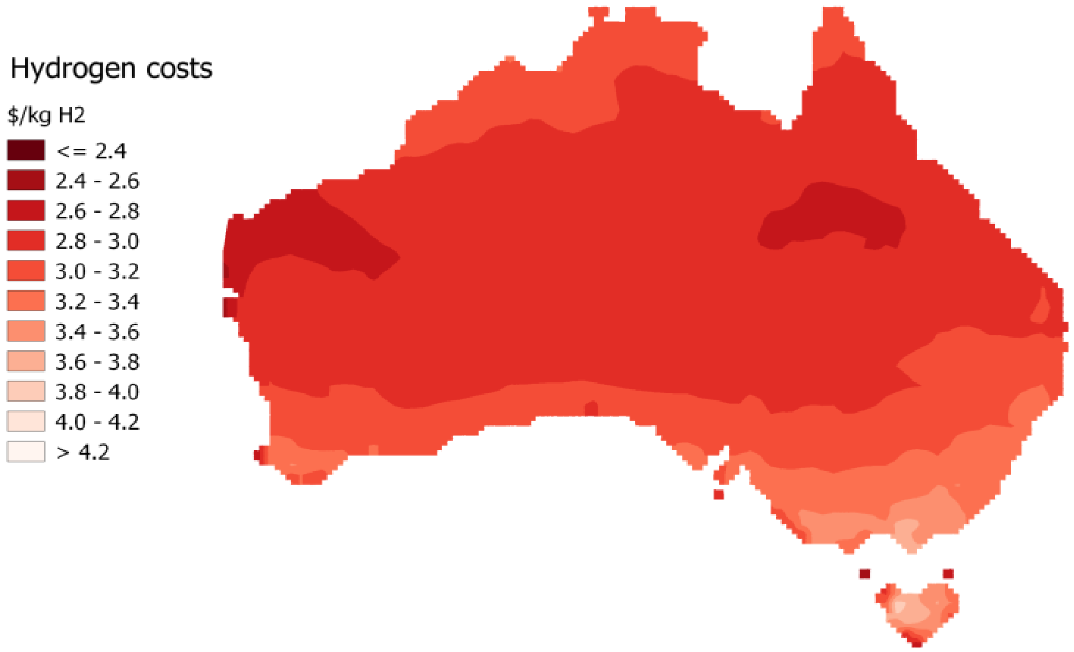


Source: Fasihi & Breyer, 2017

Japan's Energy Transition - Basic Hydrogen Strategy



Hydrogen generation costs from hybrid solar PV and wind systems in Australia in the NPS, 2040

