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The University Of Sheffield.

The Mysterious Island: The Rise of Hydrogen and Fuel Cells in Japan

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NEXT-FC
Next-Generation Fuel Cell Research Center

Graduates School of Integrated Frontier Sciences,Kyushu University
The Department of Automotive Science

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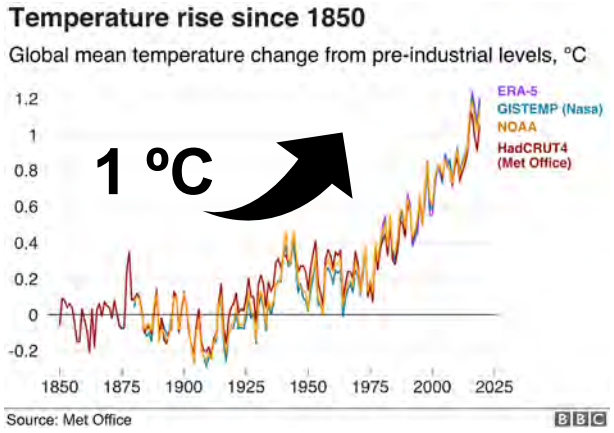
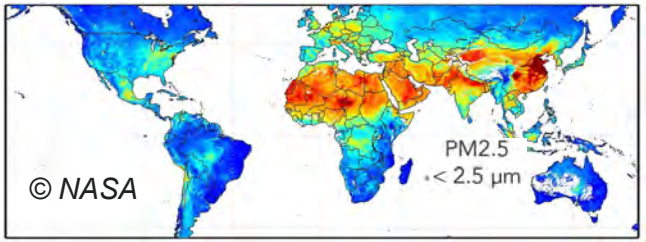
The Triple Threat of Fossil Fuels

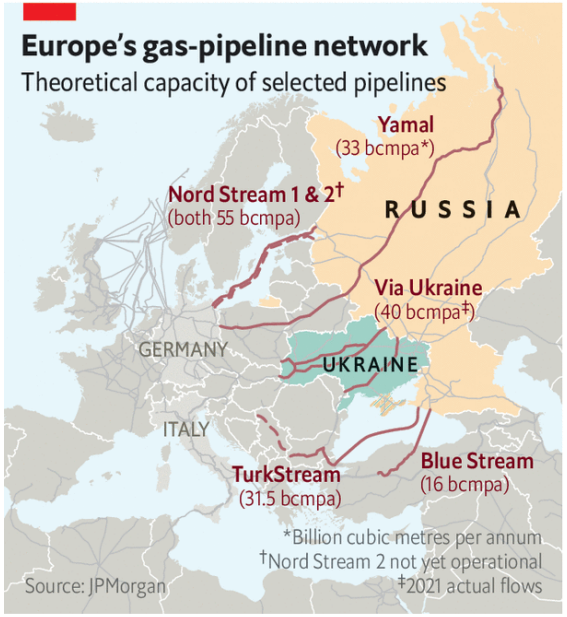
Climate Change



Public Health



Energy Security

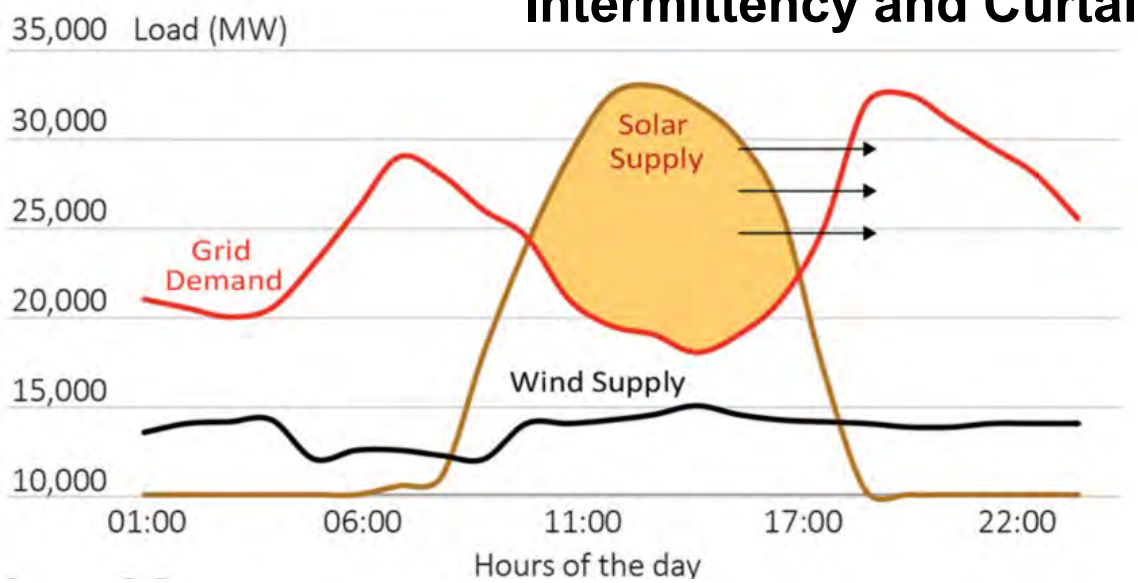


The Economist

Electrification with Renewables

Solar farm, Itoshima

Intermittency and Curtailment



Wind Lens, Karatsu

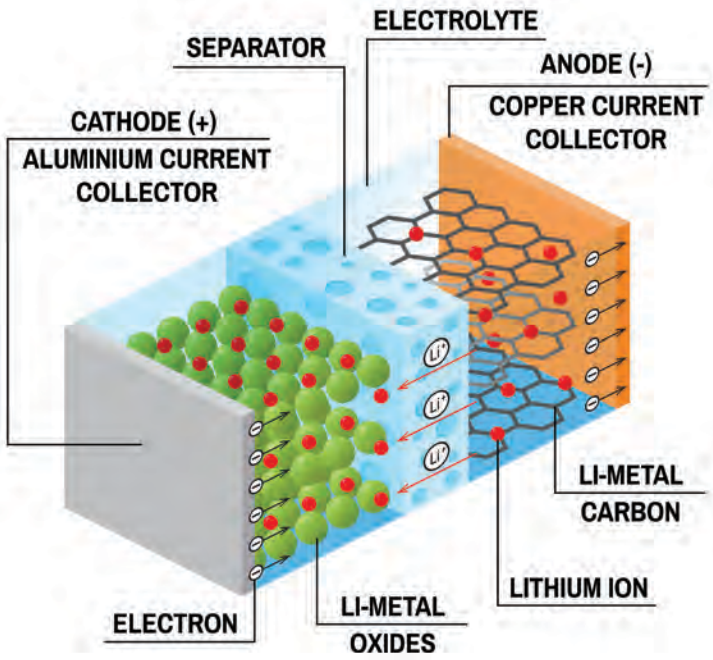
Difficult to Electrify Sectors

Steel Manufacture

Cement Production

Heating & Cooling
Mobility

Energy Storage using Batteries



Batteries are suited to **short-term** energy storage.

Cobalt, lithium and graphite are **critical raw materials** with limited supply.

Nissan Leaf BEV

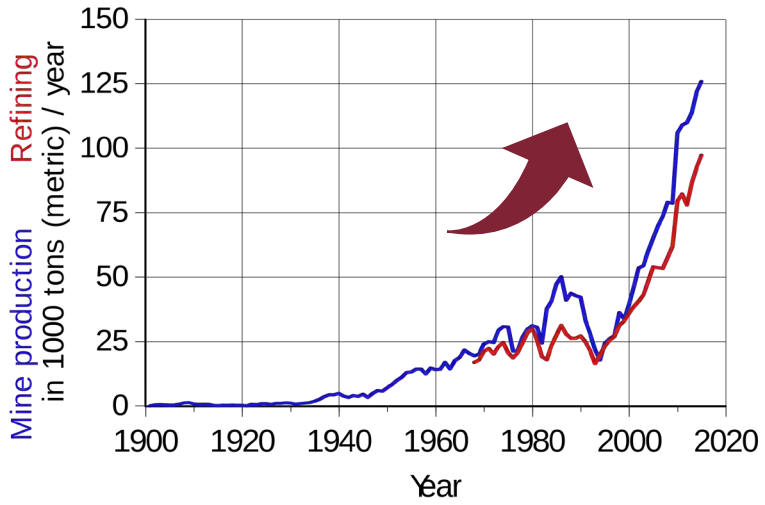
Issues with Lithium Ion Batteries

The lithium-rush threatens disastrous **ecological damage** on an industrial scale…

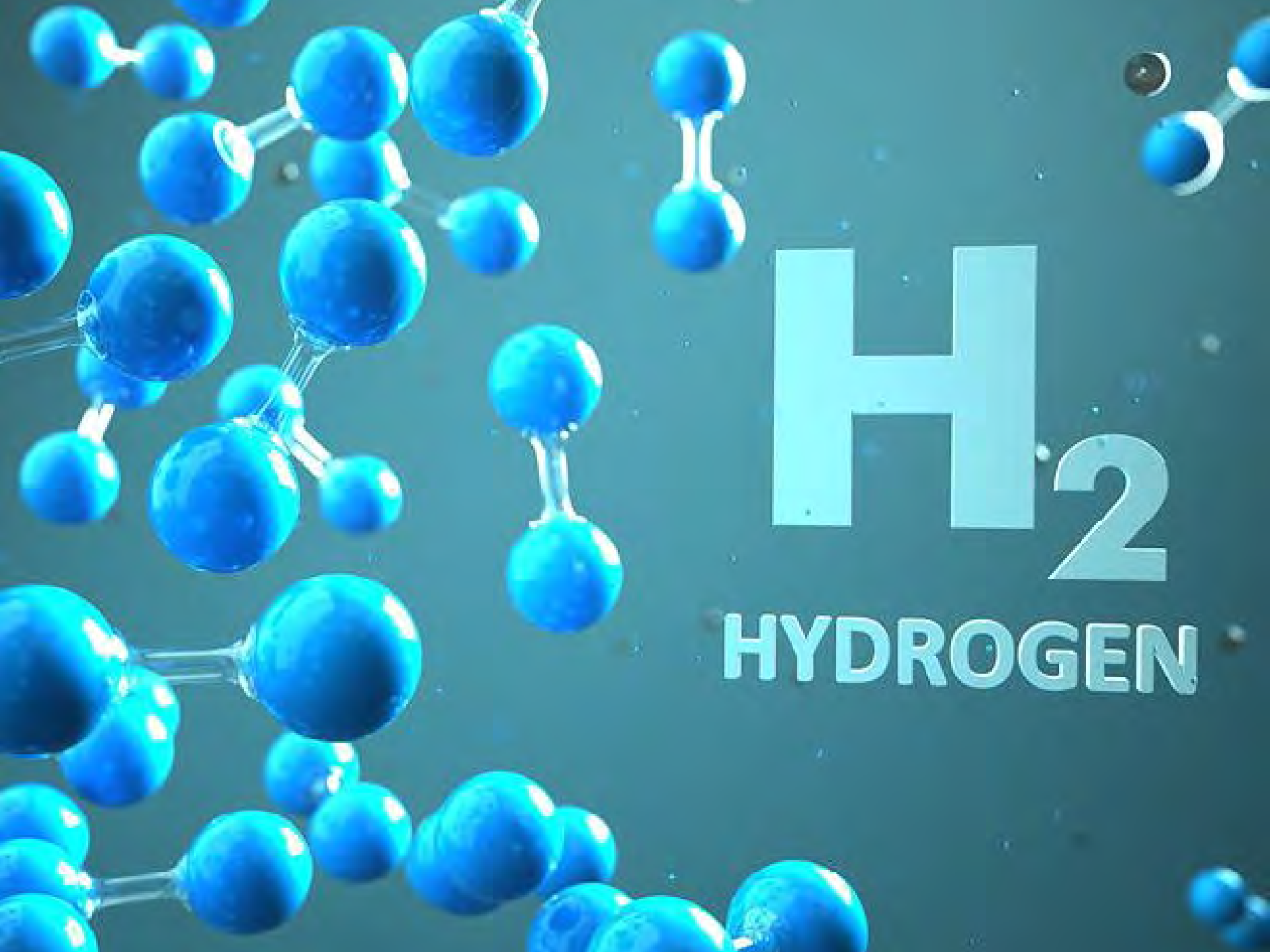
Cobalt mining in the Democratic Republic of Congo uses **child labour**…

▲ Digging for cobalt in the Democratic Republic of the Congo, where 60% of the world's supply is found. Miners often breathe in cobalt-laden dust, which can prove fatal. Photograph: Sebastian Meyer/Corbis via Getty Images

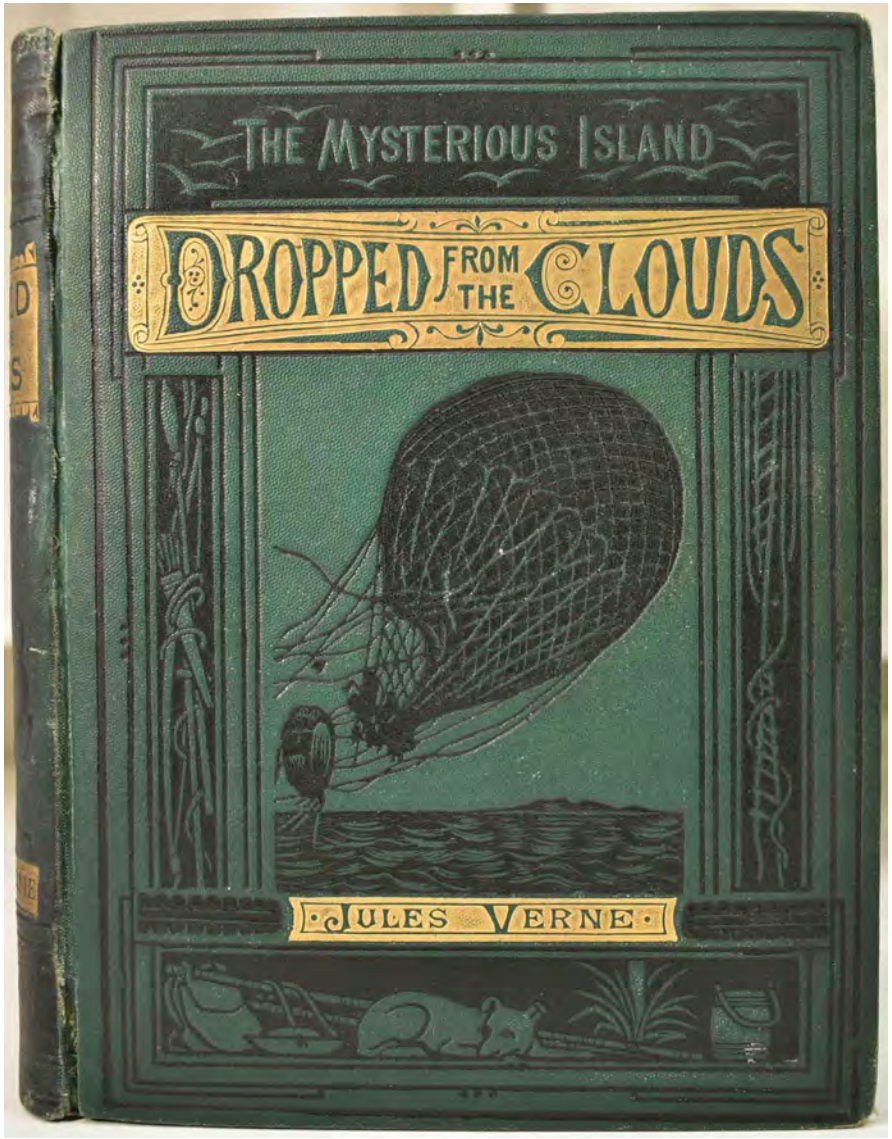
Faulty batteries can cause **fires** (Samsung Galaxy Note 7 recall cost >US$17 billion)…



Meanwhile, demand is rapidly increasing!


H2
HYDROGEN

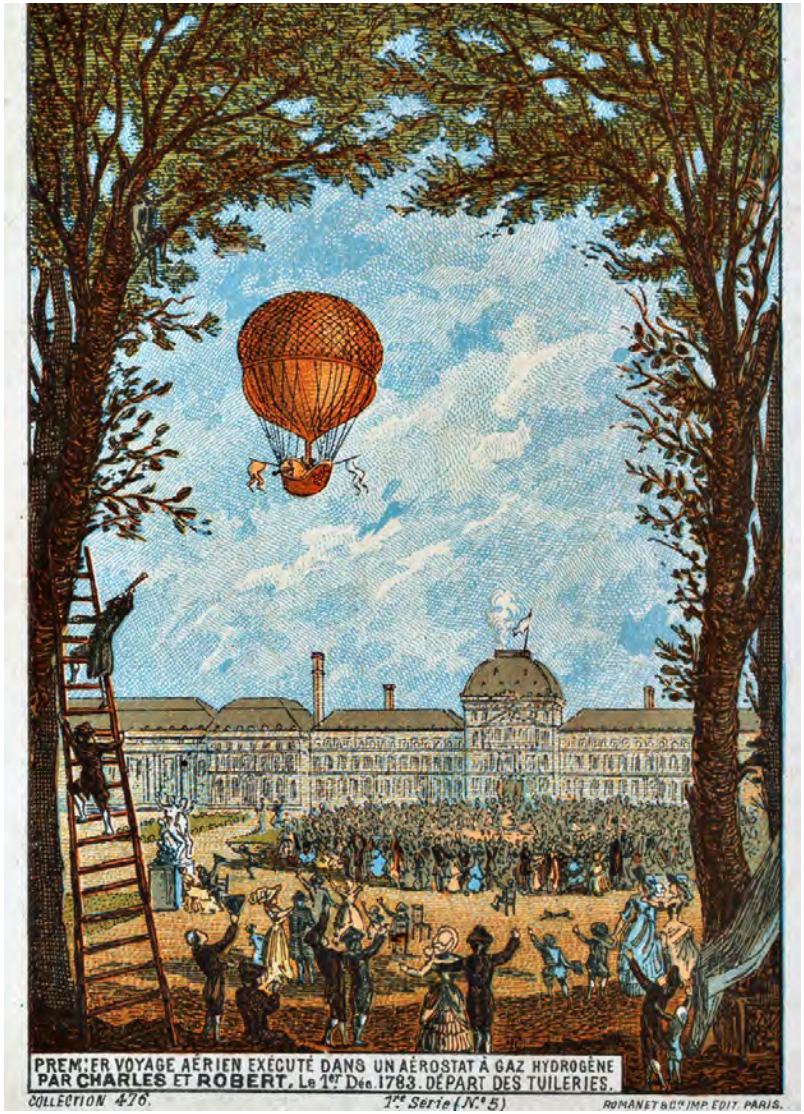
The Mysterious Island, Jules Verne (1874)



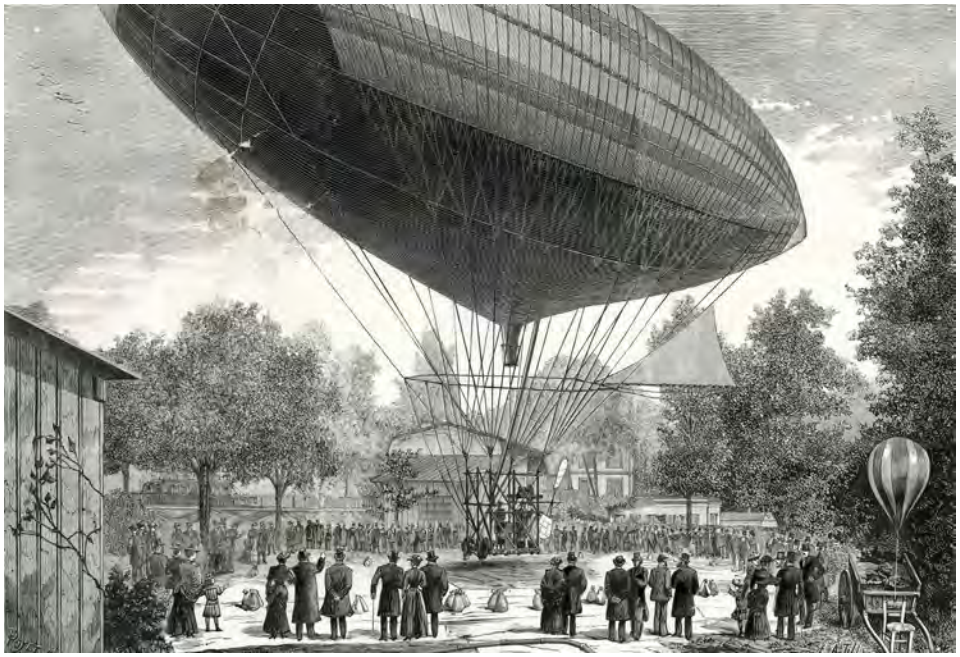
"I believe that water will one day be employed as fuel, that hydrogen and oxygen will furnish an inexhaustible source of heat and light".

Hydrogen Balloons and Airships

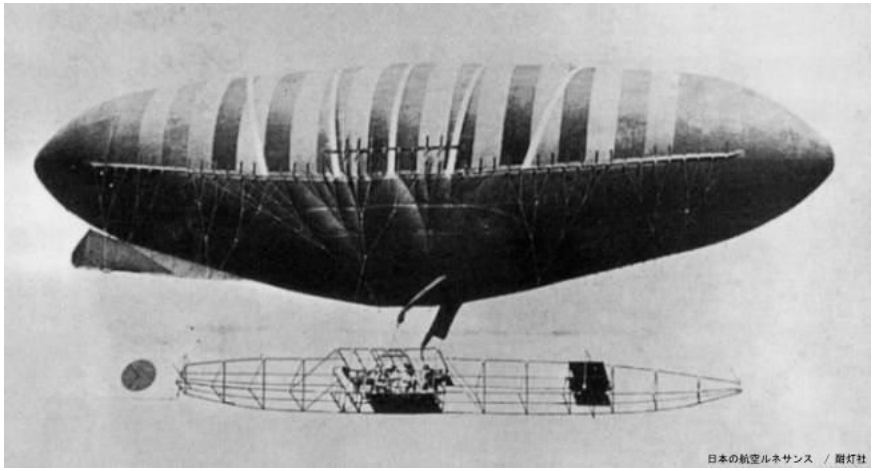
First crewed hydrogen balloon (1783)



The Hindenburg disaster (1937)…



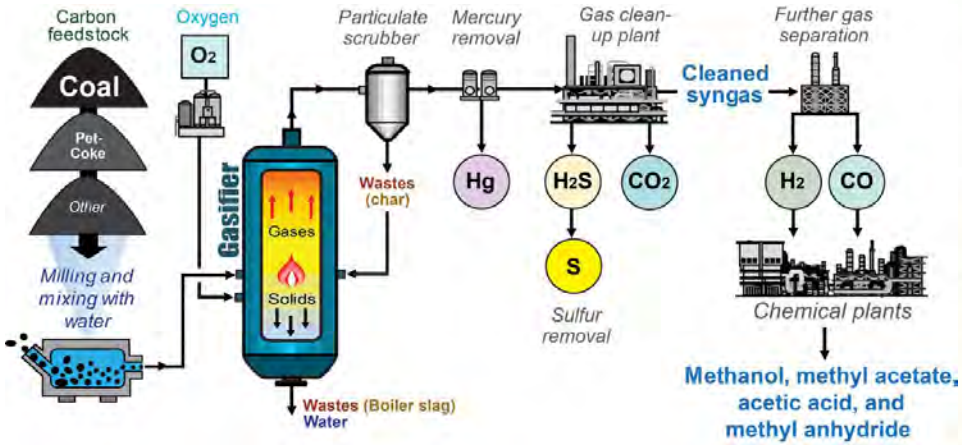
The first powered hydrogen airship (1852)



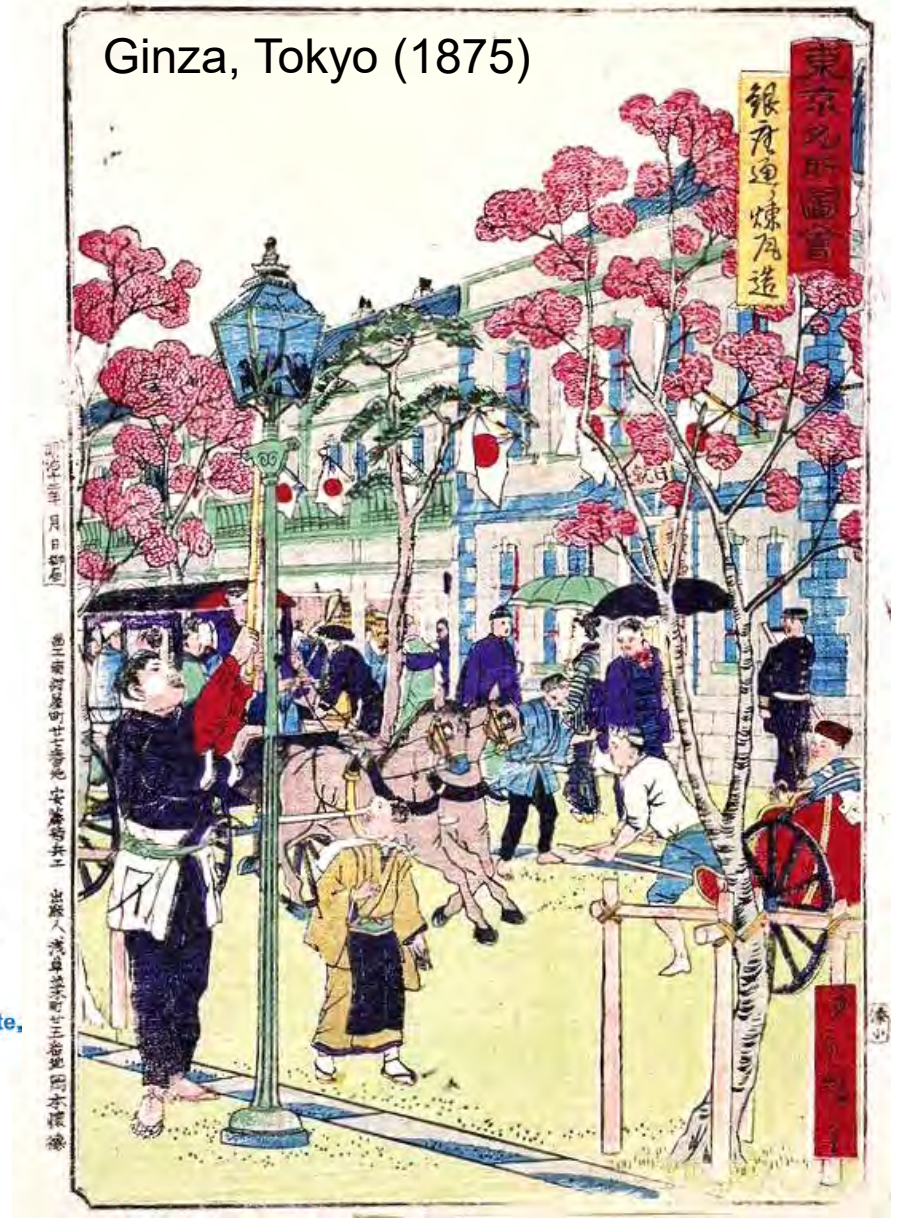
Japan's first hydrogen airship (Yamada Shiki, 1911)

Coal Gas: Hydrogen Lighting

First gas lamp in Japan (Kyushu, 1857)

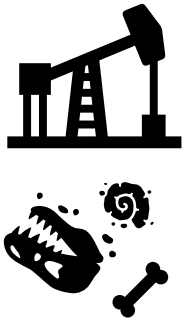


Steam reforming is still the primary method of hydrogen production today.



