Techno Disruptions coming in Hydrogen and Fuel Cells

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Industrial Revolutions follow after Energy Paradigm Shift

- Mentioned in Jeremy Rifkin's "The Green New Deal, 2020"
- Global warming accelerates energy paradigm shift to carbon neutral by 2050
- AI tech. requires much more electricity than ever before: Pro Go Player Sedol Lee 20W vs. AlphaGo 130,000W

19c

Network	**Print, Telegraph**
Energy	**Coal**
Carbon Neutral	**Nuclear**
Powertrain	**Steam engine**

20c

Network	**Telephone, Radio, TV**
Energy	**Oil, Natural Gas**
Carbon Neutral	**H2, NH3, E-fuel**
Powertrain	**IC Engine, Turbine**

21c

Network	**Internet (IoT, 5G), AI**
Carbon Neutral	**Renewable, Nuclear, H2**
Powertrain	**Battery, Fuel Cell, Motor**

Unbalanced Hydrogen Eco-system

- Some saids 2050 Hydrogen Demand is 400 Mton ~ 800 Mton
- Only Maritime fuel: 1,160 Mton
  Rough Estimate:
  No. of ocean ships: 100,000 units
  Average Power: 30 MW (50% efficiency)
  Hydrogen demand: 40 ton/day/ship
  Operation: 290 days

Korea Weak
Korea Strong

H2 Supply (Production)