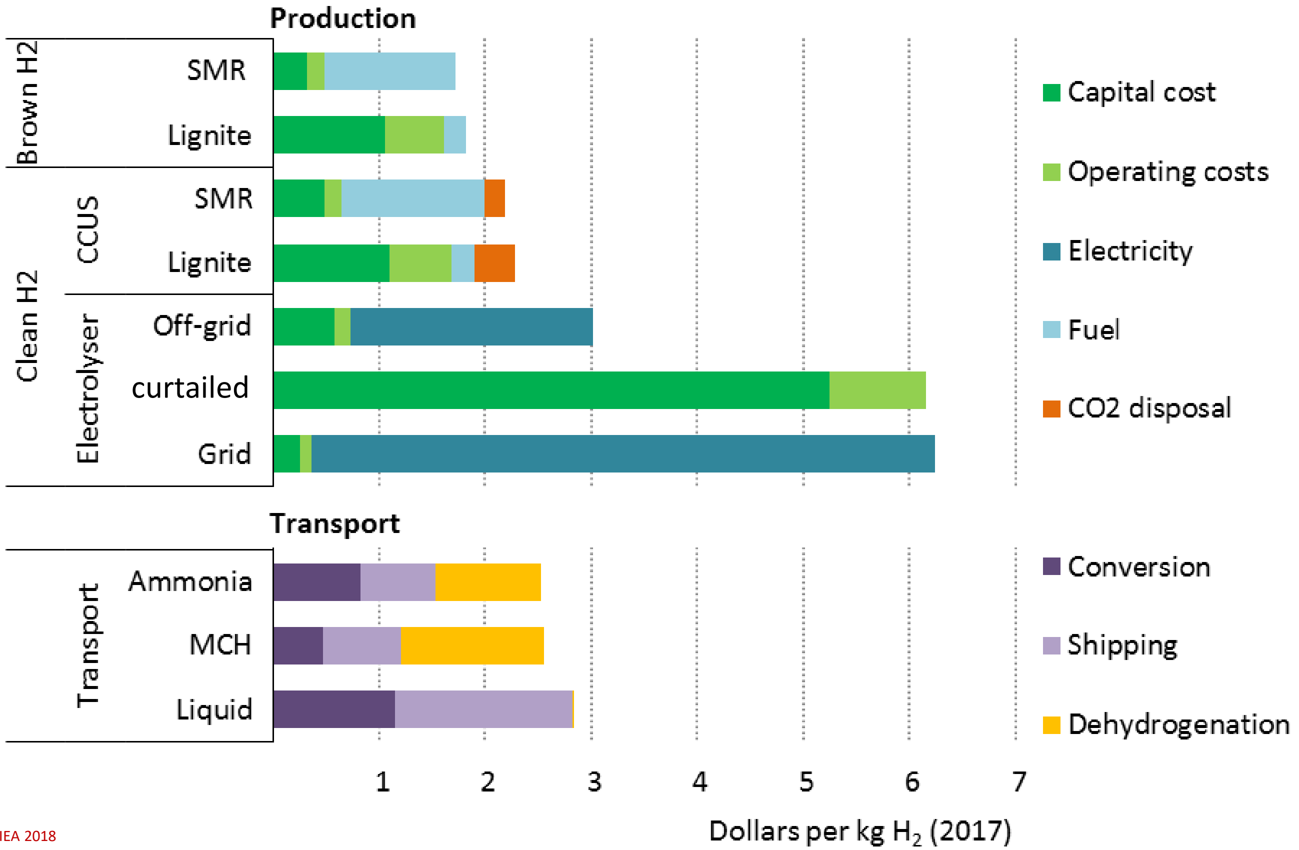


In Australia, under New Policies Scenario) hybrid solar PV and wind systems just along coast could provide **over 100 Mtoe hydrogen for less than \$3/kgH_2 in 2040**

Costs assumptions:

- onshore wind = \$1770/kW$_{el}$;
- utility-scale solar PV = \$800/kW$_{el}$; electrolyser = \$550/kW$_{H2}$;
- discount rate 8%.

Costs of H2 production in Australia and transport to Japan in the NPS Scenario, 2040



- Electrolyser capital cost = $550/kW el.
- **Grid-based electrolyser**: CF= 100%, electricity price = $123/ MWh.
- **Curtailed elect. electrolyser**: CF = 5%, electricity price $0/MWh.
- **Off-grid electrolyser**: capacity factor = 45%,
- electricity cost = $50/MWh;
- discount rate of 8%.

G20 report

...The global potential of hydrogen...

(Publication mid-June 2019 Japan – G20 presidential summit)

Chapter 3 - Analysis objectives

- Need to keep things simple. Can't be comprehensive and analyse/discuss every single supply option or route. The aim is to educate on key issues.

- **Key aim is to provide full delivered H_2 and NH_3 costs for all end-use sectors**

- Will focus only on transmission & distribution of H_2 and hydrogen-based fuels. Will not discuss synthetic gas or electrofuels (for which costs & options are well known)
  - *This does not exclude end-user sectors in Chapter 4 examining whether electrofuels or synthetic gas is a cheaper option for end-users than a pure H_2-based fuel*

