Integrating Solid-State Hydrogen Storage Materials into Town Planning for a Sustainable Urban Future

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Organization: Technological and Higher Education Institute of Hong Kong (THEi)

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FIChemE, FIMMM, FIET, FHEA

Programme Leader of BSc in Green Engineering & Sustainability

Research interest: hydrogen energy, biomass energy, battery technology, green chemical production, techno-economic analysis

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Carbon Neutral Initiatives

Climate Action

- ***Hong Kong Government initiative on Carbon Reduction:***

Hong Kong plays a part to help fulfill the obligations that China has under the Paris Agreement. As such, Hong Kong will need to review our ***climate change efforts*** every 5 years and align them with the submission timelines under the Paris Agreement.

- ***Hong Kong's 2030 Target: Carbon Peak***

Hong Kong will ***reduce its carbon intensity*** by 65% to 70% using 2005 as the base. (*Hong Kong's Climate Action Plan 2030+)*

Environmental Protection

Sustainability

Smart City

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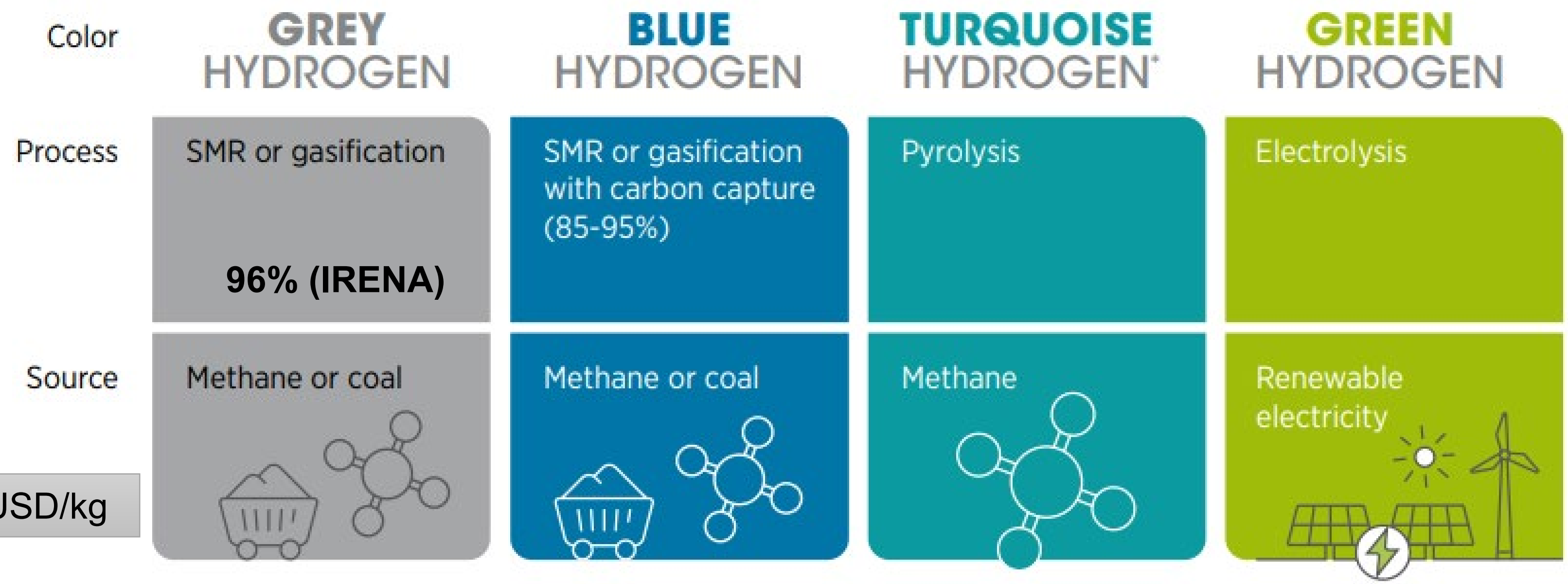
Green Hydrogen

There are many 'colors' of hydrogen – each referring to how it is produced.

Green hydrogen is the only variety produced in a climate-neutral manner.

It could play a vital role in global efforts to reach net-zero emissions by 2050.