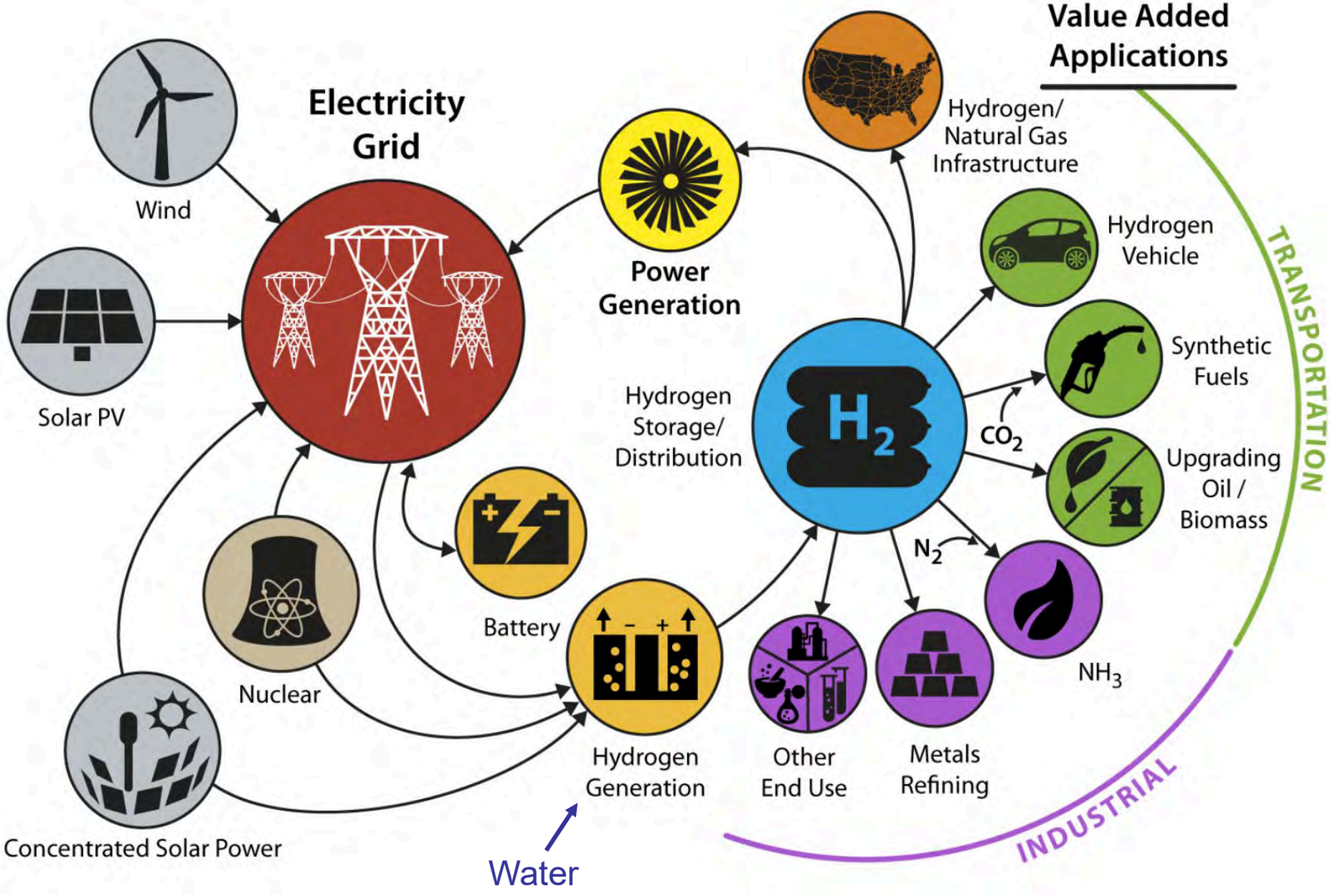
The Hydrogen Economy Today

Where does hydrogen come from?



How is hydrogen used?

The Future Hydrogen Economy



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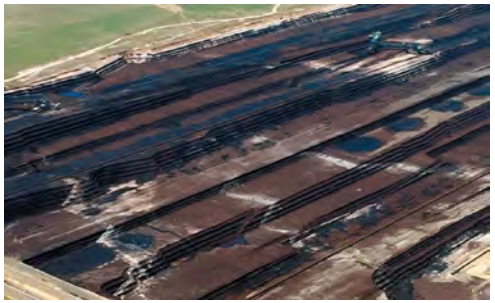
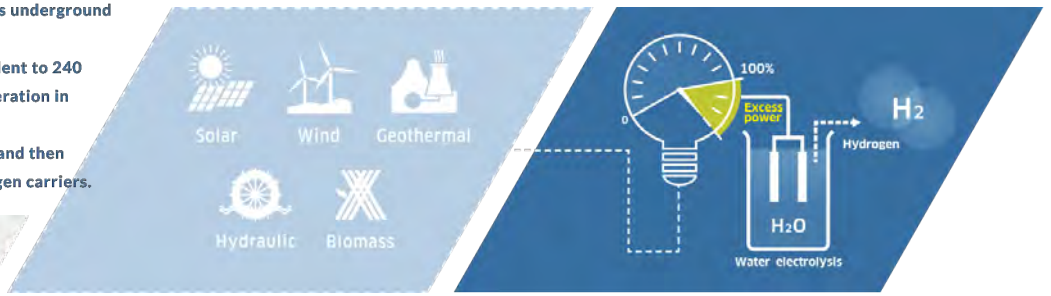
Hydrogen Distribution in Japan



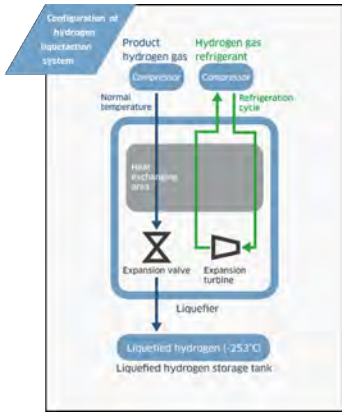
Brown coal* that exists about five meters underground in Latrobe Valley, Australia.
The reserves are estimated to be equivalent to 240 years' worth of total electric power generation in Japan.
Hydrogen is produced from brown coal, and then transported to Japan by liquefied hydrogen carriers.

Kawasaki
Powering your potential

Brown Coal Gasification + CCS (Australia)



Off-peak Renewable Electrolysis



Hydrogen Liquefaction Plants

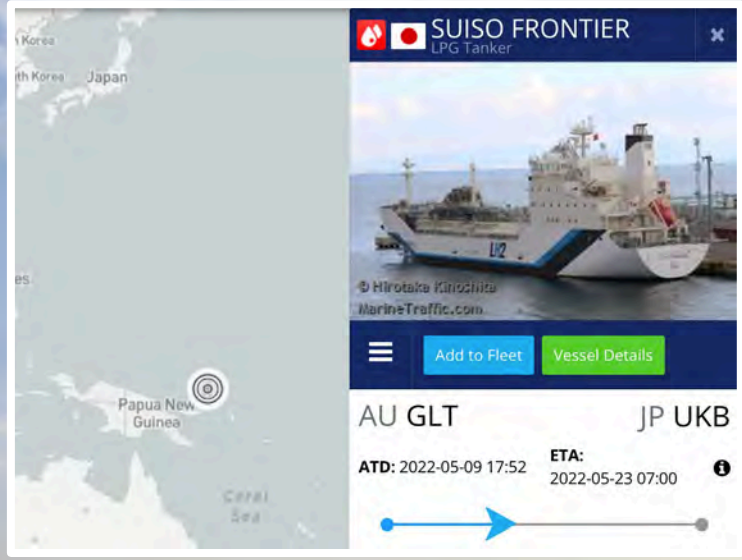
Cryogenic Liquid Hydrogen Transport to Japan

Liquid Hydrogen Storage

Liquid Hydrogen Trucks

Compressed Hydrogen Trucks

LH2


SUISO FRONTIER
LPG Tanker
Japan
Papua New Guinea
Coral Sea
© Hirotake Kinoshita
MarineTraffic.com
Add to Fleet
Vessel Details
AU GLT
JP UKB
ATD: 2022-05-09 17:52
ETA:
2022-05-23 07:00

LH2

Organic Chemical Hydride Storage

AHEAD Project

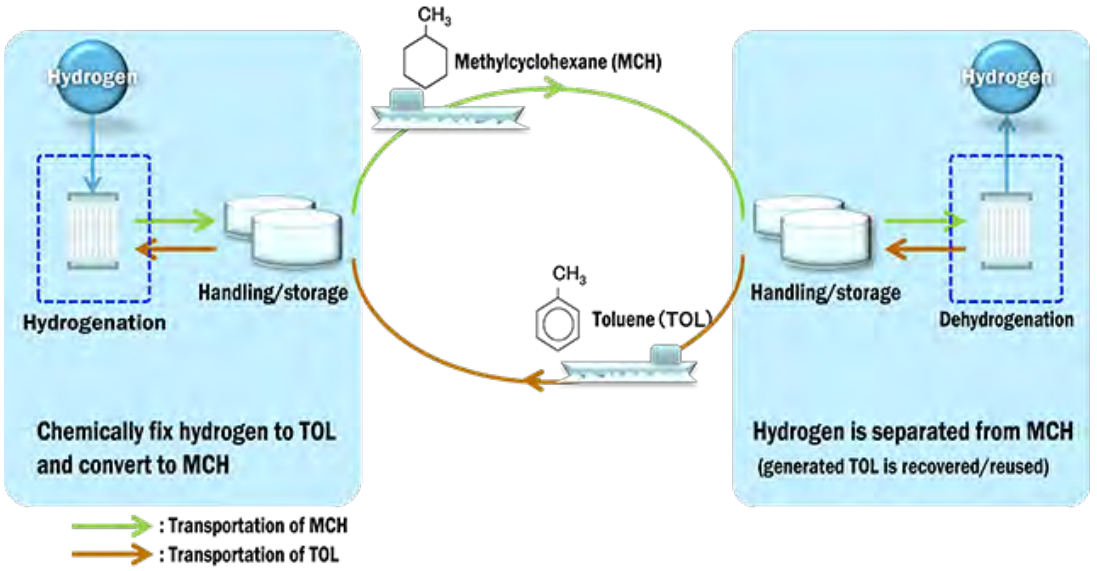
- Hydrogen produced in Brunei
- React with toluene to form methylcyclohexane (MCH).
- Transport by ship to Japan, in conventional ISO tanks.
- Dehydrogenation in Kawasaki port (MCH → toluene)
- Supplied to the Mizue thermal power plant.
- Toluene returned to Brunei where it is transformed back into MCH.

CHIYODA CORPORATION

MITSUI & CO.

MITSUBISHI HEAVY INDUSTRIES

NYK LINE NIPPON YUSEN KAISHA

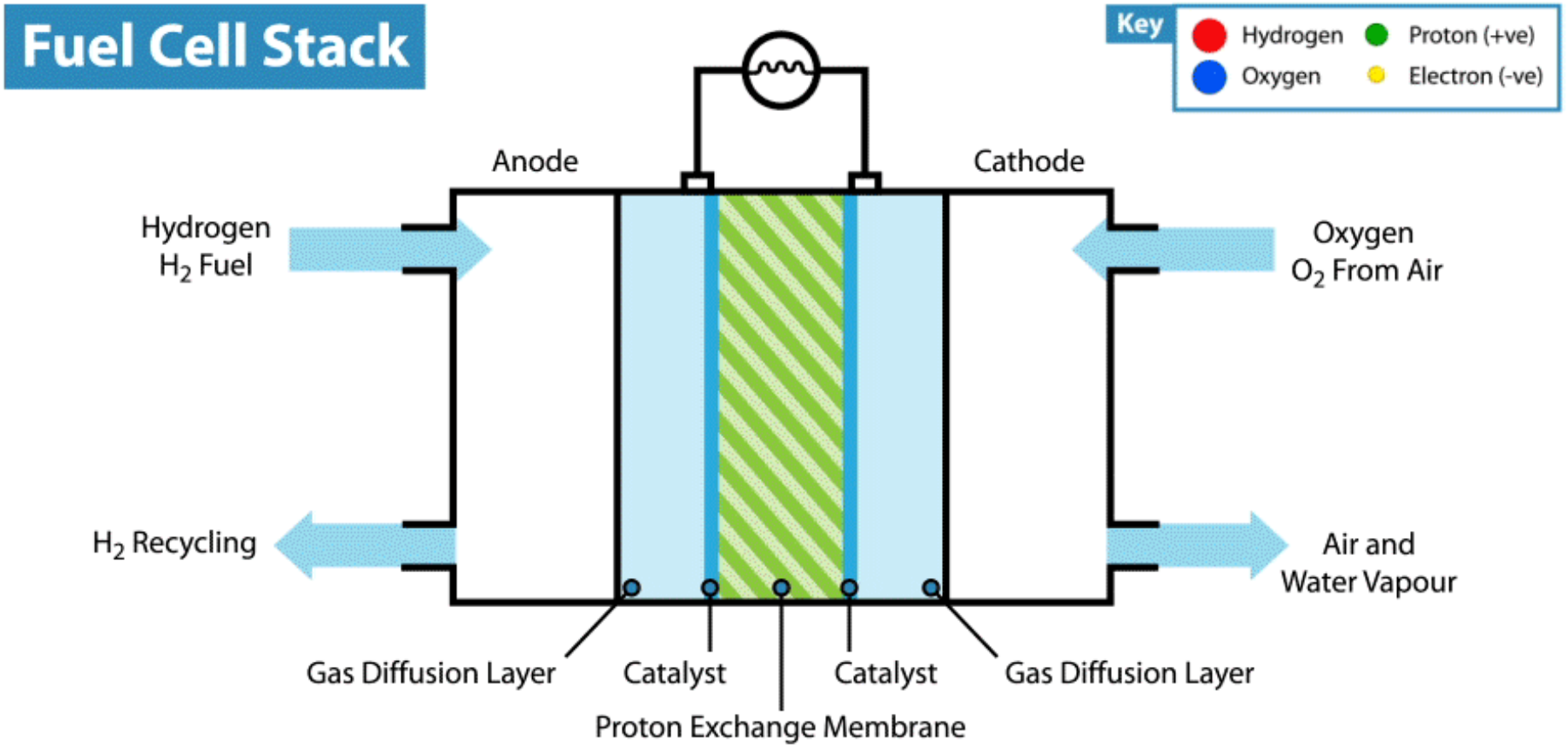


Bio-hydrogen from Waste

Flush, then fill up: Japan taps sewage to fuel hydrogen-powered cars

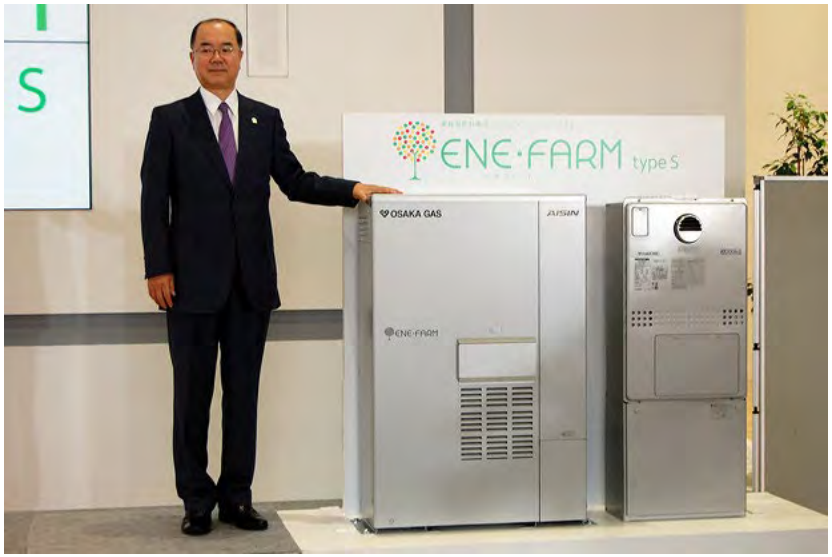
An attendant prepares to fill up a Toyota Mirai at a Fukuoka sewage treatment plant, which is creating hydrogen from biogas. (Julie Makinen / Los Angeles Times)

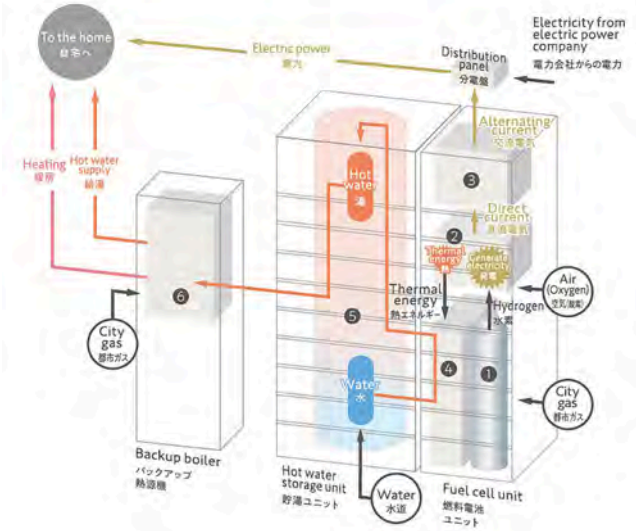
Hydrogen Fuel Cells



Hydrogen + Oxygen → Electricity + Heat + Water

Combined Heat & Power (CHP): ENE-FARM

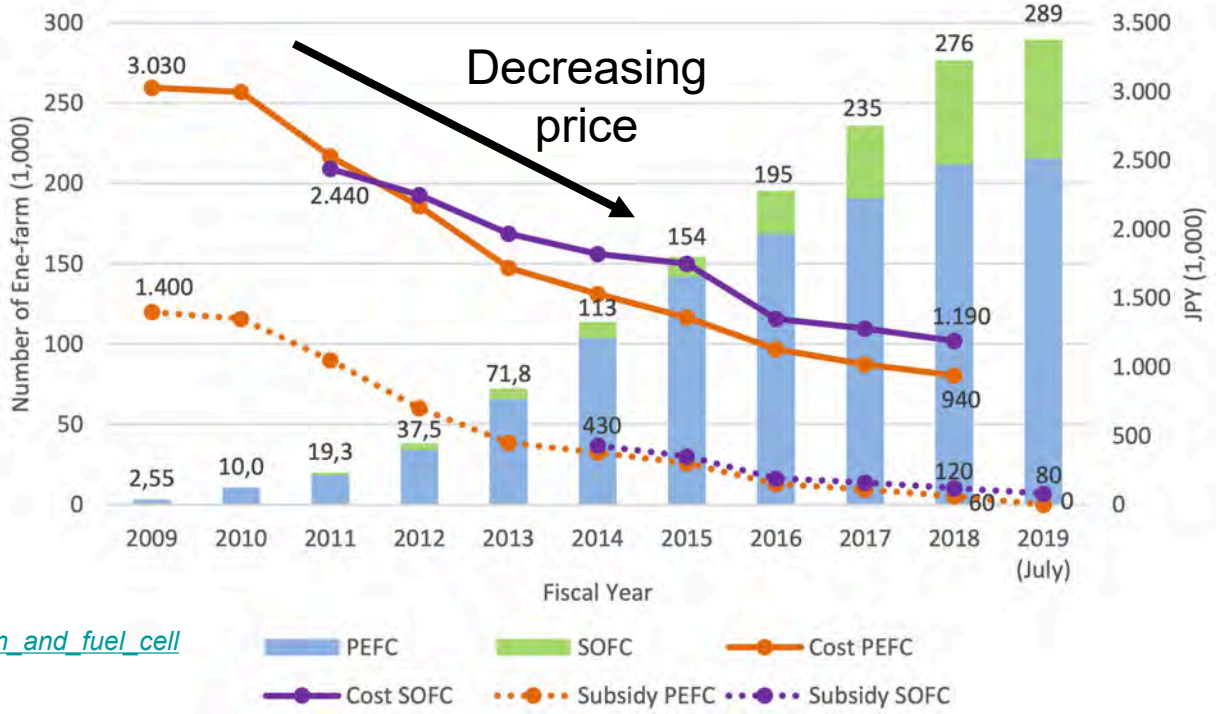




Over 320,000 units sold since 2008

Output of 700 W, with 95% efficiency

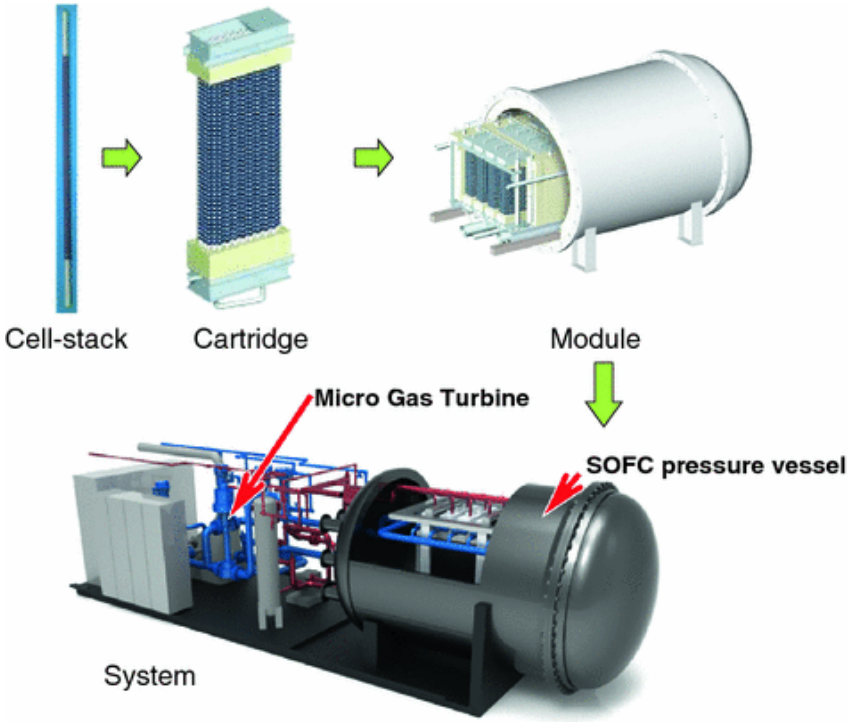
Price: ~800,000 JPY

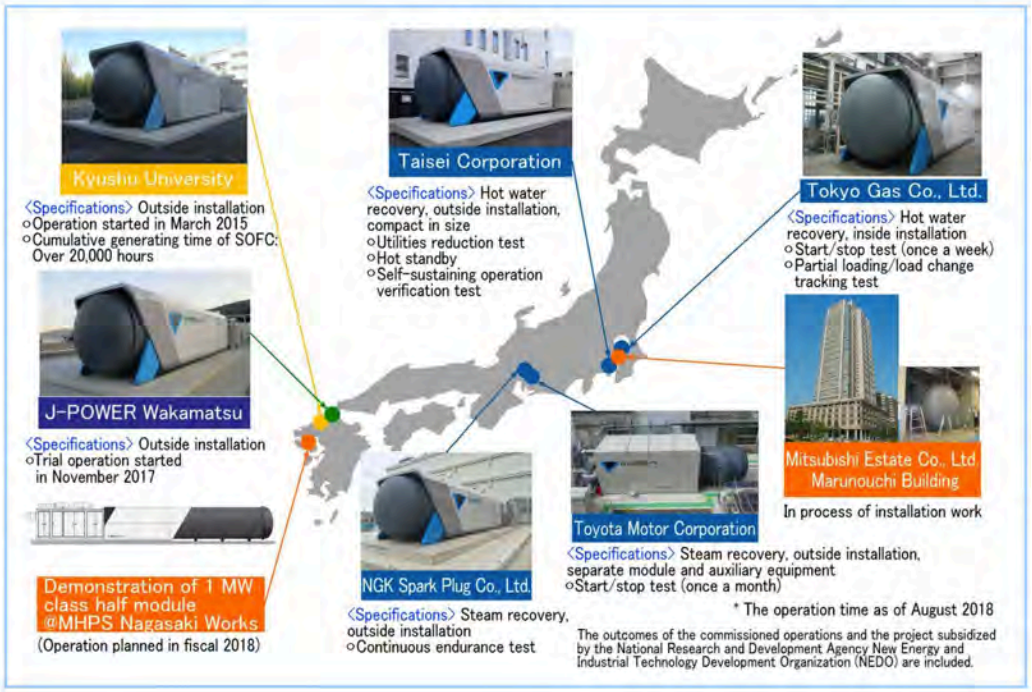


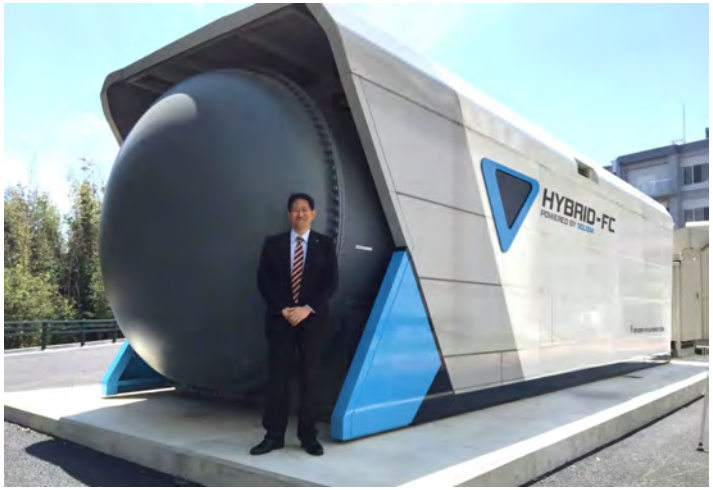
https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

Industrial Scale Stationary Fuel Cells

- 250 kW pressurized SOFC Micro Gas Turbine (800 ºC)
- Mitsubishi Hitachi Power Systems, Ltd.
- ~10 installed in Japan.

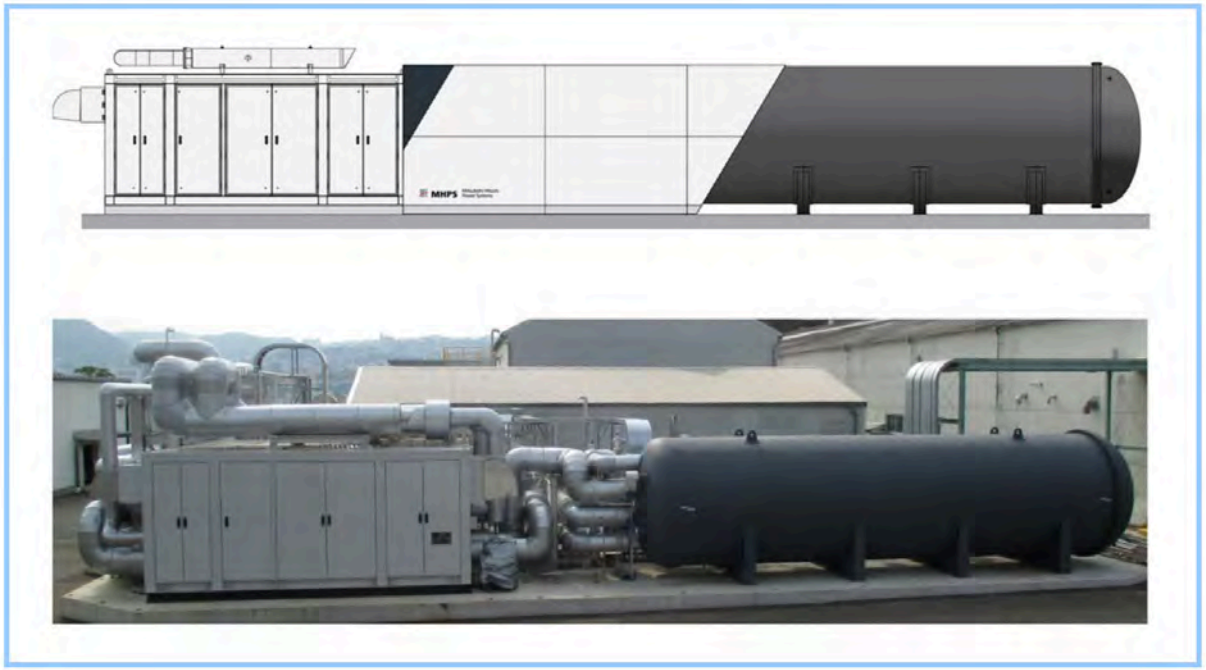






Industrial Scale Stationary Fuel Cells

1 MW Mitsubishi-Hitachi Prototype

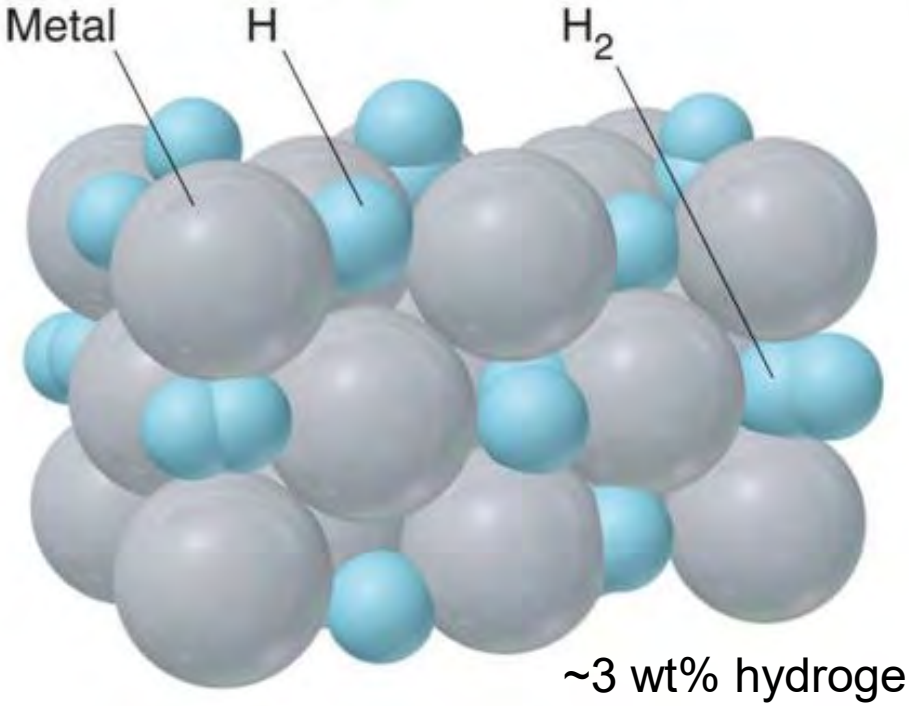


Many companies developing similar technologies:

Manu-facturer	Denso	Miura	Fuji Electric	Hitachi Zosen	MHPS	Bloom Energy
	Demostration model					Business model
Appearance						
Output	5 kW	5 kW	20 kW	50 kW	250 kW	200 kW

Early FCEV Prototypes

- In the 1990's, Japanese manufacturers took the lead in the development of fuel cell electric vehicles (FCEVs).
- These used metal hydrides to store hydrogen fuel. Later switched to compressed hydrogen tanks.