Electrolysis / Pyrolysis / Nuclear
Reforming / CO2 Capture

H2 Storage

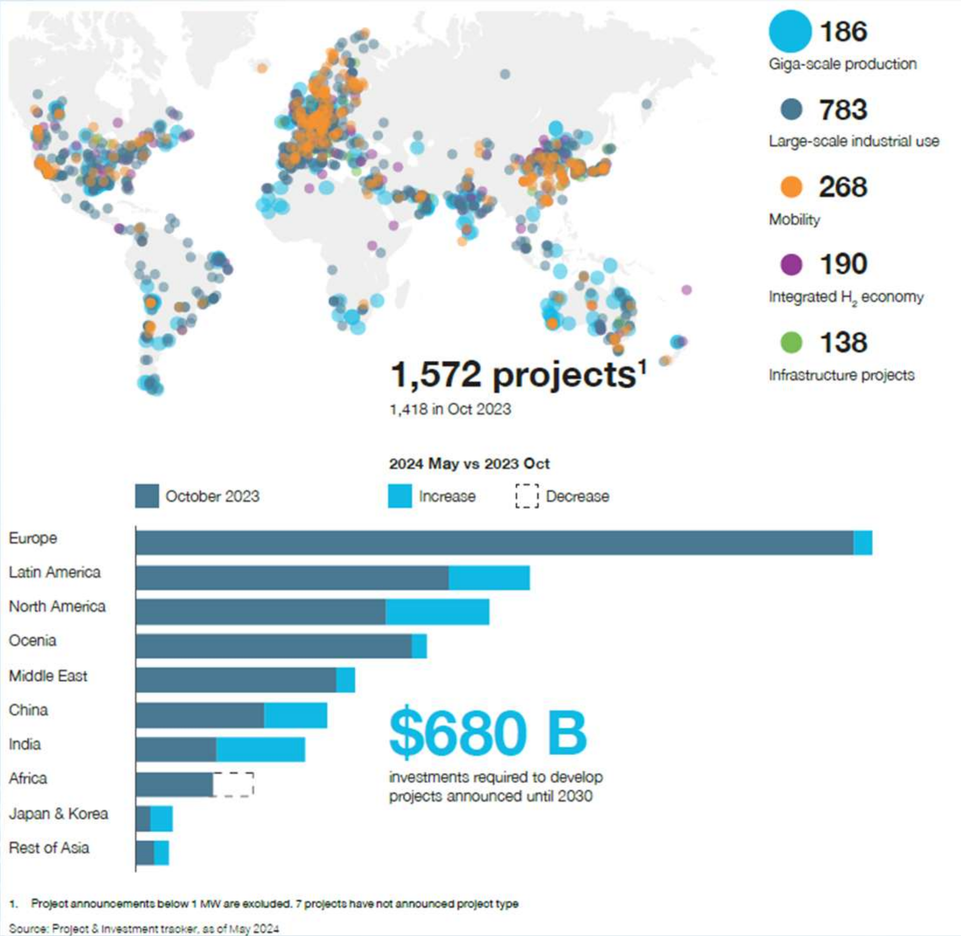
H2 Delivery

H2 Demand (Usage)

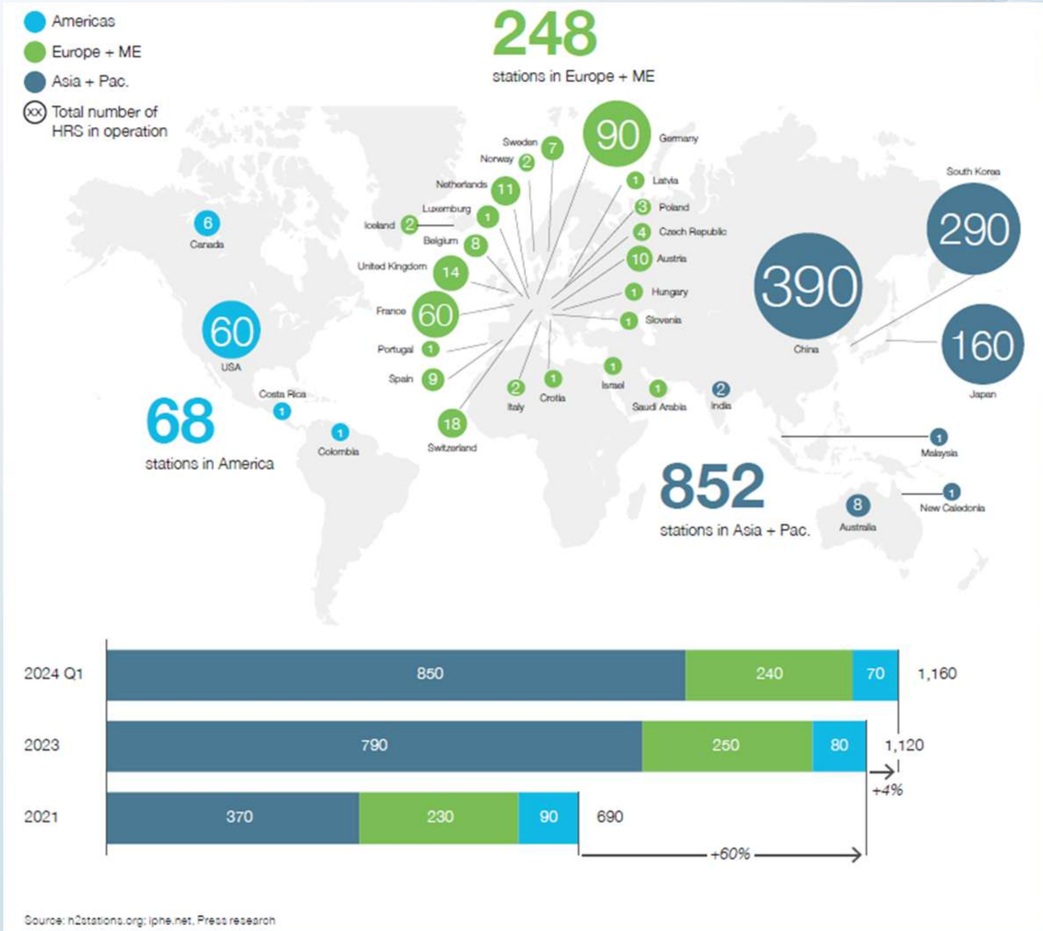
NH3 | Refining | Methanol etc. | Steel / Food | Smelting / Cement | Fuel Cell / Turbine | Fuel Cell / Engine / Turbine | CO2 Capture

