Green Hydrogen for the Future Sustainable Growth of Human Beings

- ◆ Global Warming, Carbon Cycle vs. Water Cycle
- ◆ Green Hydrogen Energy System
- ◆ Water Electrolysis
- ◆ Polymer Electrolyte Fuel Cell

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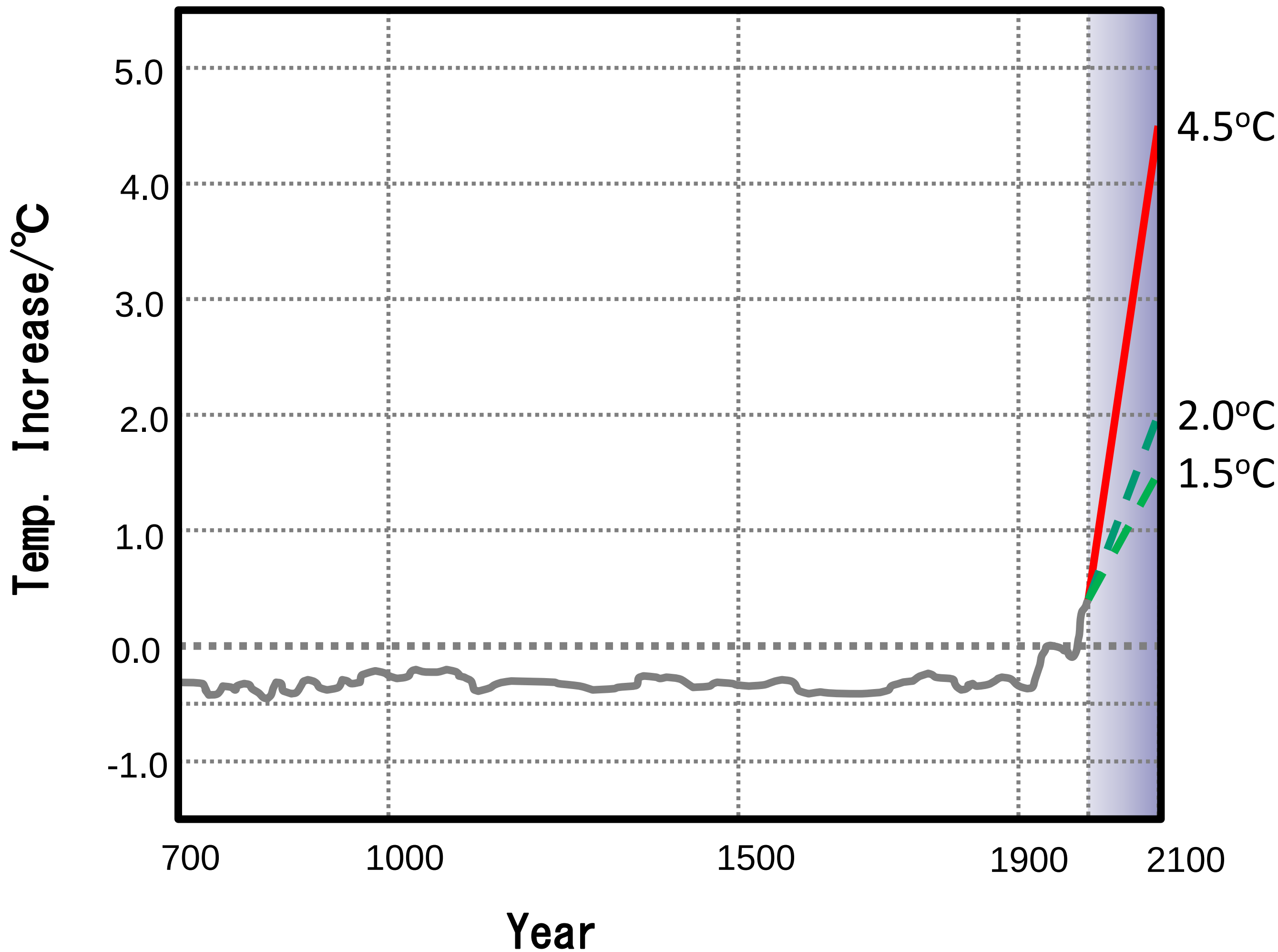
CCUS and H2 International Conf.、Feb. 20th, 2020,
Belle Salle Kanda, Chiyoda, Tokyo, Japan

Rapid Global Warming on the Earth

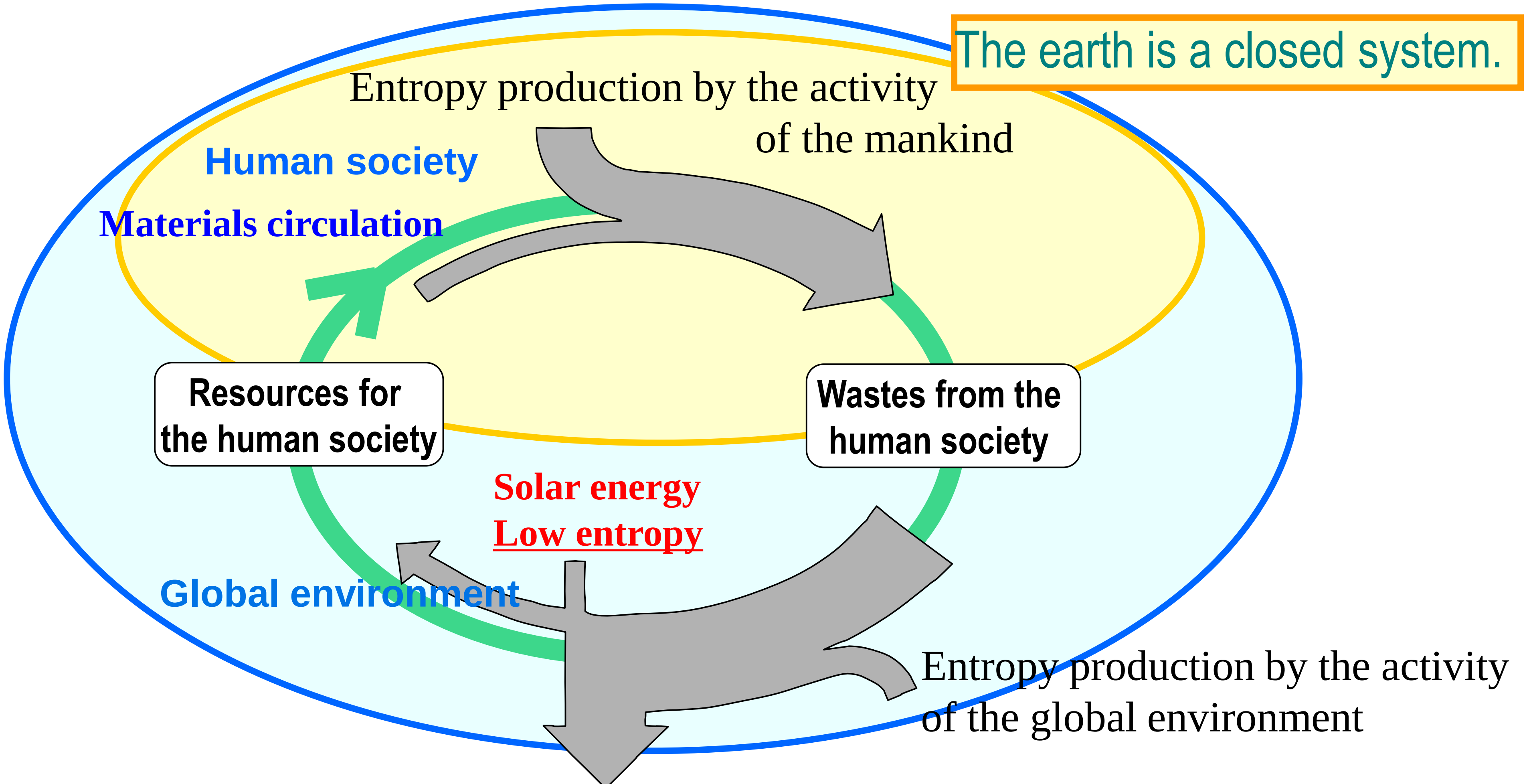
Green Hydrogen Research Center, Y.N.U.



(by IPCC 4th Report(2007)

Global entropy flow for sustainable growth

Green Hydrogen Research Center, YNU



Q: 1.2×10^{14} kW

$\Delta S = 4.7 \times 10^{11}$ kJ/K･s

Carbon cycle on the earth

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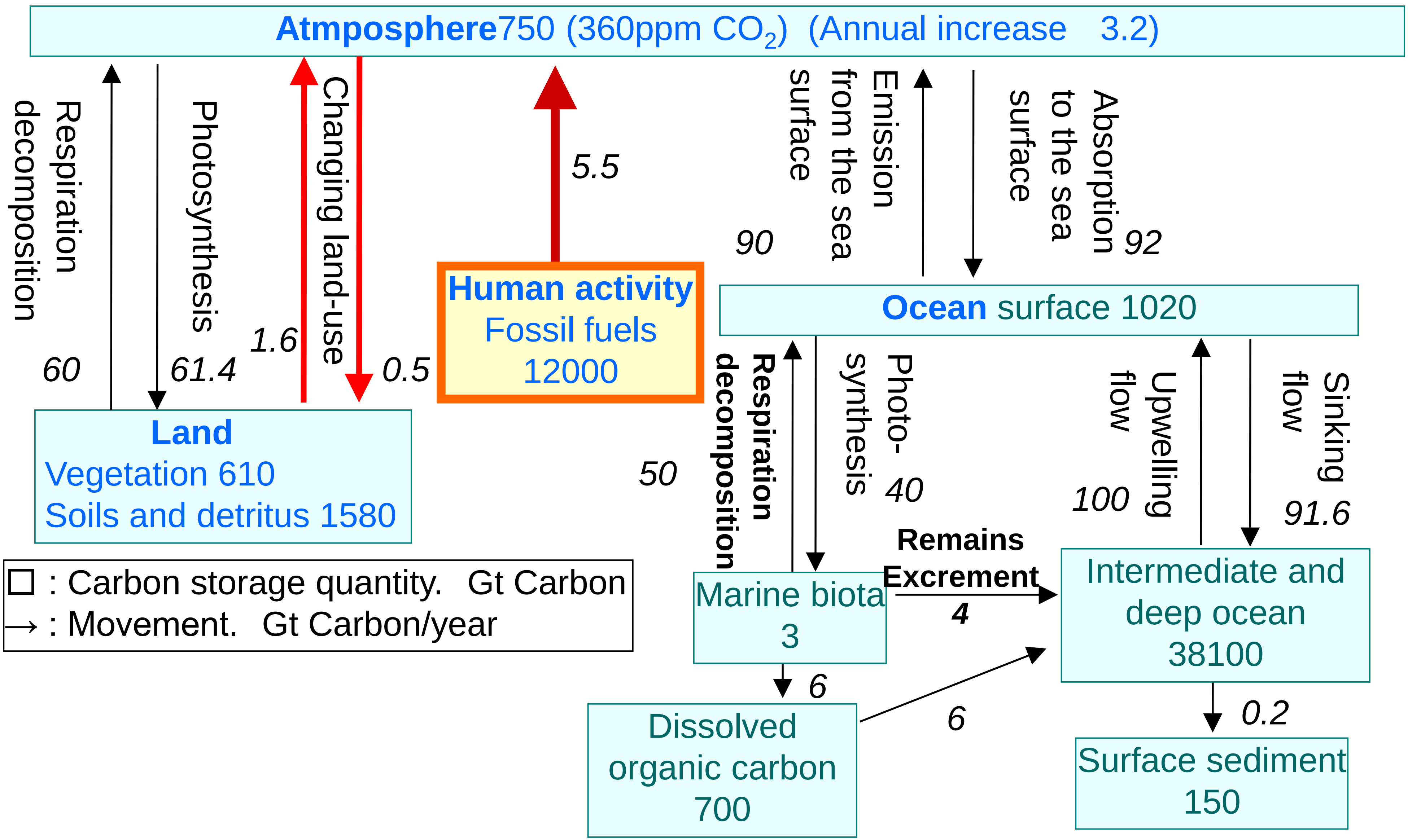