- Discuss pathways to scaling up hydrogen or hydrogen carrier infrastructure

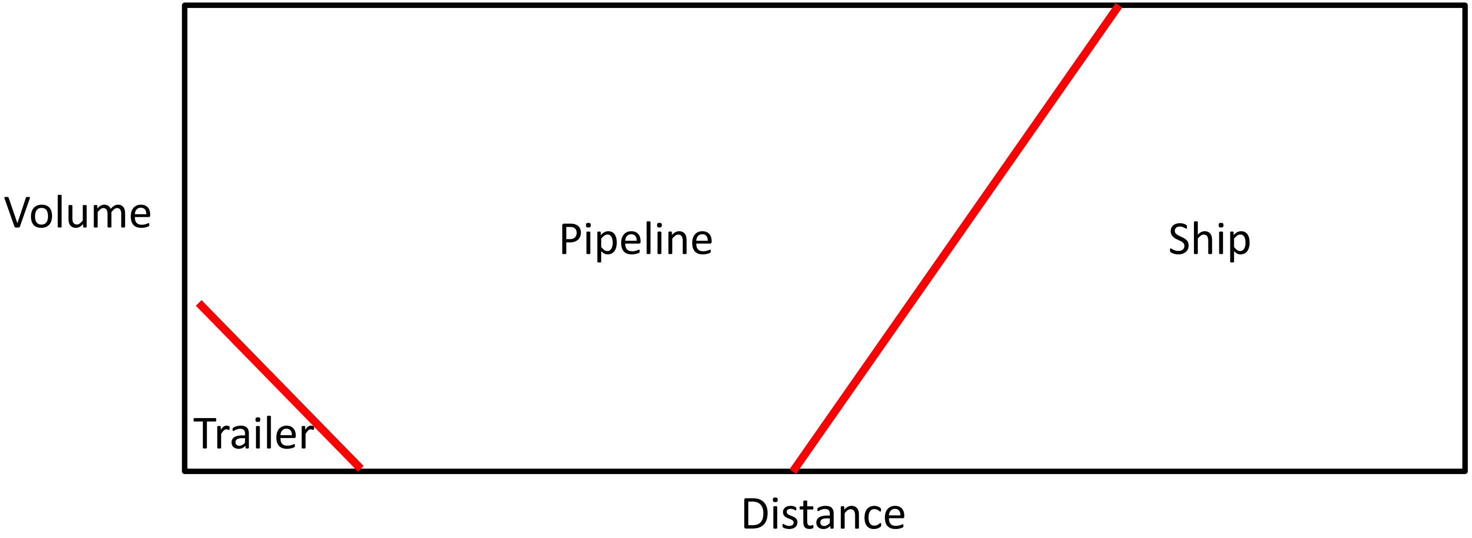
3.3 Transmission options

- Outline different transport options for transporting hydrogen. This will include a discussion for:
  - *Pure (liquid) hydrogen;*
  - *Ammonia*
  - *Liquid organic hydrogen carriers (LOHCs)*
- There are several possible LOHCs – will briefly mention a few of these, but only choose one for cost analysis

3.3 Transmission options

- For each option will focus on differences between ships and pipelines.
  - *Illustrate that choice of the cheapest option depends on distance and volume*
  - *To illustrate with examples for three vectors: costs will be provided in $/kg for a 3000 km pipeline and 8 000 km sea journey for a large-scale export facility*

Example for cheapest options for transmission of NH_3



3.4 Distribution options

- Again cheapest supply pathway depends on scale, end use sector, distance and vector.
- Will look at two different scales when considering distribution to the transport sector
- Will include a box on the possible evolution of a hydrogen supply route as demand scales up in size