Status of Global Green H2 Investment: Unbalance of Supply and Demand

※ Large Size Projects

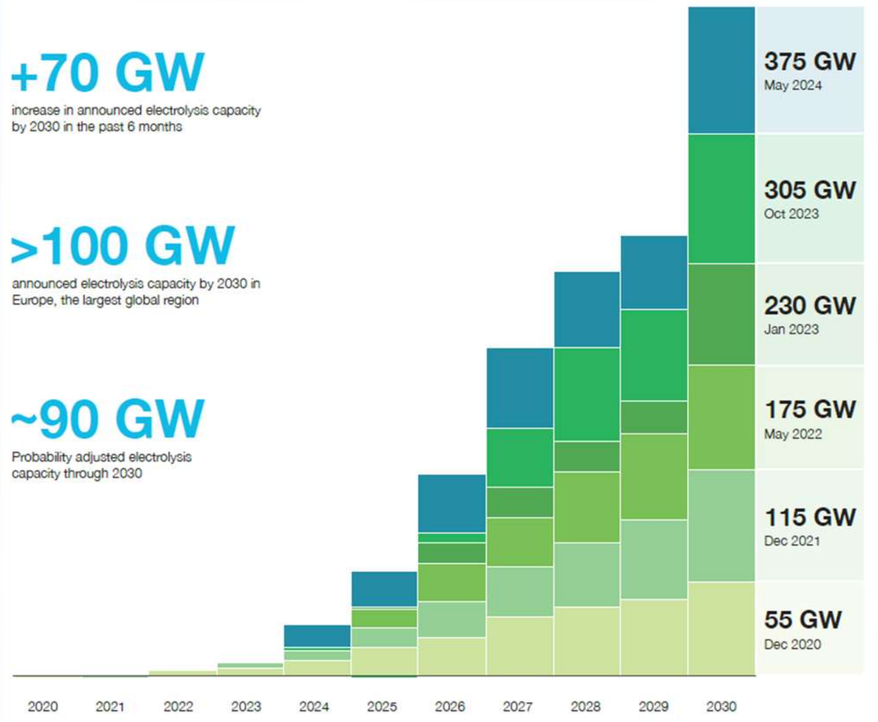


※ Construction of H2 Refueling Infrastructure



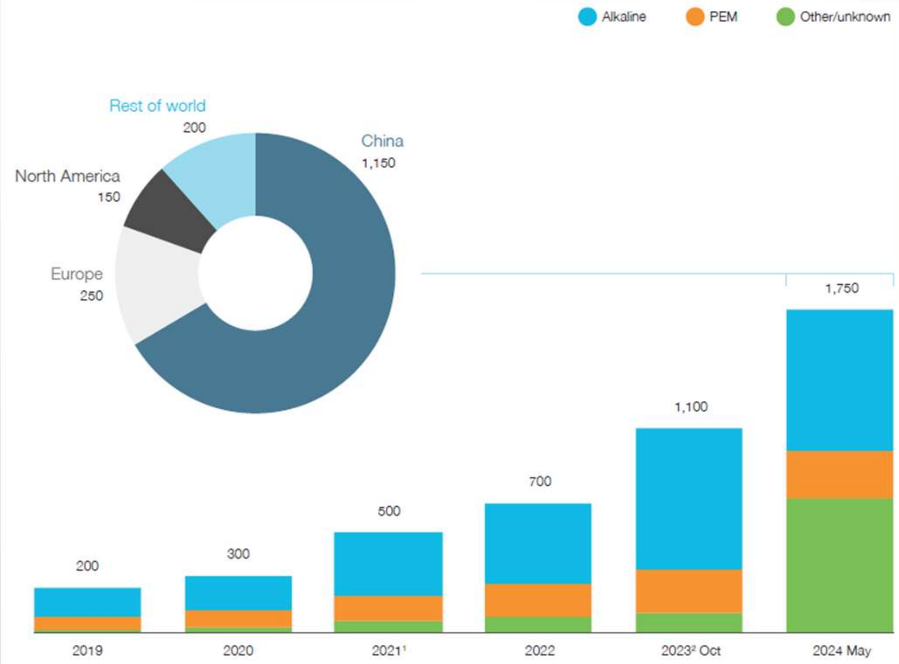
Cumulative electrolysis capacity (GW) & Actually installed(MW)