~3 wt% hydrogen

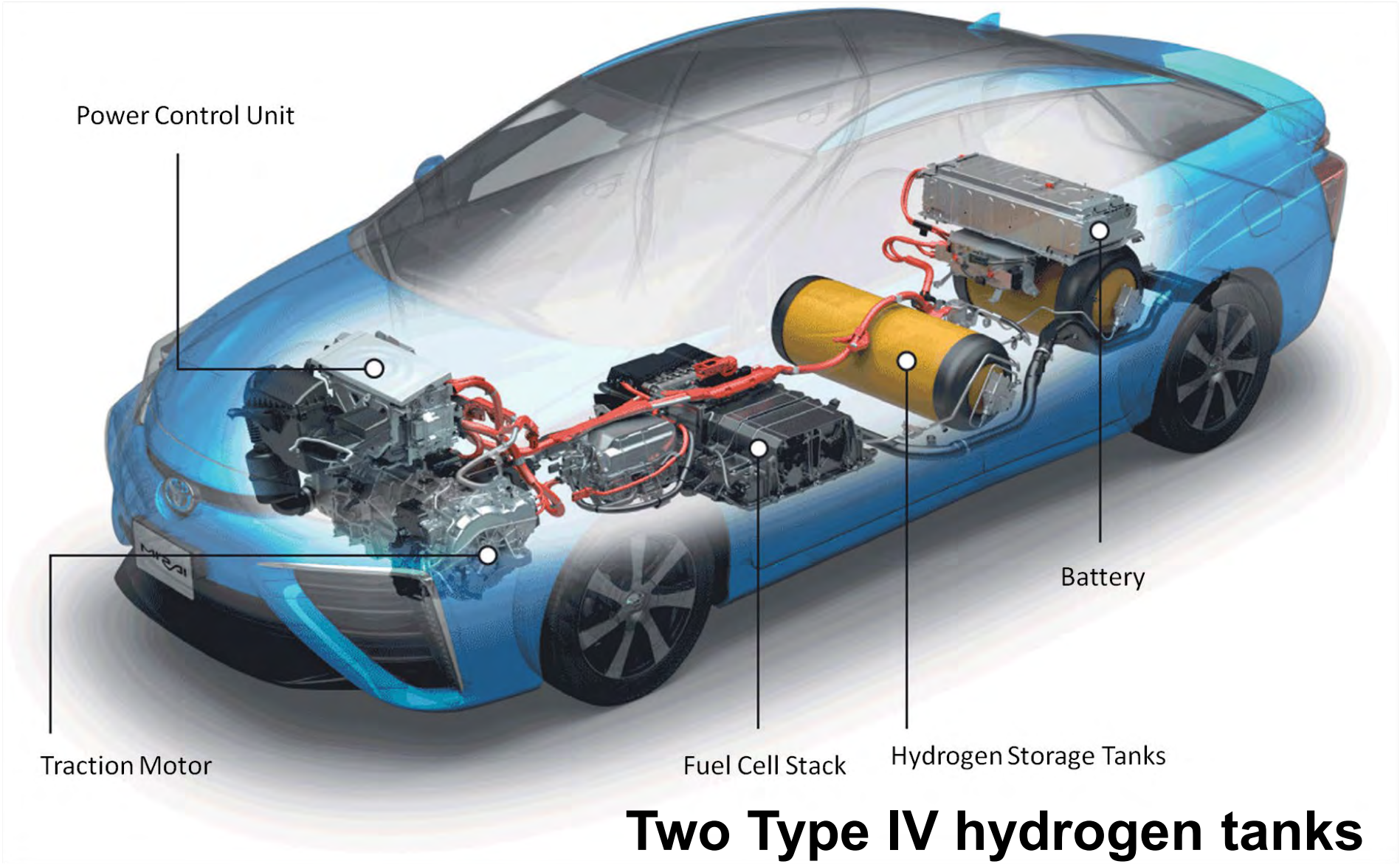
Fig. 4.26 Toyota FCHV-2 (*Source* Toyota Motor)

Fig. 4.27 Mazda Demio FCEV (*Source* Mazda Motor)

Fig. 4.28 Honda FCX-1 (*Source* Honda Motor)

First Commercially Available FCEV

Toyota MIRAI FCEV (2016)

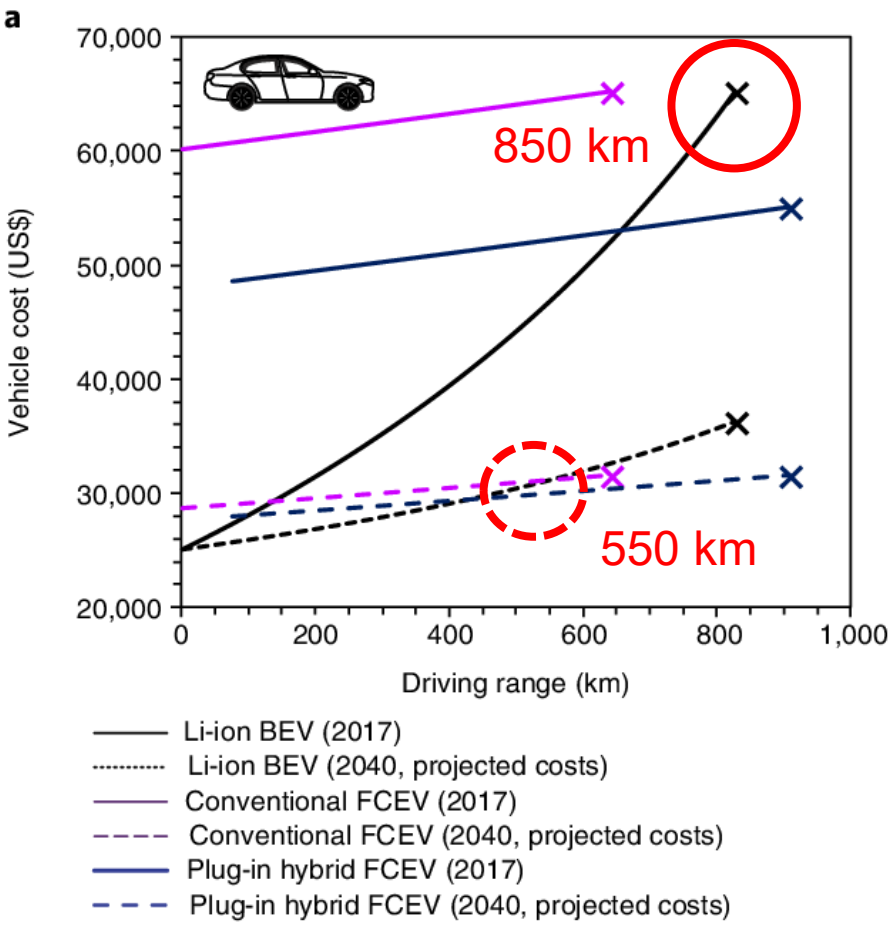


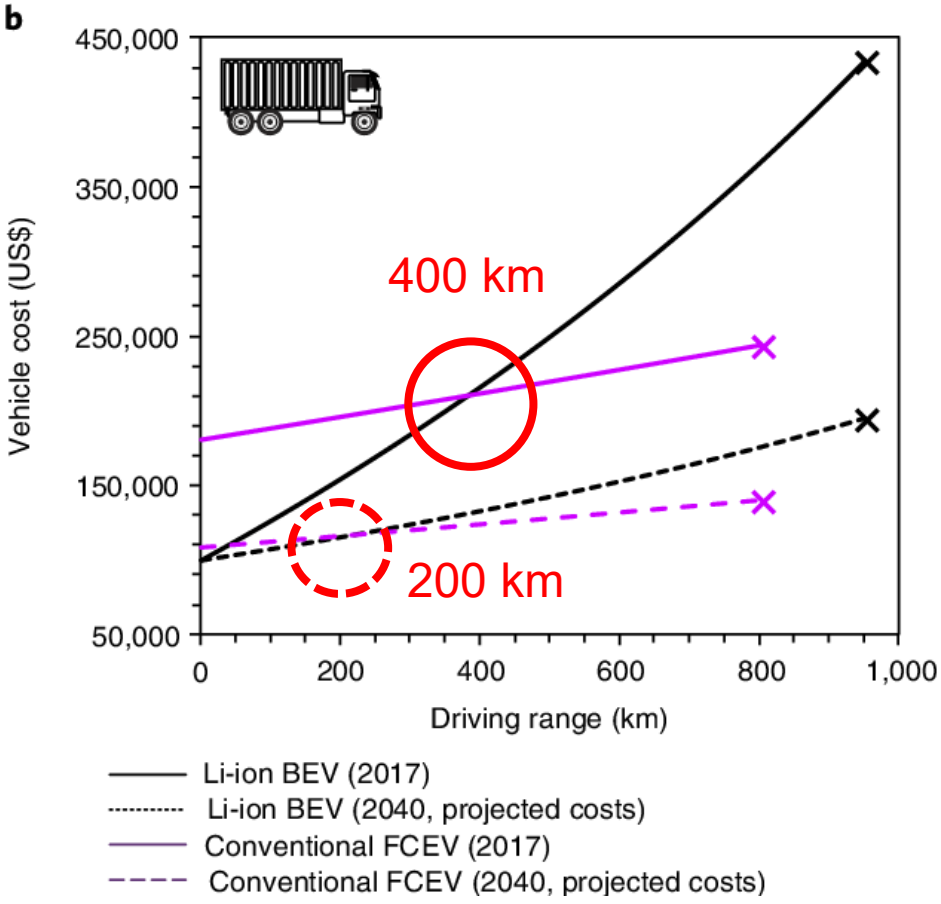
Two Type IV hydrogen tanks

2nd Generation Toyota MIRAI FCEV (2020)

- Nominal range is 650 km, but the record is 1360 km!
- Three Type IV compressed hydrogen tanks hold 6 kg H_2 at 70 MPa.
- The current price is around 60,000 EUR.

Comparison to Batteries





- For cars, the cost equivalence of FCEVs and BEVs is at ~850 km range.
- For trucks, this cost equivalence occurs at ~400 km range.
- In 2040 these numbers will be ~550 km and ~200 km, respectively.
- **Fuel cells better suited to long rang and/or large scale applications.**

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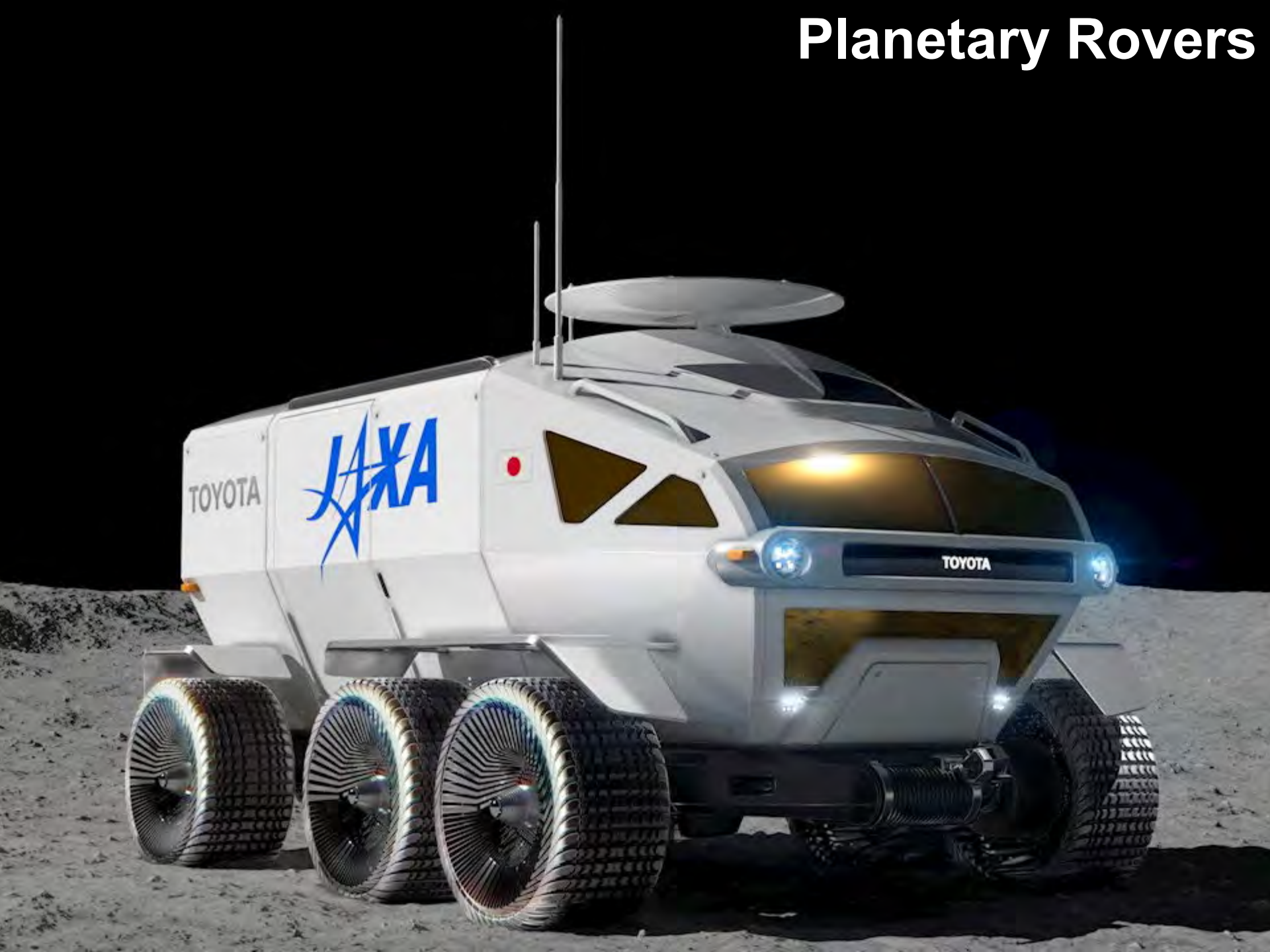
Diversity of Fuel Cells

FUEL CELL BUS
S-F141
H2 水素

Planetary Rovers



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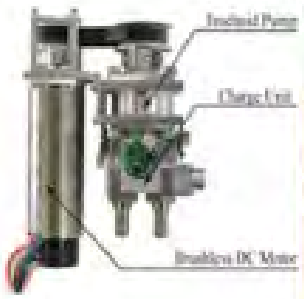
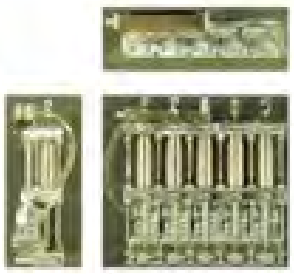
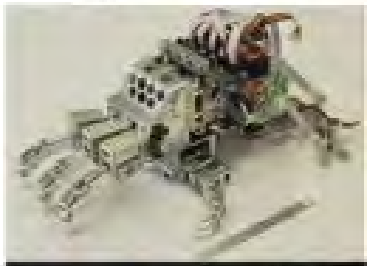
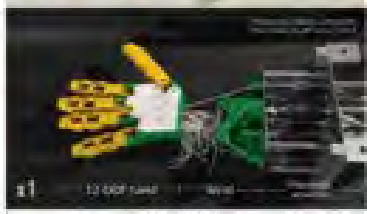
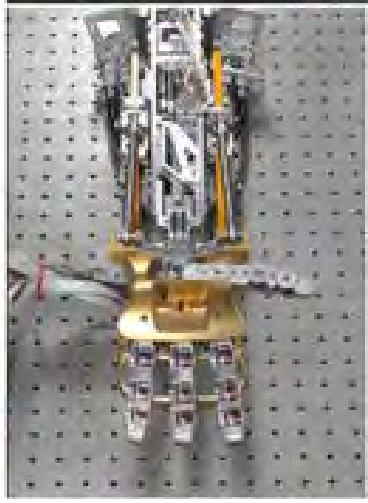
HYDRA-NEDO Humanoid Robot











https://roboticsnakamura.wordpress.com/personal/current-research-2016-1/

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Kyushu University Hydrogen Project

Hydrogen Town (>150 PEFCs)

HYDROGENIUS

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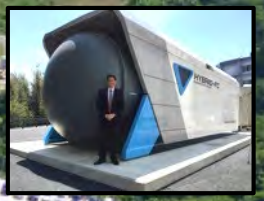
Q-PIT

INAMORI CENTER

NEXT-FC
Next-Generation Fuel Cell Research Center

International Research Center for Hydrogen Energy (HY30)



Graduates School of Integrated Frontier Sciences,Kyushu University
The Department of Automotive Science

Future Energy Demonstration Facility

Department of Hydrogen Energy Systems

HyTReC

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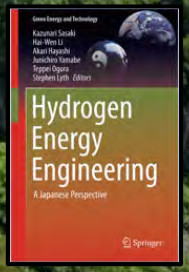
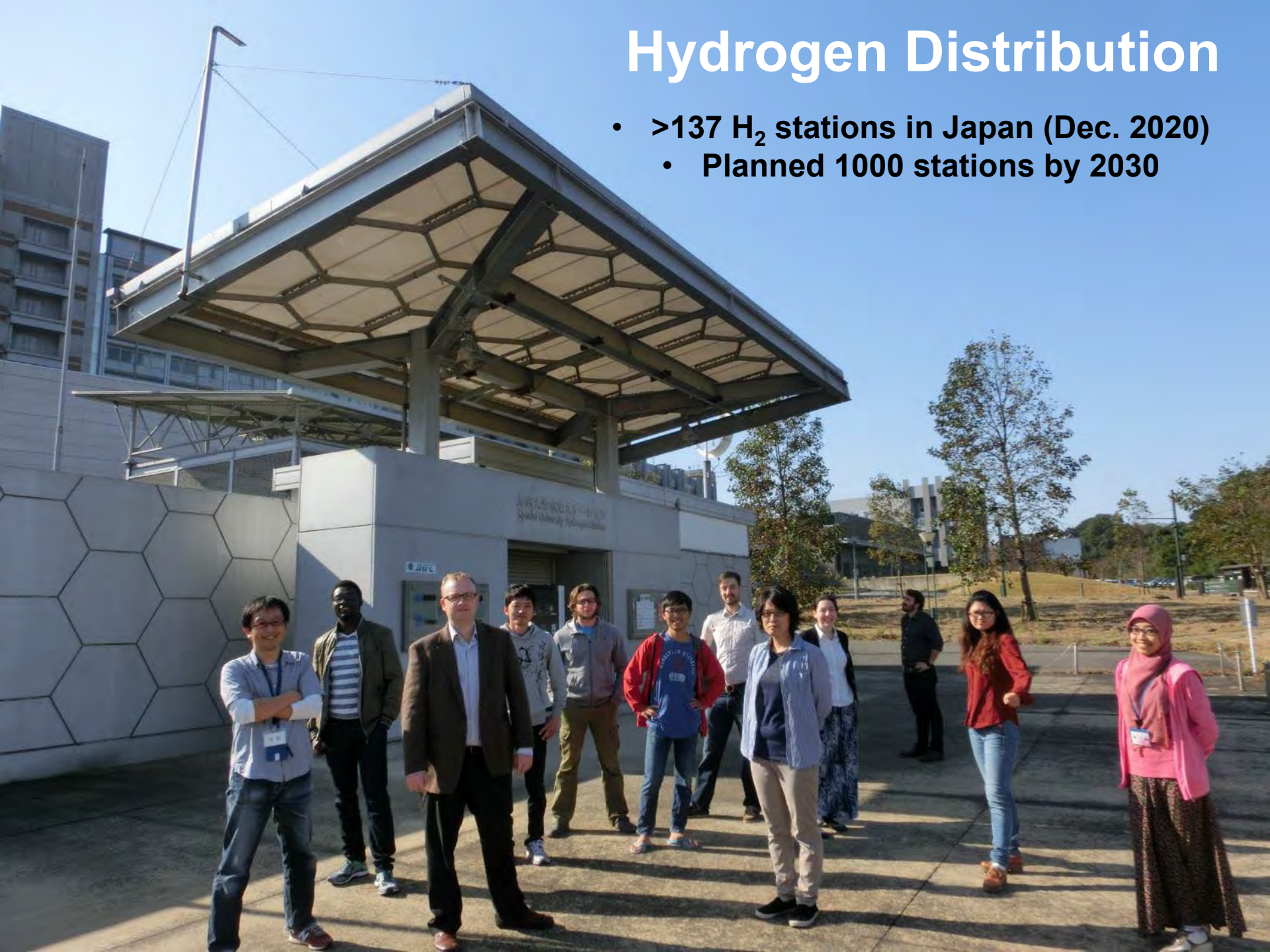
Energy Week 2020
Energy Intelligence Beyond Borders: Sharing Sustainable Energy Visions
[Mon] 27 Jan.– [Fri] 31 Jan., 2020
KYUSHU UNIVERSITY Ito Campus, Hospital Campus / Tosu SLRC / Denki Building KYOSOKAN



Hydrogen Distribution

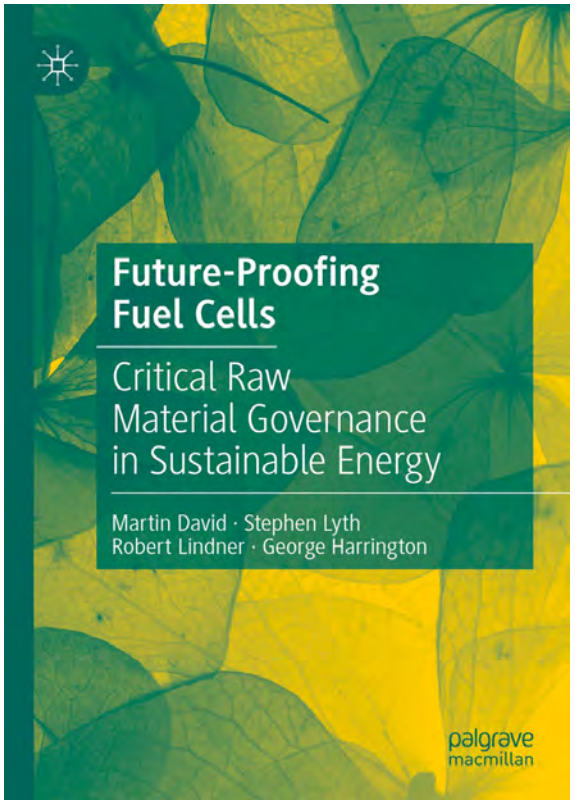
- >137 H_2 stations in Japan (Dec. 2020)
  - Planned 1000 stations by 2030



Platinum Demand for FCEVs

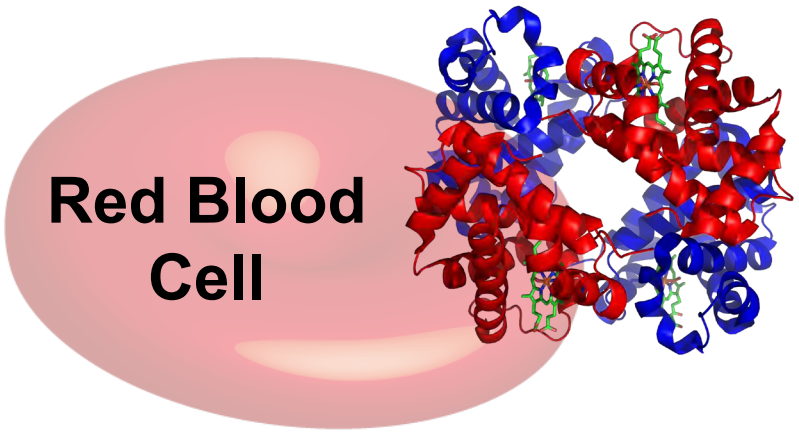
- Fuel cells require platinum catalysts, but platinum is a critical raw material.
- Around 190 tones of Pt is extracted annually (only 10,000 tons in history).