Water cycle on the earth

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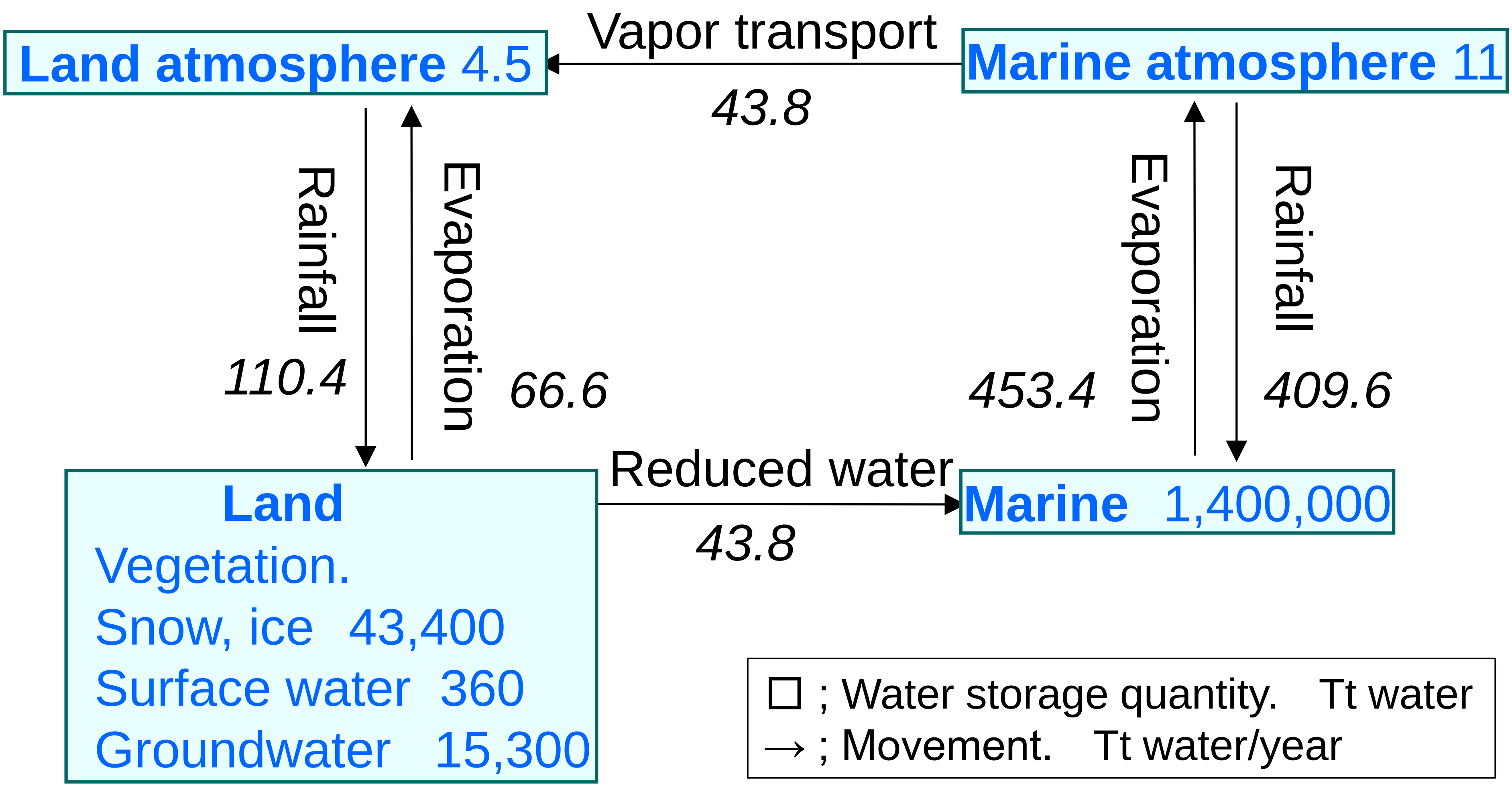

Hydrogen Economy and Water Circulation

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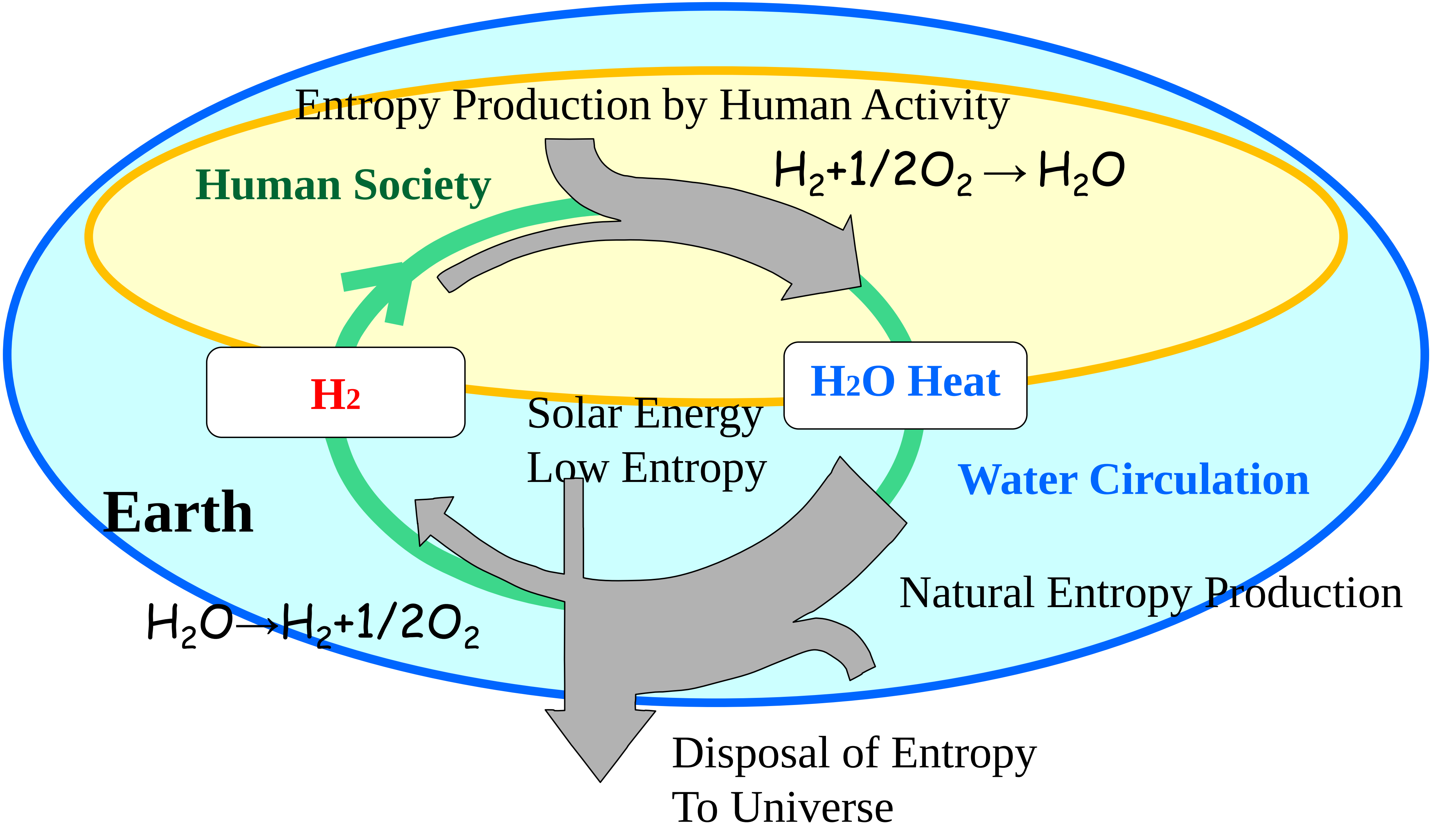

Comparison between water cycle and carbon cycle

	carbon		water
Total amount	54Tt	27000 Times	1,460,000Tt
Atmosphere abundance	750Gt	21Times	15.5Tt
Annual movement from atmosphere	152Gt/yr	3160 Times	496Tt/yr
Average retention period in atmosphere	5 yaer	180 Times	10 day

EIF (Environmental Impact Factor) of Carbon

Carbon (CO_2) Emission by Energy Consumption / Natural Carbon Circulation

	Earth	Japan
Natural Carbon Cycle	150Gt/y	0.37Gt/y
Carbon (CO2) Emission by Energy Consumption	5.5Gt/y	0.32Gt/y
EIF of Carbon	**0.036**	0.86

D.S.Shimel; Terrestrial ecosystems and the carbon cycle, global change biology(1995)