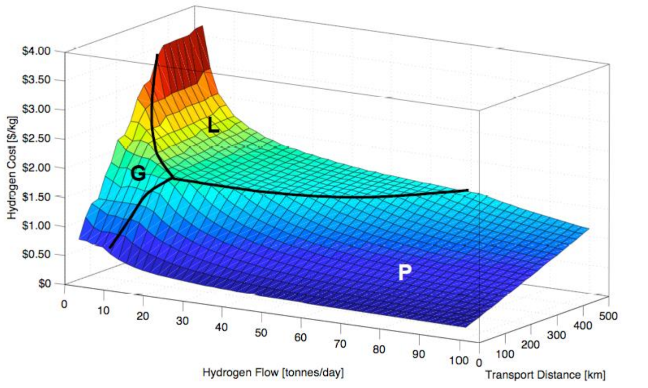
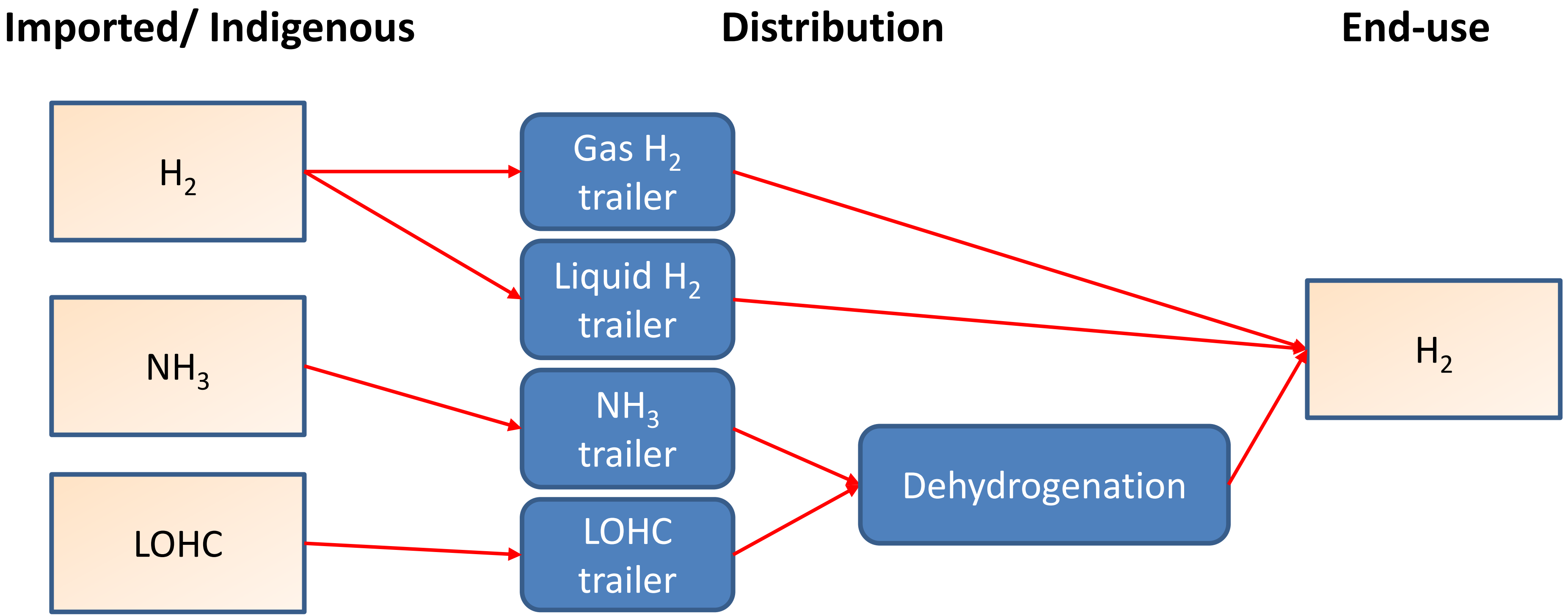