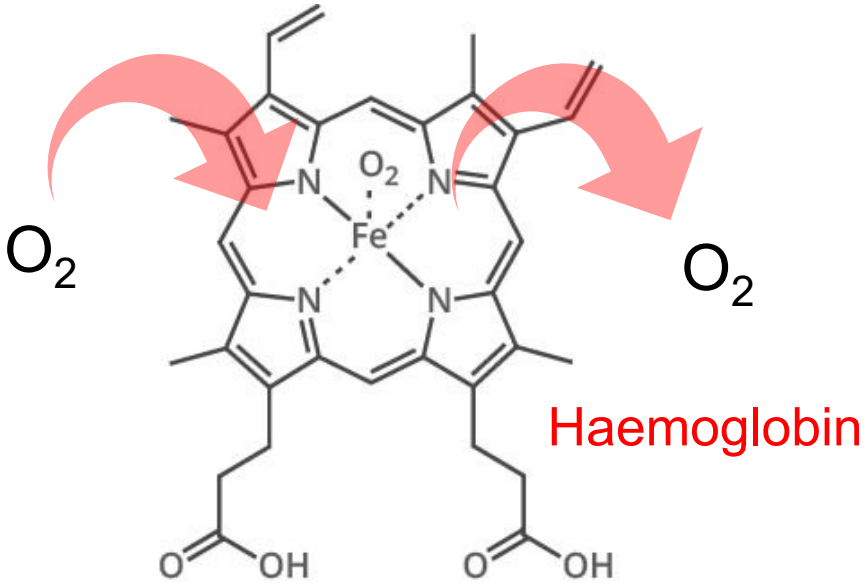
Equivalent Production Volume	Cumulative FCEVs (2019)	Cumulative BEVs (as of 2019)	Annual ICEs (2019)	Cumulative ICEs (as of 2019)
Number of FCEVs	25210	5 million	92 million	1.6 billion
Pt Required (tonnes)	0.756	150	2760	18,000
% of annual production (190 tonnes)	0.4	79	1453	9474
Time to extract Pt	1.5 days	284 days	14.5 years	95 years



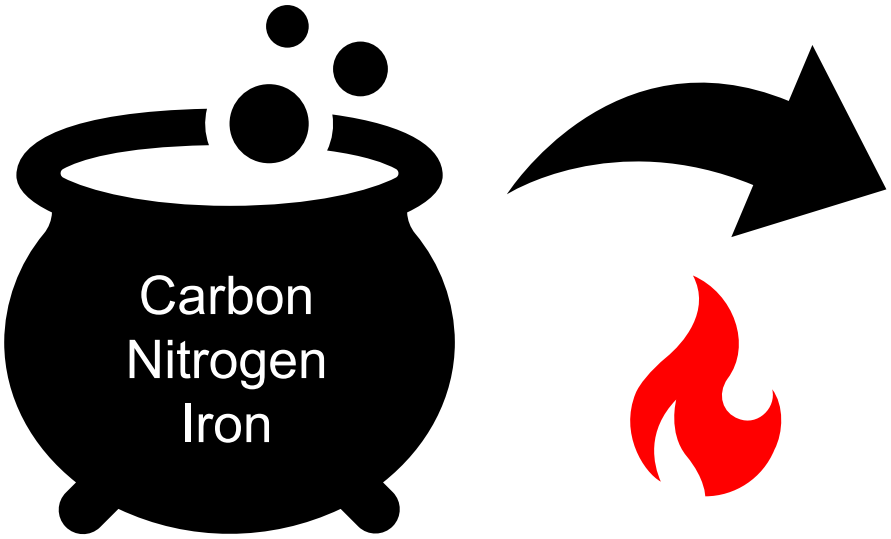
- Matching BEV units manufactured to date would require **150 tons** of Pt.
- Replacing every ICE vehicle would require **~18,000 tons** of platinum.
- This does not take into account other important applications.

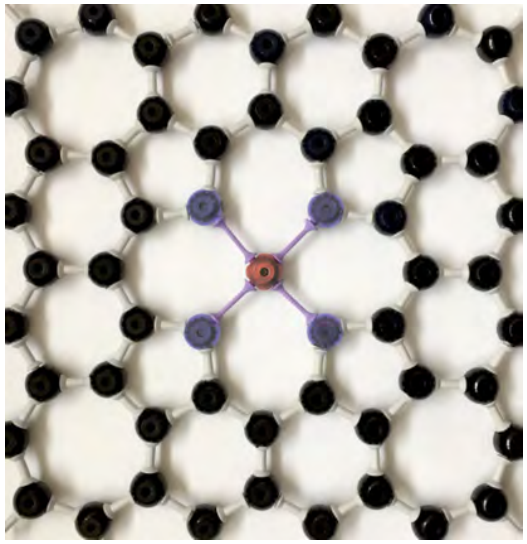
Platinum-free Electrocatalysts





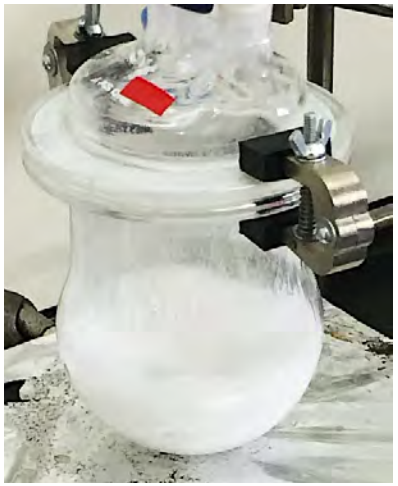
$Hgb\ (Fe^{2+}) \leftrightarrow Hgb\ (Fe^{3+})$





KYUSHU UNIVERSITY

Synthesis of Nitrogen-doped Carbon



Ethanol + Triethanolamine + Sodium

STP
24h
→

Sodium Alkoxide

900ºC
2h
→

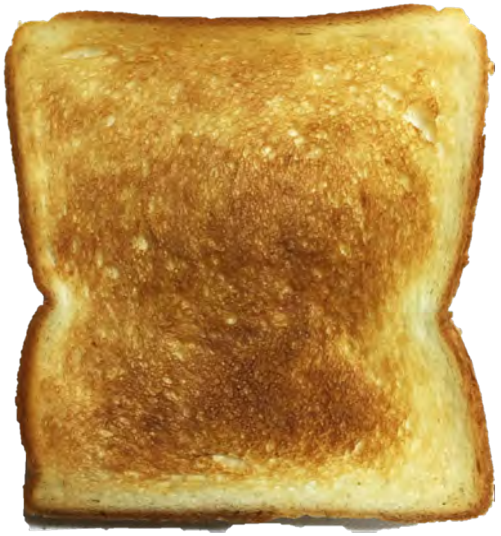
Nitrogen-doped Carbon Foam

Four + Water + Yeast

Mix
→

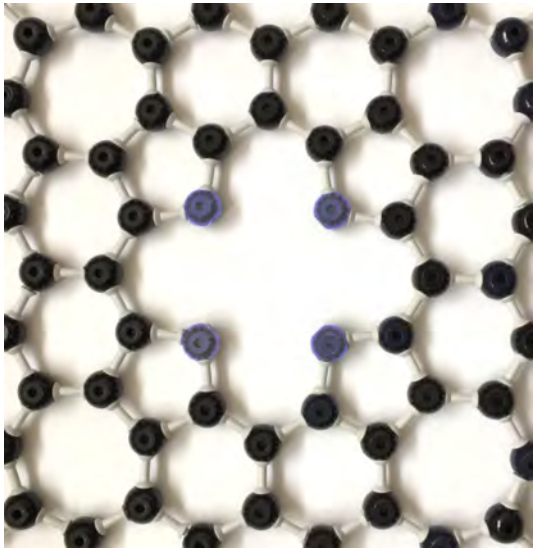
Dough

180ºC
1 h
→



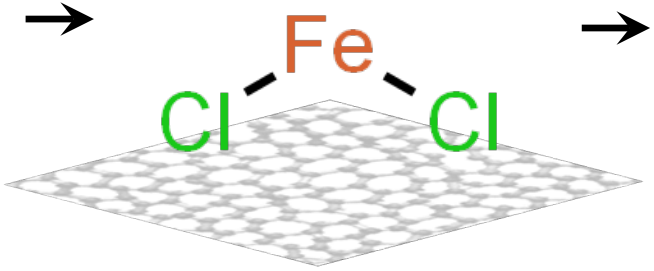
Bread (Toast)

Metal Decoration of N-doped Carbon



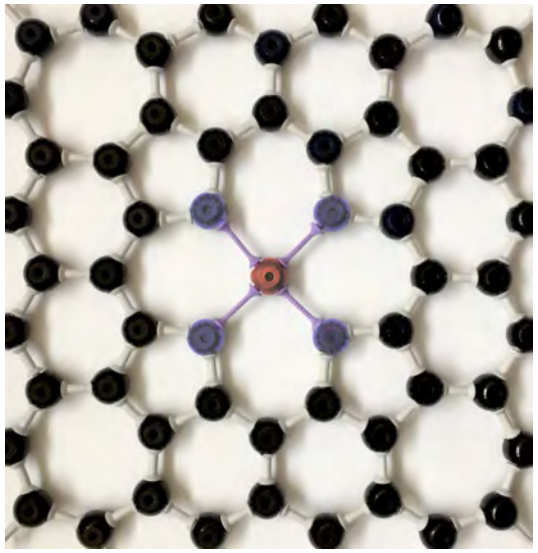
Water + Iron Chloride + Nitrogen-doped Carbon

Dry →



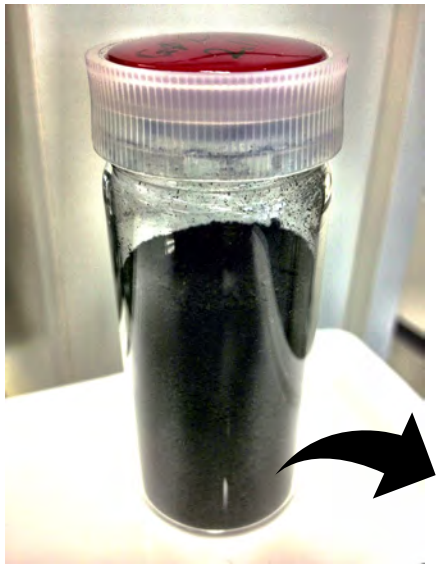
Iron Chloride + Nitrogen-doped Carbon

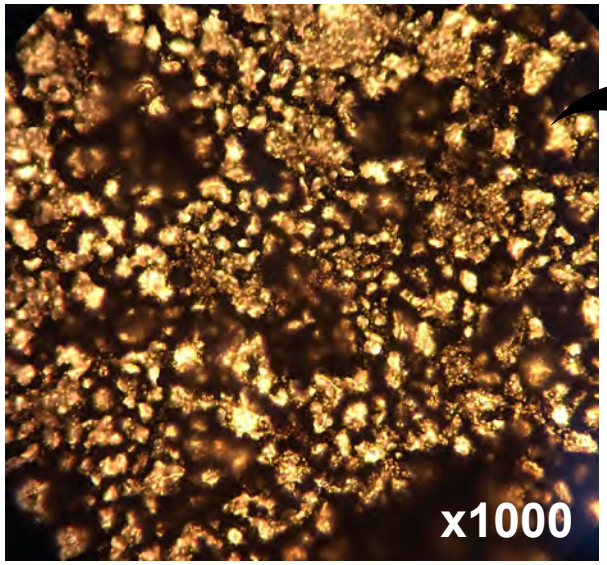
Heat →

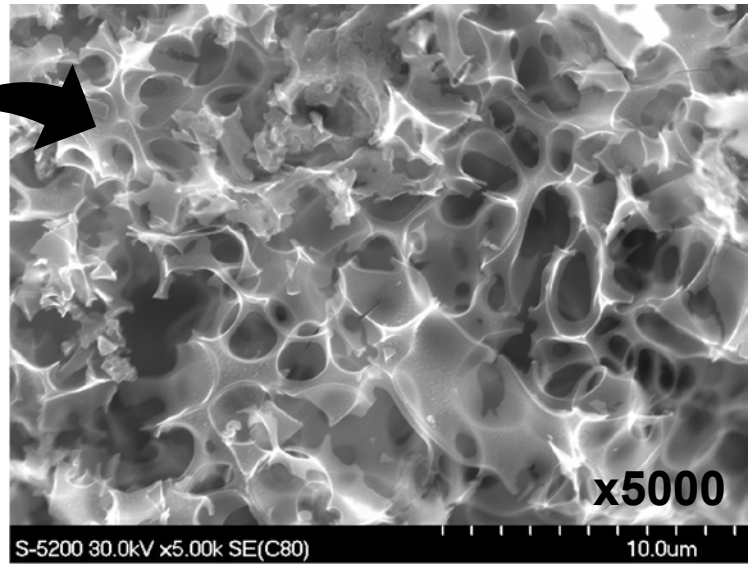


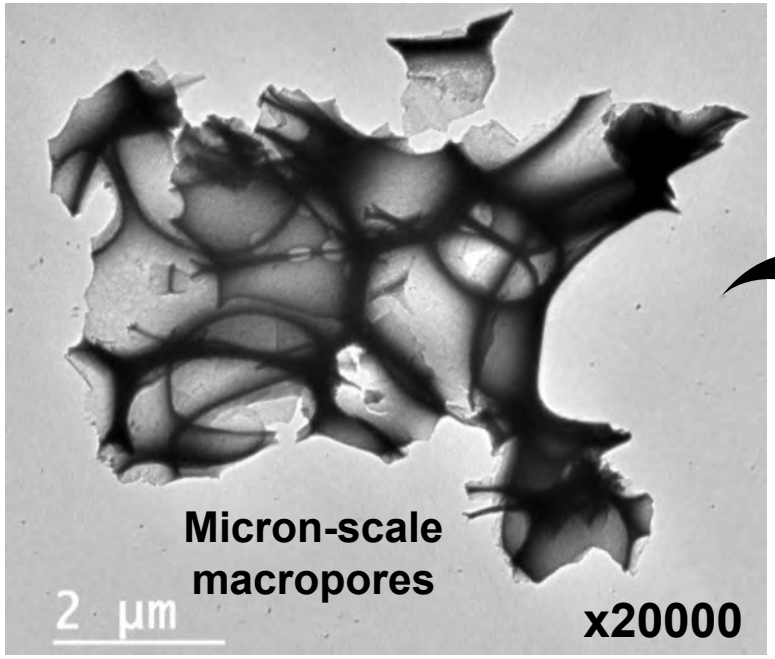
Fe-N-C Catalyst

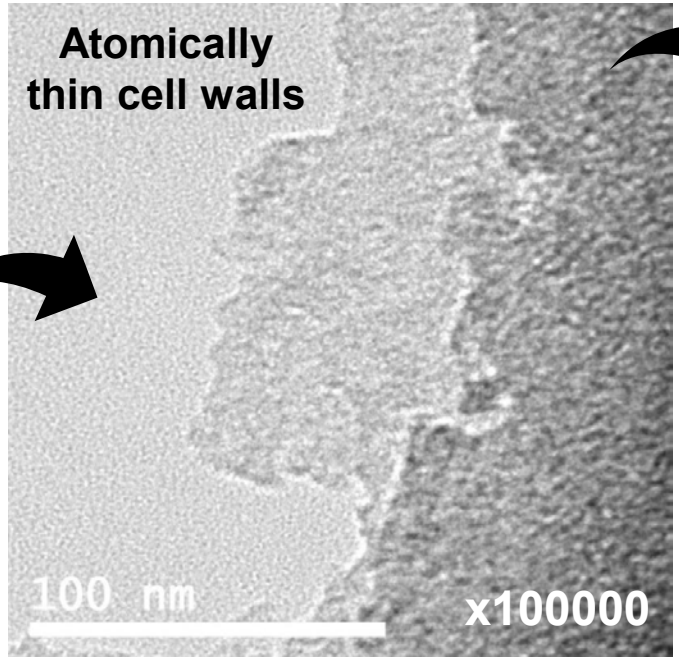
Microstructure of the Support

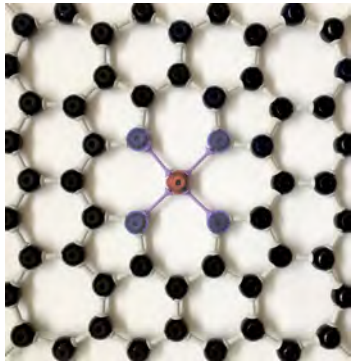






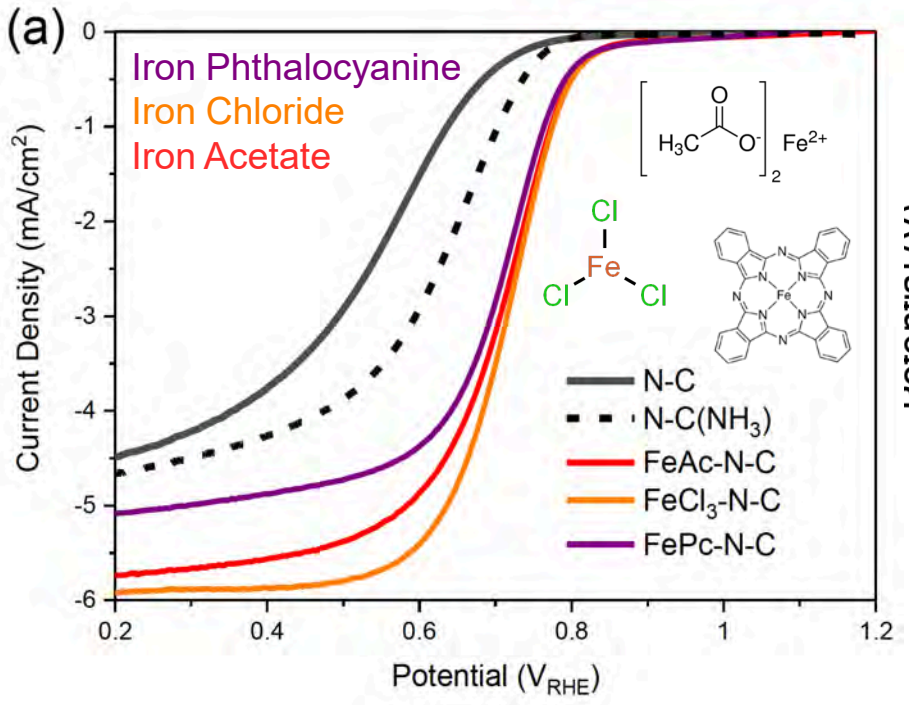


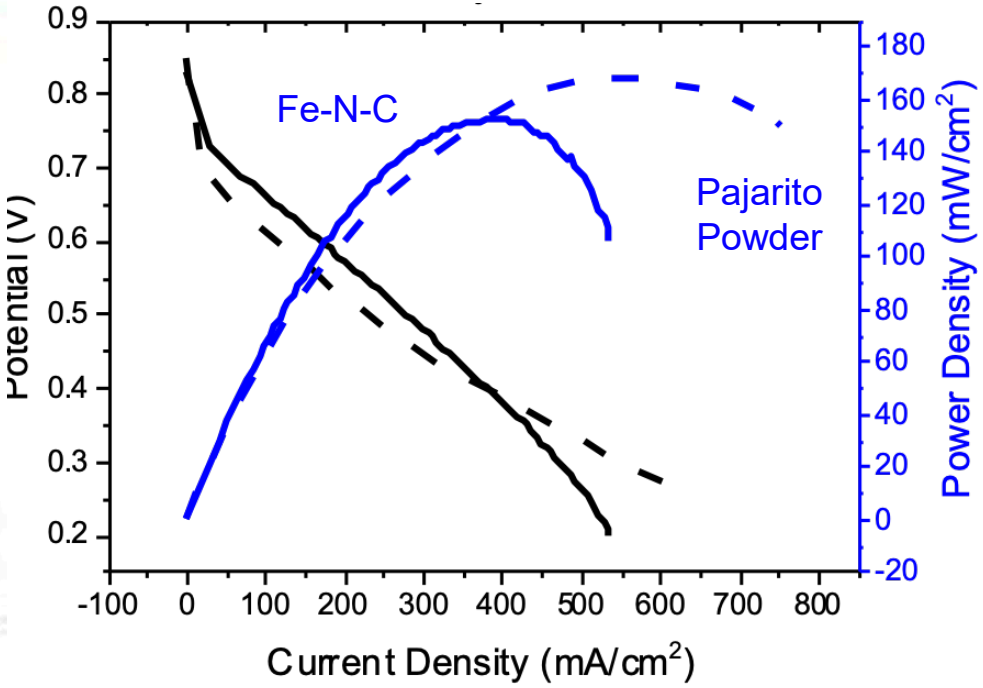




Very large
surface area

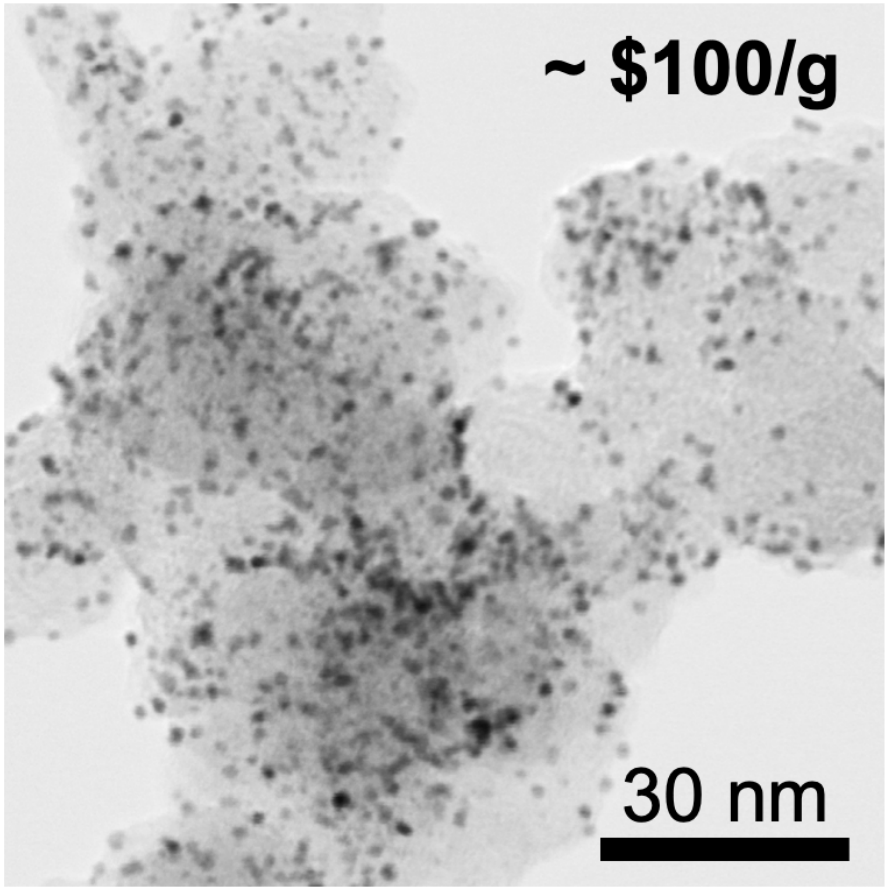
Platinum-free Electrocatalysts

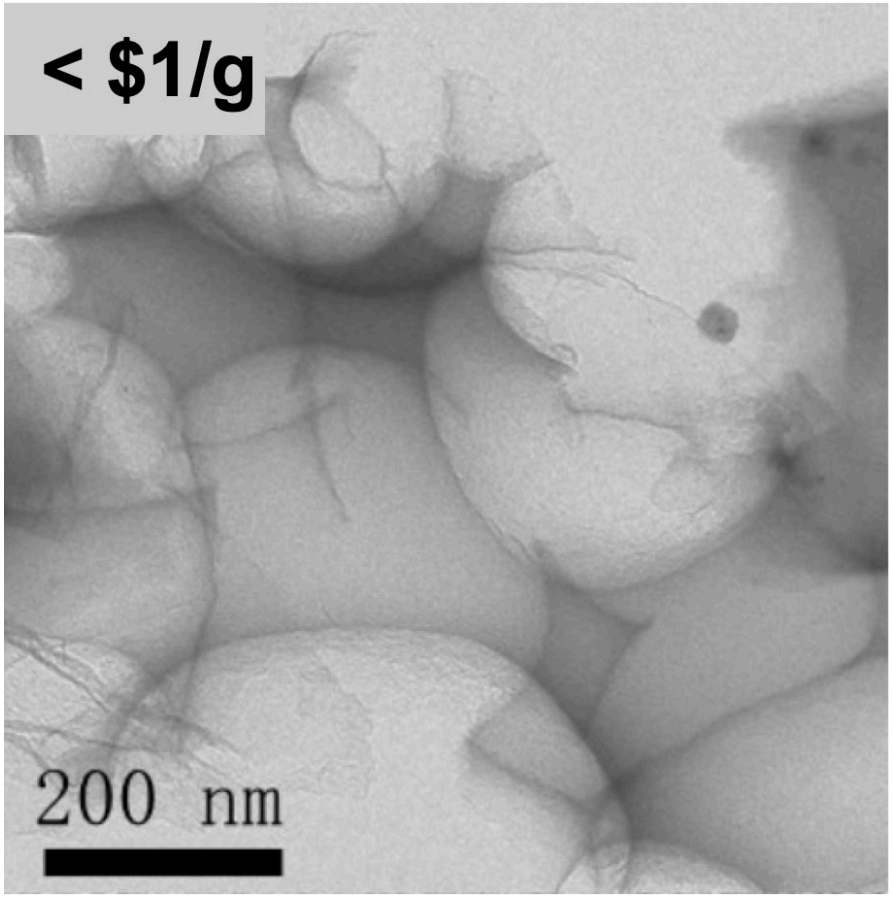




- Investigation of different iron sources on the oxygen reduction activity.
- Differences due to porosity induced in the nitrogen-doped carbon support.
- Fuel cell performance similar to commercially developed Fe-N-C catalyst.
- Advantage is low cost – still much work needed to compete with performance of platinum in real-world hydrogen fuel cell applications.

1. Gram-Scale Synthesis of Alkoxide-Derived Nitrogen-Doped Carbon Foam as a Support for Fe-N-C Electrocatalysts, Nanotechnology 31, 225401 (2020)
2. Durability of Template-Free Fe-N-C Foams for the Oxygen Reduction Reaction in Alkaline Solution, Journal of Power Sources, 375, 244-254 (2018)
*3. Identification of Catalytic Sites in Co-N-C Materials for Oxygen and Hydrogen Electrochemical Reactions, **Nature Communications**, 8, 959 (2017)*



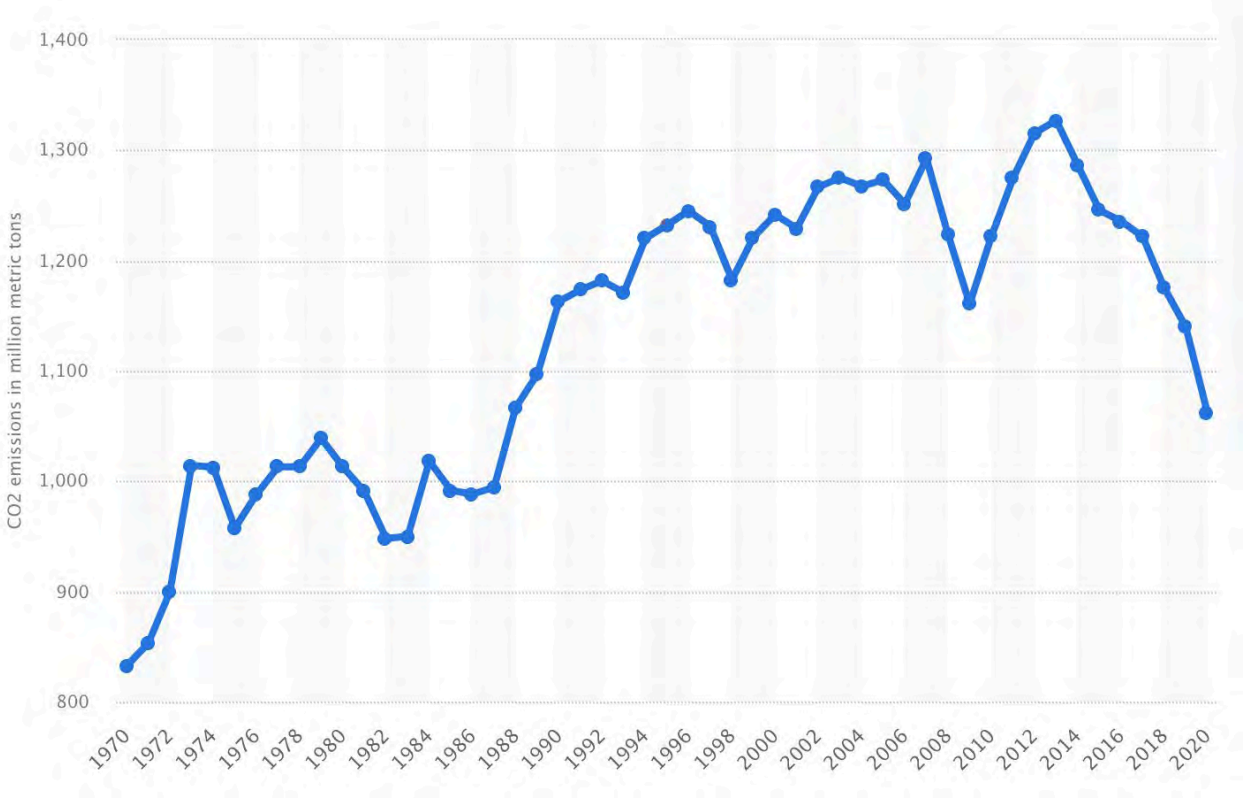


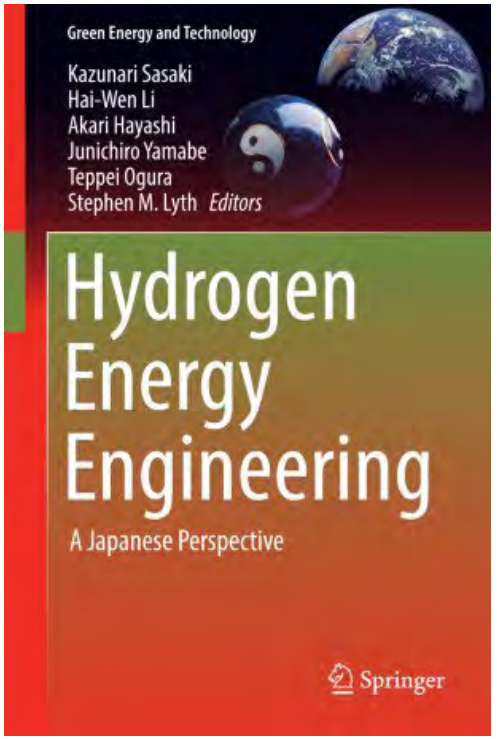
Platinum-decorated carbon black (Pt/C) electrocatalysts are very expensive.