1.5–2.5 USD/kg

2.5–7 USD/kg

Image: International Renewable Energy Agency

Hydrogen Supply in Hong Kong

- Towngas

- Other H_2 suppliers, e.g. Linde

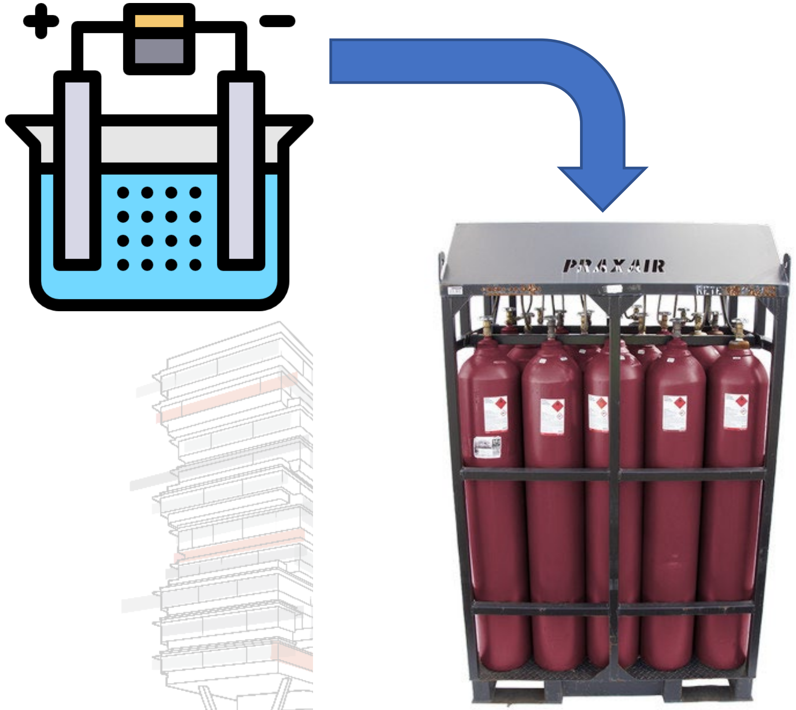
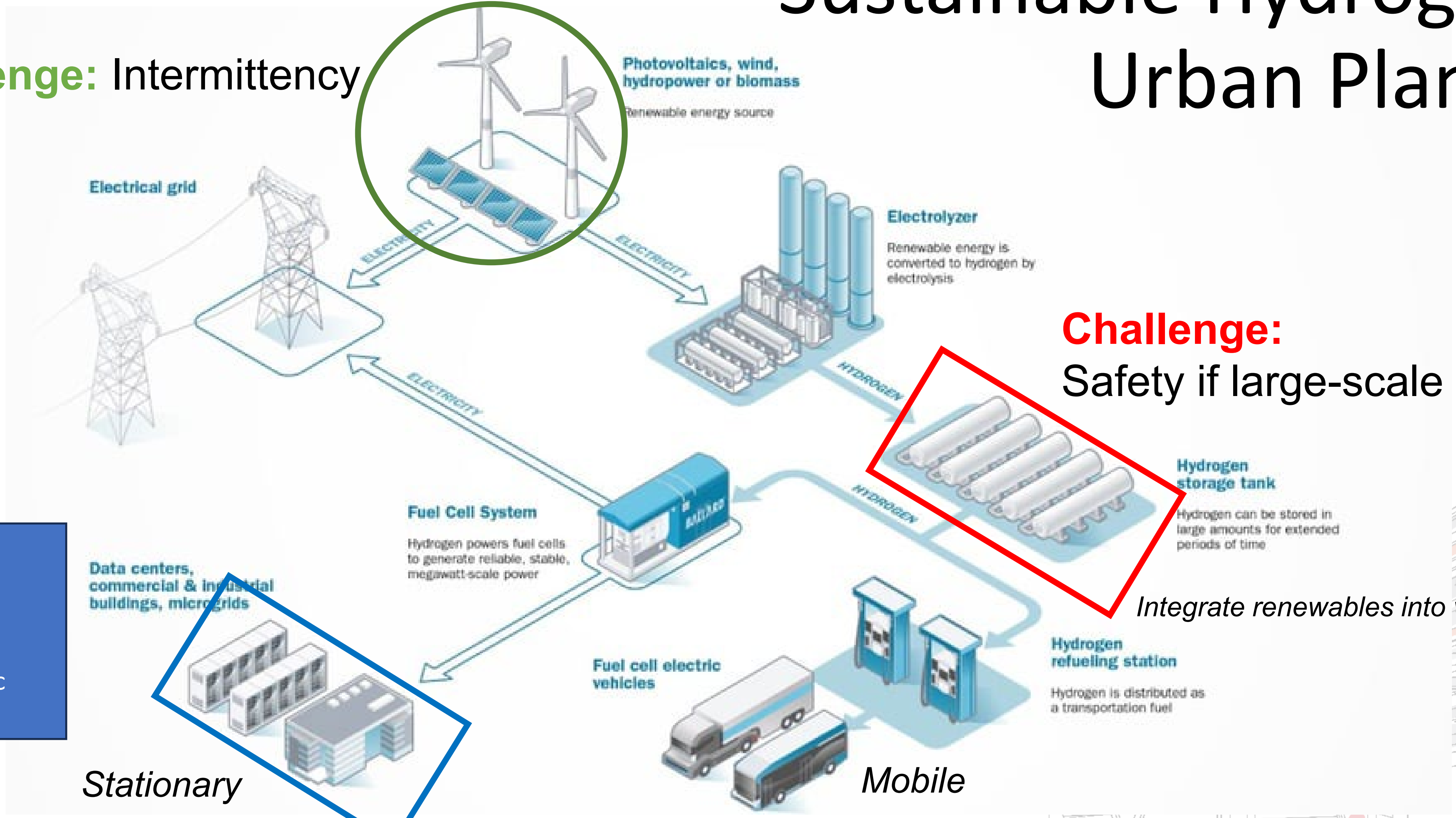


Photo adapted from *HK Towngas, South China Morning Post, Linde Gas & Equipment Inc.*

Sustainable Hydrogen in Urban Planning

Challenge: Intermittency



Challenge:
Safety if large-scale storage

Integrate renewables into various sectors

Large scale:
⩾ metric tons

Small scale:
kg to ⩽ metric tons

Stationary

Mobile

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Image: https://blog.ballard.com/powergen/renewable-energy-storage

Sustainable Hydrogen in Urban Planning

The successful development of hydrogen storage solutions is essential for the penetration of hydrogen at each level of the energy supply chain, e.g. backup power, data centers, hospitals, etc.

