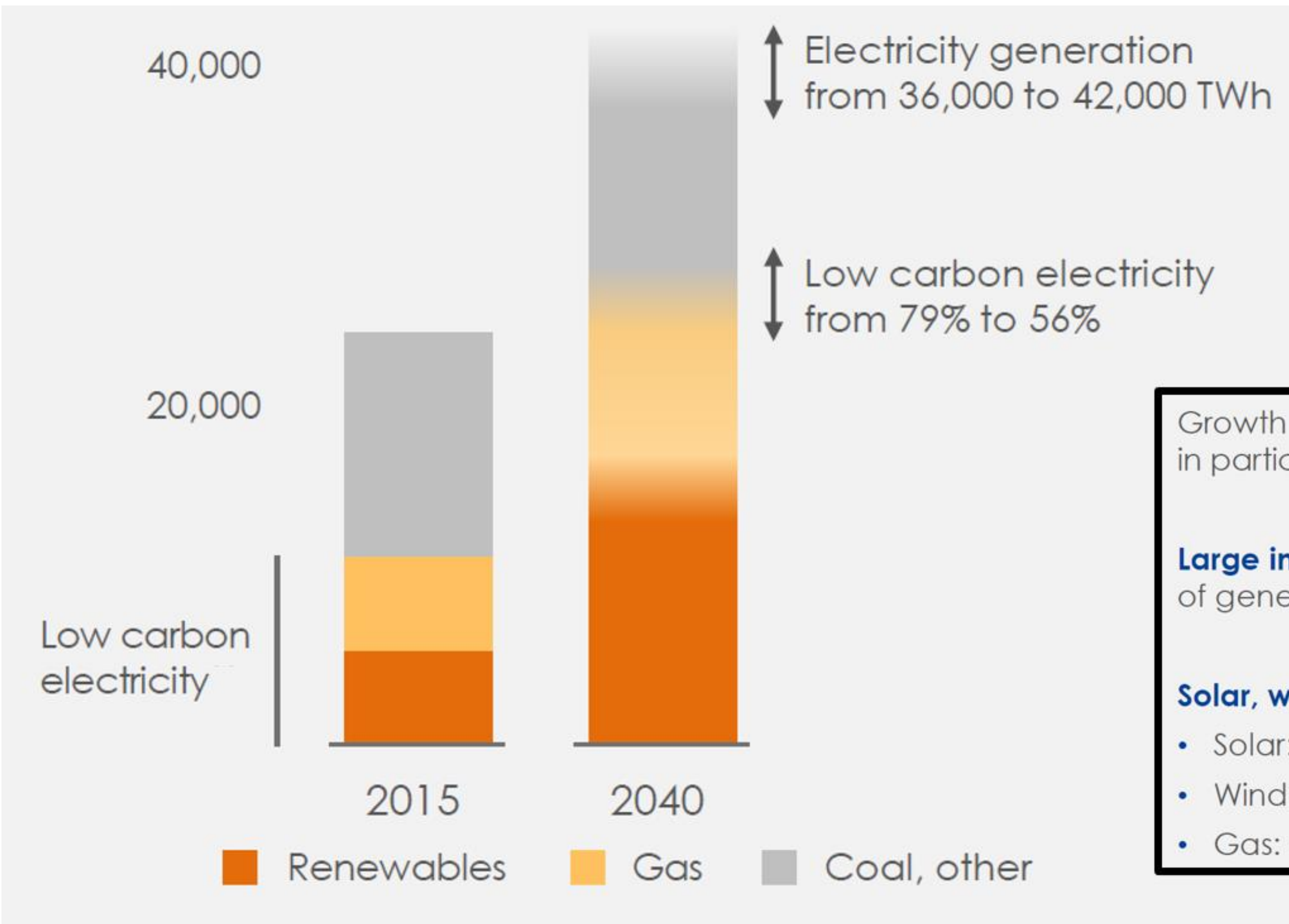
Économie de l’hydrogène

Quelle place pour le Québec ?

Philippe A. Tanguy
Polytechnique Montreal

Global Electricity Demand (in TWh)



Growth driven by non-OECD countries, in particular **China and India**

Large increase in gas and renewables share of generation by 2040

Solar, wind and gas: x 2.5 over 2015-40

- Solar: +9-13%/y
- Wind: +6-9%/y
- Gas: +2-3%/y

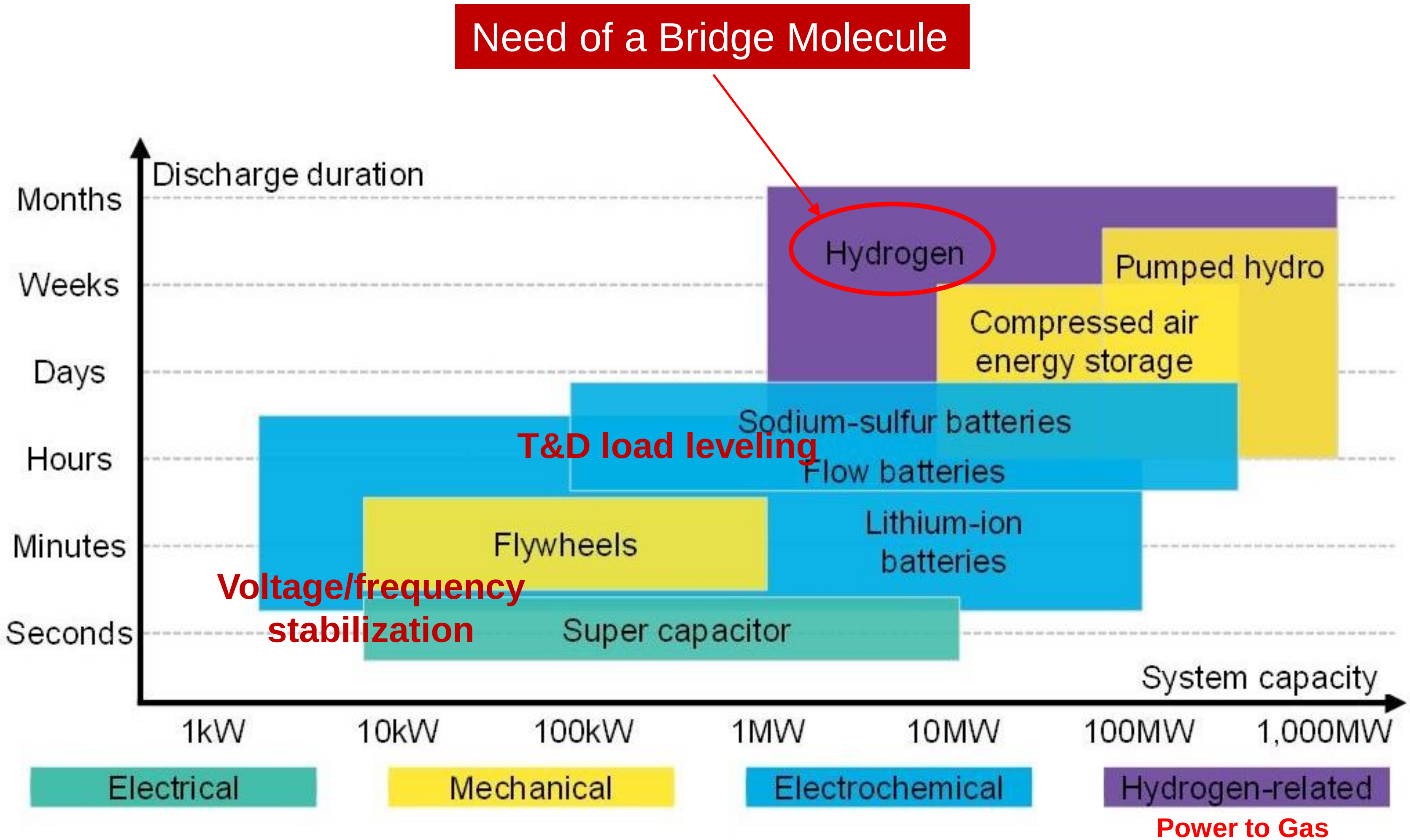
IEA Scenarios 2018

Ensuring the Security of Supply

Buffering capacity: 15-20%

?