Iron-decorated nitrogen-doped carbon foam (Fe-N-C) is a cheaper alternative.

Thank you for your attention.

CO_2 emissions in Japan since 1970





lyth@kyudai.jp

Bumps on the road to hydrogen mobility:

Experiences from Japan, California and Germany

Carbon Neutral Society Action Month 20 May 2022

Assoc. Prof. Gregory Trencher

Kyoto University: Graduate School of Global Environmental Studies

INTRODUCTION

WHY FUEL-CELL VEHICLES (FCEVs)?

A ’battle is occurring between battery electric vehicles (BEVs) and fuel-cell electric vehicles (FCEVs) (De Kaa 2017)

Numerous countries are pursuing electrification via both technologies:

- **Asia:** Japan, Korea, China
- **USA:** California, New England
- **Europe:** Germany, England, France

But in 2021, global on road-vehicle numbers:

BEVs: 11,000,000

FCEVs: 40,000

International Energy Agency (2021)

LEADING MARKETS

In all markets, BEV sales are dwarfing FCEVs

However, interest in passenger FCEVs remains high:

- Suitability for larger platforms (SUVs etc)
- Reduce costs for heavy-duty market via economies of scale in part production
  e.g. fuel cell stacks, tanks, refuelling stations
- Fewer land requirements for infrastructure compared to BEV charging
- Attractive ZEV solution for users unable to install home chargers
  => e.g. in rental properties, multi-family apartments
- Attractive driving ranges and refuelling times
  => Potential to increase driving range with more tanks and higher fuel-cell efficiency
- Less reliance on precious raw materials (cobalt, lithium, copper etc.)

LEADING MARKETS

California, Japan and Germany are three leading markets for:

- Testing and developing FCEVs
- Vehicle adoption
- Installation of refuelling stations

Japan's situation

- Two car makers serially producing FCEVs: Toyota and Honda
- Long history of R&D in fuel cells (stationary and mobile)
- FCEVs are a key part of road electrification strategy

LEADING MARKETS

Half of global market

	March 2022				2030 target		
	Japan*	**California**	**Germany**	**Global**	**Japan**	**California**	**Germany**
FCEVs (on-road)	~6,900	~9,650	~1,500	~42,000	800,000	1,000,000	n/a
FC buses (on-road)	104	54	70	~600	1200	≥25% of all zero-emission buses	n/a
Refuelling stations (operating retail)	159*	52	91	~530	1,000	1,000	n/a
FCEV to station ratio	43 : 1	185 : 1	16 : 1	79 : 1	800 : 1	1,000 : 1	n/a

California's stations are heavily used. Japan and Germany underused

* Includes truck-based mobile stations

Sources

Japan: Data for FCEVs and refuelling stations from industry correspondence, obtained for February and March 2022 respectively. Data for fuel-cell buses from METI (2021) with figures for March 2021**; Germany:** Website of National Organisation Hydrogen and Fuel Cell Technology (NOW) accessed March 2022; California: CEC & CARB (2021) with figures for December 2021; **Global:** IEA (2022) with figures for June 2021.

INTRODUCTION

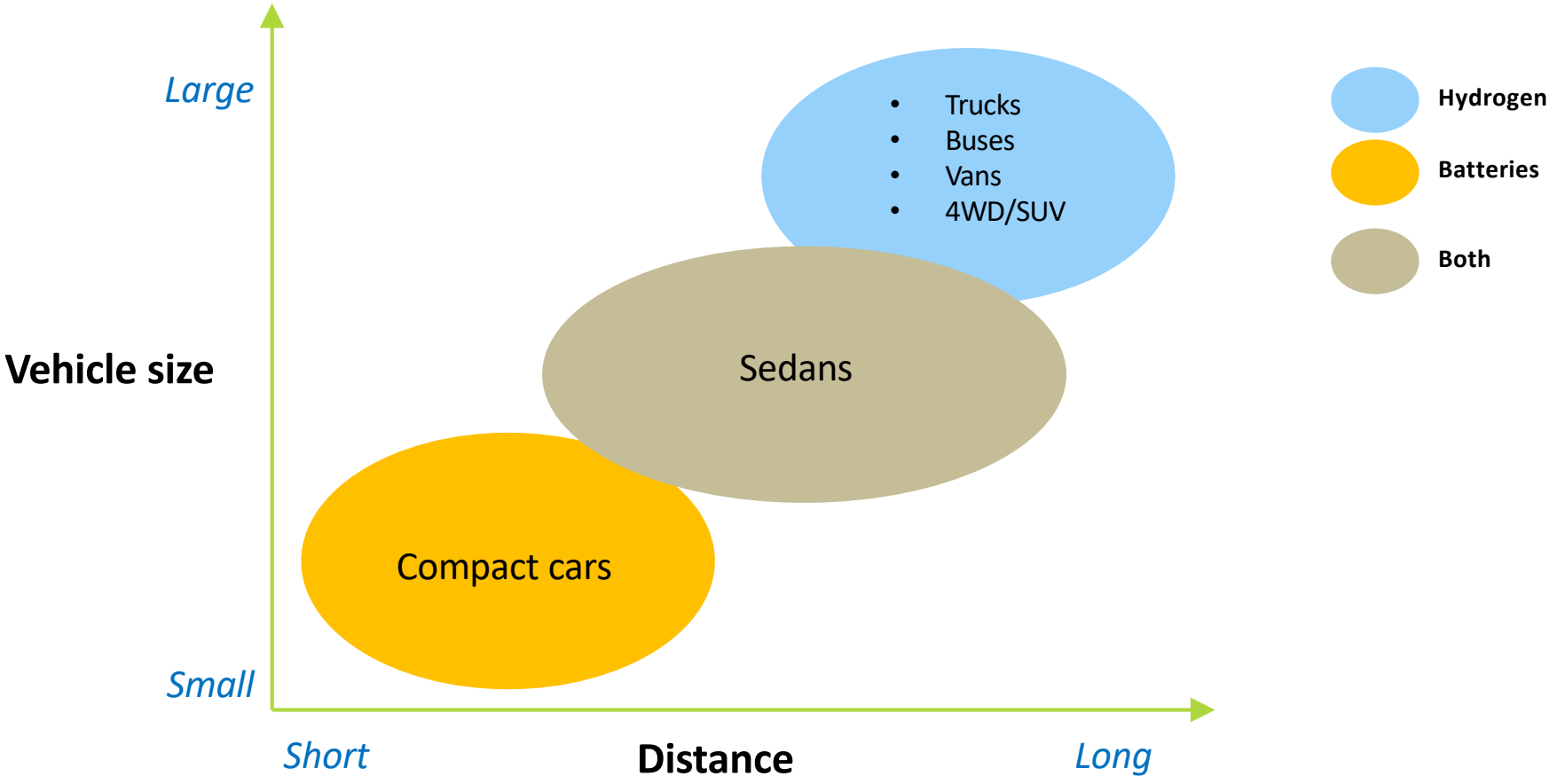
FUELLING STATION IN TOKYO

https://clicccar.com/2015/04/23/304336/

INTRODUCTION

FUEL CELL BUS AT TOKYO STATION

APPLICATION OF EACH TECHNOLOGY: TRADITIONAL VIEW



PROGRESS IN BEV MOBILITY

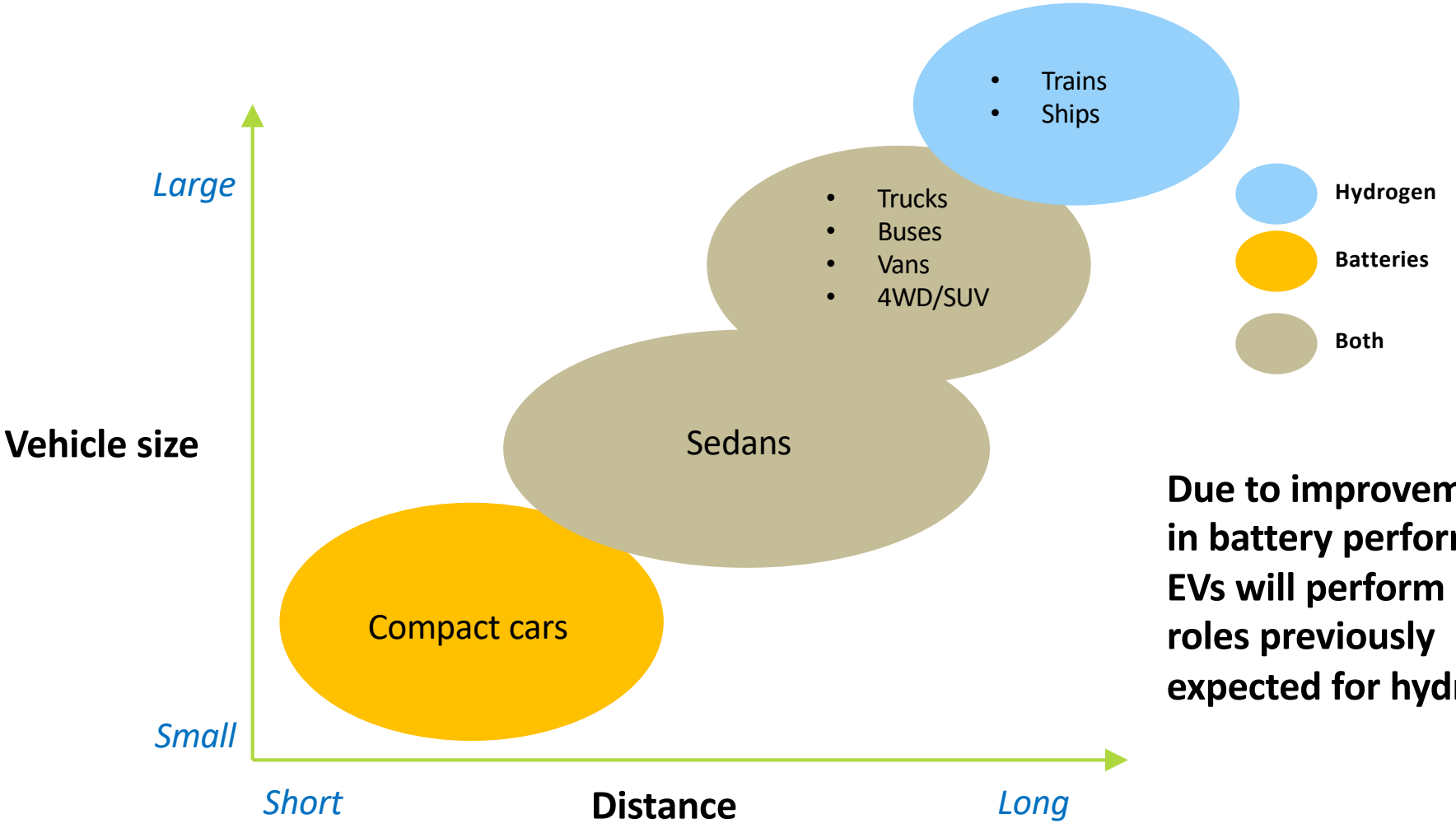
https://www.electricmotornews.com/gb/eventi/autobus-elettrici-articolati-byd-norvegia/

Battery electric bus (BYD) in Europe

https://robbreport.com/motors/cars/ford-f-150-lightning-everything-we-know-1234614318/

BEV pick-up truck (Ford) in USA

APPLICATION OF EACH TECHNOLOGY: NEW VIEW



Due to improvements in battery performance, EVs will perform many roles previously expected for hydrogen

DIFFUSION BARRIERS

BARRIERS RELATED TO VEHICLE PRODUCTION

How to increase the supply of FCEVs?

How to accelerate technological progress?

How to lower costs?

SUPPLY-SIDE: SUPPORTING STRATEGIES

Germany and Japan	Stimulating effect on FCEV production
State support for R&D	Uncertain
Testing and knowledge sharing platforms mediated by government	Uncertain

Japan	Stimulating effect on FCEV production
Sharing of patents and supply of fuel cell and tank systems by Toyota	Uncertain

California	Stimulating effect on FCEV production
Regulation: Forced minimum production of ZEVs *=> FCEVs receive high credits from driving range and travelling provision*	Certain

SUPPLY-SIDE: SITUATION

FCEV production is still limited, insufficient to drive market growth

Japan: ~7,000 in circulation against government target of 40,000

=> Only Toyota producing. Honda suspended FCEV production.

Germany: Local automakers not currently producing

=> Overall, automakers focusing ZEV portfolios on BEVs

=> But BMW *iX5* expected in 2022

Barriers for automakers

- **Cost:** Technological difficulty of mass-producing fuel cells and fuel tanks at low-cost
- **Infrastructure:** Limited availability prevents the ability to produce in volume
- **Time:** Setting up part supply chains requires several years

These barriers are lower in the BEV market

INFRASTRUCTURE BARRIERS

How to build a fleet of refuelling stations at low-cost?

REFUELLING STATIONS: SUPPORT POLICIES

Construction subsidies	Strategy
Germany	Government subsidies ~50% of construction costs
Japan	Same
California	Same

Operation support	Strategy
Germany	• None
Japan	• Subsidies from national/local government • Revenue via JHyM platform
California	Revenue via market mechanisms: • Low Carbon Fuel Standard (carbon credits from fuel sales) • Capacity payments to larger stations

OEMs and government provide revenue support

Market mechanisms provide revenue

REFUELLING STATIONS: BARRIERS

Germany and Japan

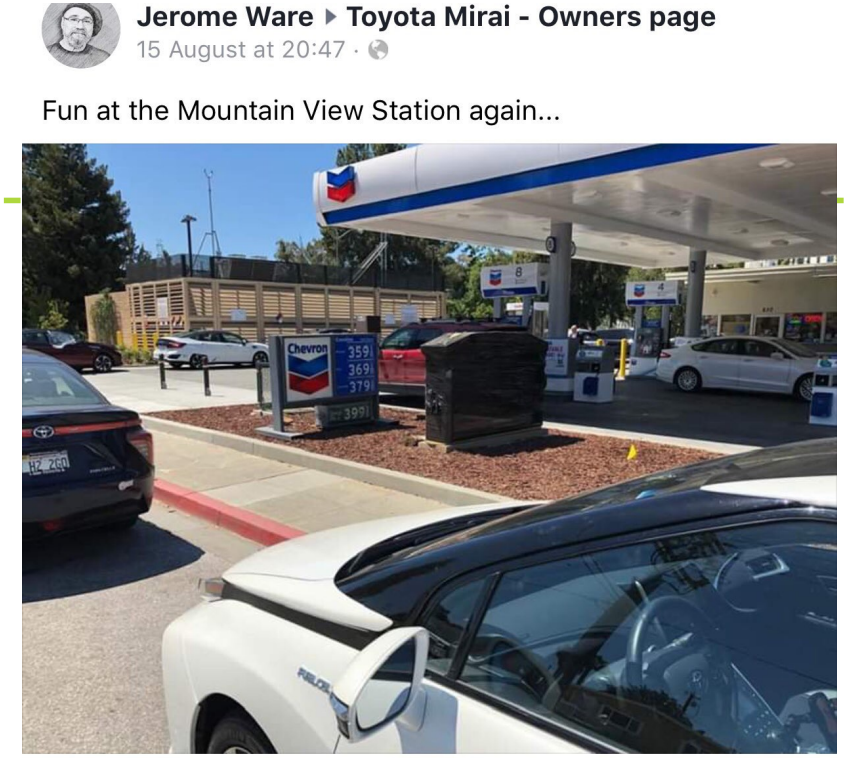
Underused stations due to low vehicle to station ratio

- Japan = 43:1
- Germany and 16:1

"The business case is a nightmare"
(Stakeholder in Germany)

California

- **Overused** stations (and breakdowns) due to high vehicle to station ratio



https://cafcp.org/stationmap

REFUELLING STATIONS: BARRIERS

Inconvenience in refuelling station network is:

- Damaging public reputation of technology
- Causing some drivers to abandon the technology (reported in California and Japan)
- Constraining FCEV production ambitions from OEMs

ADOPTION BARRIERS

How to encourage drivers to buy FCEVs?

ADOPTION: BARRIERS

Consumer subsidies	Explanation
Germany	National government: • Private buyers: EUR 7,500 • Fleet buyers: Up to 80% of cost difference
Japan	**National subsidy (~$18,000)** Local subsidy (Tokyo ~$8,500)
California	State government (~$4500) *inc. for leases

Big subsidies but no ownership incentives

Other	Explanation
Germany	Tax waivers (motor vehicle tax)
Japan	Tax waivers (stamp duty etc.)
California	• **Free fuel from OEMs (3-years or $15,000)** • Free use of carpool lanes (HOV decal) • Lease arrangements to decrease ownership cost

Small subsidy but big ownership incentives

ADOPTION: BARRIERS

All markets

Running costs (from fuel) are much higher than BEVs. The incentive to buy is low

Germany and Japan

Most FCEVs bought by corporations (companies, municipalities)

"I cannot remember seeing one private fuel cell car in Germany"
(Stakeholder in Germany)

"If consumers are not seeing them on the streets, why would they go and buy one?"
(Stakeholder in California)

"What is missing is the fuel cell Tesla. Without Tesla, I don't think there would be hype with BEVs" (Stakeholder in Germany)

SUMMARY

SUMMARY

KEY MESSAGES

All markets

Speed of FCEV rollout behind initial expectations, with BEVs racing into market

Main reasons

- Low supply of FCEVs
- High cost or making/purchasing
- Limited refuelling infrastructure

Positive signs

- Hyundai FCEVs entering Japan
- Honda will re-enter market
- All three markets expanding refuelling infrastructure

www.japantimes.co.jp

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Article

Drivers and Barriers to the Adoption of Fuel Cell Passenger Vehicles and Buses in Germany

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* Correspondence: g-trencher@tohoku.ac.jp

Abstract: As policymakers and automotive stakeholders around the world seek to accelerate the electrification of road transport with hydrogen, this study focuses on the experiences of Germany, a world leader in fuel cell technology. Specifically, it identifies and compares the drivers and barriers influencing the production and market penetration of privately-owned fuel cell electric passenger vehicles (FCEVs) and fuel cell electric buses (FCEBs) in public transit fleets. Using original data collected via a survey and 17 interviews, we elicited the opinions of experts to examine opportunities and obstacles in Germany from four perspectives: (i) the supply of vehicles (ii) refuelling infrastructure, (iii) demand for vehicles, and (iv) cross-cutting institutional issues. Findings indicate that despite multiple drivers, there are significant challenges hampering the growth of the hydrogen mobility market. Several are more pronounced in the passenger FCEV market. These include the supply and cost of production, the lack of German automakers producing FCEVs, the profitability and availability of refuelling stations, and low demand for vehicles. In light of these findings, we extract implications for international policymakers and future studies. This study provides a timely update on efforts to spur the deployment of hydrogen mobility in Germany and addresses the underrepresentation of studies examining both buses and passenger vehicles in tandem.

Keywords: fuel cell electric vehicles; hydrogen; battery electric vehicles; Germany; barriers; drivers; policy

check for updates

Citation: Trencher, G.; Edianto, A. Drivers and Barriers to the Adoption of Fuel Cell Passenger Vehicles and Buses in Germany. *Energies* **2021**, *14*, 833. https://doi.org/10.3390/en14040833

1. Introduction

Open access

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journal homepage: www.elsevier.com/locate/egyr

ELSEVIER

Strategies to accelerate the production and diffusion of fuel cell electric vehicles: Experiences from California

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ABSTRACT

Fuel cell electric vehicles (FCEVs) can play a key role in accelerating the electrification of road transport. Specifically, they offer longer driving ranges and shorter refuelling times relative to Battery Electric Vehicles (BEVs) while reducing needs for space-intensive public charging infrastructure. Although the maturity and market penetration of hydrogen is currently trailing batteries, transport planners in several countries are looking to both technologies to reduce carbon emissions and air pollution. Home to the world's largest on-road fleet of FCEVs, California is one such jurisdiction. Experiences in California provide an ideal opportunity to address a gap in literature whereby barriers to FCEV diffusion are well understood, but knowledge on actual strategies to overcome these has lacked. This study thus examines governance strategies in California to accelerate the production and diffusion of FCEVs, key outcomes, lessons learned and unresolved challenges. Evidence is sourced from 19 expert interviews and an examination of diverse documents. Strategies are examined from four perspectives: (i) supply-side (i.e. stimulation of vehicle production), (ii) infrastructure (i.e. construction of refuelling stations and hydrogen production), (iii) demand-side (i.e. stimulation of vehicle adoption) and (iv) institutional (i.e. cross-cutting measures to facilitate collaboration, innovation and cost-reduction). Findings reveal a comprehensive mix of stringent regulation, market and consumer incentives, and public–private collaboration. However, significant challenges remain for spurring the development of fuel cell transport in line with initial ambitions. Highlighting these provides important cues for public policy to accelerate the deployment of FCEVs and hydrogen in California and elsewhere.

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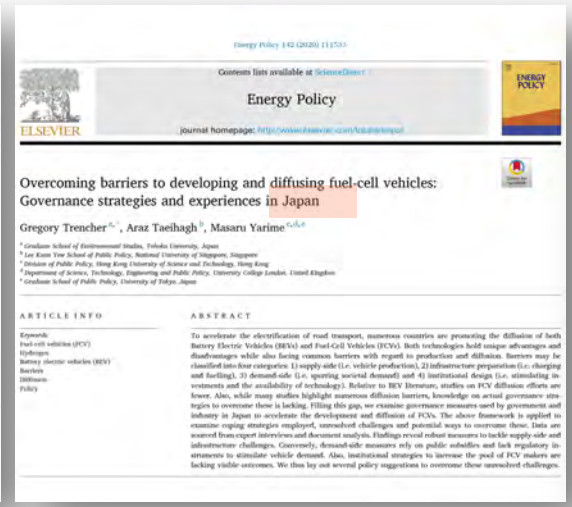

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ELSEVIER

Overcoming barriers to developing and diffusing fuel-cell vehicles: Governance strategies and experiences in Japan

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[b] Lee Kuan Yew School of Public Policy, National University of Singapore, Singapore
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[e] Graduate School of Public Policy, University of Tokyo, Japan

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Battery electric vehicles (BEV)
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Diffusion
Policy

ABSTRACT

To accelerate the electrification of road transport, numerous countries are promoting the diffusion of both Battery Electric Vehicles (BEVs) and Fuel-Cell Vehicles (FCVs). Both technologies hold unique advantages and disadvantages while also facing common barriers with regard to production and diffusion. Barriers may be classified into four categories: 1) supply-side (i.e. vehicle production), 2) infrastructure preparation (i.e. charging and fuelling), 3) demand-side (i.e. spurring societal demand) and 4) institutional design (i.e. stimulating investments and the availability of technology). Relative to BEV literature, studies on FCV diffusion efforts are fewer. Also, while many studies highlight numerous diffusion barriers, knowledge on actual governance strategies to overcome these is lacking. Filling this gap, we examine governance measures used by government and industry in Japan to accelerate the development and diffusion of FCVs. The above framework is applied to examine coping strategies employed, unresolved challenges and potential ways to overcome these. Data are sourced from expert interviews and document analysis. Findings reveal robust measures to tackle supply-side and infrastructure challenges. Conversely, demand-side measures rely on public subsidies and lack regulatory instruments to stimulate vehicle demand. Also, institutional strategies to increase the pool of FCV makers are lacking visible outcomes. We thus lay out several policy suggestions to overcome these unresolved challenges.

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Economics, Politics and Public Policy in East Asia and the Pacific

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Japan's bet on hydrogen cars needs a jump-start

19 April 2022

Author: Gregory Trencher, Kyoto University

Japan's early moves to spur the adoption of fuel-cell electric vehicles (FCEVs) have lost momentum. Encouraged by Toyota and Honda releasing the world's first mass-produced models in 2015, Japan reinforced its ambitious vision of a 'hydrogen society' and media hype boomed. But the transition is proving unexpectedly difficult. If FCEVs are to meet historical expectations and help electrify road transport, bold measures are needed to jumpstart the market.

As battery electric vehicles rapidly become the default vehicle electrification technology, Japan is still betting on hydrogen FCEVs. Rapid technological progress in batteries has eroded the range and refuelling advantages of FCEVs, but Japan's enthusiasm for hydrogen is still justified by several merits.

FCEVs do not require land-intensive charging lots — a single hydrogen station can support 1,000 vehicles. A boon in densely populated Asian countries. Smaller batteries mean that FCEVs require fewer scarce and expensive materials, providing a buffer from supply chain risks. Hydrogen is well suited to heavy-duty vehicles, freeing long-haul trucks from carting heavy and space-intensive batteries. FCEVs also provide a tangible symbol of a hydrogen society. If steel mills and chemical plants completely decarbonised, most of us would never notice, but an FCEV is a moving 'billboard'. By increasing the visibility of hydrogen technology, they can foster public and political support.