Residential area

Data Centre Power Outage
Image: https://powerwhips.com

Hospital blackouts: rising death toll
Image: NBC News

Water treatment plants
www.wsd.gov.hk

Airport – runway lighting
www.stantec.com

Telecommunication facilities
www.securitysales.com/

Emergency operations center
avispl.com/

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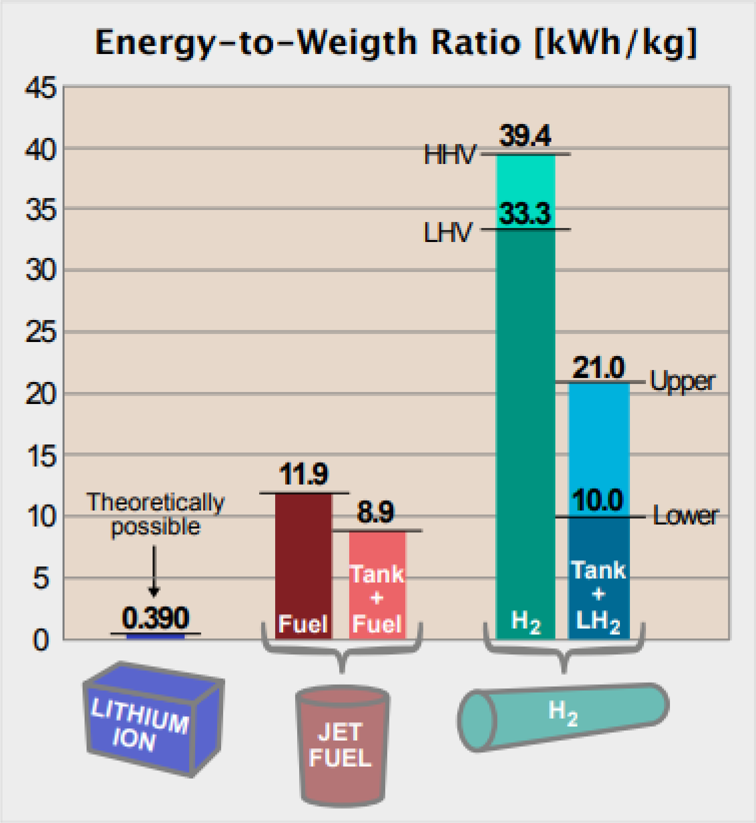
Large-scale H_2 storage vs battery

1. higher energy density – H_2 (39.4 kWh/kg) vs battery (0.15 - 0.39 kWh/kg) more energy per unit volume or mass → less space

2. Scalability - H_2 relatively straightforward , battery needs adding more individual battery units → more complex and costly

3. Long-duration storage - H_2 extended periods without significant losses, battery energy loss due to chemical reactions, leakage current and internal resistance, etc



Source: *IEEE Electrification Magazine* **2021**, *9*, 92-102.

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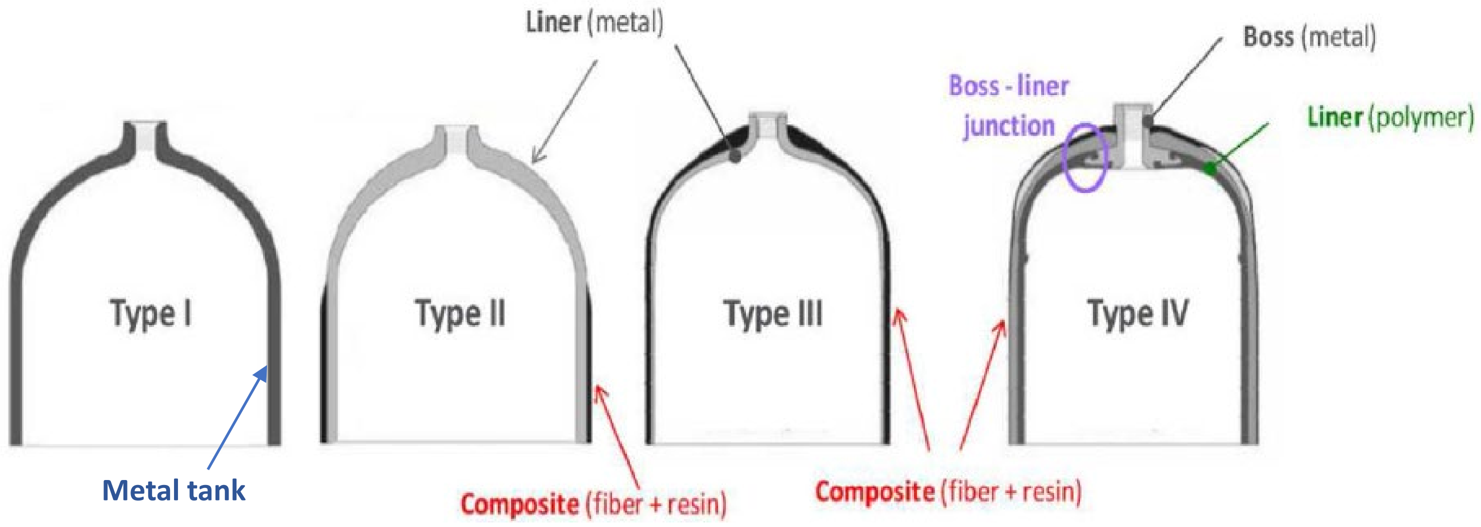
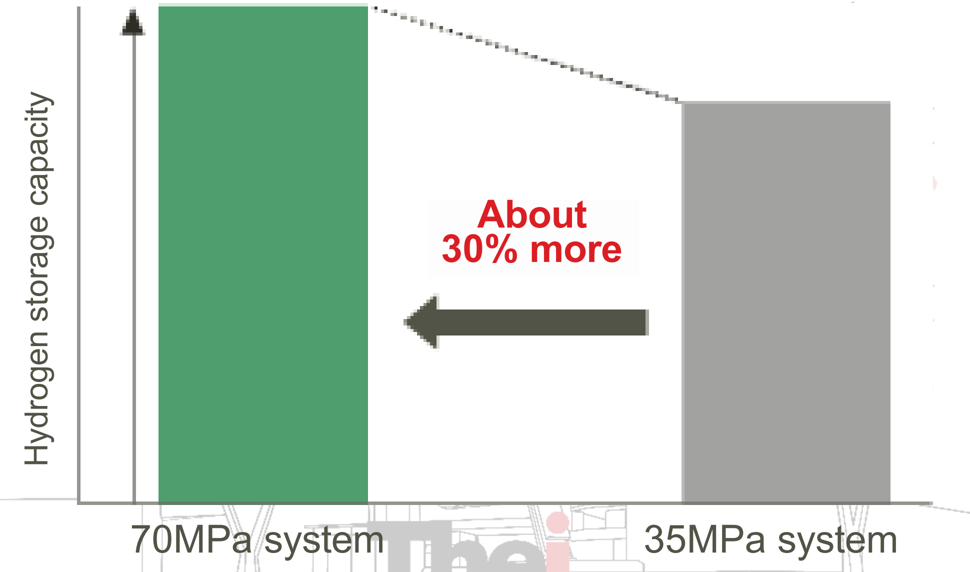
Current Technology