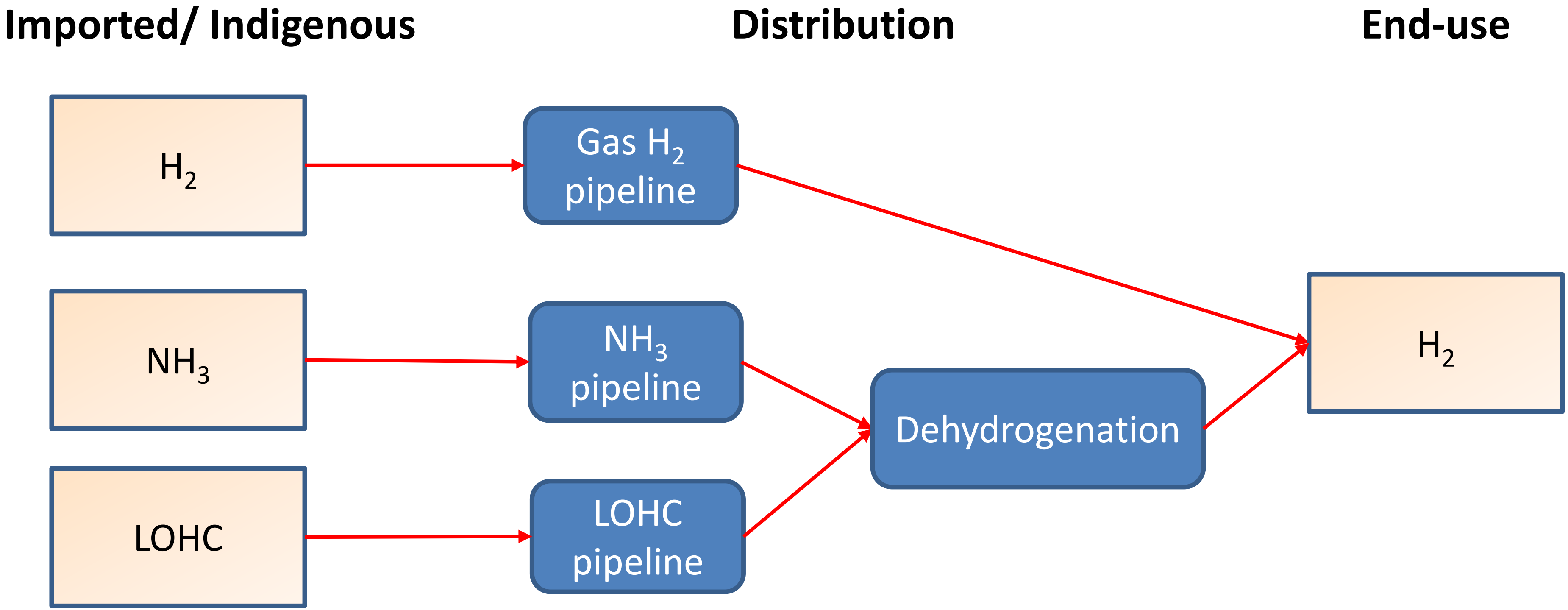