- Large electrolysis market exists and small capacity is actually installed → Huge chance for the business
- Carefully expect over 10,000GW by 2050 in order to achieve true Zero Carbon Society → 1600 Mton H2/year
- Electrolysis technologies are still not reliable, durable and cheap enough → Legal incentive and pressure (regulation) required



1. Announcements are based on publicly available data only; include projects that were announced in hydrogen production capacity and converted into electrolyzer capacity. For projects without known deployment timeline capacity additions were interpolated between known milestones; includes projects in all maturity stages.

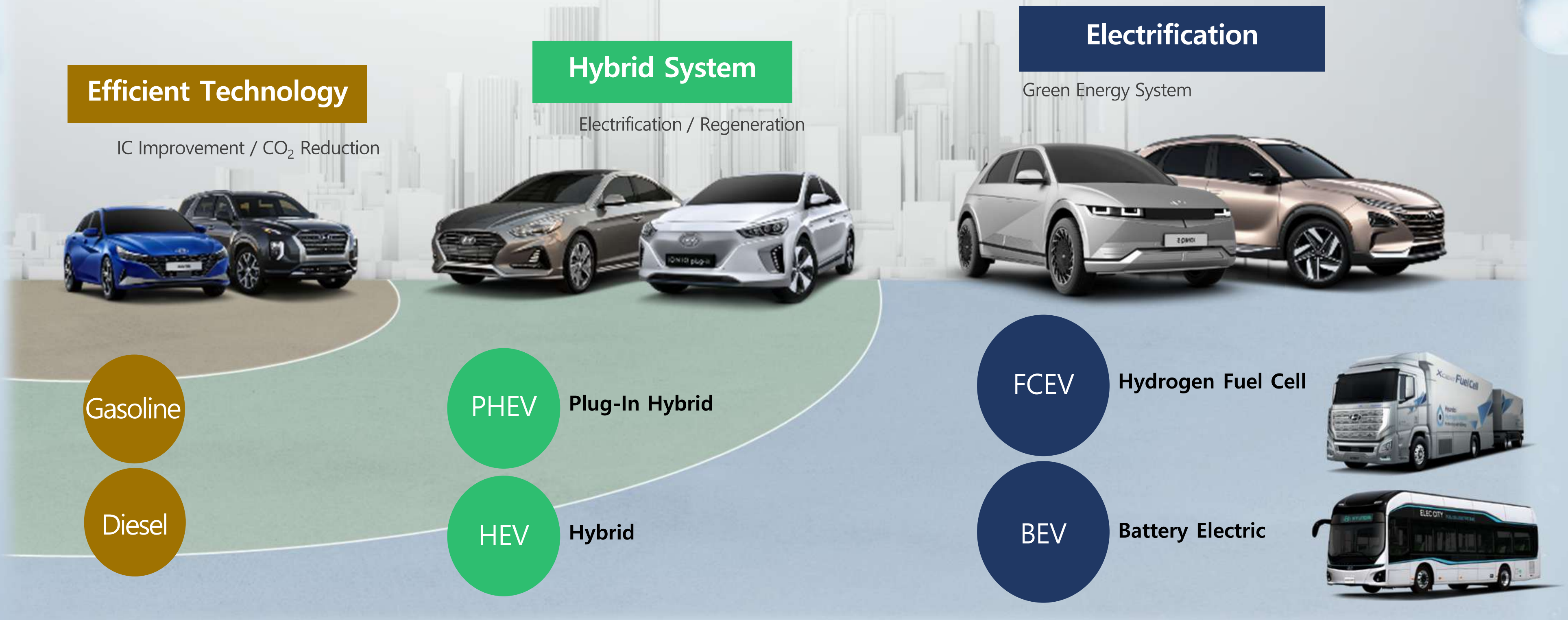
Source: Project & Investment tracker, as of May 2024