- **Type I:** withstand only up to 50 MPa
- **Type II:** 30-40% lighter, steel liner
- **Type III:** liner Al, glass fiber
- **Type IV:** plastic liner wrapped with carbon fiber and other composite materials, lightweight, durable, and have high storage capacity (H_2 density: 5.7 wt%, 70 MPa, 40 kg/m^3)

Weight ⟷ *Cost*

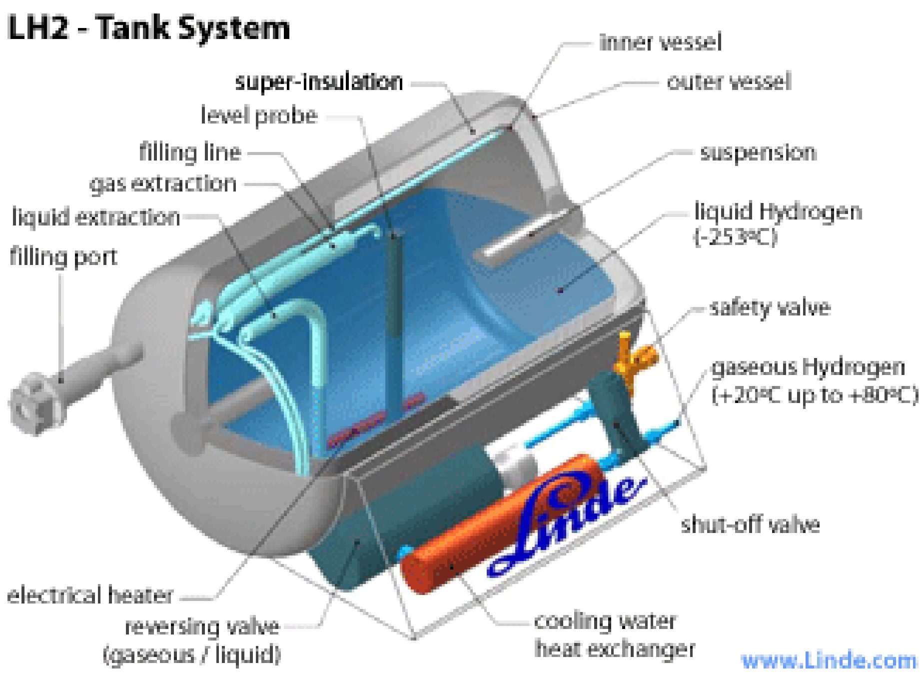


Toyota Mirai



Graphics: Nissan

Current Technology

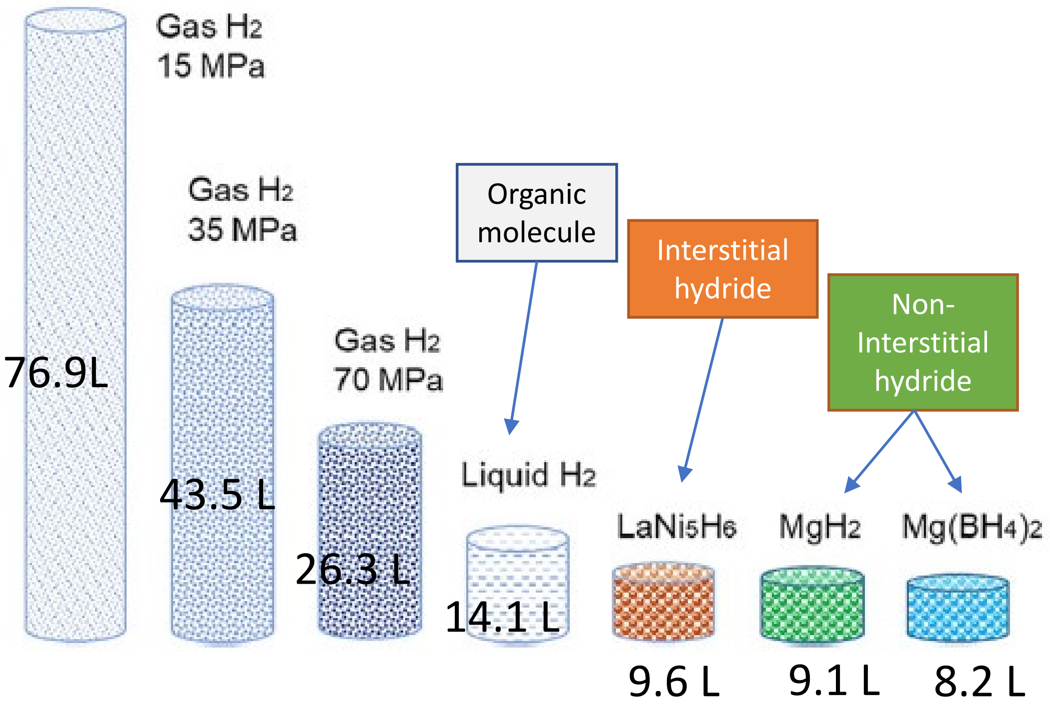


- High H_2 density: 70kg/m^3
- Low temperature (-250^{o}C)
- Consume up to 35% of the energy in the stored H_2
- boil-off losses
- Larger scale → less boil-off losses (∝ surface area to volume)

BMW Hydrogen 7

Offers 75% more energy per volume as a liquid than compressed gas at 70 MPa of pressure

H$_2$ Storage Materials (HSM) (Potential for Large-Scale Storage)



Comparison on the volumes for 1 kg H$_2$ (11,200 L) in various methods and materials.