Electricity Storage Solutions



Bloomberg 2017

Power to X

Power to Heat

- Use of RE as energy source to upgrade heat and steam
- Heat pumps, combined heat and cold storage

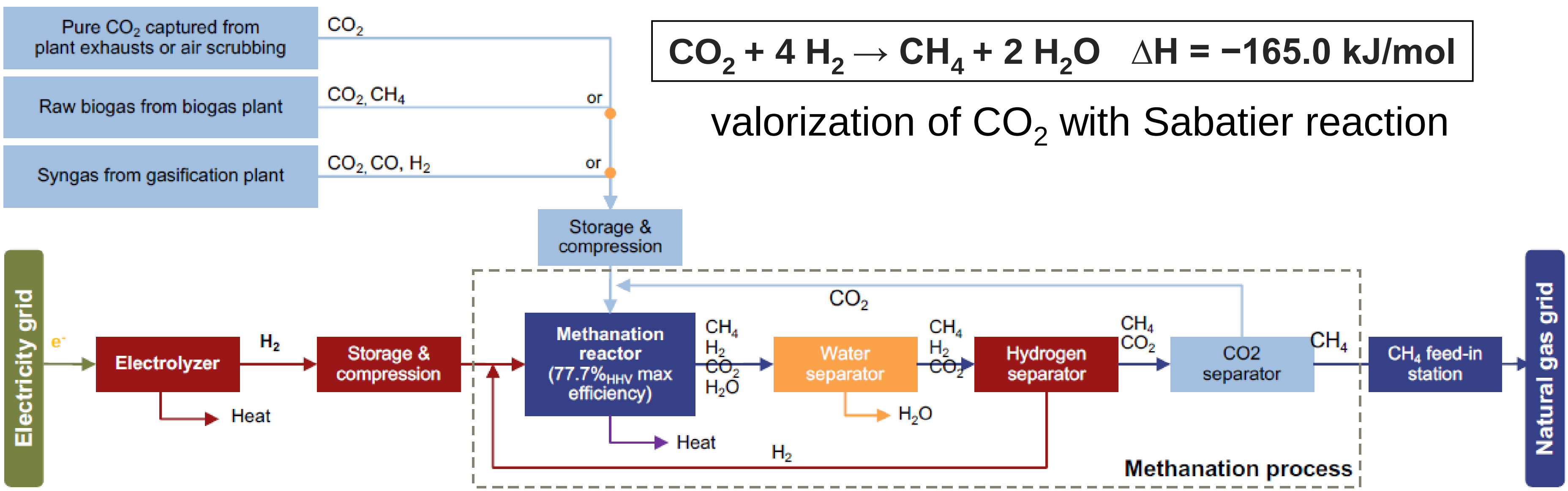
Power to Chemicals

- Use of RE as energy source for conversion of raw materials to chemicals and fuels
- Use of renewable raw materials as feedstock for chemical production, eg. biogas, biofuels, etc.

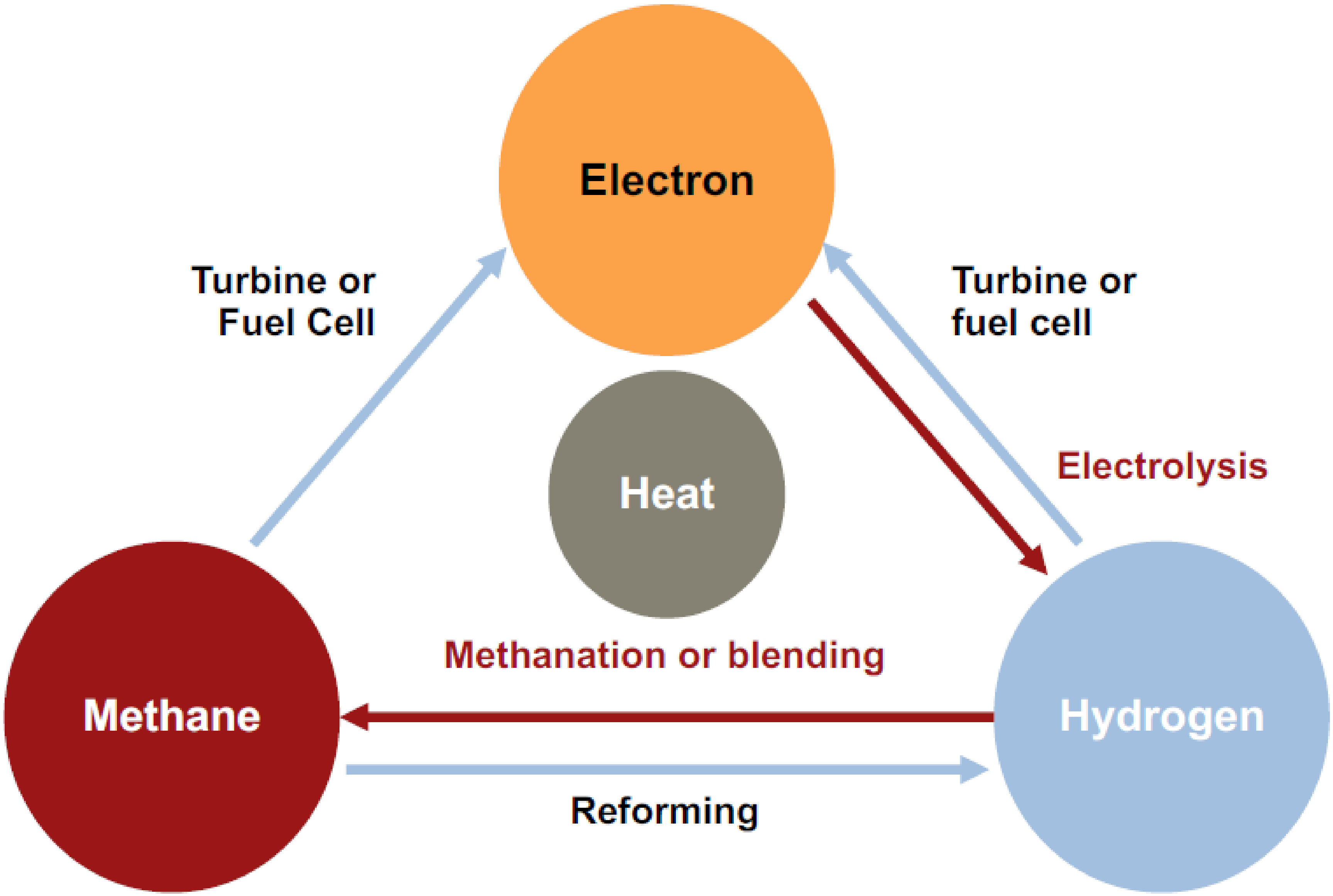
Power to Gas: H_2 or Methanation

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O \quad \Delta H = -165.0\ \text{kJ/mol}$$