Perspectives of Carbon-Free Energy Sources in the Decarbonized Society

APRU Carbon Neutral Society – Action Month
20 May 2022

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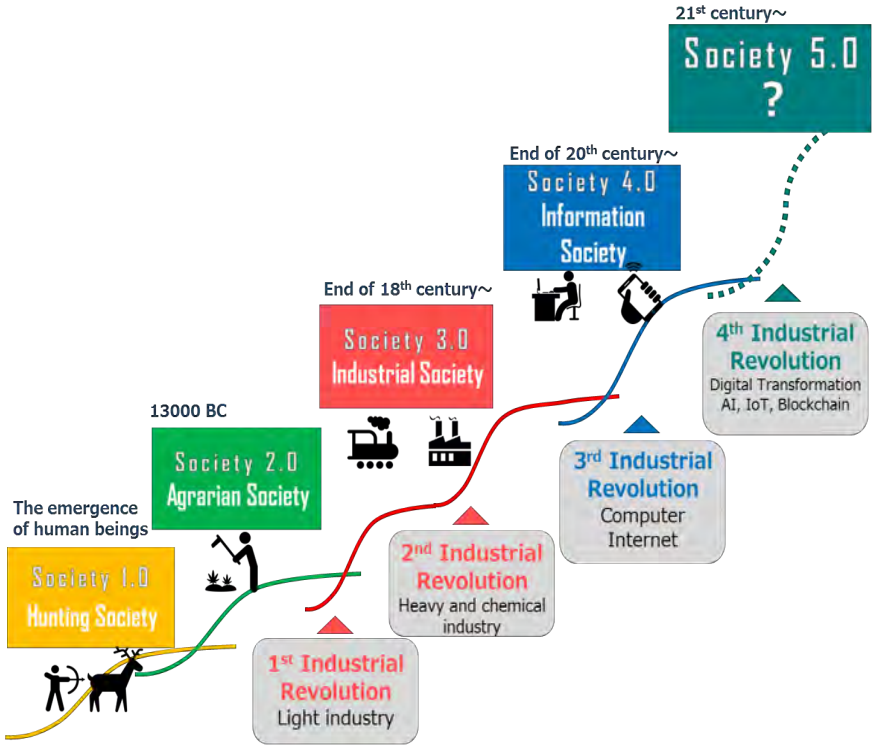
Society 5.0 and SDGs



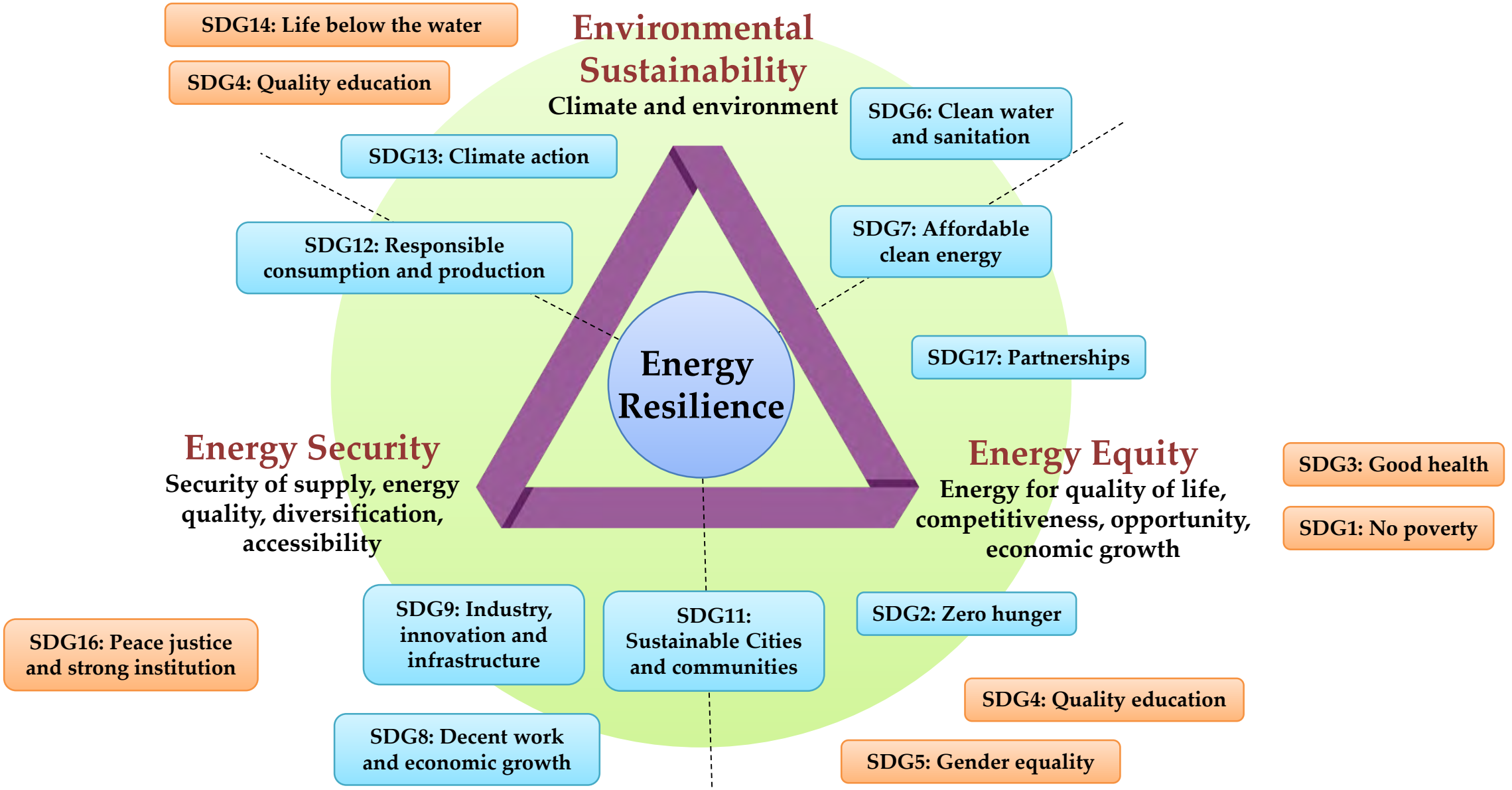
Digital Transformation × Imagination & Creativity of diverse people

Problem Solving

Value Creation

Source:
http://www.unic.or.jp/activities/economic_social_development/sustainable_development/2030agenda/sdgs_logo/

Energy Sustainability: Energy Triangle



Sustainability

- Meeting and fulfilling the needs of humanity without harming future generations.

- The sustainability pursues three types of interests:

1. ***Economic Interests***
   The economic impact on the localities where it does business, such as creating jobs, paying decent wages, and initiating public works. In addition, it also covers ending the energy poverty and strengthen economic growth

2. ***Social Interests***
   Performance in terms of social justice, such as avoiding child labor and sweatshops, and providing decent employee benefits.

3. ***Environmental Interests***
   Impact on the natural environment.

Sustainable Energy:

Sustainable provision of energy that meets the needs of the present humanity without compromising the ability of the future generations to meet their needs

Energy Transition

- Energy sector as **a key contributor** to global warming
- **Transition strategies** need to be pursued simultaneously to achieve a well **below 2 °C scenario**

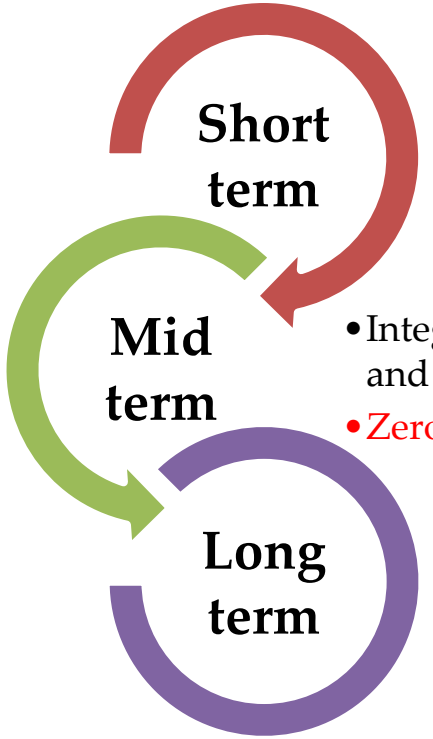
(WB2C Scenario, annual emission, 2040; business as usual 47 Gt-CO_2 with BB2C 2040 20 Gt-CO_2)

Decarbonization of power combined with extended **electrification** — 13 Gt-CO_2 (48%)

Decarbonization of activities which **cannot be cost-effectively electrified** — 4 Gt-CO_2 (15%)

Acceleration in the pace of **energy productivity** improvement to 3% per annum — 8 Gt-CO_2 (30%)

Optimization of fossil fuels use within overall **carbon budget constraints** — 2 Gt-CO_2 (7%)



Short term
- Energy efficiency
- Integration of low carbon technologies and REs

Mid term
- Integration of low carbon technologies and REs for electricity and hydrogen
- Zero emission target

Long term
- Circulated (closed circulation, local production – local consumption)

Energy Transitions Commission 2017: *Better Energy, Greater Prosperity, Achievable pathways to low-carbon energy systems*

Concerns in Energy Transition

Environmental

- Carbon emission/ neutrality
- **Balanced management** of clean air, water, soil, food, primary energy resources, etc.
- **Conservation** of biodiversity and wild life

Economic

- Dynamic change of local/national economies to the speed of change in energy transition
- **Balanced and adaptive structural changes** to facilitate new business potential and growth
- **Affordability** and economic **growth and resilience**
- **Management of vested interest** as an obstacle in transition

Social

- Challenges in fossil-dependent communities (jobs, cultural changes, economic declines, etc.)
- **Inclusive and wider benefits/impacts** from transition, including job creation, positive social experiences, etc.
- Social acceptability and well-being
- Mutual capacity building and understanding toward **inclusive culture**

Minimization of climate change risks, and correlation of energy with other aspects

UNECE. ECE Energy Series 67, 2020

Transformation in Energy System and Price

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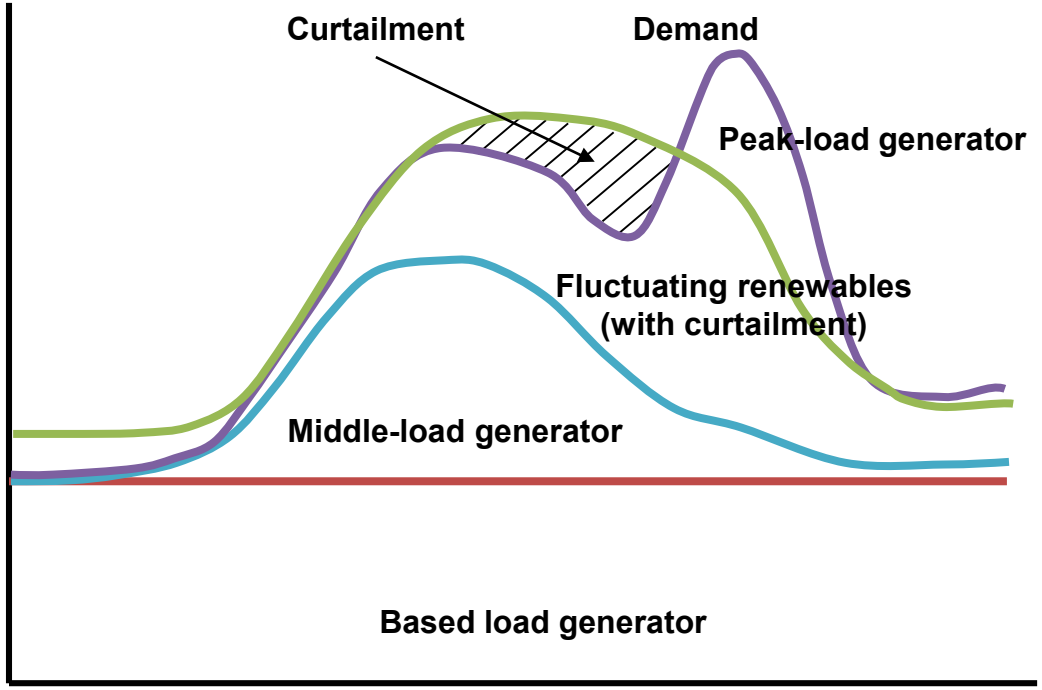
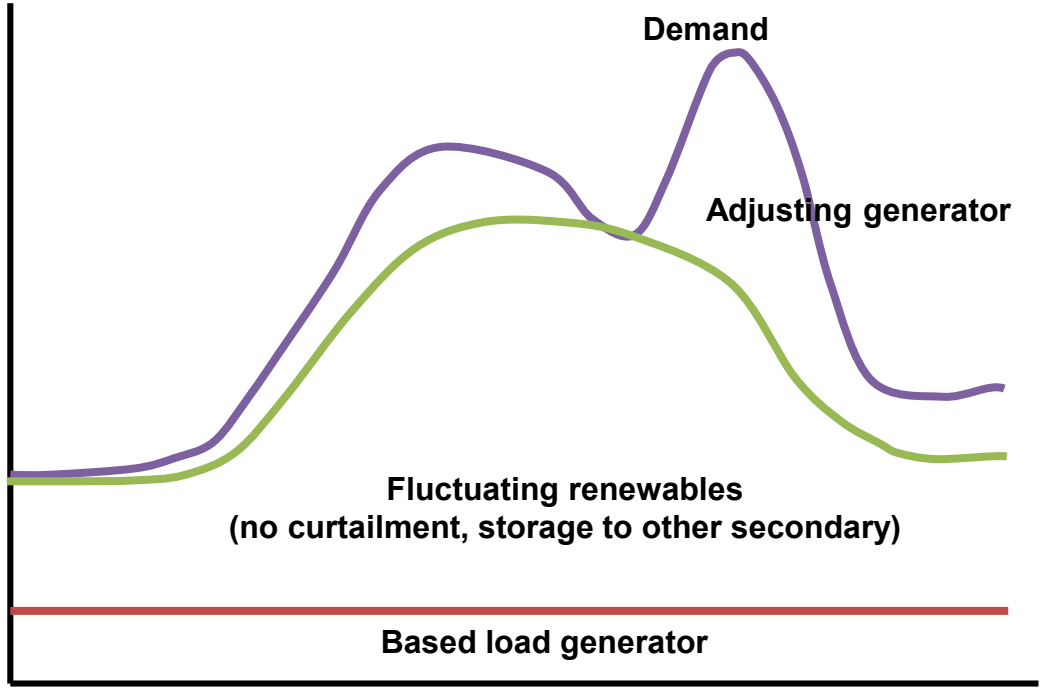
Current condition



Future



- High-ratio of base-load generator (nuclear, coal, hydro)
- Small share of renewables
- Curtailment of renewables due to limitation in adjusting/transmitting capacity
- Middle-load and adjusting generators dominated by fossils (gas, oils)
- Limited energy storage and fast-responsive system
- Higher price for renewables (although fluctuating)

- Lower ratio of base-load generator (nuclear, biomass, waste, geothermal, hydro)
- Larger share of renewables
- Lower price for fluctuating sources
- Minimization in curtailment of renewables
- Significant role for middle-load and adjusting generator
- Energy storage, hydrogen, fast-responsive system as middle-load and adjusting generator (higher/premium price)

Future Energy Options and Beyond Net Zero

Optimization of renewable sources

- Appropriate scenario building for each region/country
- Revaluing of biomass
- Technological maturity for potential REs
- Maintenance and parts supports/access
- Facilitative policies, incentives, and supports

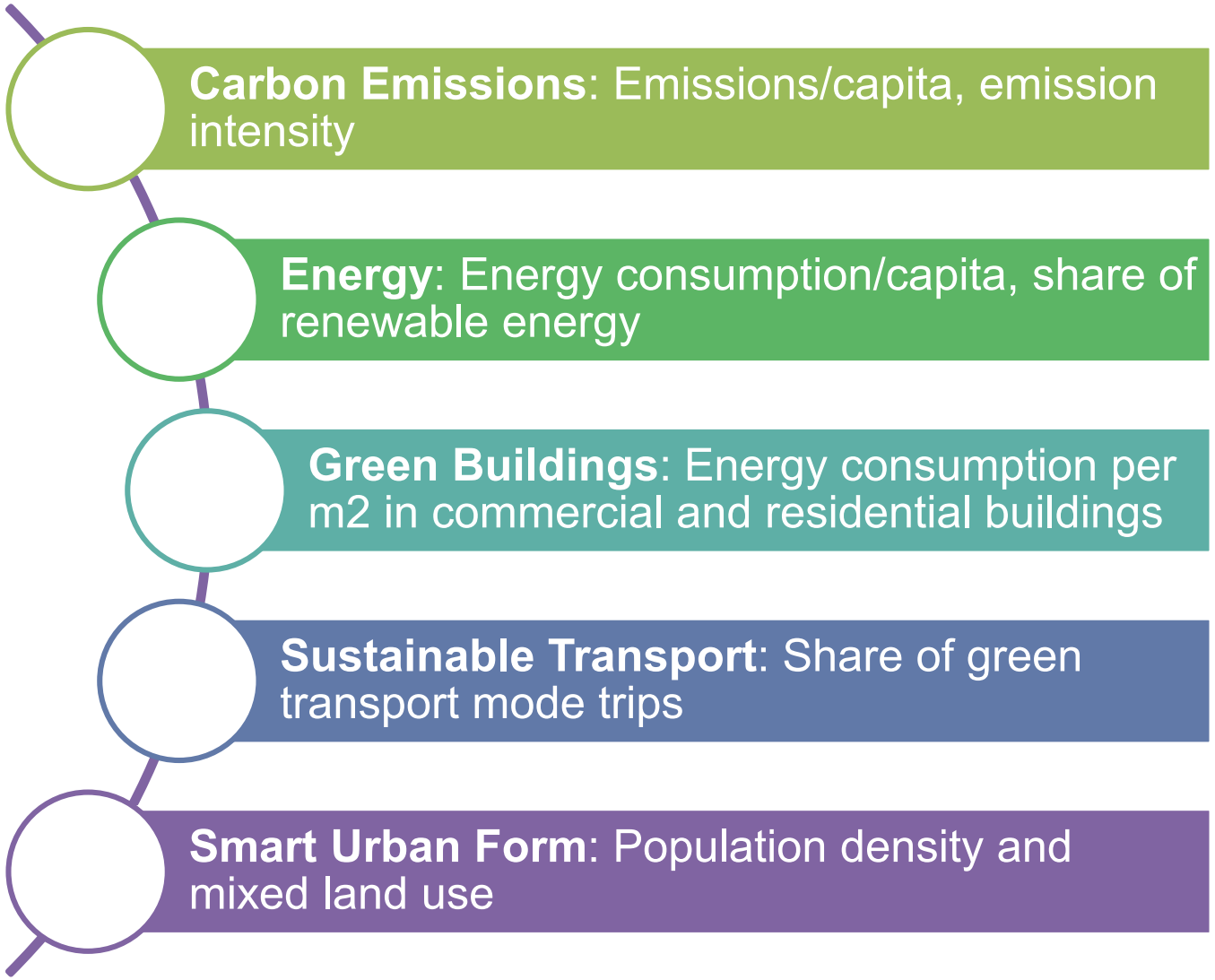
Adoption of carbon-free secondary energy sources

- Mutual utilization of electricity and hydrogen-based fuels
- Potential of metal fuels
- Integrated system toward high total efficiency

Control on CO_2 generation

- Controlling the CO_2 amount through controllable generation (emission), separation, storage/sequestration, and utilization
- Established CO_2 utilization
- Carbon tax scenarios

Indicators for Low-Carbon Growth Encouragement



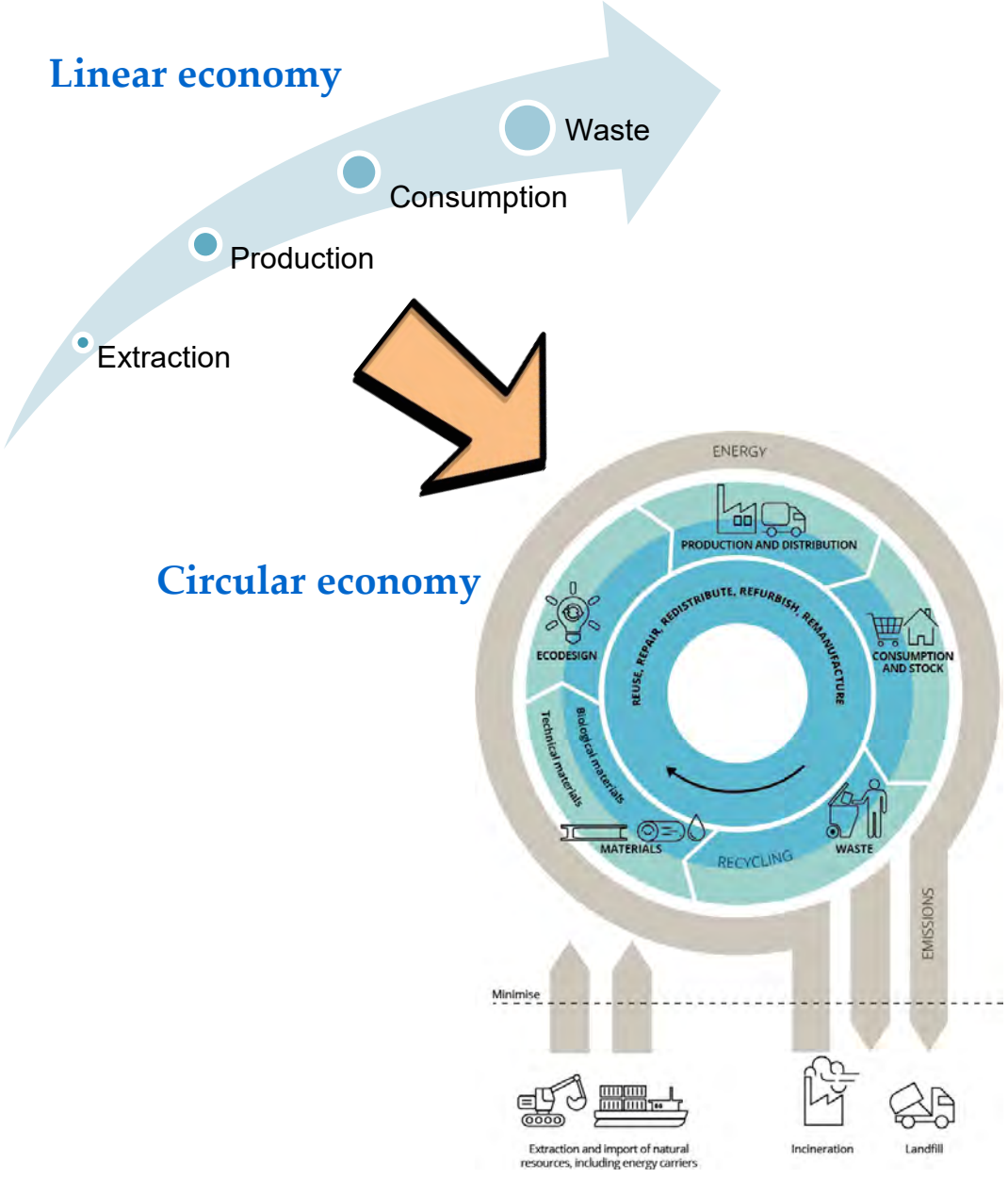
What and Why

- Direct response of local governments to the indicators
- Identification of appropriate carbon intensity indicators
- Inclusion of indicators in local government performance evaluations

- Energy efficiency measure on:
  - building material
  - transport system
  - sewerage and water supply systems,
  - street lighting, air-conditioning systems
  - energy consumption in buildings

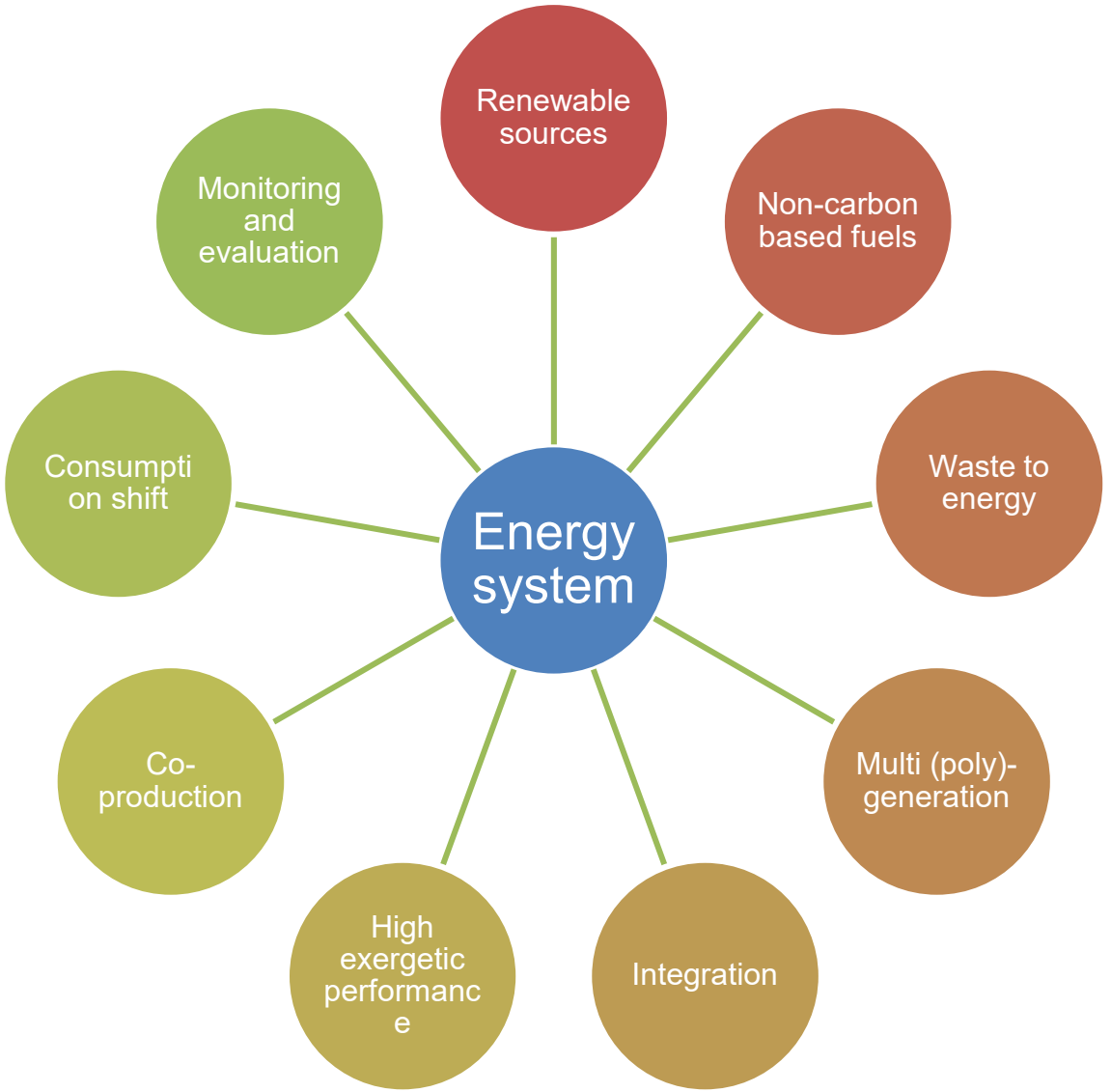
Energy Transition and Circular Economy (CE)

- Energy transition should become the driver for circular economy, combining economic and environmental gains
- Implies reduction of energy, material, waste, and emission through changes in design, production, distribution, and consumption, as well as emphasize on repair, reuse, remake, and recycle.
- Reasonable growth (economy, population, employment) with low environmental damage at both local and global levels
- Demands mutual and integrated innovation, as well as monitoring (traceability) and global network resilience
- It is needed to promote the goals of sustainable development (SD)
- Sustainable development demands other factors of social and human dimensions



Adaptive Energy Transition Toward CE and SD

- Adaptive scenarios for each different regions (resources, demand, knowledge and technological mastery)
- Progressive and dynamic transition scenario
- Mutual and bi-directional communications for all the stakeholders (both local and global, producers and consumers)
- Shift of consumption
  - Adaptive behavior
  - Ownership and responsibility
  - Concerns to the environment
- Evaluation
  - Scenario analysis
  - Energy and material flow analysis
  - Circularity evaluation
  - Impacts assessment