Advantages of Solid-State HSM: High H$_2$ storage capacity, safe, stability, portable devices and transportation

Disadvantage: Limited kinetics, require high temp/pressure, costly, cycling problem

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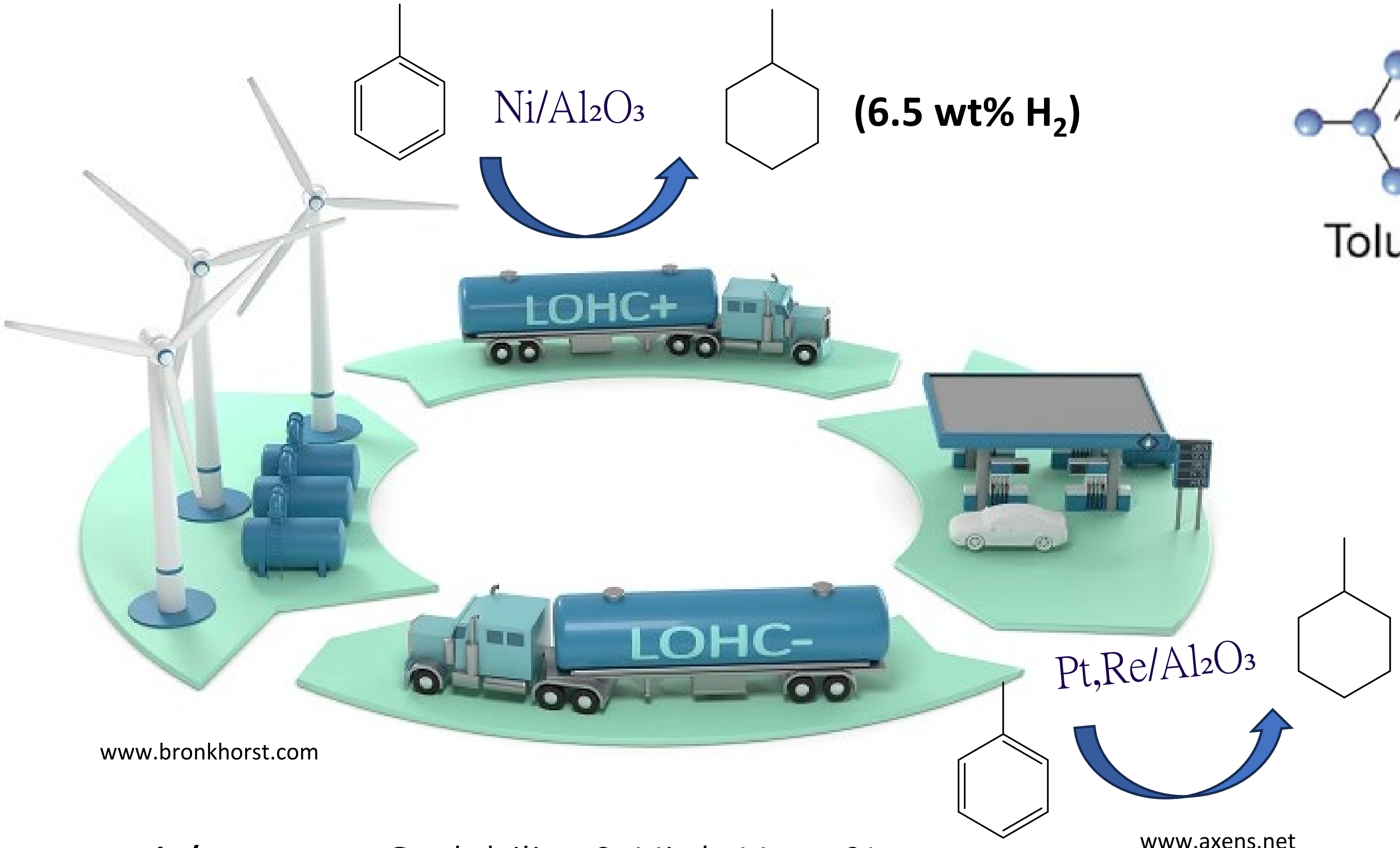
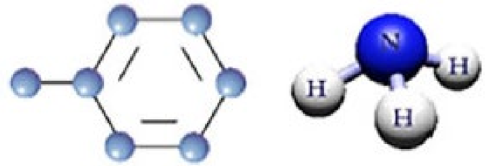
Perspectives and challenges of hydrogen storage in solid-state hydrides. *Chinese Journal of Chemical Engineering* **2021**, *29*, 1-12.

Liquid organic hydrogen carrier (LOHC)

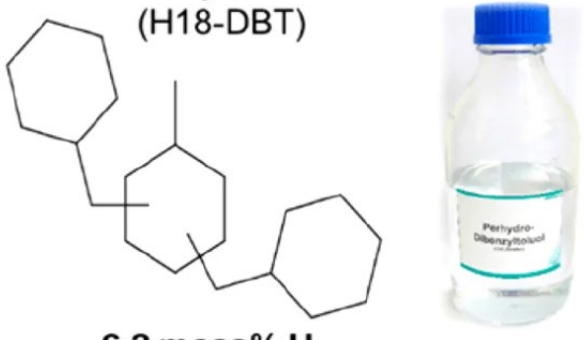




Toluene Ammonia

Formic acid (CH_2O_2)
(4.4 wt% H_2)

perhydro dibenzyltoluene
(H18-DBT)



6.2 mass% H_2

Organic Liquid
(e.g. cycloalkanes, heterocycles, ammonia)
Accounts of Chemical Research 2017, 50, 74.