EIF (Environmental Impact Factor of Hydrogen

= (H_2O through H_2 Energy System) / (Natural Water Vaporization)

	Earth	Japan
Annual Vaporizaiton	5×10^{14}t /y	2.3×10^{11}t/y
H_2O through H_2 Energy System	5×10^{10} t/y	1.4×10^{9}t/y
EIF of H_2	～0.0001	0.006

Dependence of EIF on Consumption Density (2004-2013)

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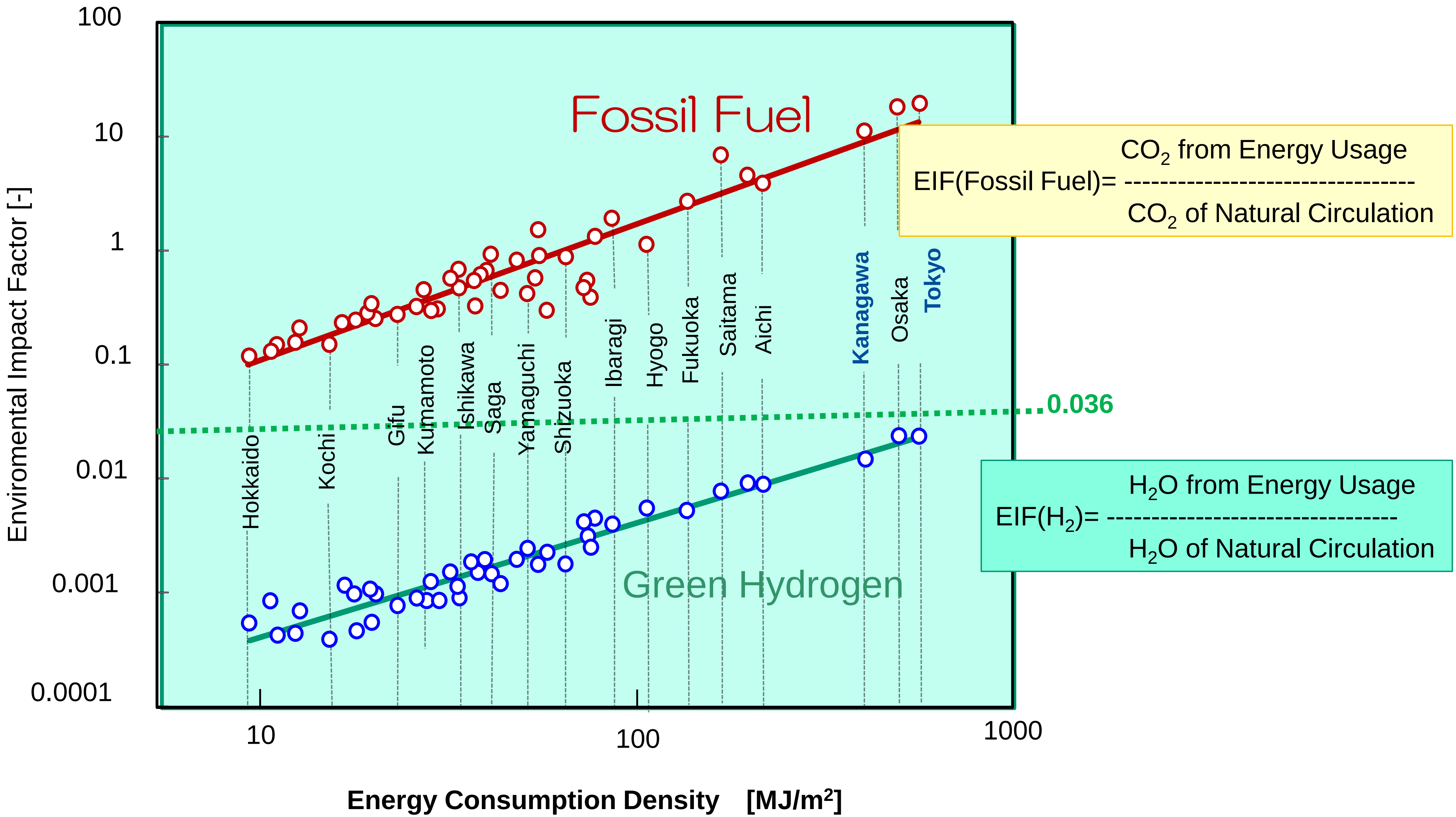

Green Hydrogen Energy System

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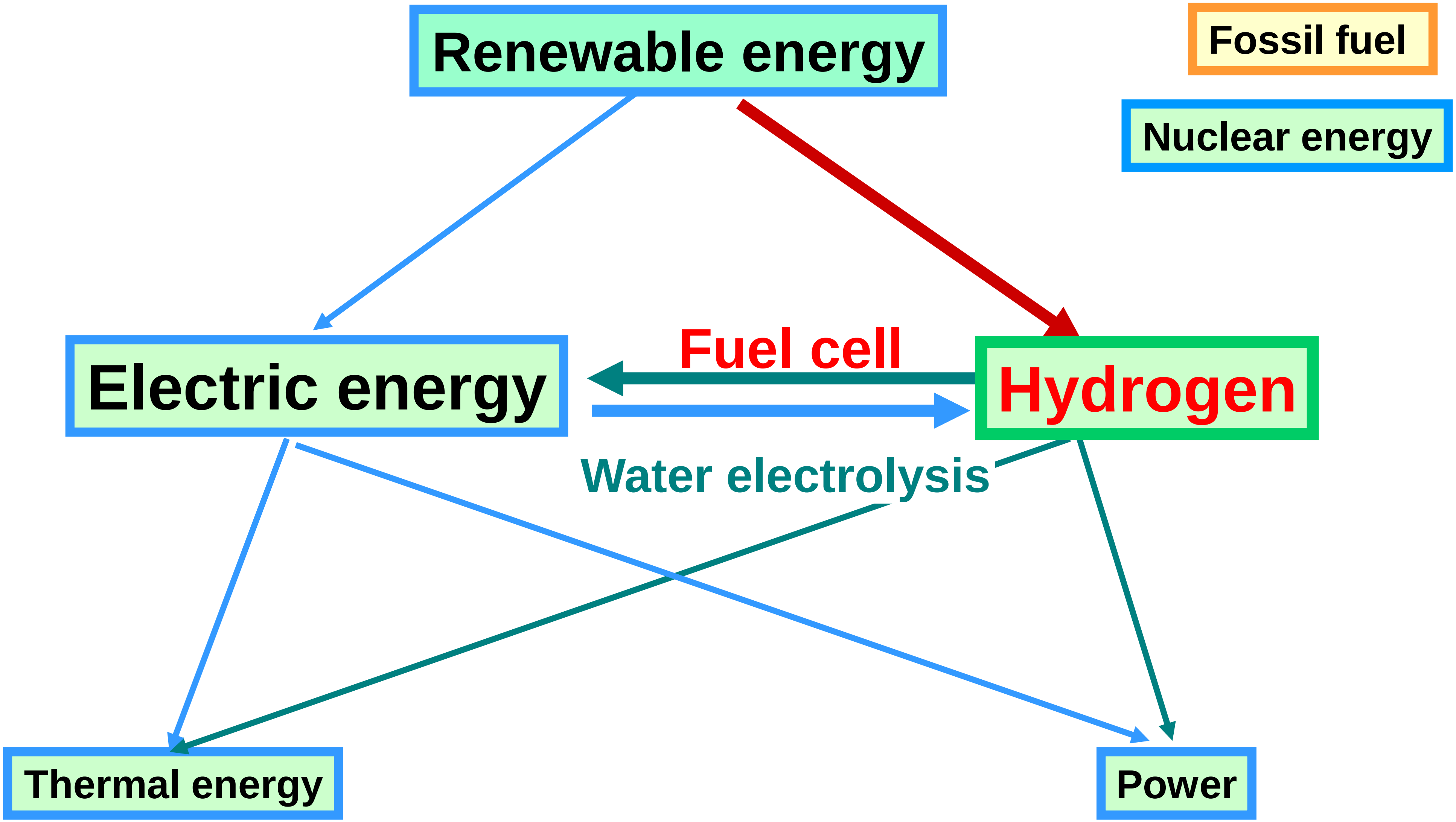

Green Hydrogen: Hydrogen from water using renewable energy.