valorization of CO_2 with Sabatier reaction



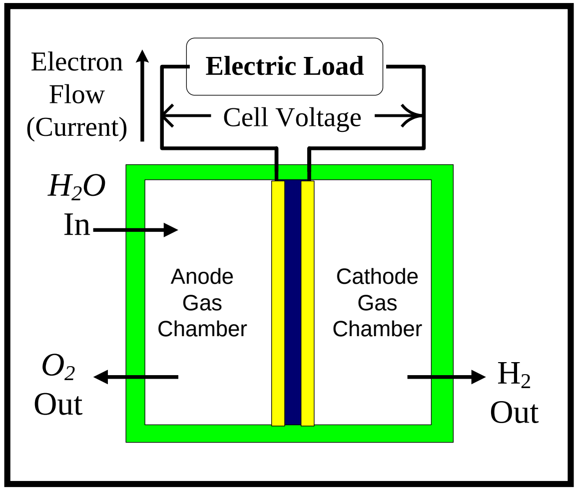
Pathways between Energy Carriers



Power to H_2 - Water Electrolysis

- Electrolysis of water is the decomposition of water (H_2O) into oxygen (O_2) and hydrogen gas (H_2) due to an electric current being passed through the water.

Flow Diagram for Electrolyzer



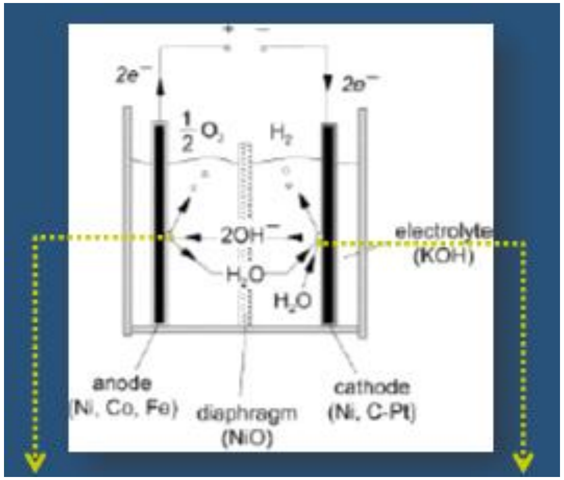
The electrolyzer reactions are:

Anode: $H_2O \rightarrow 2H^+ + ½\ O_2 + 2e^-$

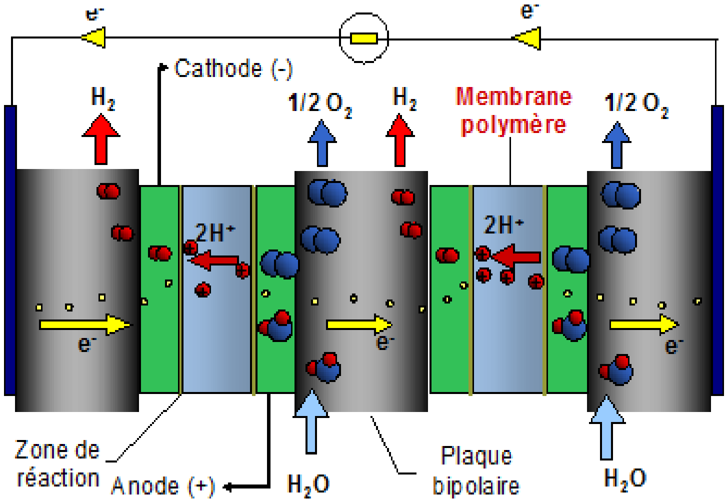
Cathode: $2H^+ + 2e^- \rightarrow H_2$

Overall: $H_2O \rightarrow H_2 + ½\ O_2$

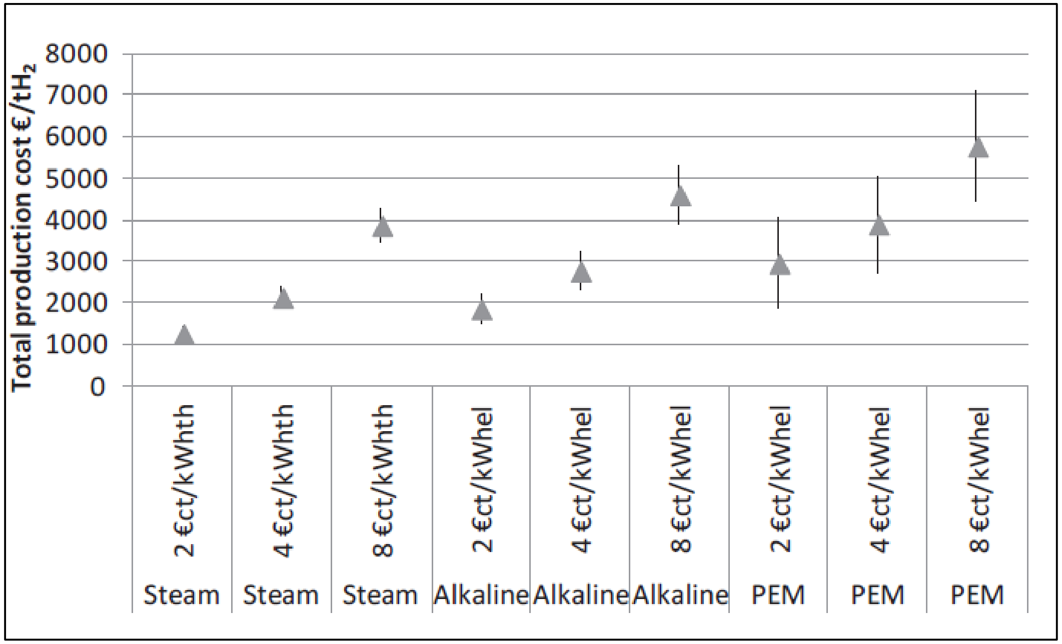
H_2 Production Costs



Alkaline



PEM



Dechema 2017

Storage & Transport of H_2

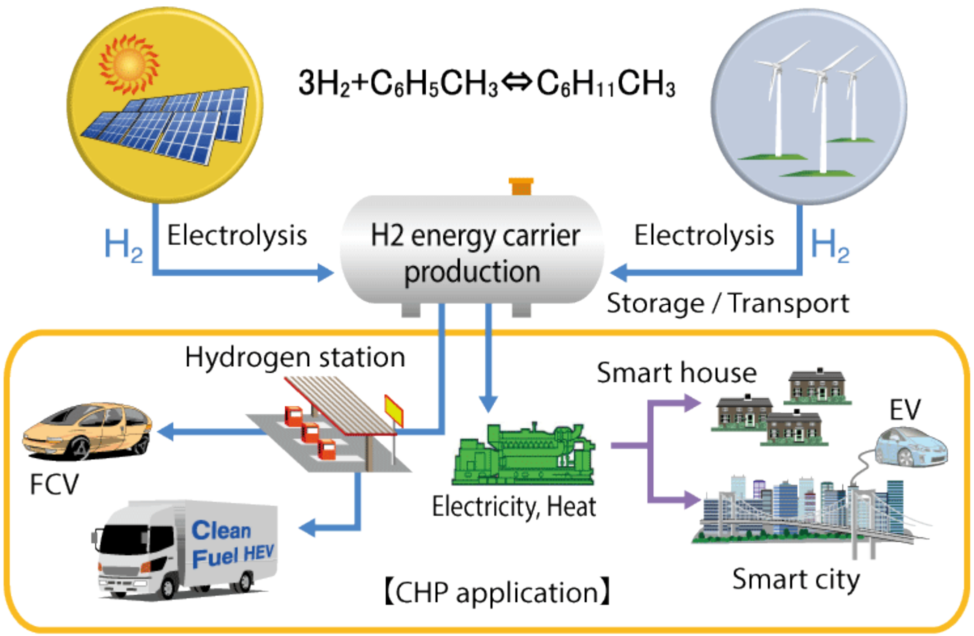
- Gas
  - Horizontal or vertical cylinder vessel @ 50 – 900 bar
  - Typically, 160 kg @ 200 bar
  - Delivery by trucks (pipeline possible @ 40-70 bar)
  - Can be stored in underground salt cavern