Advantages: Scalability & High H_2 wt%
Disadvantage: energy intensive, costly, materials degradation

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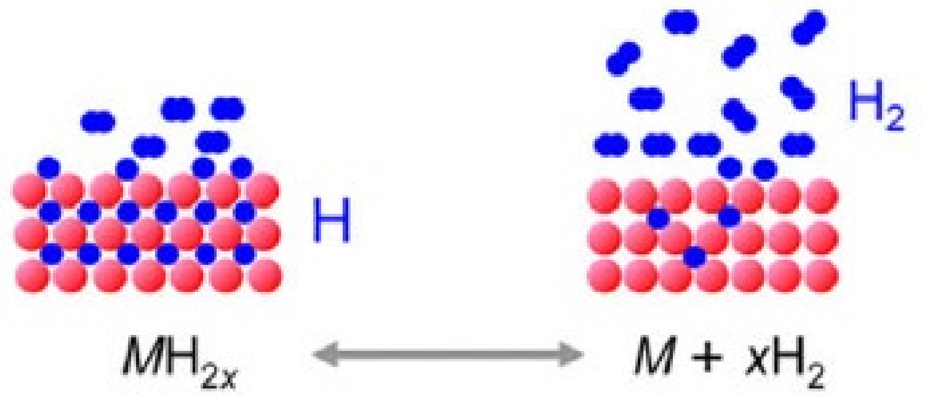
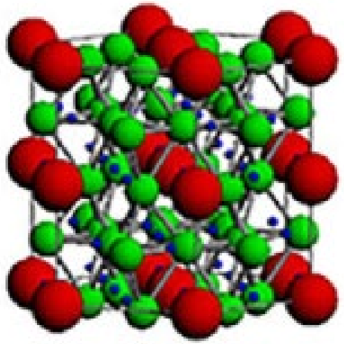
LaNi$_5$H$_6$ (interstitial)

- H_2 forms metallic bonds in Interstitial hydride Materials

Advantages: Reversibility, safety
Disadvantage: Slow kinetics, materials degradation

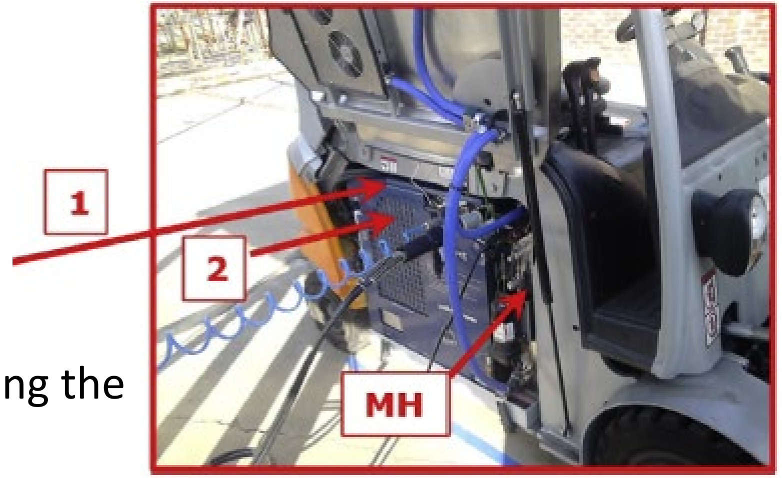




LaNi$_5$H$_6$

AB$_5$-type alloy **(1.88 wt% H$_2$)**

Forklift application



1. DC/AC

2. Filling the MH

3. Compressor and Dispensing system

HySA Systems Competence Centre

Application of hydrides in hydrogen storage and compression: Achievements, outlook and perspectives. *International Journal of Hydrogen Energy* **2019**, *44*, 7780-7808.

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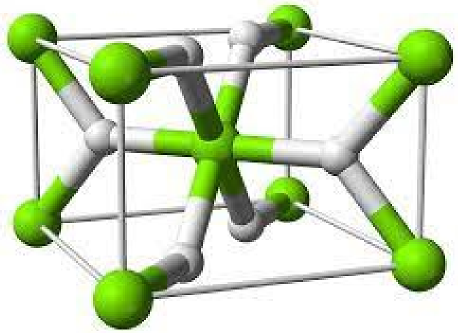
MgH$_2$ (non-interstitial)

Advantages: Abundant and low-cost, Reversibility
Disadvantage: Slow kinetics, materials degradation, high temperature requirement



MgH$_2$ – Rutile structure (H/M = 2)

MgH$_2$ (7.6 wt% H$_2$)
POWERPASTE

Direct hydrogenation of Mg metal at high pressure and temperature (200 atmospheres, 500 °C)

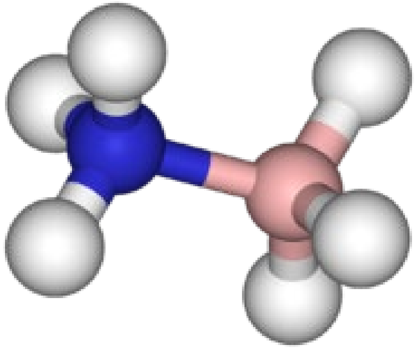
At 287 °C it decomposes to produce H$_2$ at 1 bar pressure. The high temperature required is seen as a limitation in the use of MgH$_2$ as a reversible hydrogen storage medium.

$$MgH_2 \rightarrow Mg + H_2$$

MgH$_2$ also readily reacts with water to form hydrogen gas

Solid Borane Materials

Advantages: Fast kinetics, high H_2 wt%
Disadvantage: Reversibility, cycling problem



Ammonia borane (NH_3BH_3)
(19.6 wt%)

- **Thermolysis**

$$NH_3BH_3 \xrightarrow[\Delta]{-H_2} [NH_2BH_2] \xrightarrow[\Delta]{-H_2} [NH{=}BH] \xrightarrow[\Delta]{-H_2} 1/n\ (BN)_n$$

- **Catalytic dehydrocoupling**

$$NH_3BH_3 \xrightarrow[cat]{-H_2} [NH_2BH_2] \xrightarrow[cat]{-H_2} [NH{=}BH] \xrightarrow[cat]{-H_2} 1/n\ (BN)_n$$