Figure 6 Minimum hydrogen transmission costs as a function of H_2 flow and transport distance

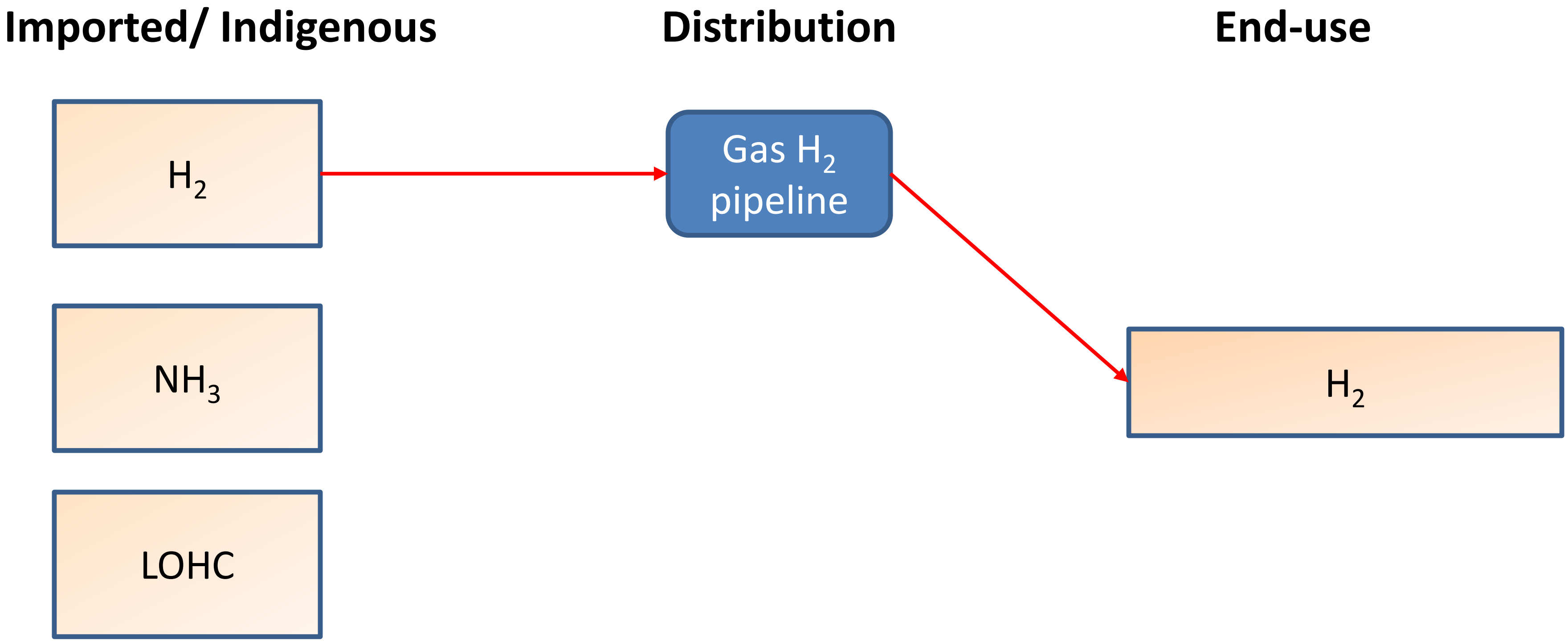