1. Growth from 2020 to 2021 driven by 160 MW Ningxia Project
2. Growth from 2022 to 2023 driven by 260 MW Kuqa Green Hydrogen Project, currently the largest operational electrolyzer

Source: IEA Global Hydrogen Review 2021 & 2022; Project & Investment tracker, as of May 2024

Road Mobility Electrification



※ Mass Production of Hybrid Systems

Toyota (6)	Honda (1)	Hyundai (2)	Ford (3)
1.8L, 2.0L, 2.5L, 4.0L, 2.4 Turbo, 3.5L Turbo	2.0L	1.6L, 1.6L Turbo (TMED-II 2.5L coming)	2.5L, 2.0L Turbo, 3.5L Turbo

※ Battery Cell Companies

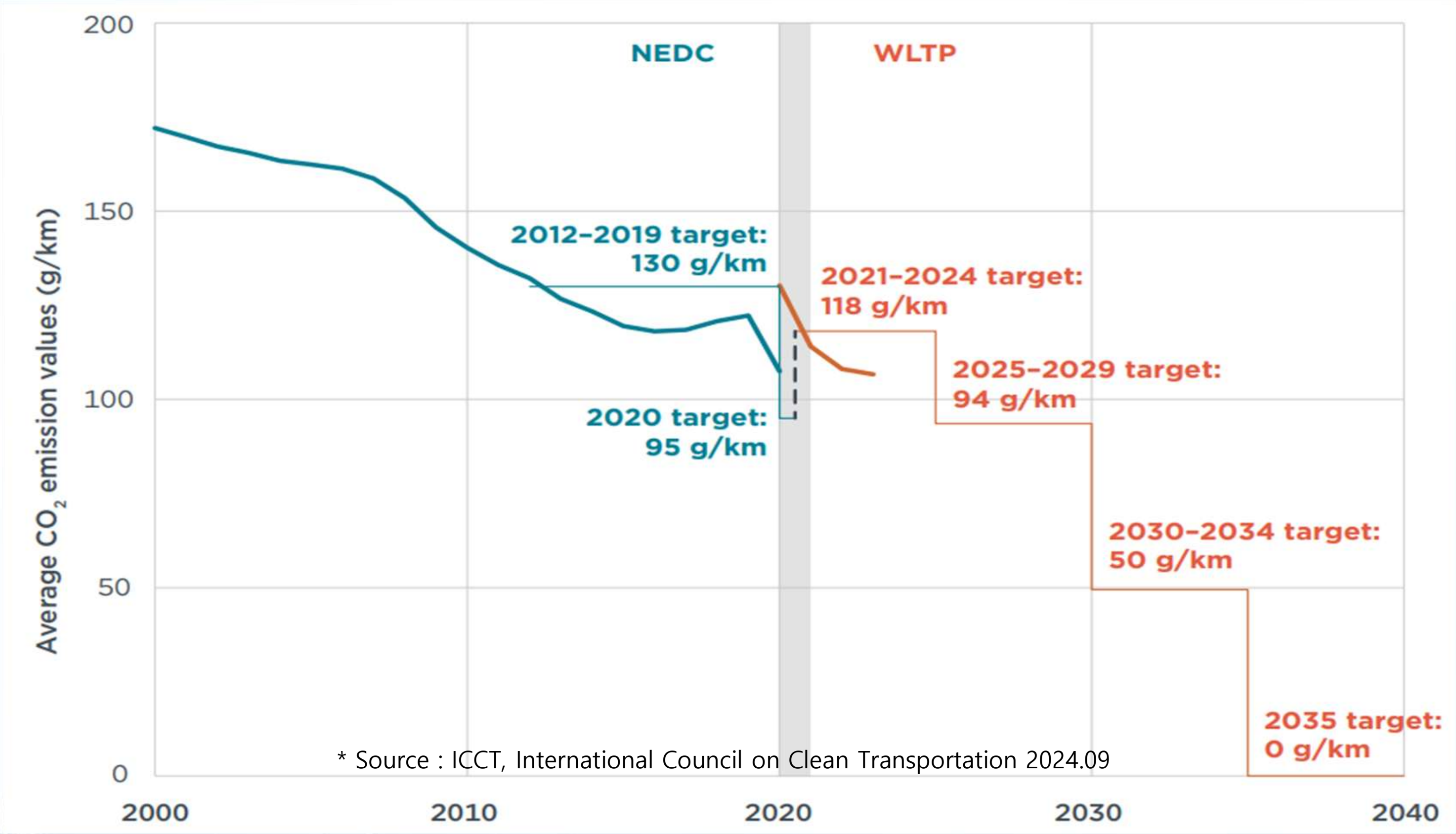
- LG Energy Solution
- SK on
- Samsung SDI
- CATL
- BYD (OEM)
- … Tesla?