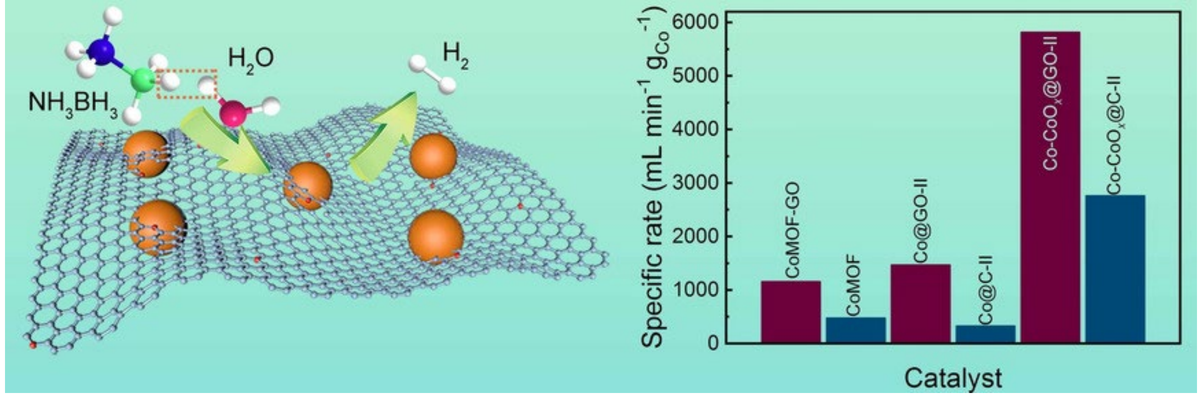
- **Catalytic hydrolysis**

$$NH_3BH_3 \xrightarrow[cat]{2\ H_2O} 3\ H_2 + NH_4BO_2$$

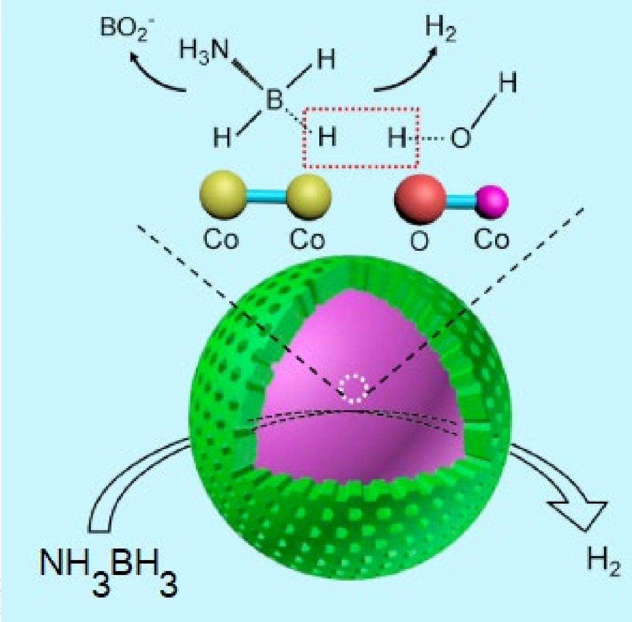
Require an efficient catalyst!

Solid Borane Materials Research

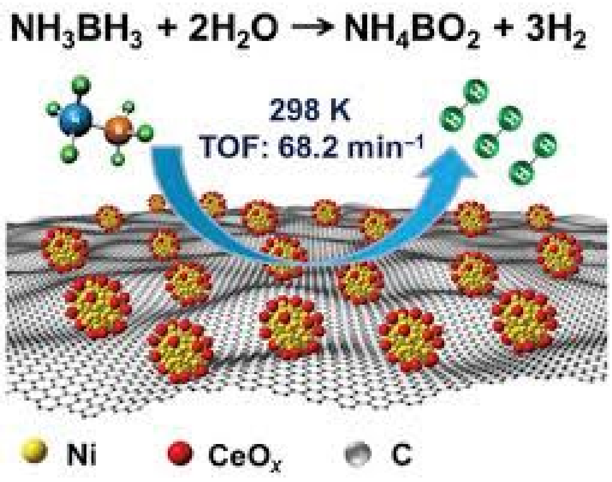
Co-CoO$_x$ Graphene nanocatalysts



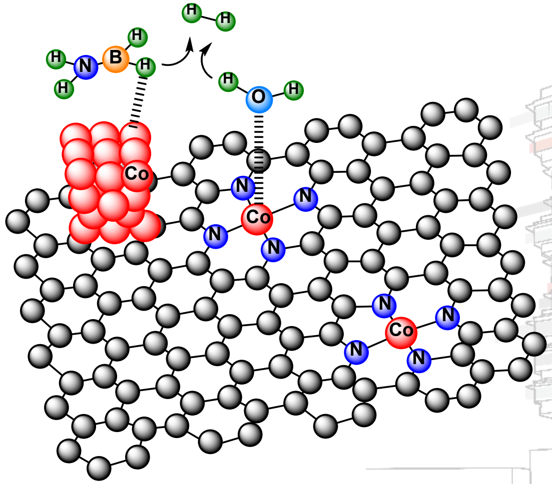
Chinese – An Asian Journal , 2020, *15*, 3087-309.



ACS Sustainable Chemistry & Engineering 2019, *7*, 9782-9792.



Nano Research 2018, *11*, 4412–4422.



Journal of Materials Chemistry A 2021, *10*, 5580-5592.

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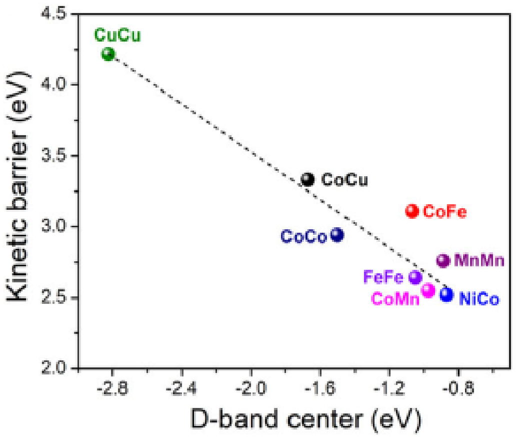
Our Research

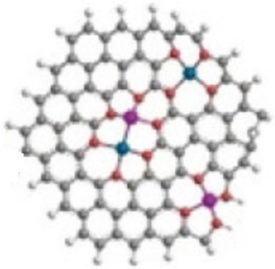
- To use single atom strategy and past experience to solve challenging energy and emerging environmental problem.