Future of Primary Energy

Fossil Energy

Limited resources: ultra high efficiency for use

Nuclear Energy

Against earth quake and tsunami

Waste treatment

Safety science for nuclear usage

Renewable energy

Hydroelectric power

Photovoltaic power

Biomass energy

Geothermal energy

Wind power

Storage and Transport of Renewable Energies

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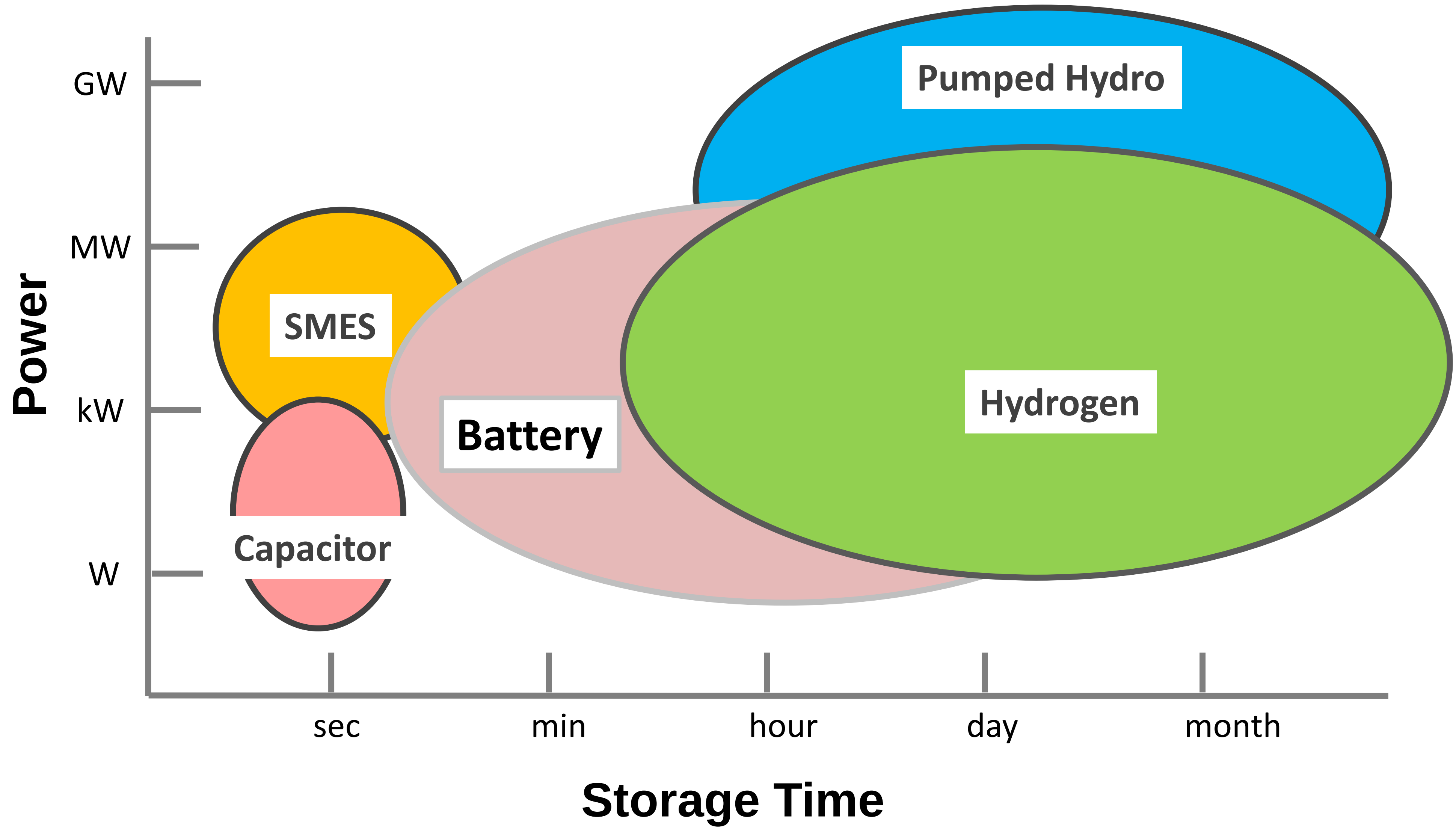
➢Storage of Electricity

- ◆Mechanical storage (compressed gas, fly wheel)
- ◆SMES
- ◆Capacitor
- ◆Battery
- ◆**Hydrogen (or chemical)**

  gas, liquid, metal hydride, organic hydride
- ◆Pumped hydro

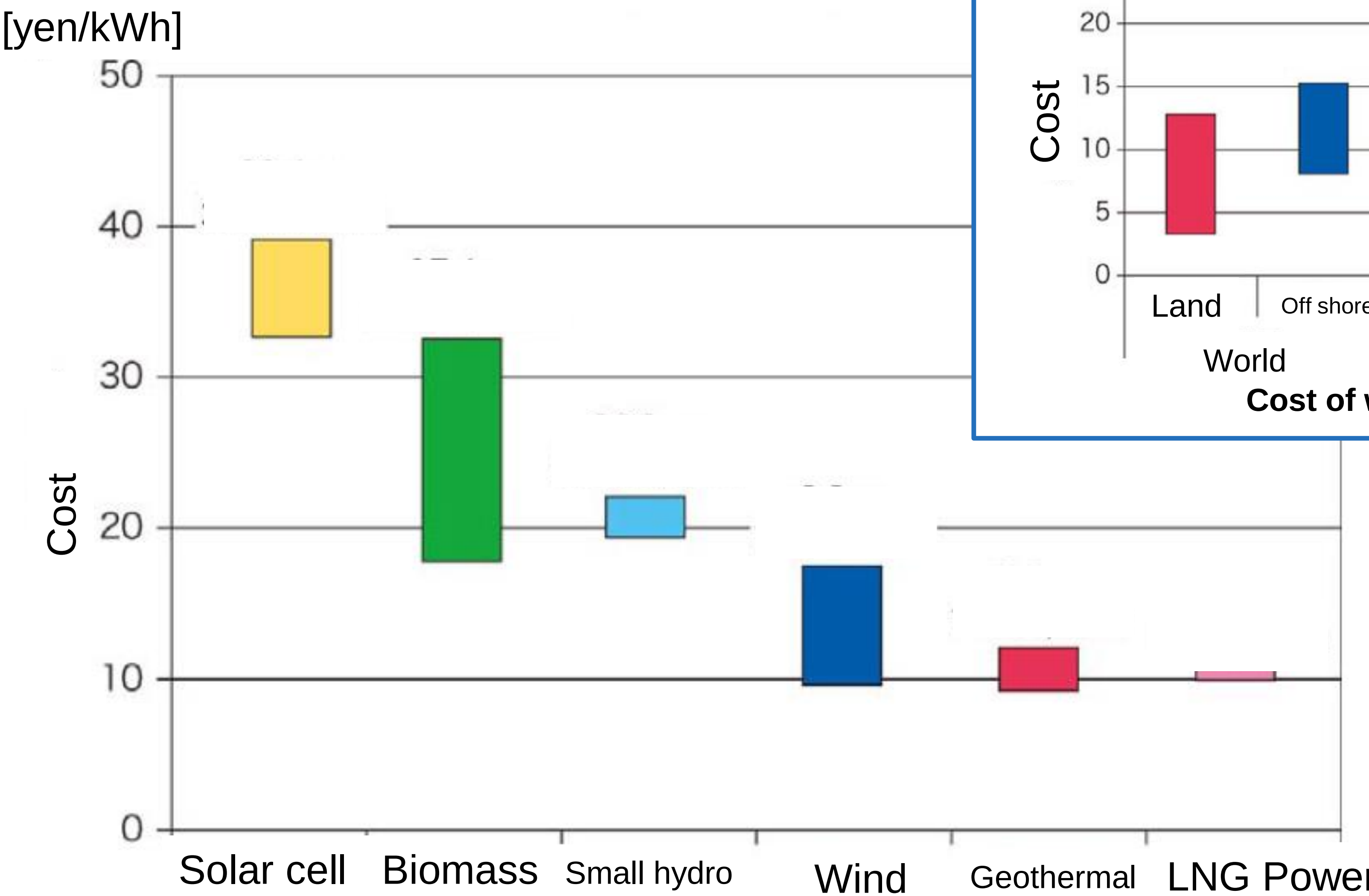
➢Long distance transport of electricity

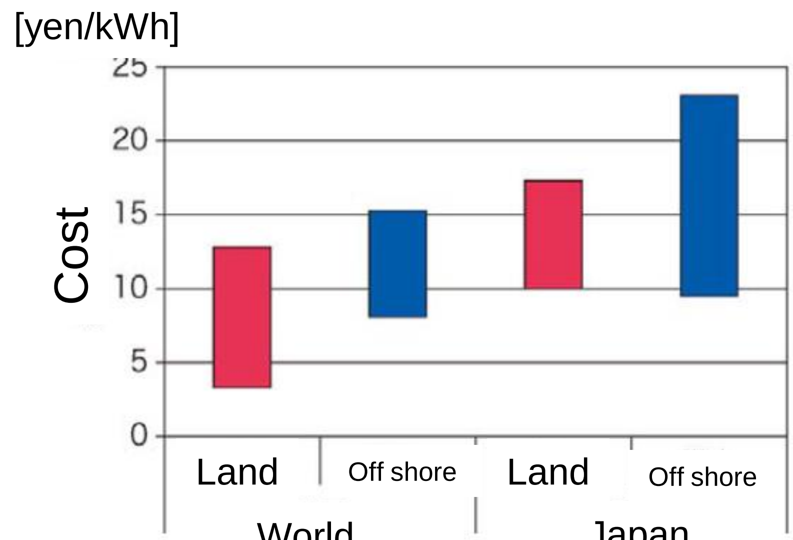
- ◆ Liquid hydrogen
- ◆ Organic hydrogen (Toluene/MCH system)



Comparison of storage system of electric power

Cost of power generation in Japan





Cost of wind power

（NEDO report）

Hydrogen production method

Hydrogen from water

- Water electrolysis : Electricity from renewable energy .

  Alkaline Water Electrolysis

  Polymer Electrolyte Water Electrolysis.

  High Temperature Water Vapor Electrolysis.

  .

- Thermochemical process : Heat (1000 ^{o}C or lower) of HTGR, solar heat etc.

  Multi-step chemical reaction

- Direct thermal decomposition : High temperature over 4000 ^{o}C.

  Separation at temperature.

- Photo decomposition : Photo-chemical reaction

  Complete decomposition using visible light is still impossible.