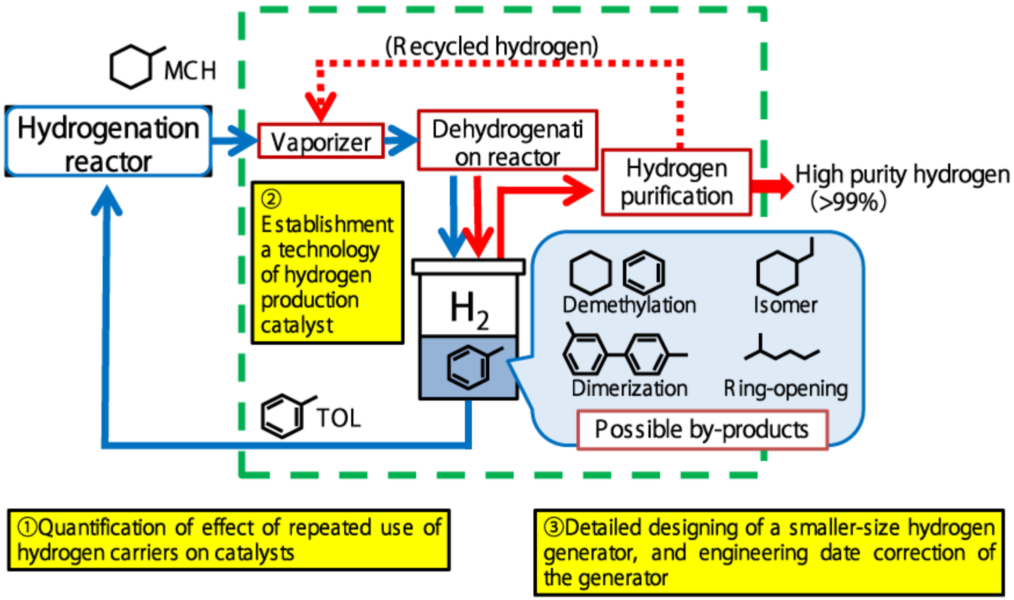
- Liquid
  - Cryogenic vertical tank @ -253°C and Patm
  - Typically, 600 kg
  - Boil-off is an issue for long-term storage

- Solid
  - Storage by adsorption-desorption on a metal hydride e.g. Mg Hydride

Storage & Transport of H_2 - Chemical Carriers

- Chemical
  - MCH

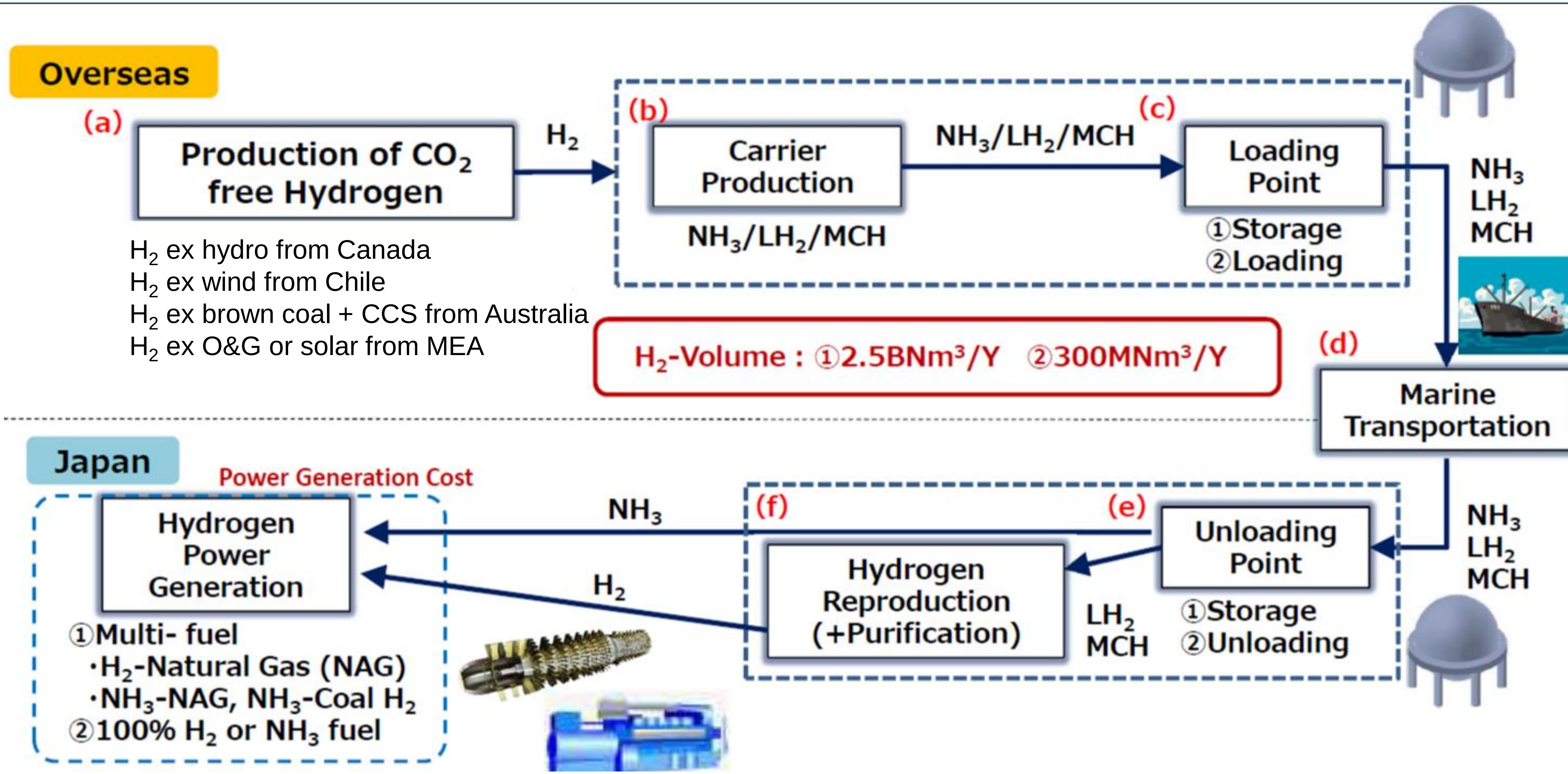




Sources: Chiyoda and JXTG Nippon Oil and Energy

  - NH_3 route - Haber-Bosch technology $3H_2 + N_2 = 2NH_3$ (400 C, 200 bar, Fe catalysis)
  - Compounds of NH_3
  - MetOH, DME, Formic Acid