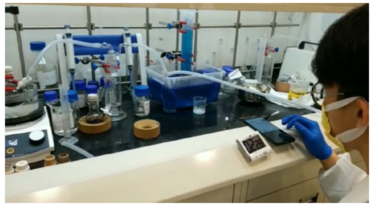
Research & Catalyst Development

Theoretical Screening

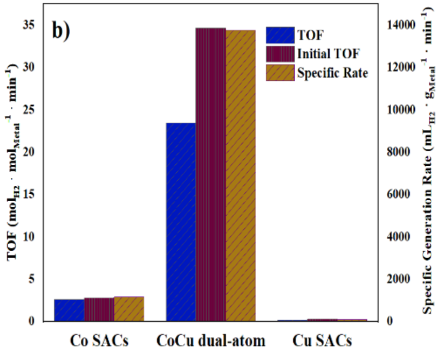


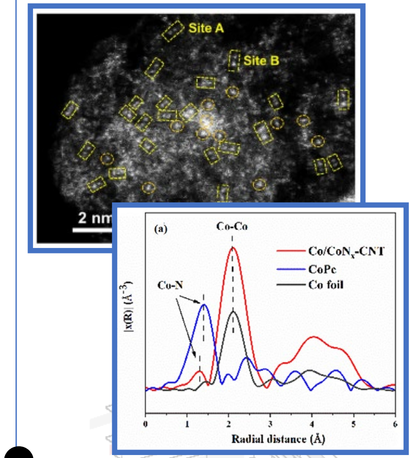
Experimental Design: Support the dual-atom on carbon support



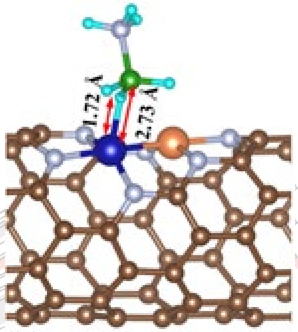


Catalytic Evaluation





Characterization e.g. HAADF-STEM, XANES and EXAFS



Theoretical Validation

- *Journal of Materials Chemistry A* 2022, *10*, 5580-5592.
- *Journal of Visualized Experiments* 2021, DOI: 10.3791/62965.
- *Catalysts* 2020, *10*, doi:10.3390/catal10070723.
- *Angewandte Chemie International Edition English* 2010, *49*, 8708-8711.

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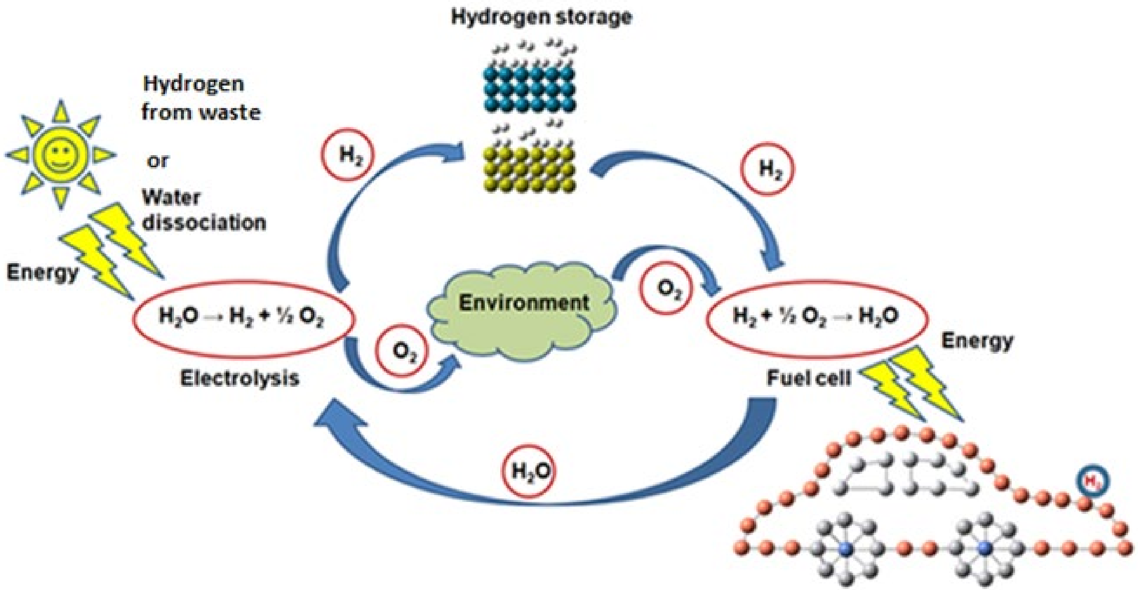
Conclusion

1. Green H_2 could further accelerate the carbon reduction in Hong Kong for sustainable urban development.

2. Several options for large-scale H_2 storage, such as liquid- and solid-state storage, however, challenges such as kinetics and cycling problem need to be solved.

3. The manufacturing of these HSM could cause another issue in carbon emission, low-carbon chemical production has to be designed.



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UGC/IDS(R)25/20 - Establishment of the Centre for Interdisciplinary Research on Food By-products Utilization (CIFU)
UGC/IDS(C)14/B(E)01/19 - Development of Renewable Energy for Decarbonizing and Modelling Sustainable Transport and Logistics Operations in Smart Cities of Greater Bay Area
PRP/051/20FX - High-efficient Recycling of End-of-life Electric Vehicle Batteries for Energy Storage Material Regeneration

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Thank you!

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