Characteristics of Water Electroysis

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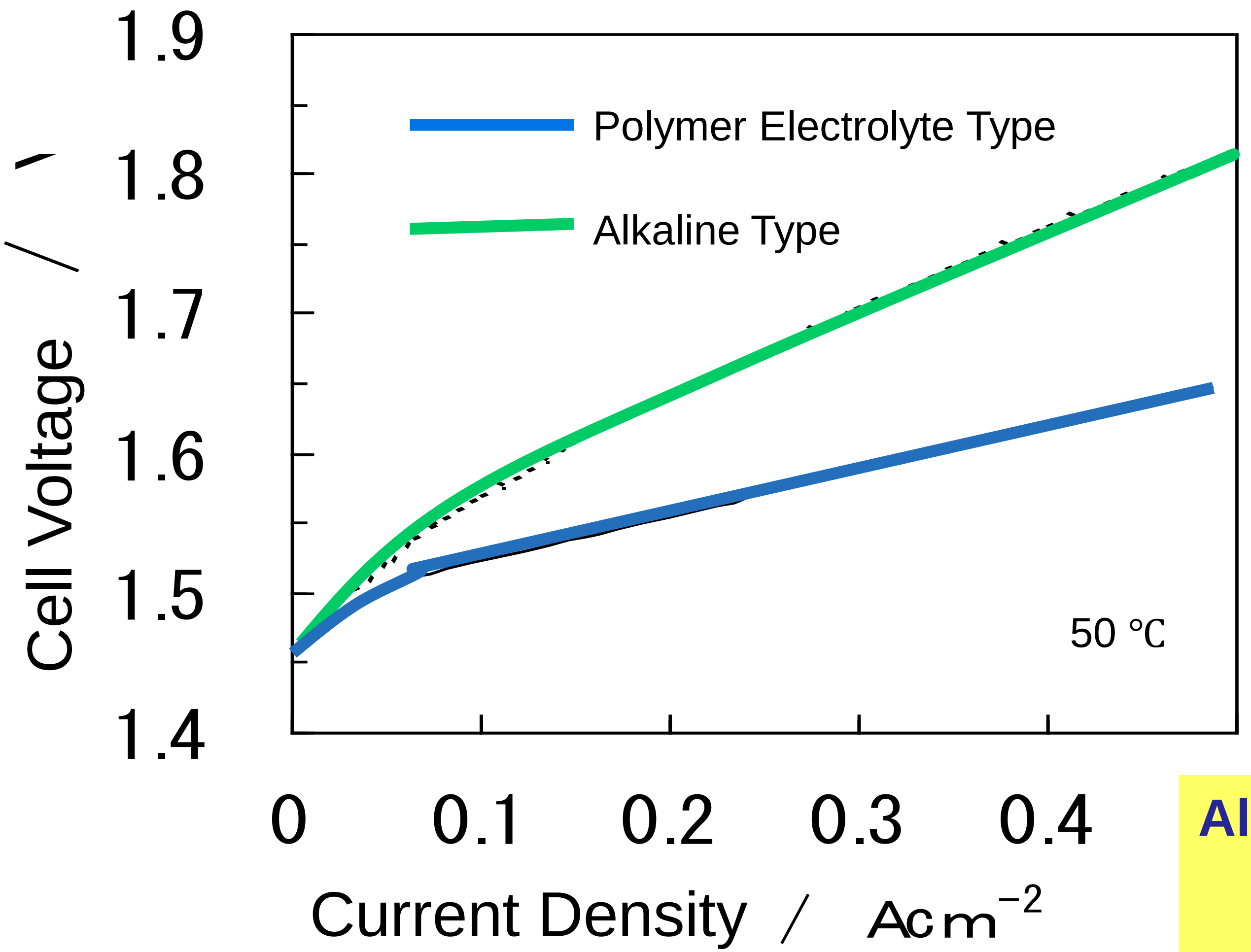

Alkaline Electrolyzer
- **Commercially available**
- **Cheap (Fe or Ni Electrode)**

Polymer Electrolyte Electrolysis
- **High Density, High Efficiency**
- **Expensive (Pt or Ir base)**

Polarization of Pt in Aqueous Solution

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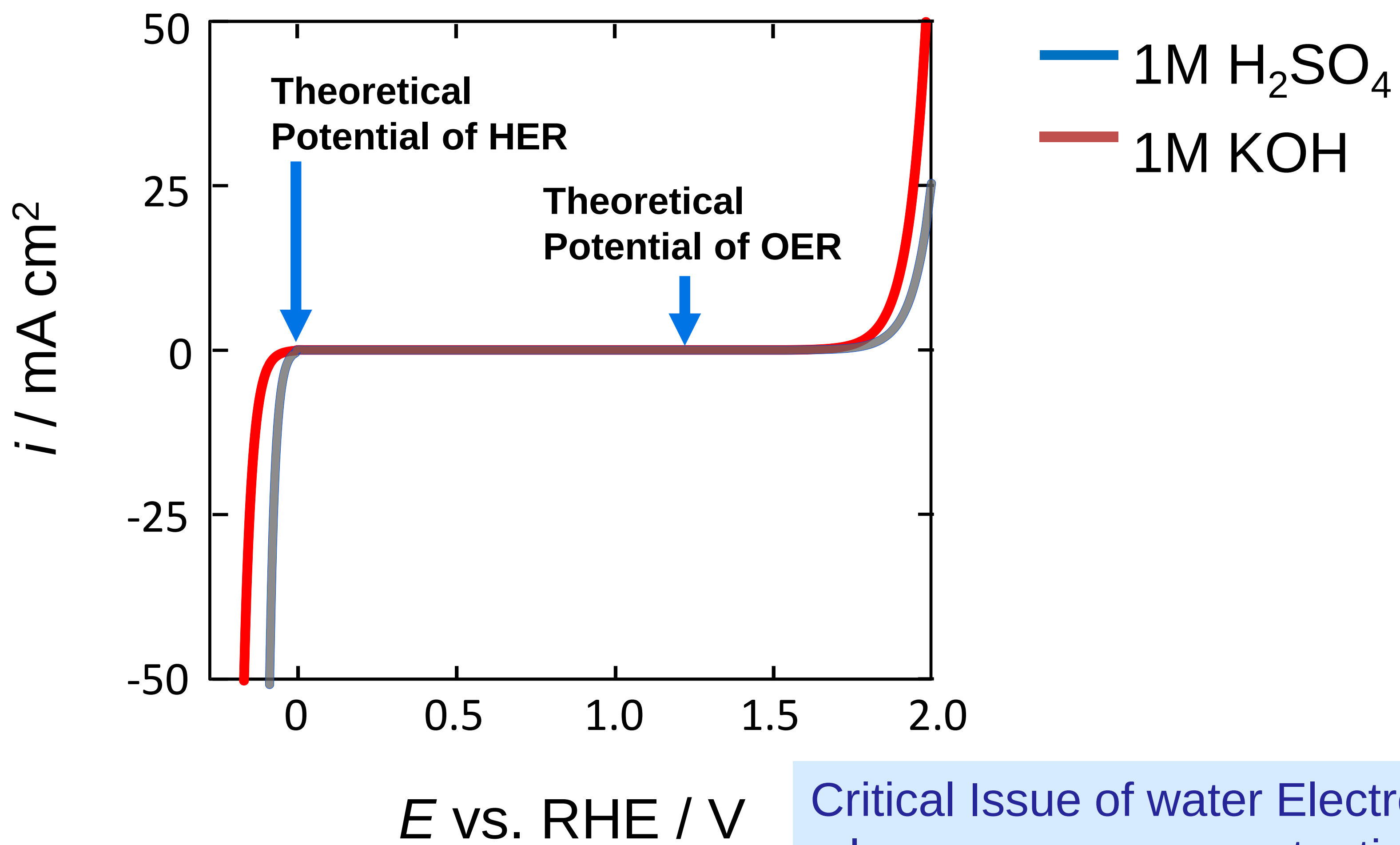

Critical Issue of water Electrolysis
large oxygen over potential
=> Voltage loss

A New Electrode Material is needed.

Commercial Alkaline Water Electrolyzers in 1970s

Green Hydrogen Research Center, Y.N.U.

Company	Stuart Energy (Electrolyzer)	ABB(BBC)	Norsk Hydro	De Nora	IHT(Lurgi)
Method	Monopolar	Bipolar	Bipolar	Bipolar	Bipolar
Pressure(kg/cm^2)	normal	normal	normal	normal	30
Temp.(℃)	70	80	80	80	90
Electrolyte(KOH, %)	28	25	25	29	25
Current Density(A/m^2)	1,340	2,000	1,750	1,500	2,000
Cell Voltage(V)	1.9	2.04	1.75	1.9	1.86
Current Efficiency(%)	>99.9	>99.9	>98	98.5	98.75
Power Consumption (kWh/Nm^3H_2)	4.9	4.9	4.9	4.6	4.5

Target: From 5 kWh/Nm^3H_2 to 4 kWh/Nm^3H_2

Energy change of water formation reaction(25^{o}C)

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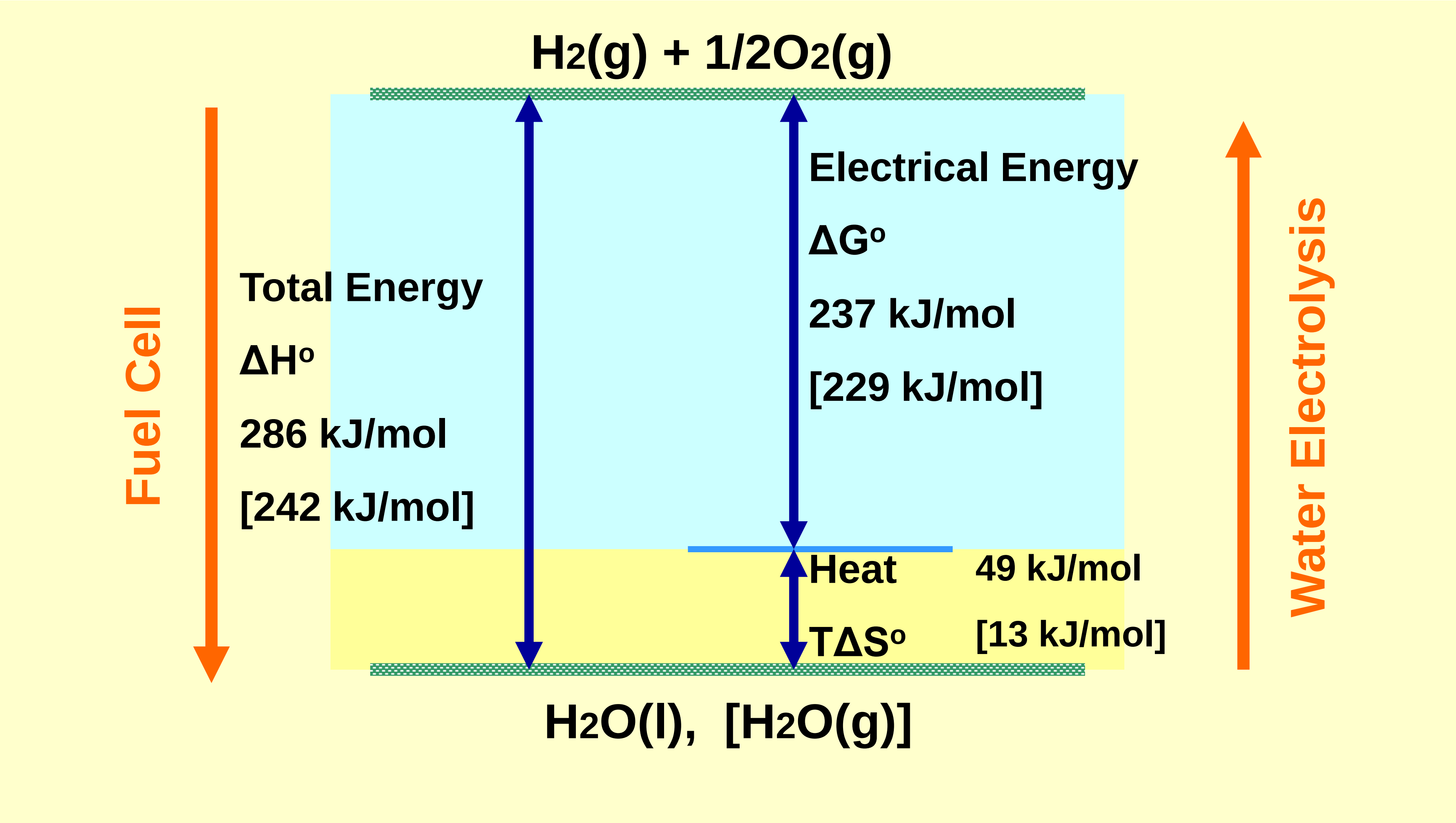