Japan H_2 Supply Model



Muraki 2017

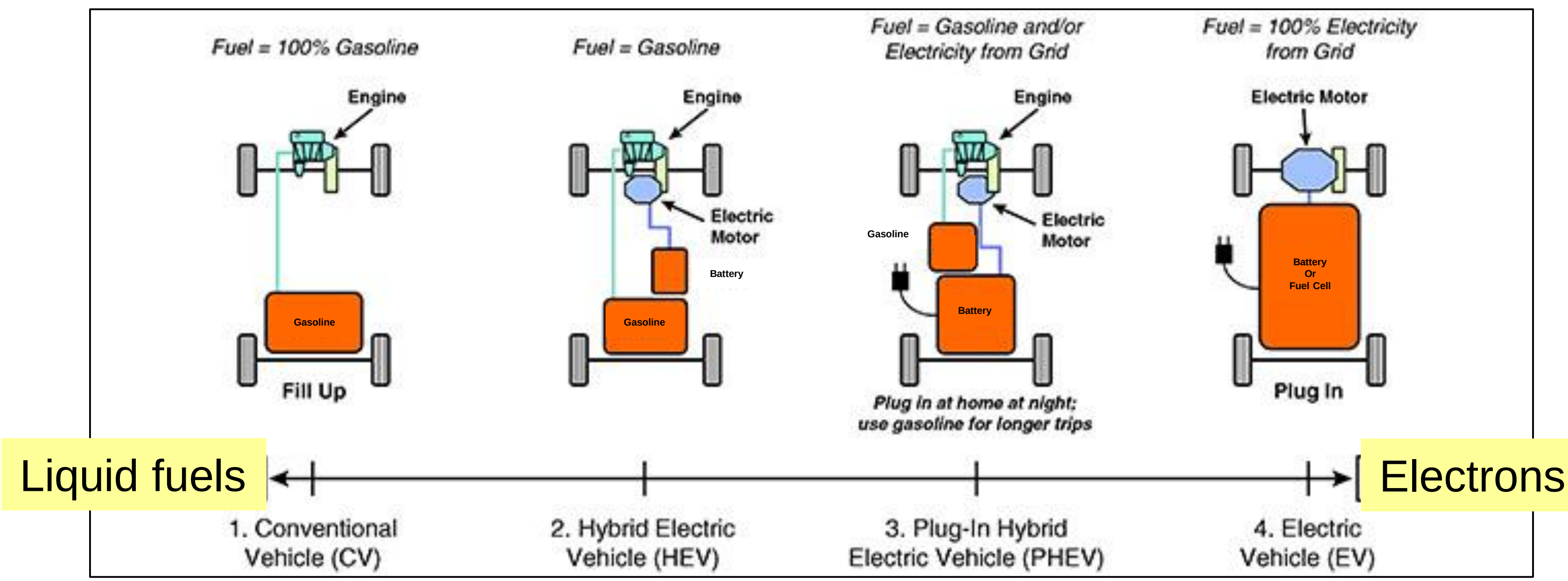
MetOH is also an option

- NH_3 can be co-fired with coal in flame-based power plant – Up to 20%
- NH_3 in a gas turbine, pure or mixed with NG (Tohoku univ.) – NOx emissions can be controlled.
- NH_3 can be used as a feed for high temperature solid oxide fuel cells (Kyoto univ.)

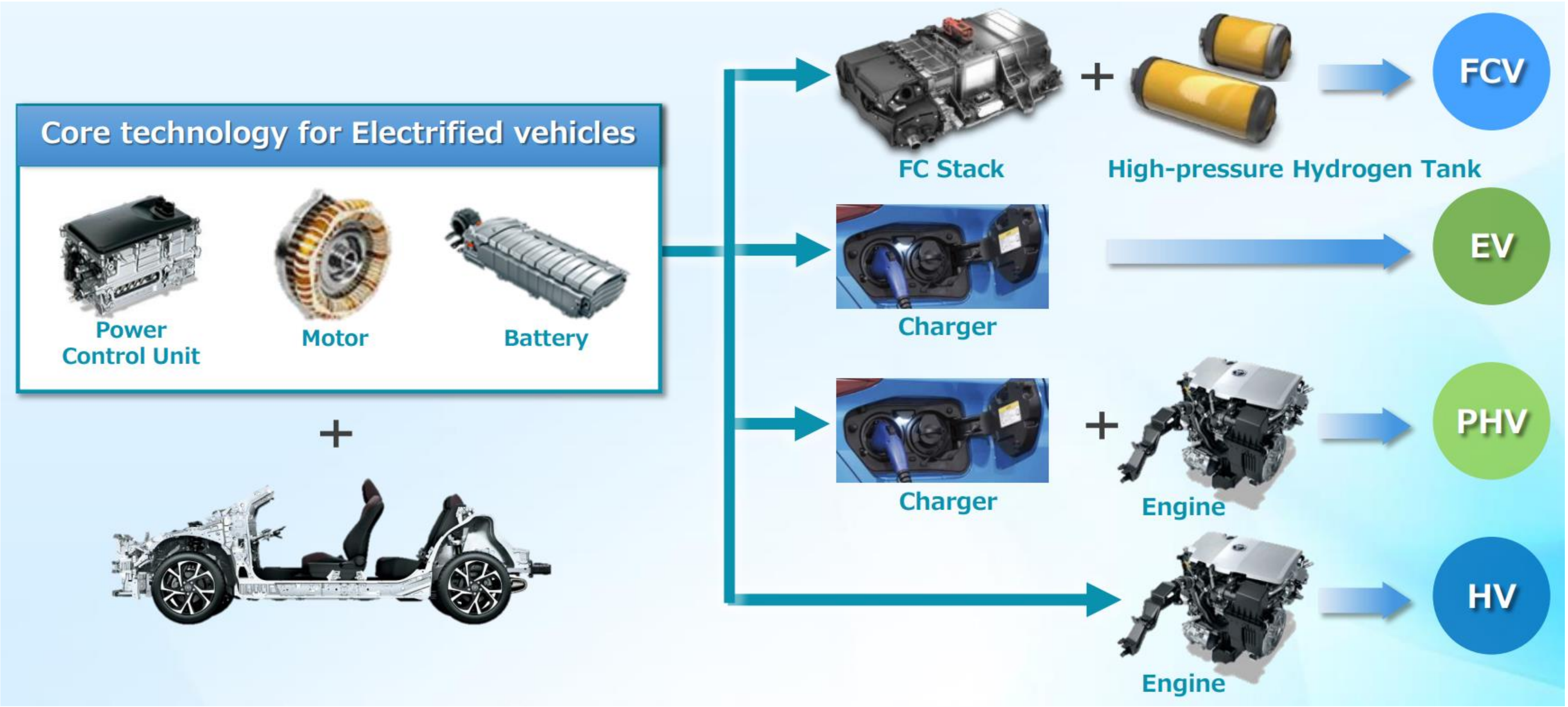
Decarbonizing Mobility

$$[T]CO_2 = \frac{[T]CO_2}{[T]energy} \times \frac{[T]energy}{kilometers} \times \frac{kilometers}{vehicles} \times vehicles$$

Emissions from the transport sector = Carbon intensity of energy × Energy intensity per kilometer × Average distance travelled per vehicle × Global fleet of vehicles