3.4 Distribution – small scale transport



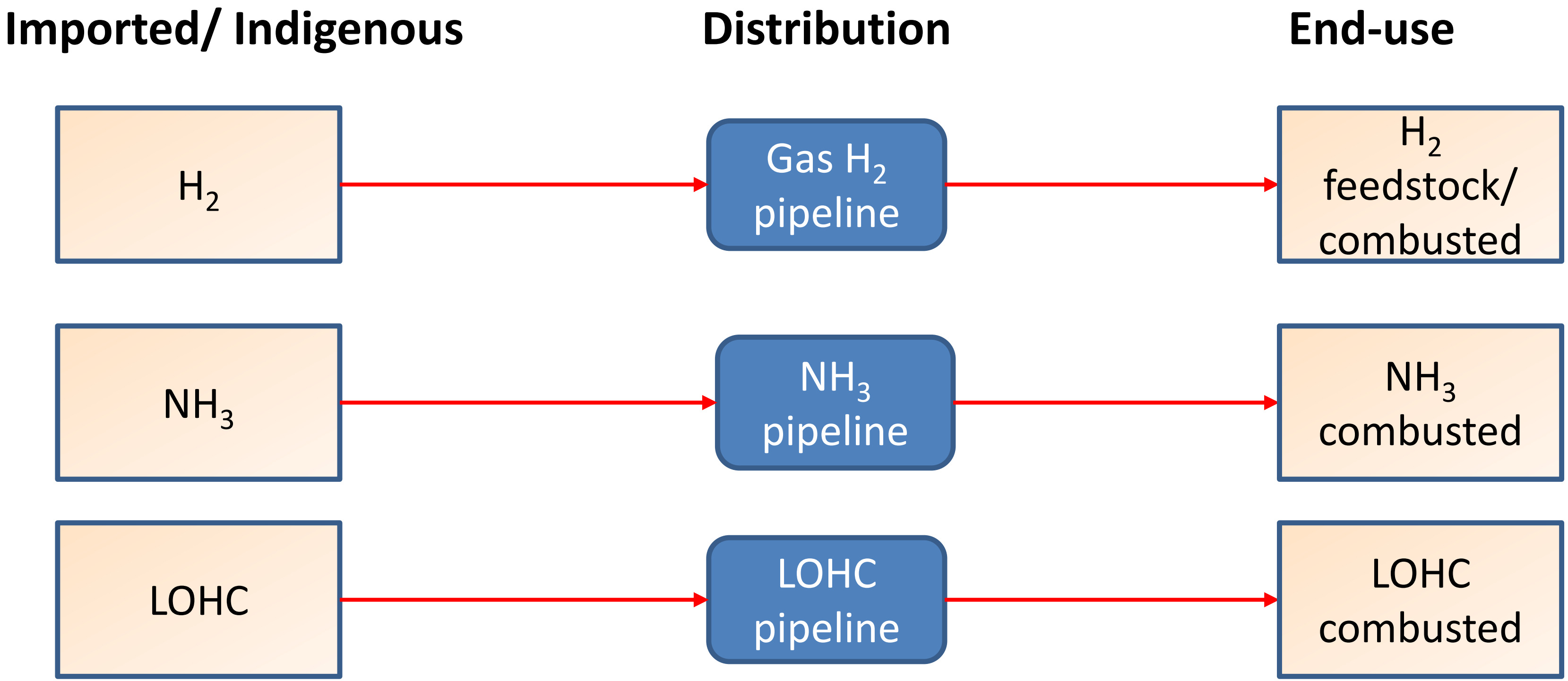
3.4 Distribution – large scale transport