Temperature Dependence of Water Formation Reaction

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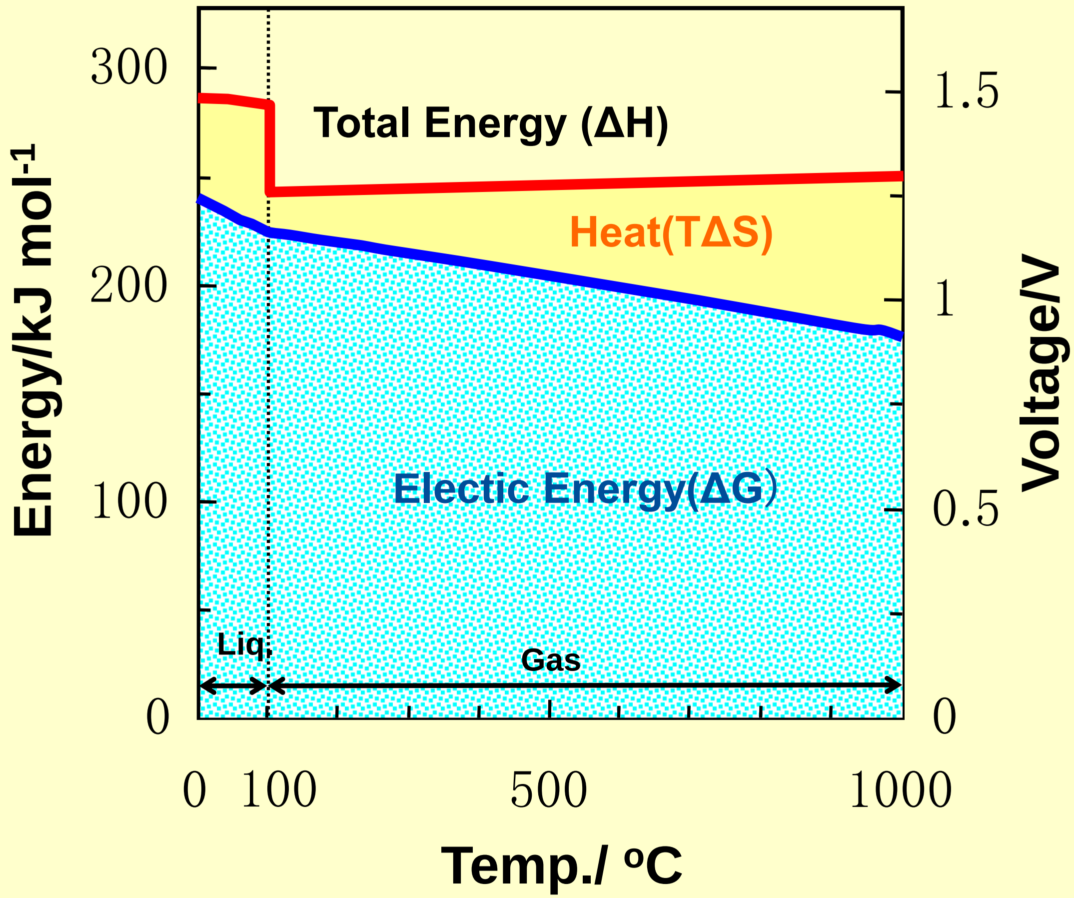

$H_2 + 1/2O_2 = H_2O$

Theoretical Voltage of Fuel Cell and Water Electrolysis

Low Temp. > High Temp.

Theoretical Efficiency of Fuel Cell vs Carnot Efficiency

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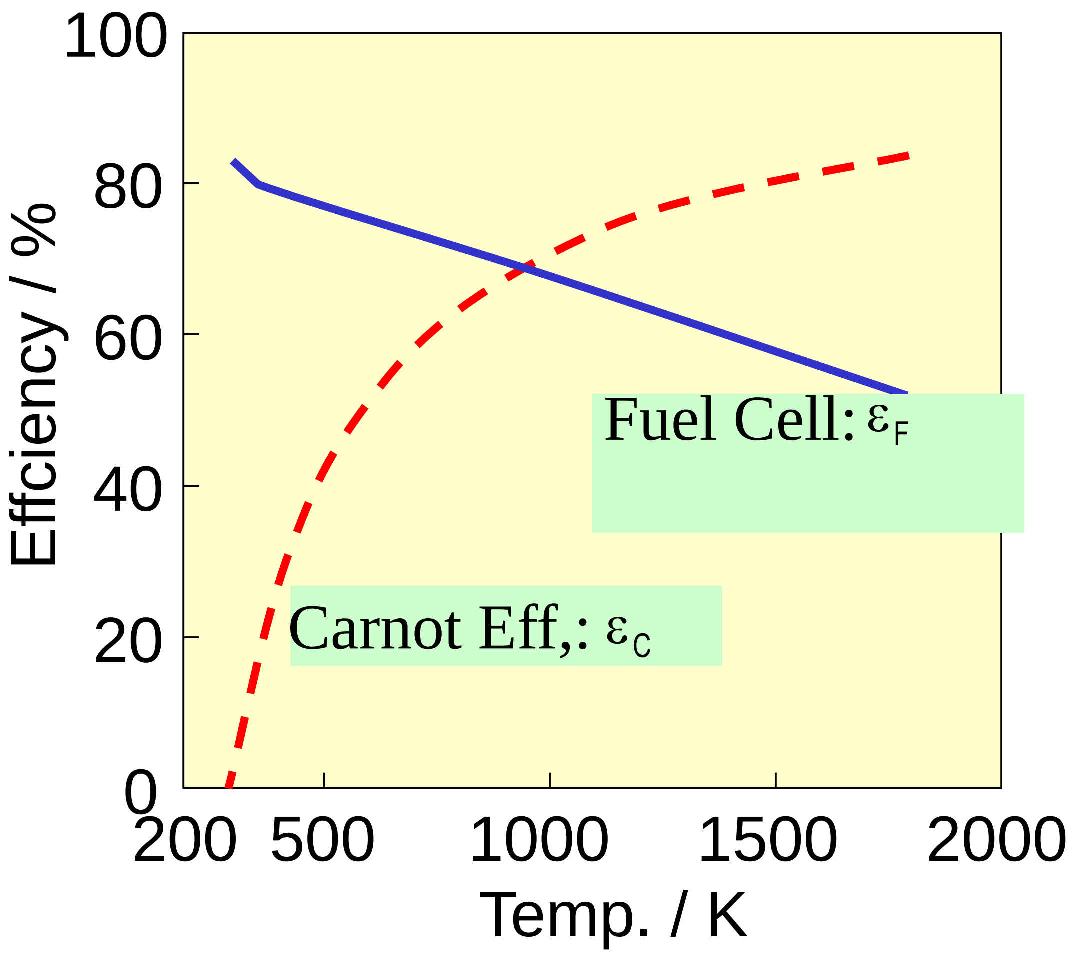


$$\varepsilon_F = \Delta G(T) / \Delta H^{o}(298)$$
(HHV)

$$\varepsilon_C = (T_H - T_L) / T_H$$

Fuel Cells

PEFC: Room Temp.～120℃

AFC:Room Temp.～200℃

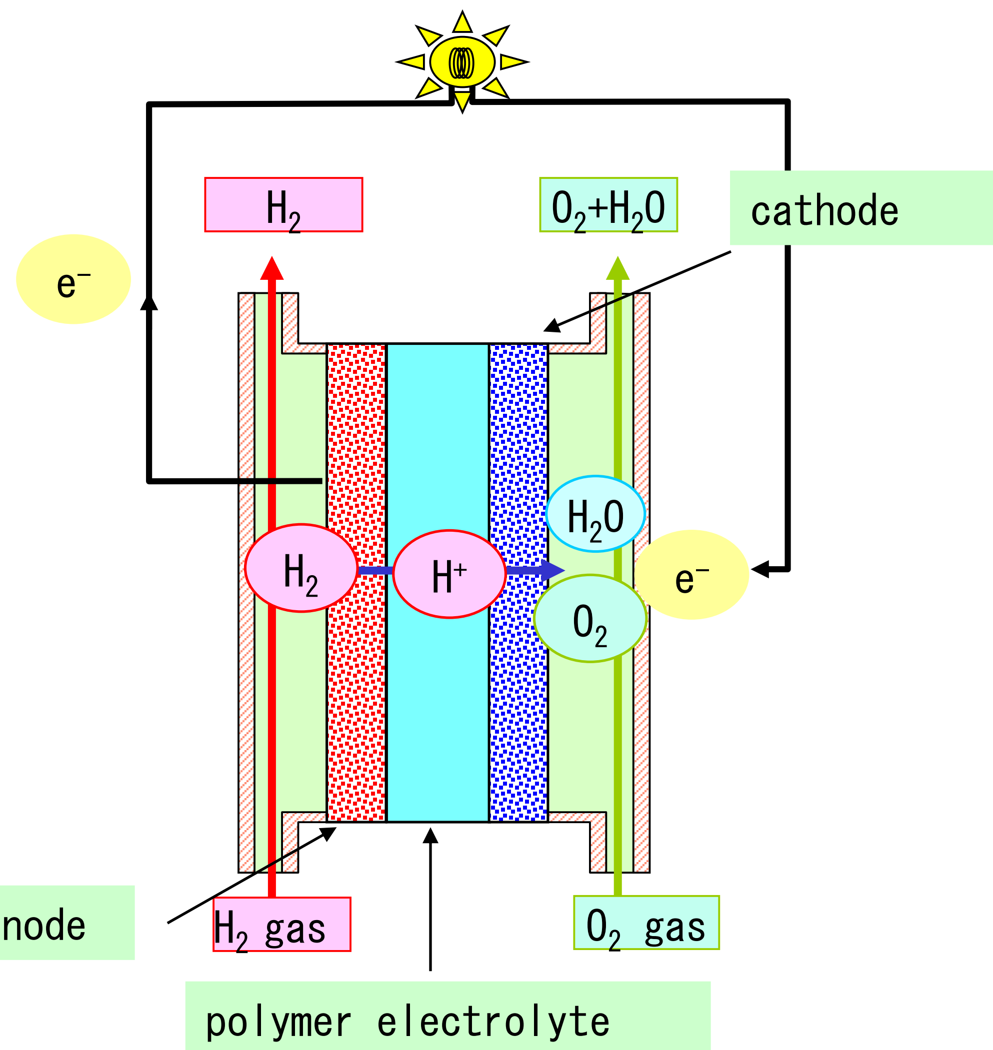
PAFC:120～200℃

MCFC:600～650℃

SOFC:600～800℃

Polymer Electrolyte Fuel Cell (PEFC)