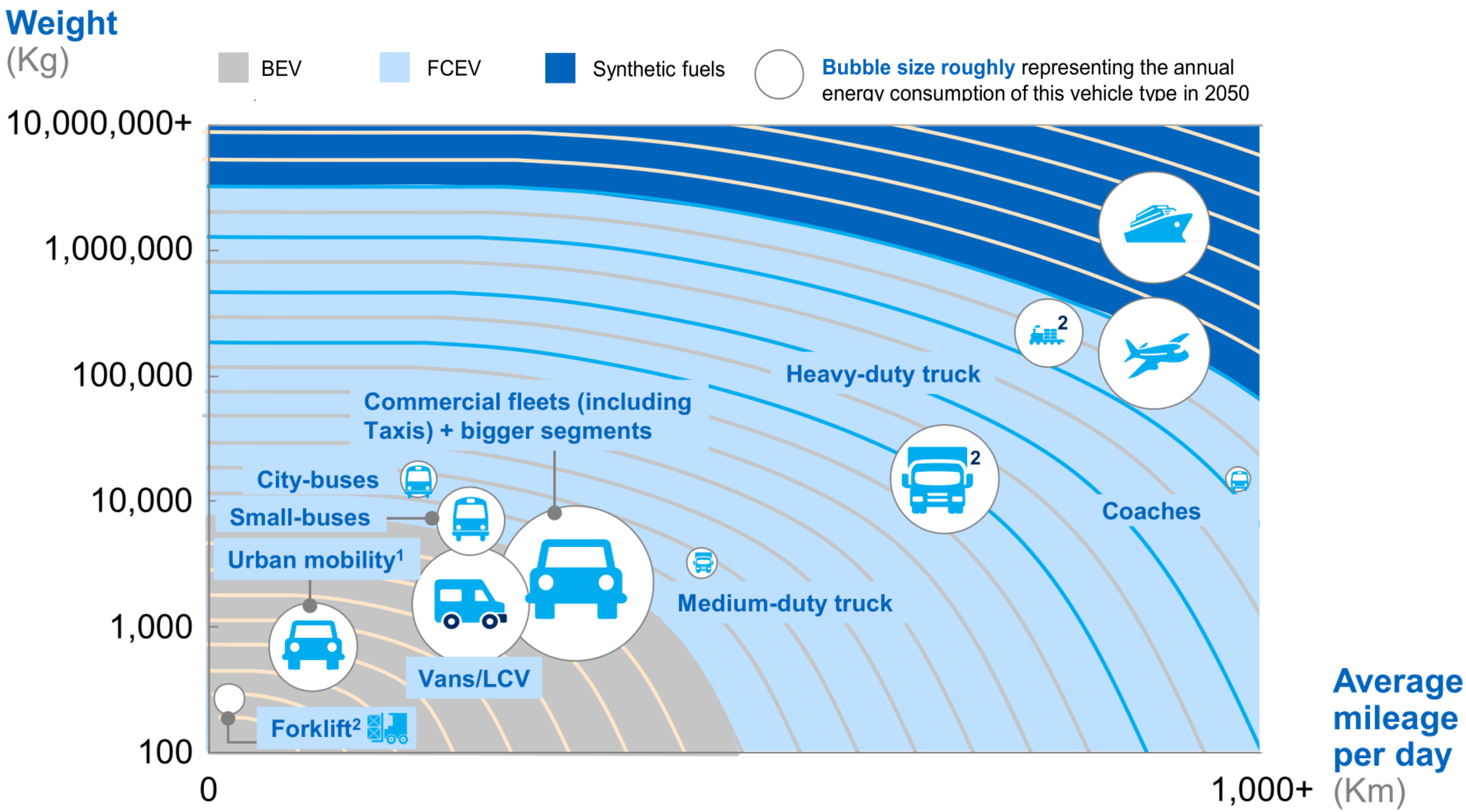


Electrical Mobility: Recharging or Refuelling?



Toyota 2018

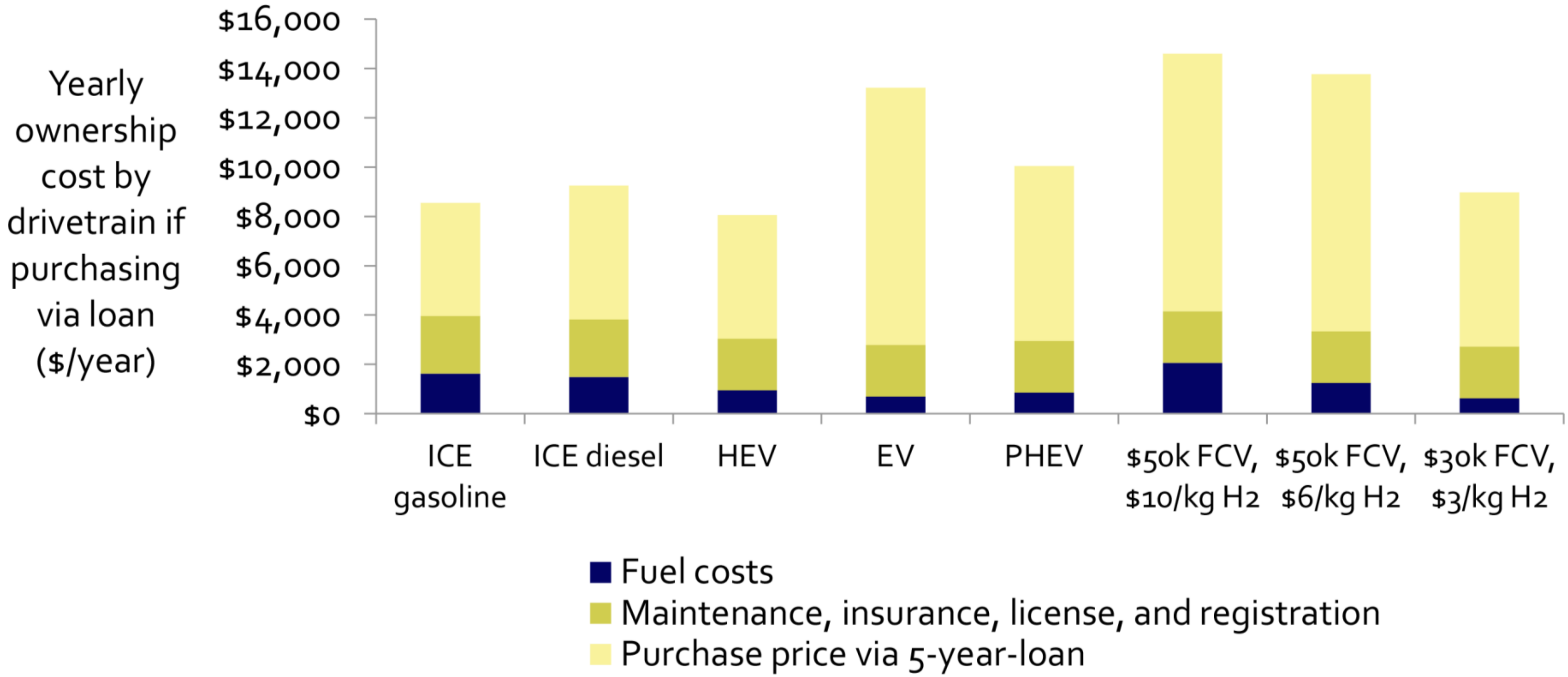
Battery and Fuel Cell Electrical Vehicles



1 Battery-hydrogen hybrid to ensure sufficient power
2 Split in A- and B-segment LDVs (small cars) and C+-segment LDVs (medium to large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand

Sources: Toyota, Hyundai, Daimler, H2 Council

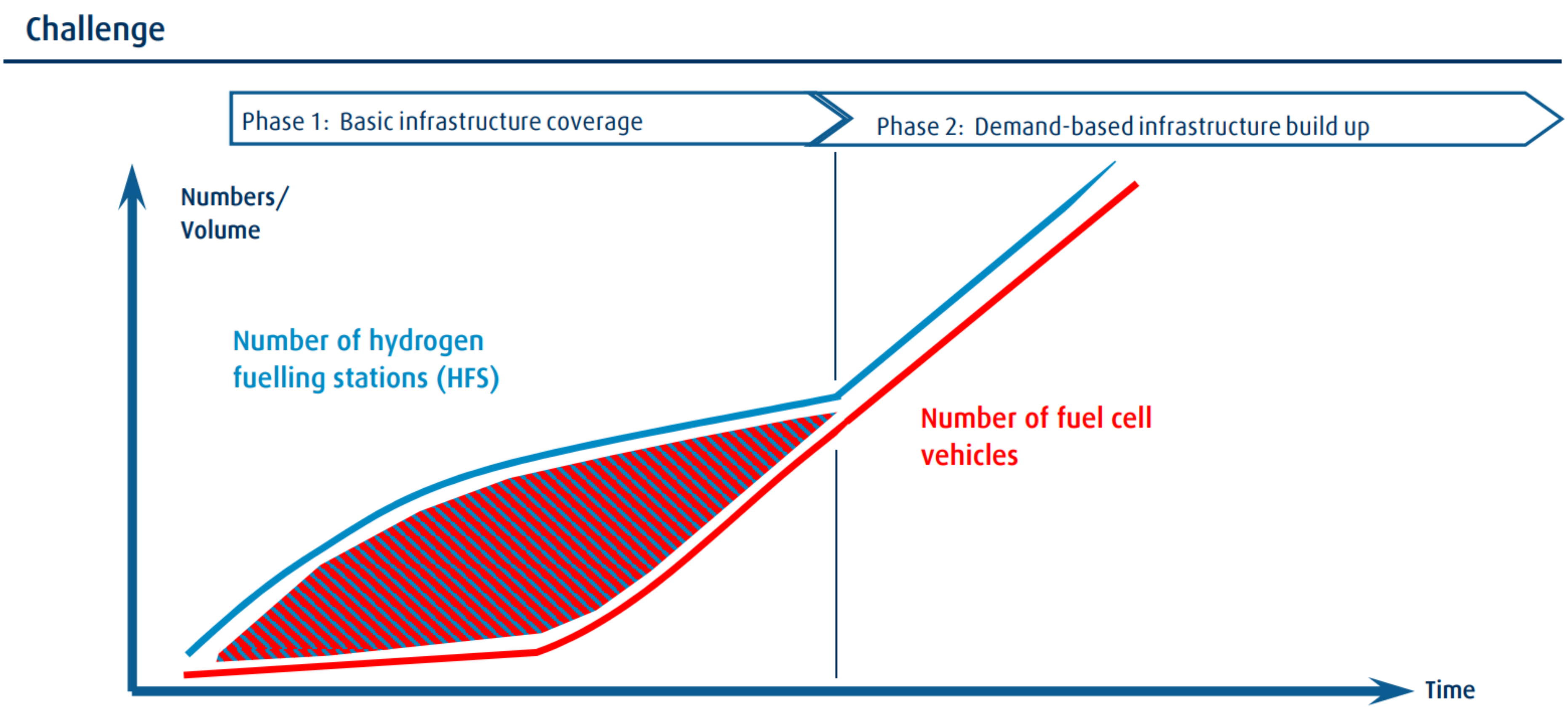
Vehicles - Total Cost of Ownership



Lux Research 2017

Fuel Cell Vehicles Need to Reach $30,000 Price and $3/kg Hydrogen to Match Hybrid Ownership

Deployment Challenge of Hydrogen Stations



- PPP involving governments, car manufacturers and the energy suppliers
- ZEV mandate
- Grants and subsidies

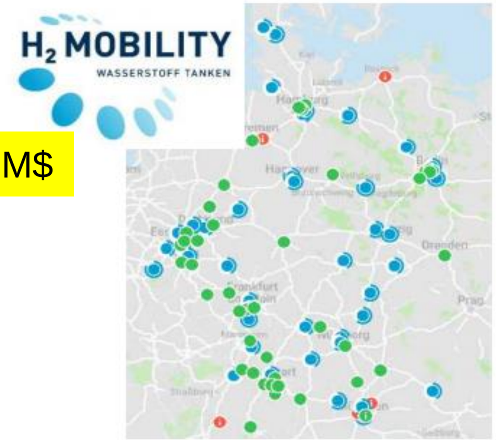
Examples of Deployment in Selected Regions

2.8 M$

- **HRS**: 100+ (today); 160 (2020)
- **FCEV**: 3,000 (today); 40,000 (2020)
- **Support**:
  Capex funding for HRS,
  2.5 – 3.3 mio JPY bonus per car purchased

2-3.5 M$

- **HRS**: 30 (today); 65 (2020)
- **FCEV**: 5,000 (today); 18,500 (2020)
- **Support**:
  Capex funding for HRS,
  ZEV mandates,
  LCFS credits



1.2-1.8 M$

- **HRS**: 50 (today); 100+ (2020)
- **FCEV**: 400 (today); 1,000 (2020)
- **Support**:
  Capex & Opex funding for HRS,
  500k JPY bonus per car purchased

Linde 2018

China Roadmap

		2020	2025	2030
Hydrogen Infrastructure	Hydrogen Station	≤ 100	≤ 300	≤ 1,000
	Hydrogen Delivery	High pressure hydrogen storage and transportation	Cryogenic liquid hydrogen delivery	High-density organic liquid hydrogen storage and delivery at normal pressure