Energy-related keys toward realization of CE and SD

Smart Cities

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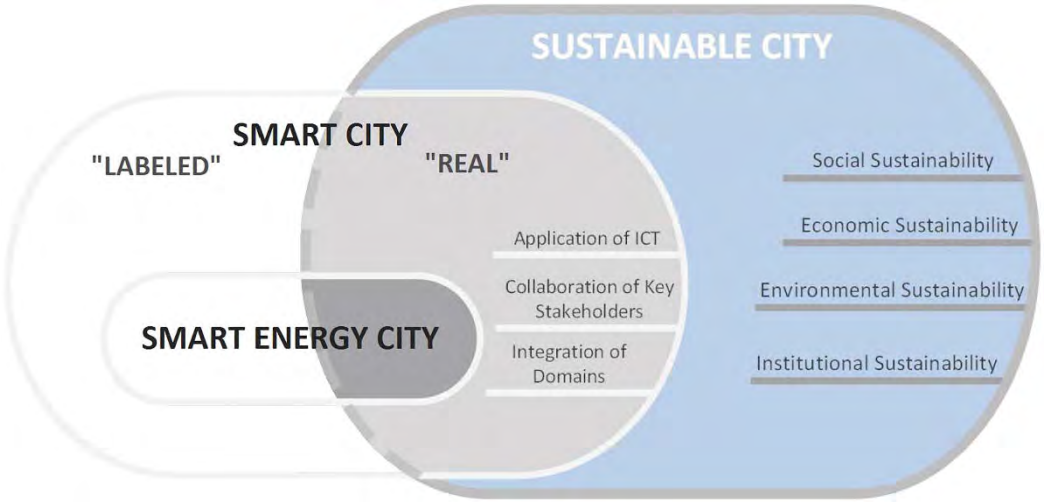
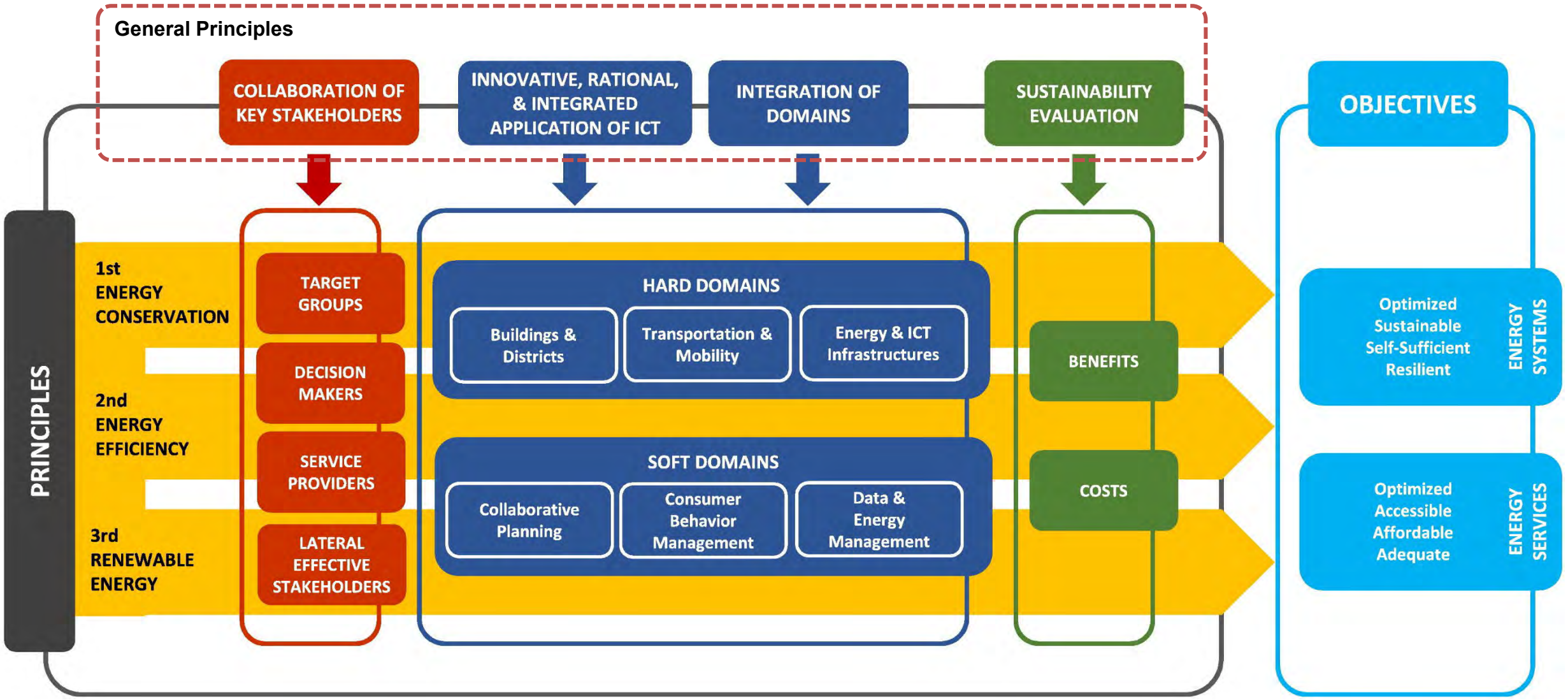
A city that makes use of *advanced information and communications technologies* (ICTs) to make the critical infrastructure components and services of a city in a more *aware, interactive*, and *efficient* way

Aims of a Smart City

- Provide a **high quality of life**
- Ensure **resource efficiency** and **reduce costs**
- Result in **sustainable growth** and **economic prosperity**
- Increase **interaction** between government and citizens



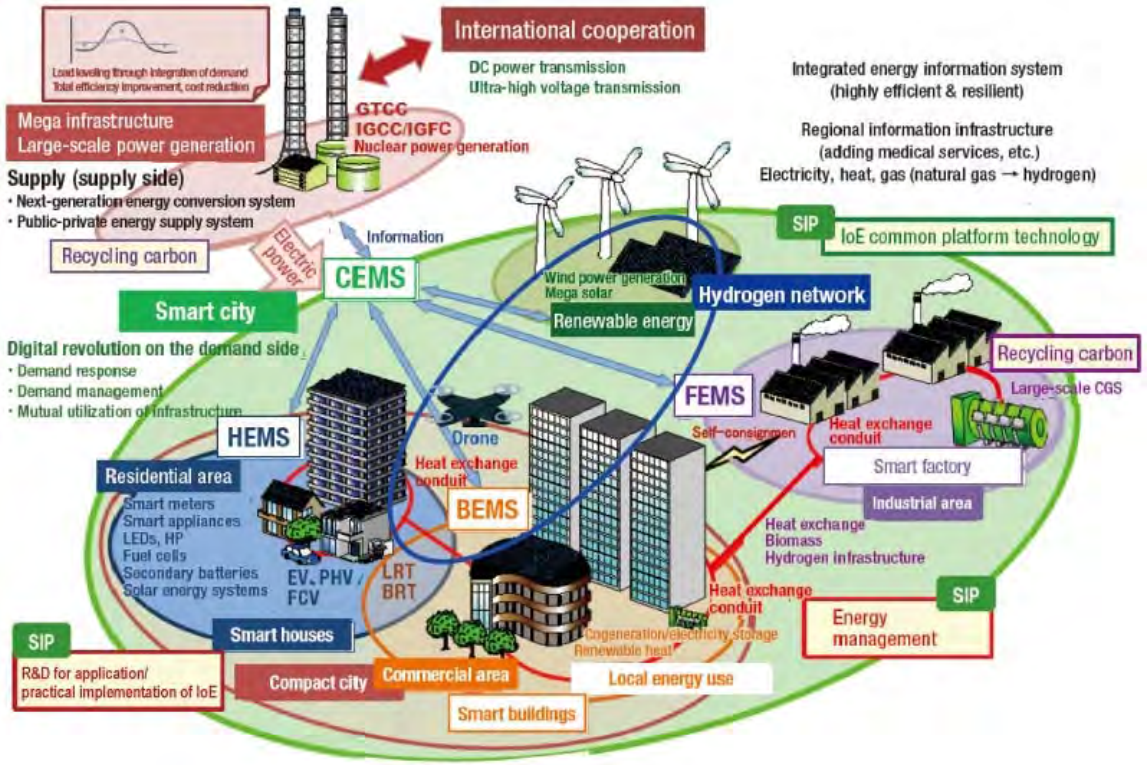
Energy and Living Space Development



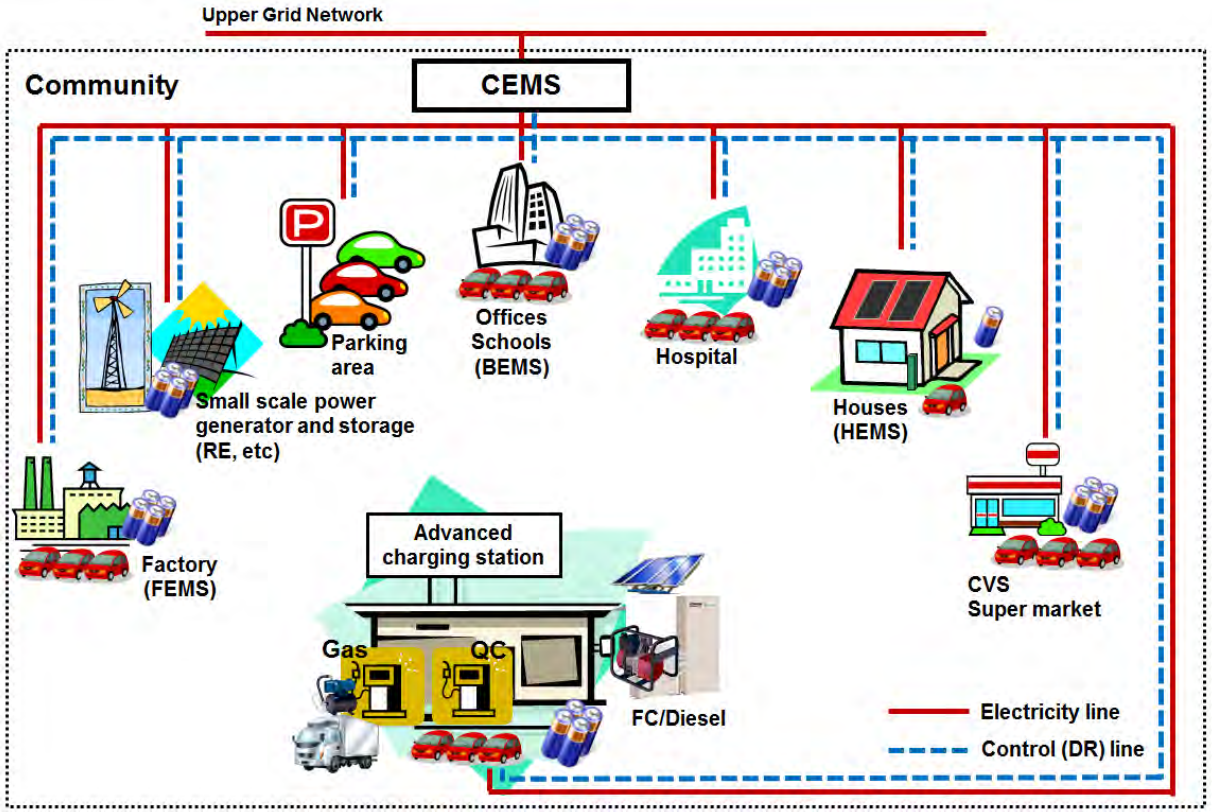
Mosannenzadeh et al. Smart energy city development: A story told by urban planners. *Cities* 64 (2017) 54-65

Pezzutto et al. FP7 SINFONIA project, deliverable 2.1 SWOT analysis report of the refined concept/baseline (SINFONIA deliverables) European Academy of Bolzano, Bolzano (2015)

Connected Community Energy Management



Internet of energy (IoE)



Possible structure of CEMS including both electricity and control lines

- The initiatives of CEMS comes from the needs of harmonization between optimal energy services, potential economy and environmental benefits.
- CEMS manages the overall energy supply and demand across the community. It communicates the information with other systems both inside and outside of the community.

Smart Energy Systems

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An approach in which **smart electricity, thermal and gas** grids are combined with **storage technologies** and coordinated to identify **synergies** between them in order to achieve an **optimal solution** for each individual sector as well as for the overall energy system

Smart electricity grids

Connects flexible electricity demands such as heat pumps and electric vehicles to the intermittent renewable resources such as wind and solar power

Smart thermal grids

connect the electricity and heating sectors. This enables the utilization of thermal storage for creating additional flexibility and the recycling of heat losses in the energy system

Smart gas grid

connect the electricity, heating, and transport sectors. This enables the utilization of gas storage for creating additional flexibility. If the gas is refined to a liquid fuel, then liquid fuel storages can also be utilized

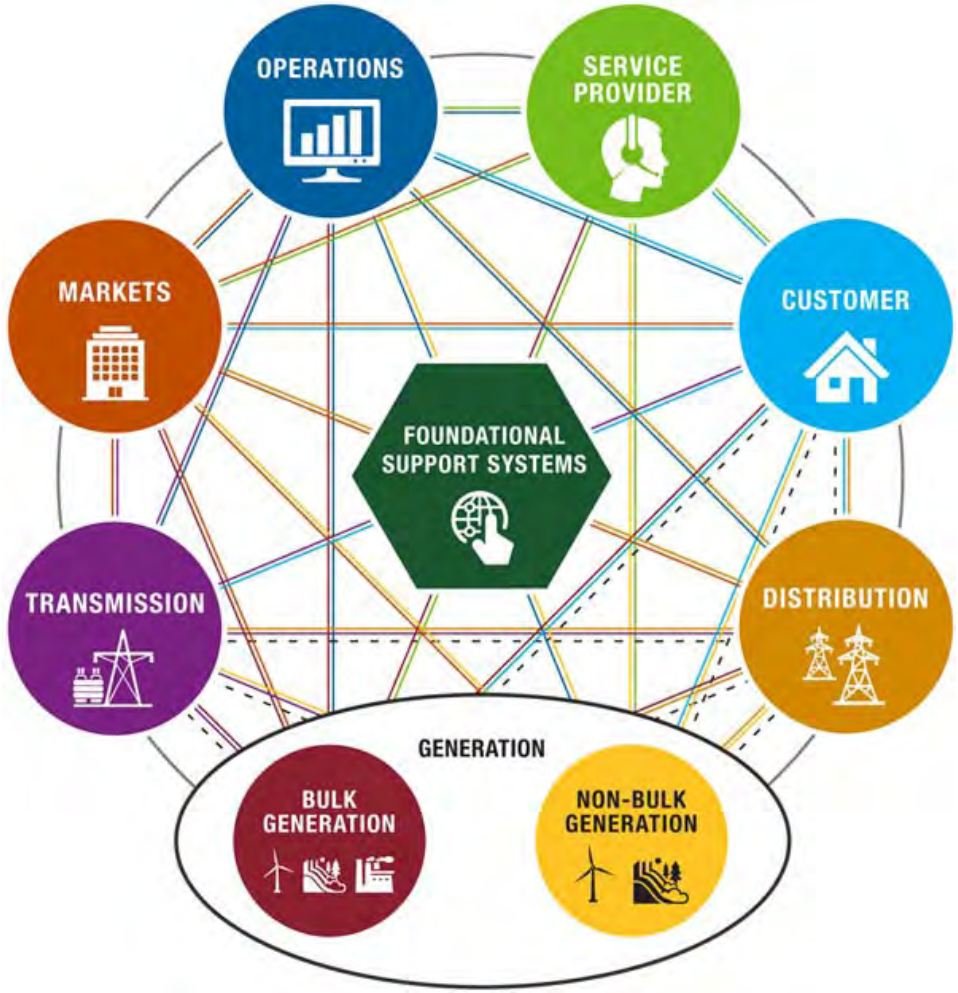
Lund H, Ostergaard PA, Connolly D, Mathiesen BV. Smart energy and smart energy systems. Energy 137 (2017) 556-565

Smart Electricity Grid

Electricity network using **digital** and other **advanced technologies** to monitor and **manage the transport of electricity** from all generation sources.

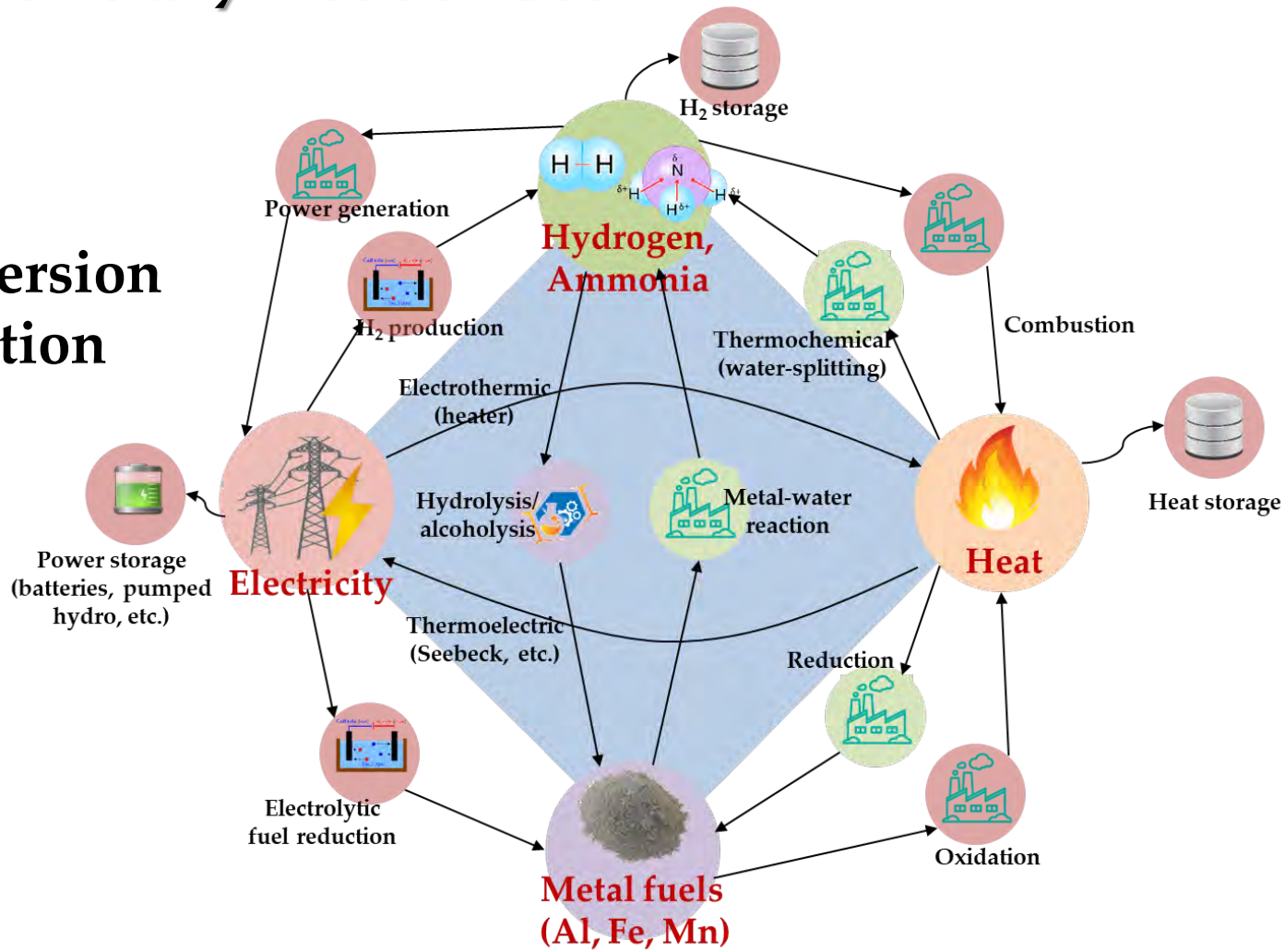
Key Characteristics

- Uses information technologies to improve how electricity travels from power plants to consumers
- Allows consumers to interact with the grid
- Integrates new and improved technologies into the operation of the grid
- Self healing: grid detects, analyzes, responds,…
- Provides power quality to consumer and industry
- Accommodates demand responds, combined heat and power, wind, PV, and end-use efficiency
- Transform the power sector into a secure, adaptive, sustainable and digitally



Carbon-free secondary resources

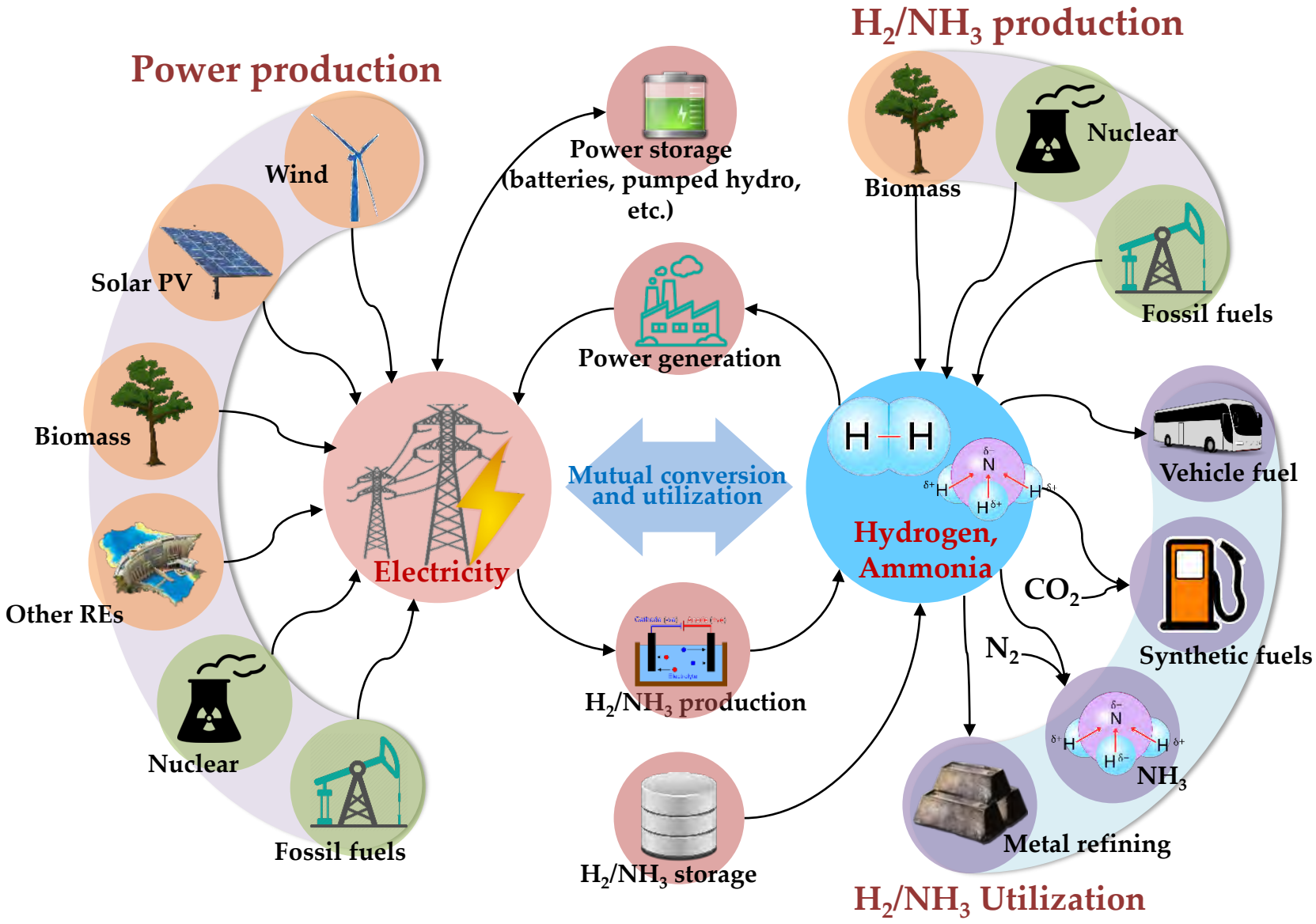
Mutual conversion and utilization



Mutual utilization of carbon-free secondary energy resources

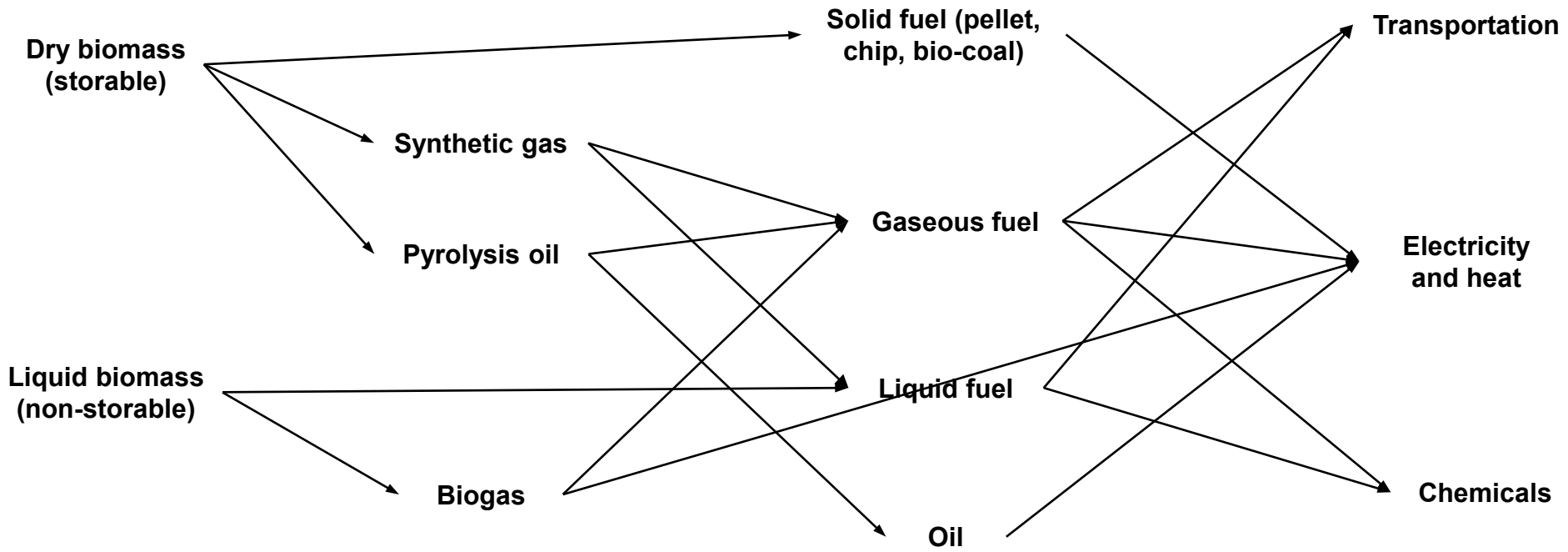
- Efficient conversion of primary to secondary energy sources
- Mutual conversion and utilization among potential carbon-free secondary resources

Mutual co-utilization of Electricity and H2-based fuels

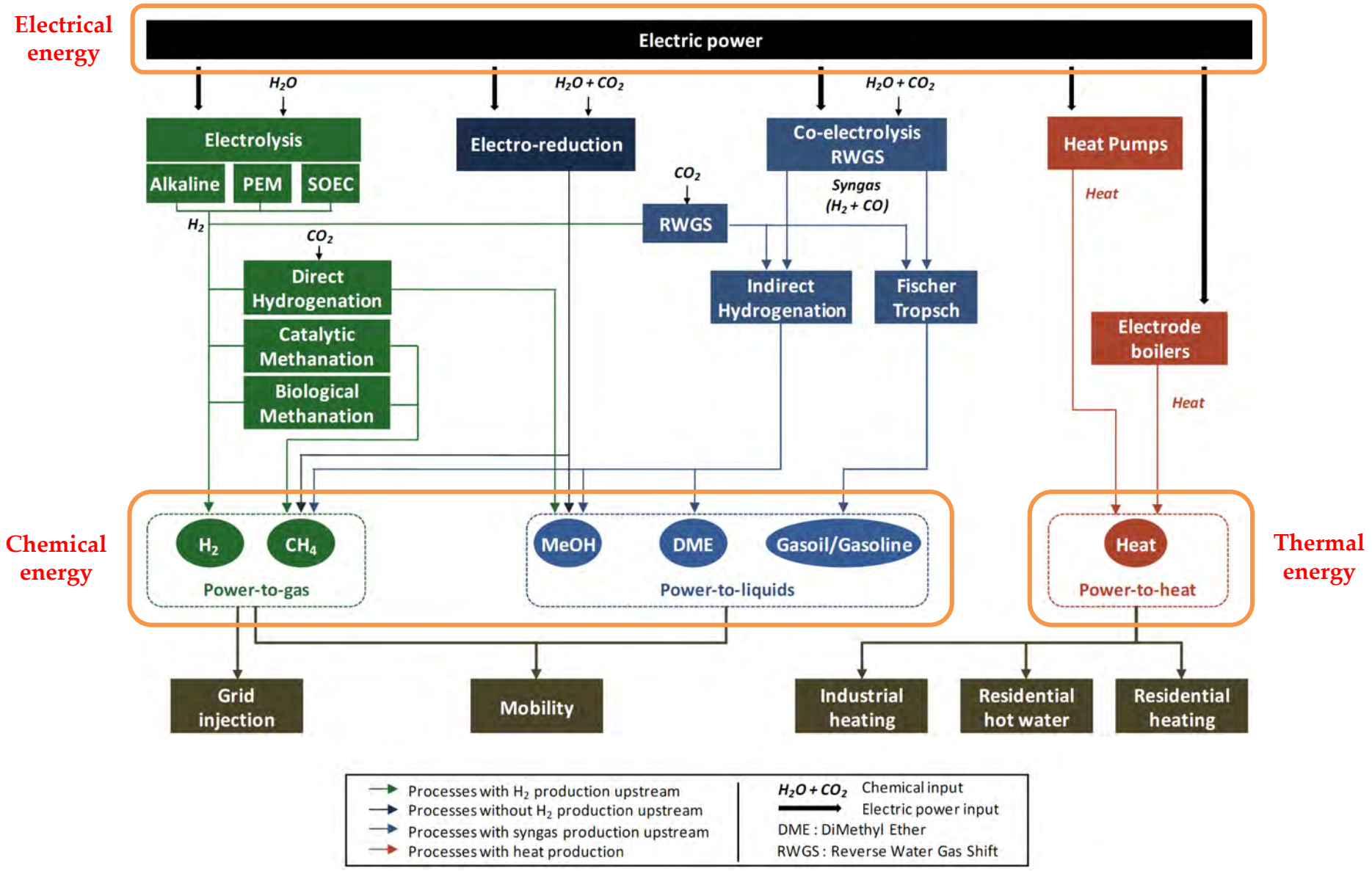


Reevaluating and Revaluing Biomass

- Optimum utilization of its characteristics (carbon neutral, storability, flexibility)
- Biomass has high flexibility to be converted to various kinds of fuels and broad utilization
- Excellent storability to provide stable and balanced energy supply, as well as storage and transportation
- Short-to-long terms energy supply
- Restructurization of energy price (base load, as well as green, supply can be higher than fluctuating one)
- Complex and standalone (single) conversion system leads to low energy efficiency
- Integration with other resources and the need for advanced and integrated system to realize high total energy efficiency