Green Hydrogen Research Center, YNU



Characteristics

- High power density
- Low operation temperature

Applications

- Co-generation system (CHP)
- Fuel Cell Vehicle
- Mobile power source

Major technical issues

- Cost down
- Improvement of performance

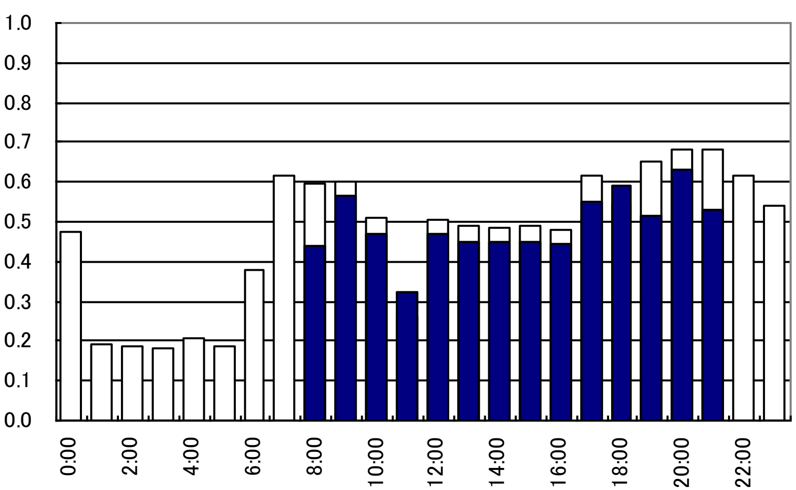
1 kW PEFC at my home (2005.7.09 -)

1 kW home cogeneration system
- The commercialization started in 2009.
- Over 300,000 units are operating in Japan.

Capacity
- 1 kW – 700 W
- Hot water (60ºC, 200 L)
- Daily Start and Stop without N_2 purge (Hot water oriented mode)

Life > 10 years

The cost target: 7,000 US$/unit in 2020.



Month	CO_2 Reduction kg-CO_2	CO_2 Reduction %
Jan	17.5	11.5
Feb	38.3	21.6
Mar	41.8	21.9

FCVs in Japan

Compressed H_2 gas (70 MPa)

Driving Range > 650 km

Life > 10 years (5000 h)

Cold start at - 30°C

Output Power: 3 – 3.5 kW/L

→ **NEDO's new target is 9 kW/L in 2040.**

Commercialization has started in 2014.

Target 200,000 FCVs with 320 H_2 Stations in 2025.

1st Hydrogen Fuel Cell Vehicle in Japan (1988)

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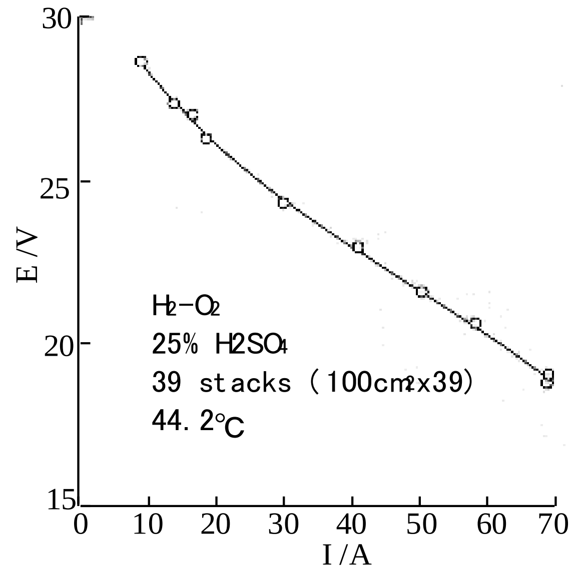
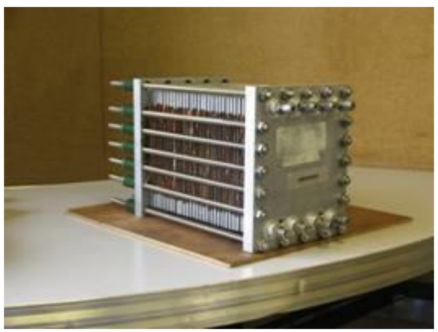




1.1 kW, H_2/O_2-100cm^{2}x39 cells
Sulfuric Acid Type
Speed: 30 km/h

S. Motoo, R. Hirasawa, K. Ota, R. Furuya (Yamanashi Univ., Univ. of Tokyo, Yokohama Nat. Univ.)

Problems of Pt catalyst

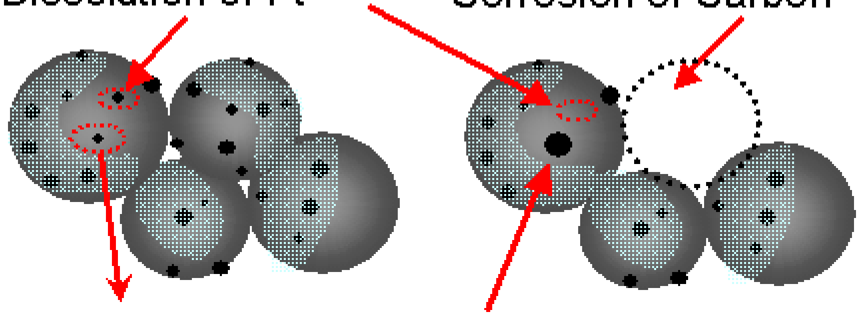
Problems of cathode catalyst

- **Resources of Pt**
  High cost and limited ! !

- **Instability of Pt cathode**
  Limit of reduction for Pt usage!

Dissolution of Pt

Corrosion of Carbon

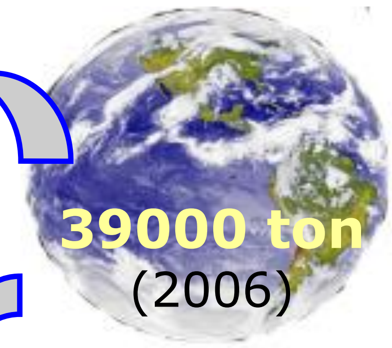


Agglomeration of Pt

100 kW FCV

→50 g Pt !!

Pt resources



800 million

Number of motor vehicles (2009)

965 million
(in the world)