Ballard 2018

H_2 Valorization in Mobility: Other Applications

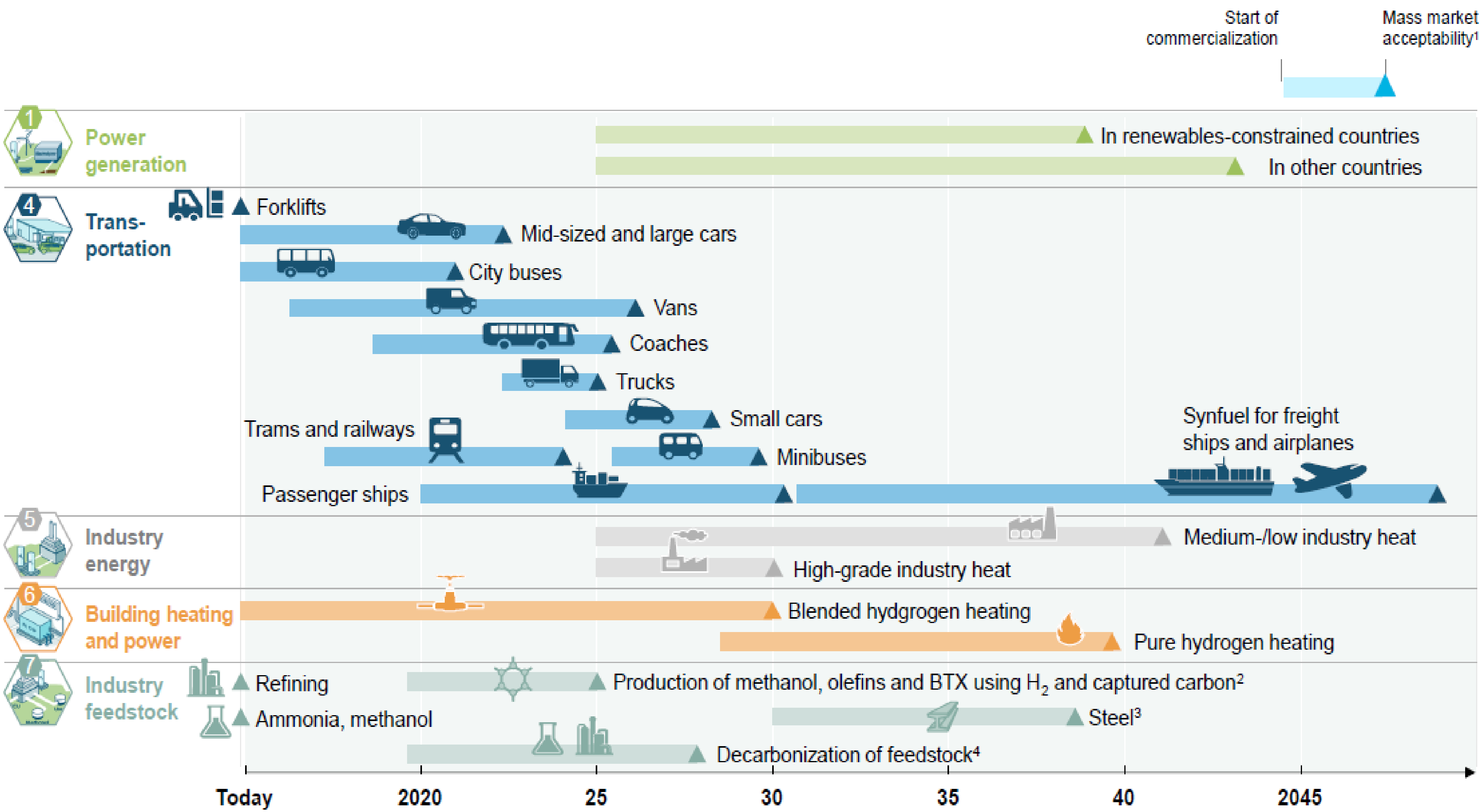
Alstom - Coradia ILint

Buses by Solaris, Ballard, Daimler…

Nikola - 800 semi trucks ordered
by Anheuser-Busch

Pipistrel/Hydrogenics/DLR/Ulm Univ

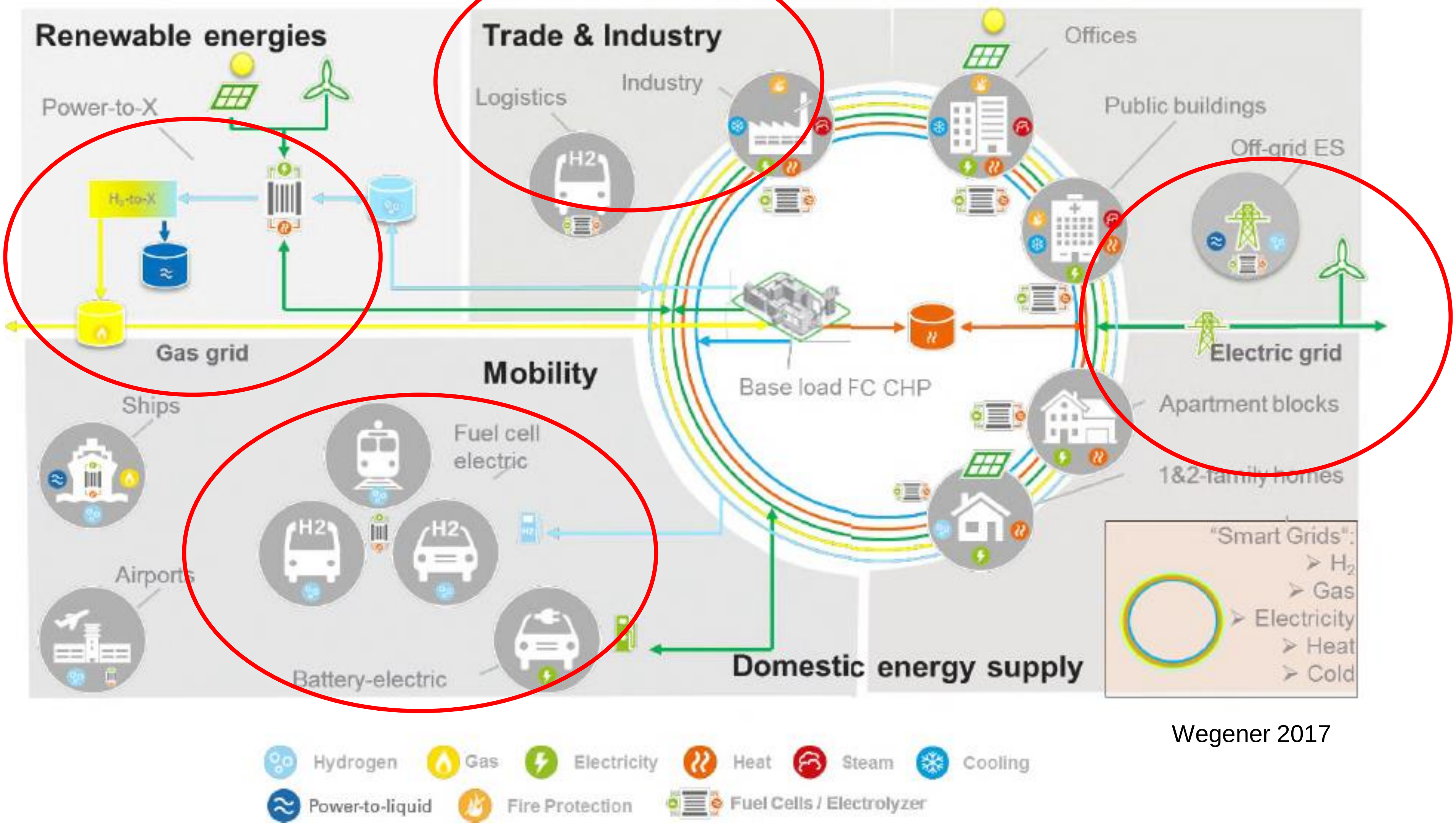
H_2 Technology Timeline



1 Mass market acceptability defined as sales >1% within segment in priority markets
3 DRI with green H_2, iron reduction in blast furnaces and other low-carbon steel making processes using H2
2 Market share refers to the amount of production that uses hydrogen and captured carbon to replace feedstock
4 Market share refers to the amount of feedstock that is produced from low-carbon sources

H2 Council 2017

A Vision of the Future Energy System



Wegener 2017

H_2, NG and electricity carriers
Integration of power and gas grids

Activity Highlights in Canada

Industry

- Ballard (one of the pioneers - FC technology)

Mireo Siemens train

- Hydrogenics (PEM electrolysers and HRS)

Academia

- Univ British Columbia (Clean E Research Center with H_2 station)
- UQ Trois-Rivières (H_2 solid storage)
- Univ Sherbrooke (Biomass)
- Polytechnique Montreal:
  - MCH catalysis
  - Direct use of clean power in chemical processes (microwave)
  - Green E cluster (being discussed with governments and industry)