Mutual Conversion of Secondary Energy Sources



Hydrogen: Flexible Secondary Energy Source and Potential Energy Carrier

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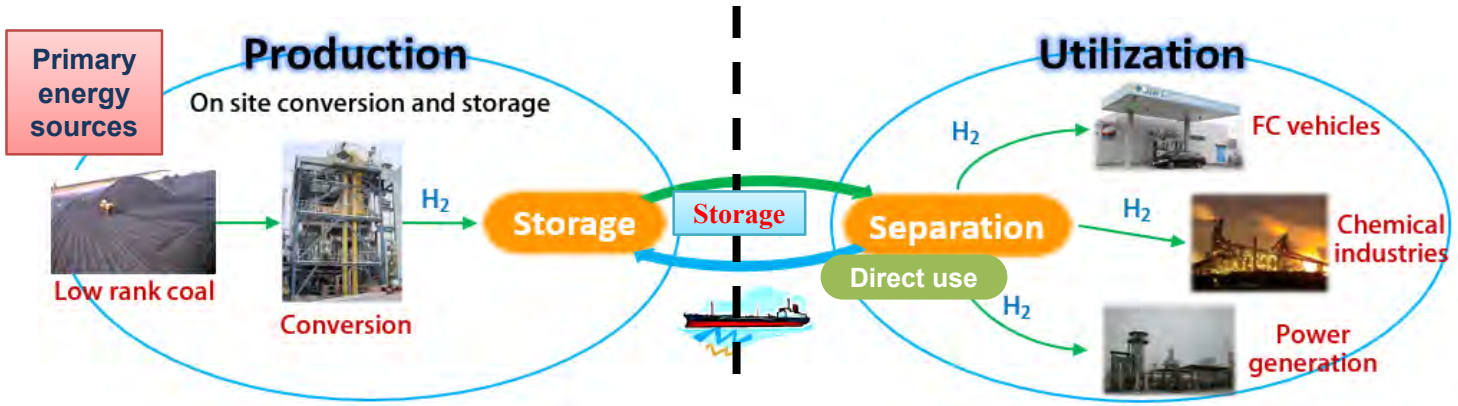
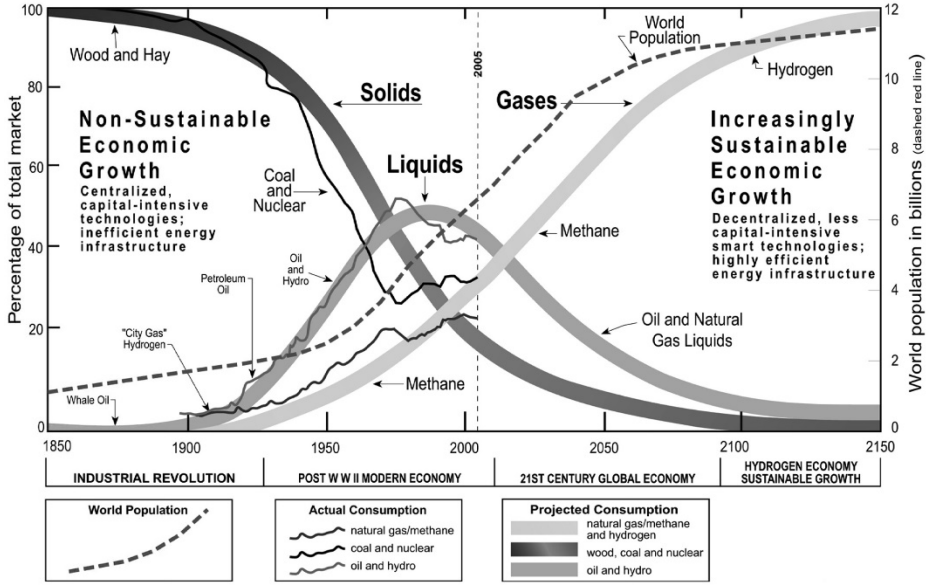
>50% of global H2 transport needs by 2050

Already more than **10 000** tpd by 2030

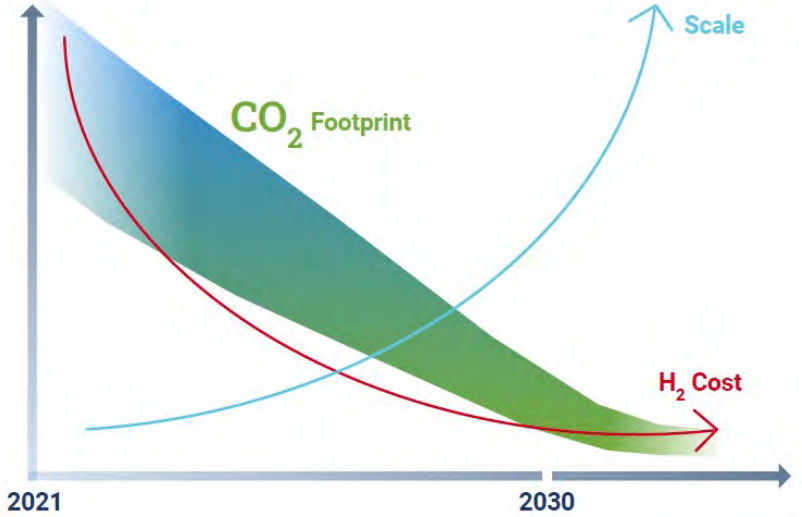
- Hydrogen as potential secondary energy source (cleanliness, high efficiency, high variety of production and utilization)
- Utilization of hydrogen: reciprocating combustion engine, fuel cells, combustion, co-combustion, etc.
- Energy density by weight is high (33 kWh/kg), but by volume is very low (3 Wh/l)
- Produced mainly from natural gas, oil reforming, coal gasification, water electrolysis



H_2 production and utilization



Global energy systems in transition sources



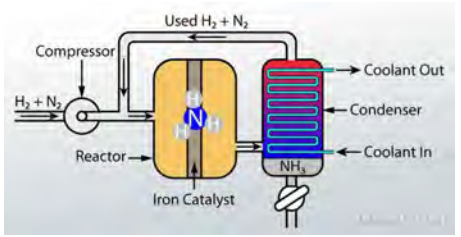
Decarbonization pathway toward zero carbon

R.A.H. Iii. The age of energy gases. Int J Hydrogen Energy, 27 (1) (2002), pp. 1-9

Hydrogen and Ammonia Applications

Aviation

Industrial applications (amines, alcohols, cycloalkanes, hydrogen peroxide)



Ammonia production

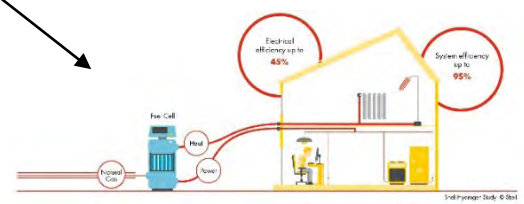
Maritime vehicles

H2/ NH_3

Large-scale power generation

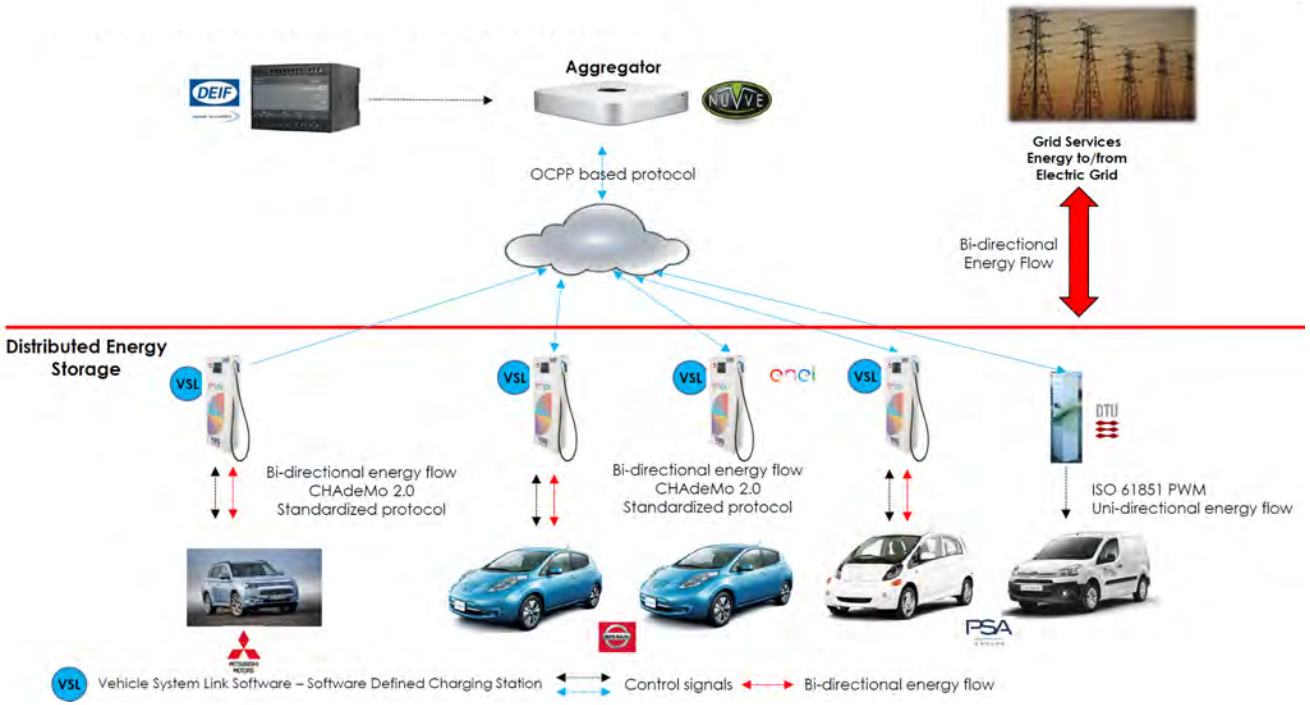
Trains, buses

Material handling vehicles

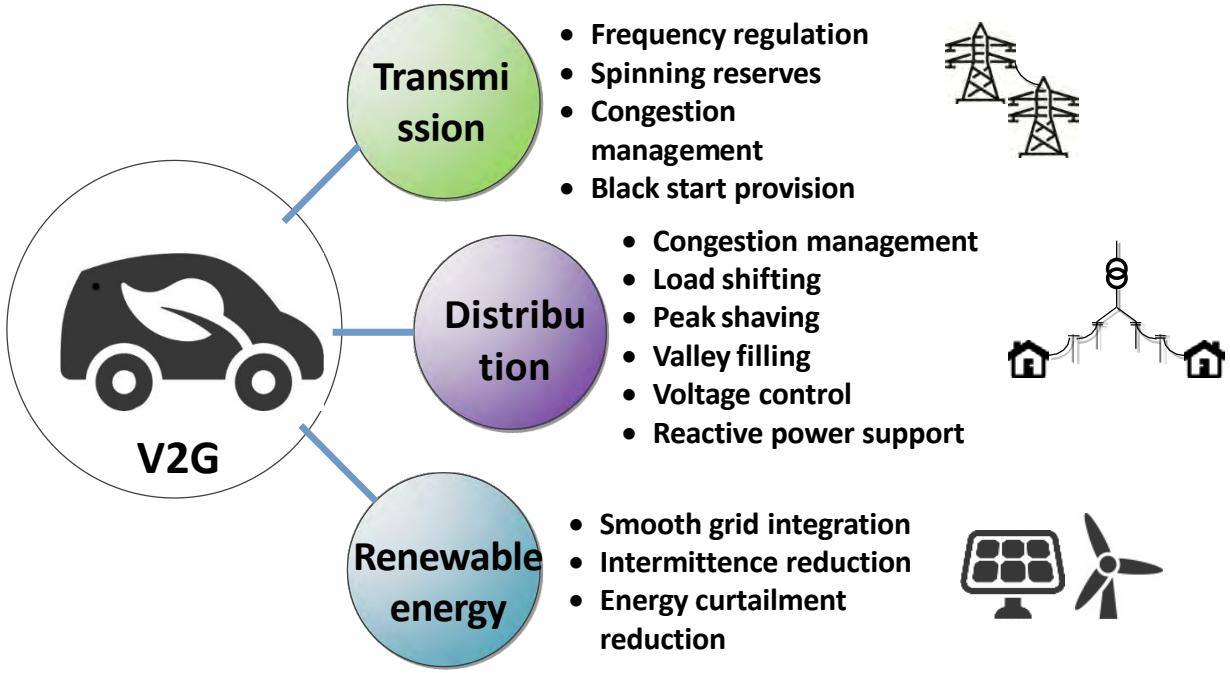


Domestic power generation

Electric Vehicle and Vehicle-to-Grid (V2G) Technology



Conceptual architecture of V2G technology
(Source: Parker project final report)



Various ancillary services which can be provided through V2G

- Integration of transportation and energy sectors
- V2G facilitates new economic and social opportunities to the owners/drivers, not only as transportation, but also energy services
- Increasing the total energy efficiency and reducing CO2 emission

Carbon Utilization

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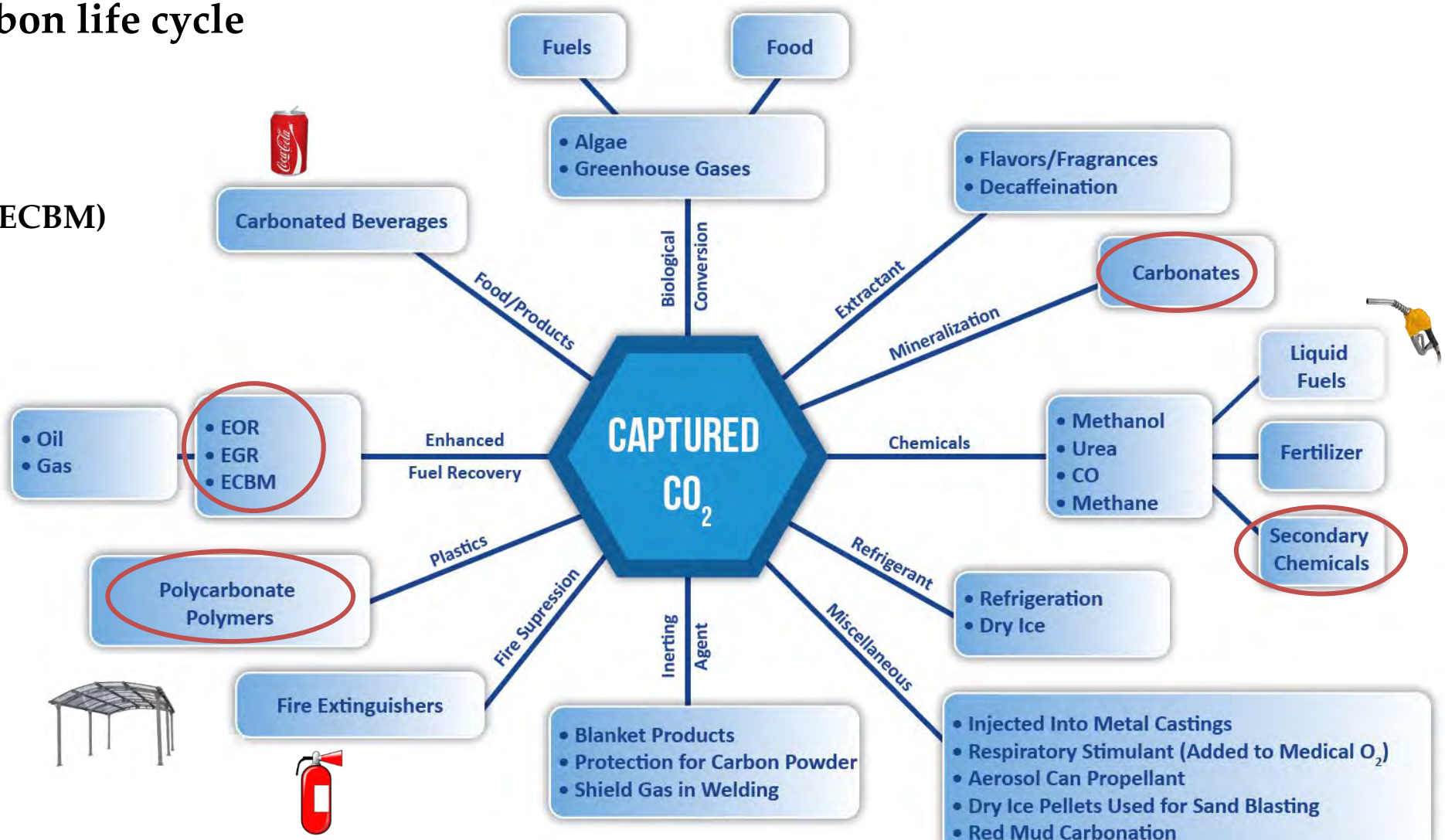
Toward longer carbon life cycle

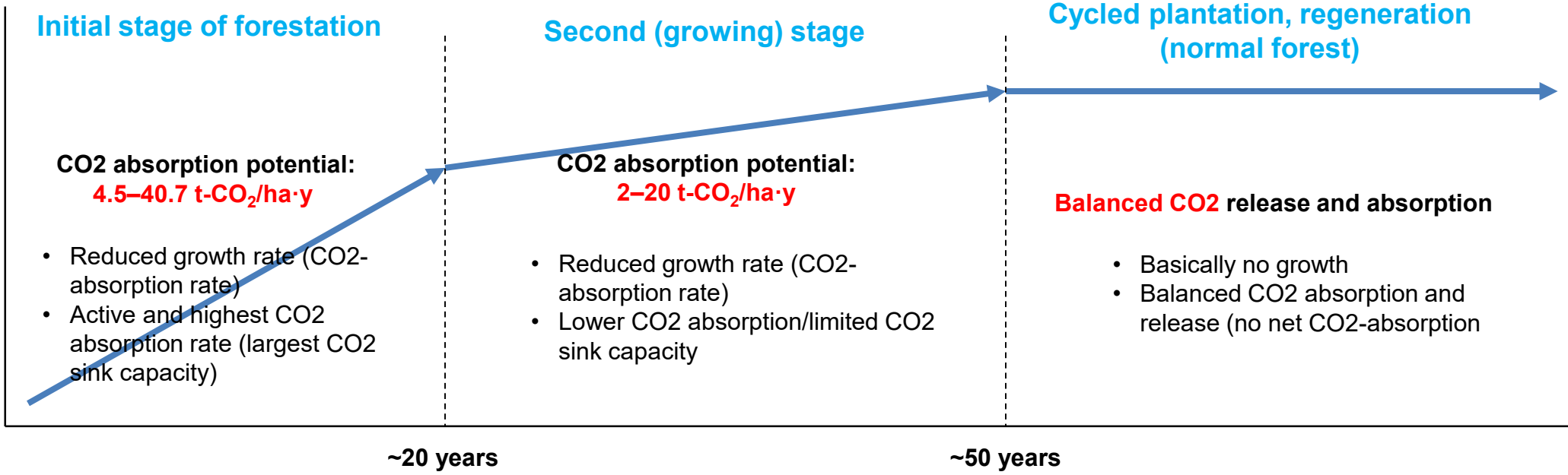
- **Materialization**
- **Mineralization**
- **Sequestration** (EOR, ECBM)



Source: U.S. DOE, National Energy Technology Laboratory, CO2 Utilization Focus Area, at https://www.netl.doe.gov/research/coal/carbon-storage/research-and-development/co2-utilization

Coupling the Forestation in Energy Transition

- The plants have the highest carbon absorption rate for their first 5-20 years, and then it decreases. Once the plantation cycle has been reached (e.g., after 50-60), there is no further positive carbon absorption.
- Coupling the CO2 capture by forestation (especially for initial 20 years growth) in the energy transition (establishing H2/NH3 readiness level, etc.)
- In the future, through cycled plantation, the forest is potential to supply the biomass as promising carbon neutral feedstock/fuel (after 50-60 years from forestation/plantation)
- Furthermore, through advanced technologies (CCUS, chemical looping, etc.), the carbon emission can be controlled to be zero or negative emission (controllable emission, after 2050/2060)



CO_2 Capture by Forestation

- Planted forests and woodlots have the highest CO2 removal rates, 4.5–40.7 t-CO_2/ha·y during the first 20 years of growth.
- Mangrove tree restoration was the second with rates up to 23.1 t-CO_2/ha·y in the first 20 years post restoration.
- Natural regeneration removal rates were 9.1–18.8 t-CO_2/ha·y during the first 20 years of forest regeneration
- Agroforestry has the lowest and regionally broad removal rates (10.8–15.6 t-CO_2/ha·y)

Table 1 Removal factors (tons CO_2 ha^{-1} $year^{-1}$) and associated uncertainty (CI95) of the planted forests and woodlots FLR and subcategories, for stand ages of 0–20 years old

Planted species	Climatic region	Removal rate (t CO_2 ha^{-1} $year^{-1}$)	Half CI95
Oak	Temperate, humid	9.5	3.5
	Temperate, dry	5.3	3.5
	Tropical, dry	18.4	1.0
Teak	Tropical, humid	30.8	4.1
	Tropical, dry	12.7	1.5
Eucalyptus	Temperate, all	37.9	5.5
	Tropical, humid	40.7	9.5
	Tropical, dry	38.8	6.0
Broadleaf[a]	Boreal	8.0	1.0
	Temperate, all	11.8	1.4
	Tropical, humid	25.3	3.9
	Tropical, dry	10.7	0.6
Pine	Boreal	10.2	4.9
	Temperate, humid	21.1	4.5
	Temperate, dry	7.6	2.0
	Tropical, dry	21.0	2.0
Conifer[b]	Boreal	4.5	1.0
	Temperate, humid	11.6	3.6
	Temperate, dry	6.4	1.9
	Tropical, humid	23.6	2.8
	Tropical, dry	38.7	2.5

[a] Excluding eucalyptus and teak

[b] Excluding pine

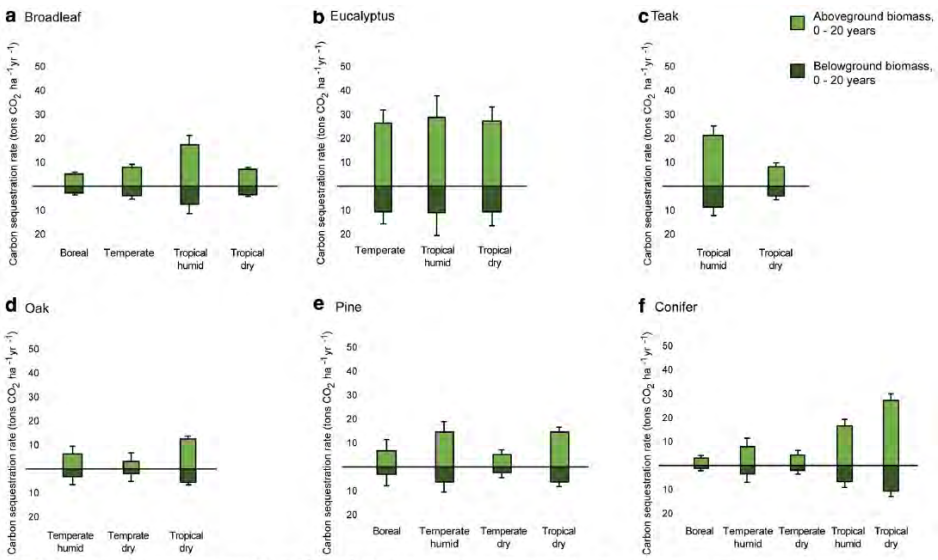


Fig. 2 Carbon sequestration rate (tons CO_2 ha^{-1} $year^{-1}$) of the six plantations and woodlots groups (**a** broadleaf excluding eucalyptus and teak, **b** eucalyptus, **c** teak, **d** oak, **e** pine, and **f** conifers excluding pine) during the first 20 years of tree growth. Light green represents aboveground biomass, while dark green represents belowground biomass. Error bars indicate the CI95 of the total biomass growth. Different bars within graphs represent climatic regions

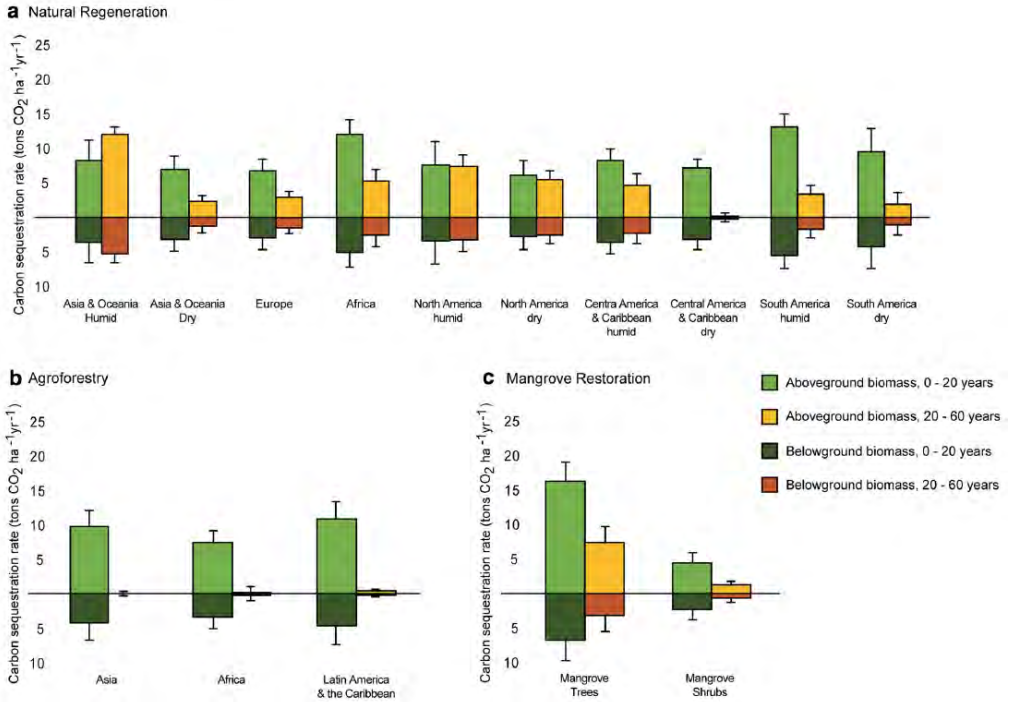


Fig. 3 Carbon sequestration rate (tons CO_2 ha^{-1} $year^{-1}$) of **a** natural regeneration FLR, **b** agroforestry FLR, and **c** mangrove restoration FLR. Green colors represent rates during the first 20 years of tree growth (aboveground biomass in light green, belowground biomass in dark green), while orange colors represent rates during 20–60 years of tree growth (aboveground biomass in light orange, belowground biomass in dark orange). Error bars indicate the CI95 of the total biomass growth. Different bars within graphs represent FLR subcategories

Bernal et al. Carbon Balance Manage (2018) 13:22. https://doi.org/10.1186/s13021-018-0110-8

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感謝！
Thank you.

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