3.4 Distribution options to be analysed - Buildings

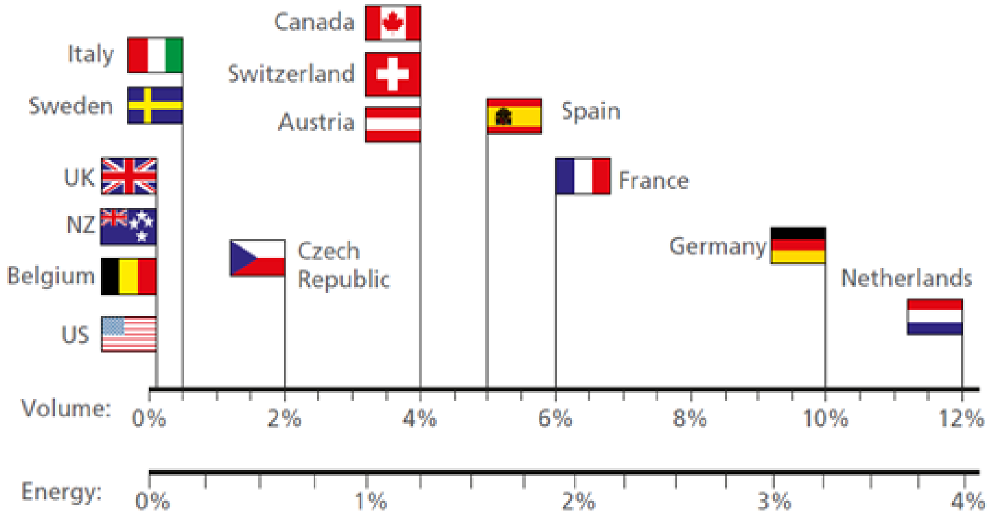


3.4 Distribution– Power/industry for combustion



3.5 Blending hydrogen in the natural gas grid

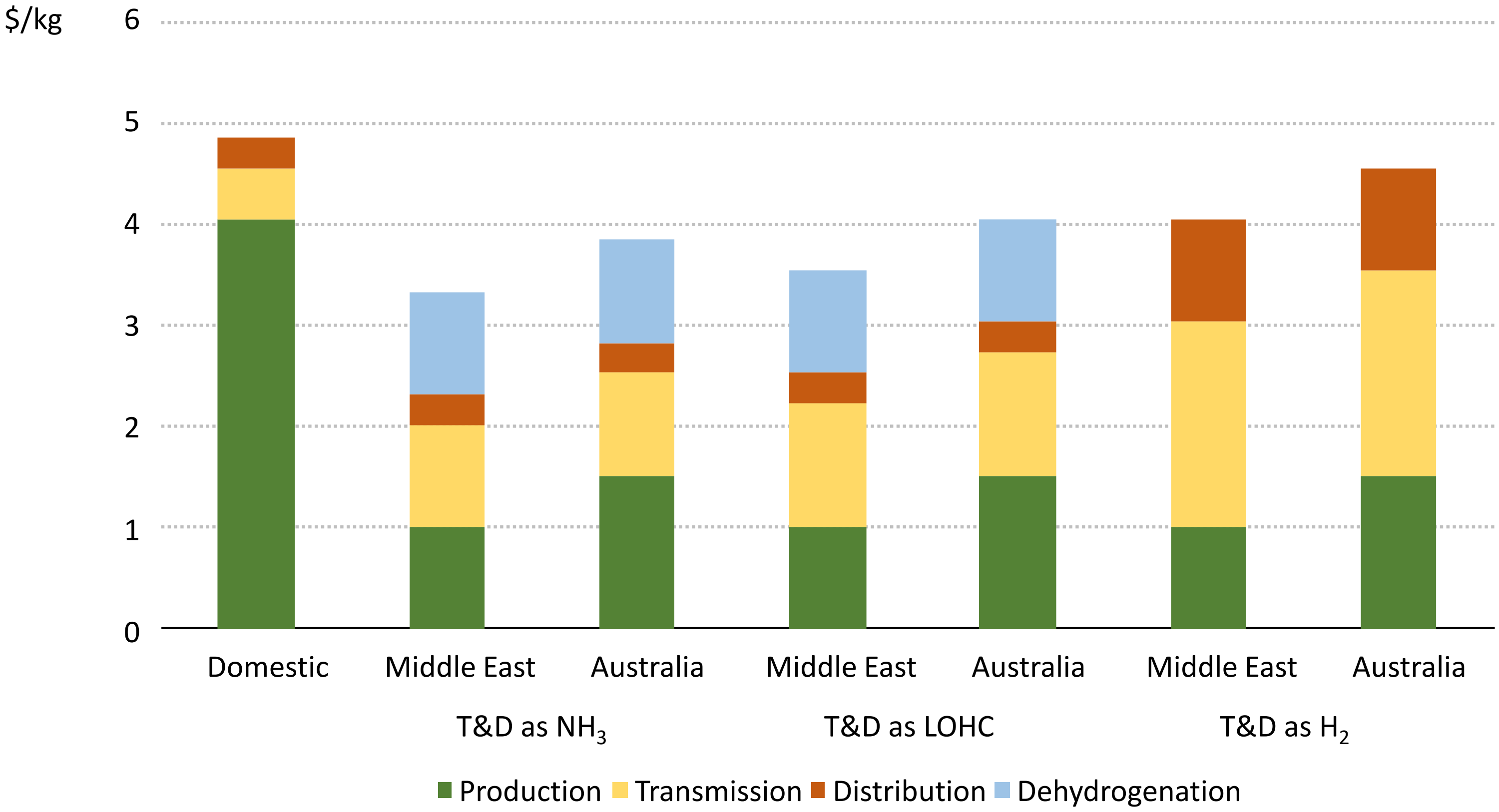
- Feasibility, implications and impact of blending pure H_2 into the natural gas grid
  - *What are regulatory limits?*
  - *What are technical limits in existing transmission/distribution infrastructure?*
  - *What are technical limits in end-user equipment?*



3.6 Illustrative trade routes

- Illustrate the previous analysis on transmission & distribution costs by looking at various supply options for three end-user and region specific demand centres
  - *Europe industrial sector (NH_3) from e.g. Norway, Morocco, Middle East*
  - *Japan transport sector (H_2) from e.g. Middle East, Australia…?*
  - *United States power sector (H_2 or NH_3) from e.g. Middle East, Chile*
- Will compare costs with cheapest way of producing H_2/NH_3 domestically vs import routes for cheapest production option in an exporter (see example on next slide)
- What additional cost reductions could be possible for these routes?

Illustration of costs for delivering H_2 to transport sector in Japan at a large scale



Costs are made up

Assumes:

SMR-CCUS in Middle East
Electrolyser in Australia
Electrolyser in Japan

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