Concept of Non Pt Cathode for PEFCs

High stability

High catalytic activity

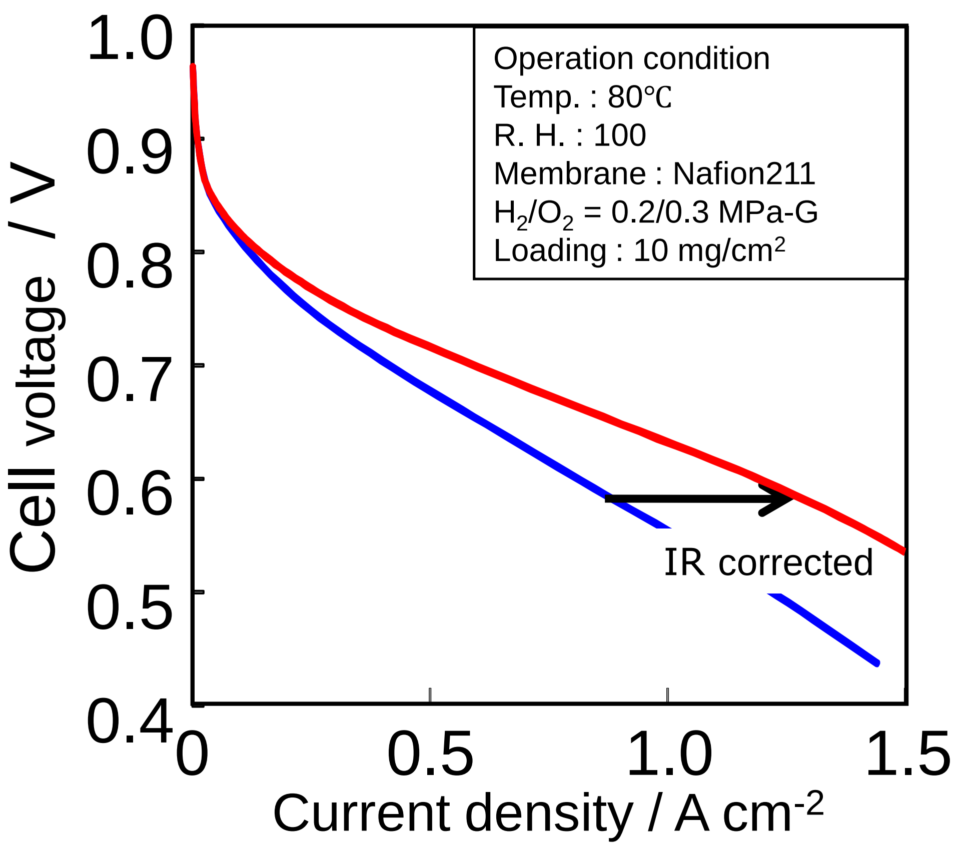
Combined

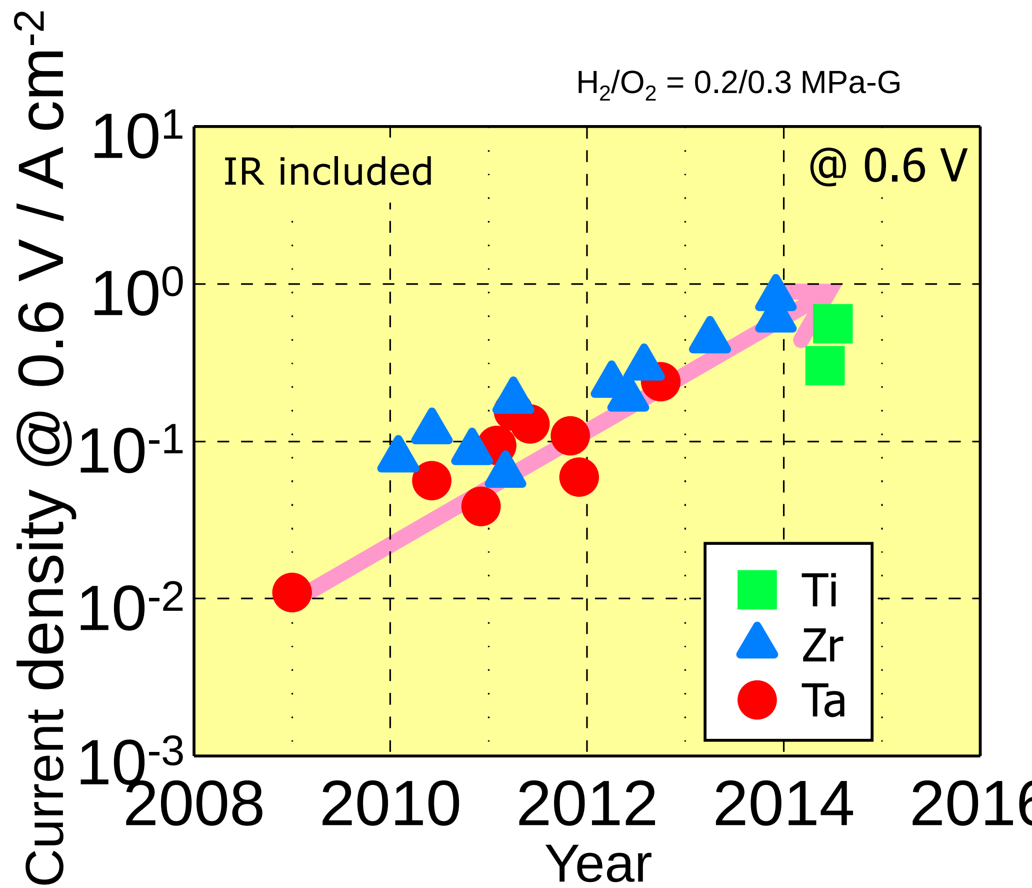
Group 4 and 5 metal oxides are stable in acid and O_2 .

→ **Development of innovative materials.**

Single cell performance

Zr oxide-based cathode





1.2 A cm^{-2} @ 0.6 V (IR corrected)

Cell performance increased drastically.

By Toppan Printing

PEFC for Future Generation

- More Stable Fuel Cell

- More Efficient Fuel Cell

Operating voltage: ~ 0.9 V
Energy Efficiency: ~ 60 %(HHV)
Operating temperature : 120 ºC or higher

Our target: NPGM Catalyst without Carbon.

Onset potential of oxide cathode

Green Hydrogen Research Center, YNU

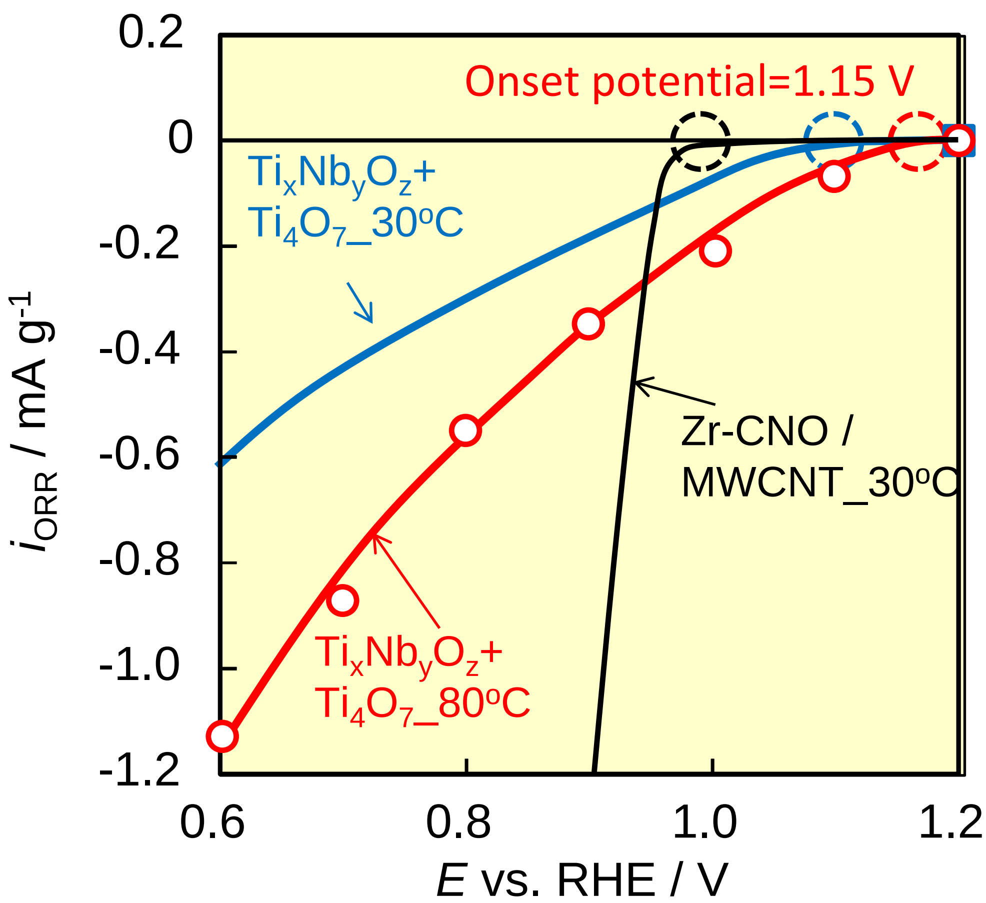


Fig. Potential-ORR current curves of $Ti_xNb_yO_z$+Ti_4O_7 and Zr-CNO/MWCNT.

High onset potential

⇩

High quality of active point.
More than Pt ?

Onset Potential during the potential Cycle

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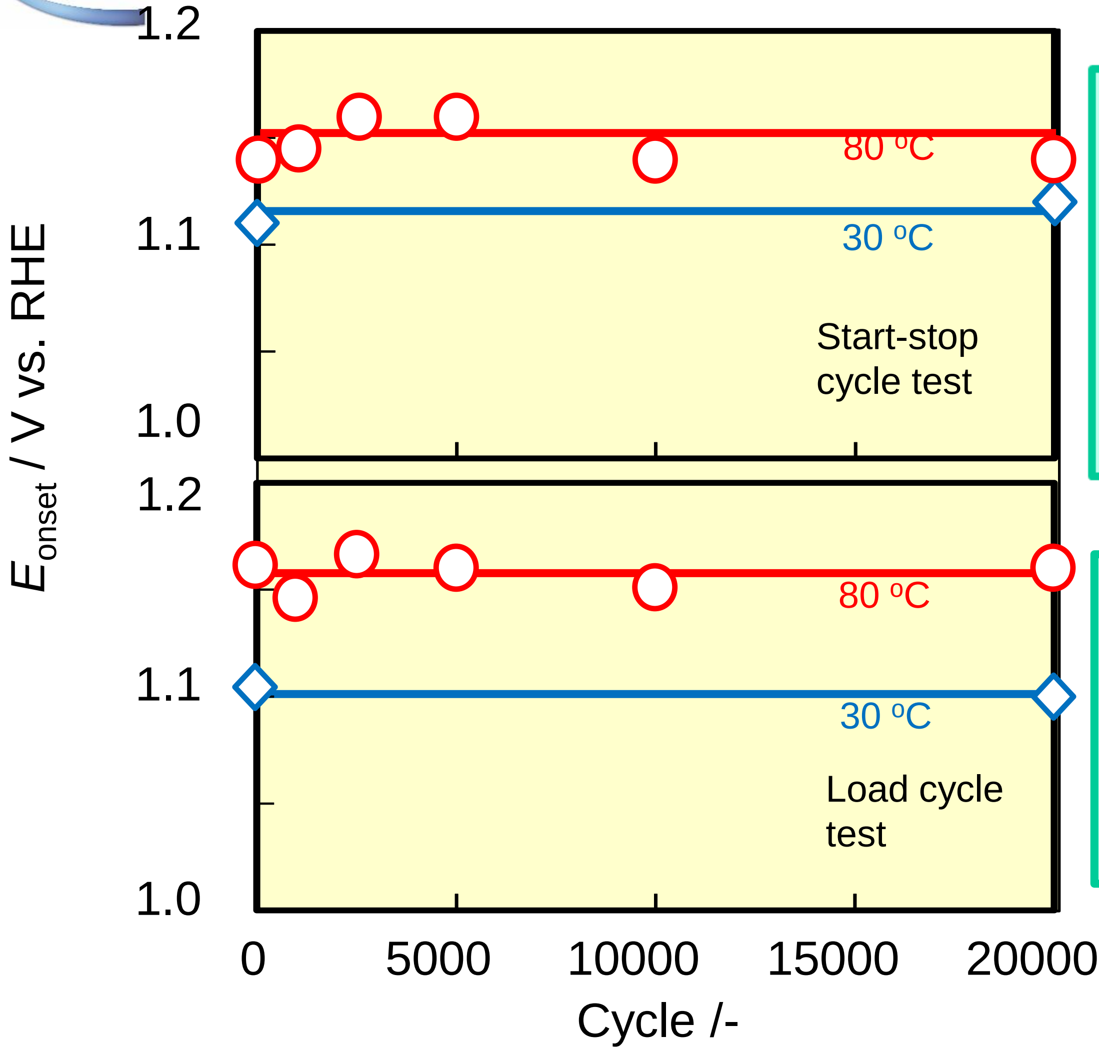

High onset potential

⇩

High quality of active point.
More than Pt ?

No change during cycles.

⇩

Active points are stable.

Fig. Onset potentials of $Ti_xNb_xO_z$ supported by Ti_4O_7.
E_{onset} ~ - 20 nA/cm^2, Ti:Nb = 85:15

Acknowledgment

The author thanks to the members of NPGM oxide cathode project for their help and the New Energy and Industrial Technology Development Organization (**NEDO**) of Japan for the financial support.

Green Hydrogen -

Key For the Future Sustainable Growth

Thank you for your kind attention!!