※ Mass Production of Fuel Cell System

Hyundai (2)	Toyota (2)	Honda (2)
Tucson FCEV, NEXO FCEV NEXO2 (2025)	Mirai 1, Mirai 2 3rd Generation(2026)	Clarity, CR-V FCEV

EU CO2 Emission Standard for Cars and Vans (Passenger Cars)

- 2025 Target can be almost met when 100% HEV is sold → Toyota do not need BEV until 2030
- 2030 Target can be met with PHEV or Mix of HEV and BEV
- 2035 BEV and FCEV possible, and also H2 or NH3 ICE



* Source : ICCT, International Council on Clean Transportation 2024.09

※ 2015 Penalty at the view of 2000
Selling 1M units per year

(170-130) X 95EURO X 1M = **3,800M EURO**

Good Intentions and
Guidances do not work.
The Answer is Penalty!!

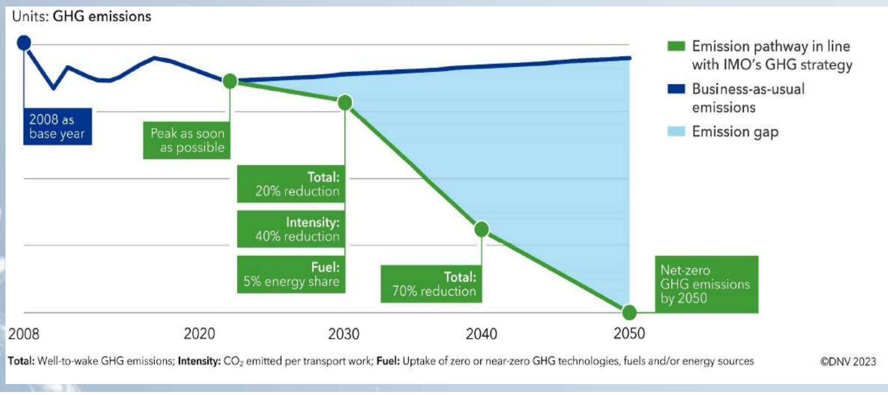
Maritime / Aviation Electrification: No competition with Battery Technology

Fuel Cell Technology for Maritime

1. Auxiliary Power Supply → Main Power for Ferry → Large Ship
   (Required Power: 3~75MW, Container 75, LNG 30, Oil Tanker 20, Tug 3)

2. FuelEU Maritime Regulation become fully active from Jan. 2025
   → More powerful than EU CO2 regulations for passenger vehicles

3. IMO Strategy on Reduction of GHG Emissions ('23.7): Zero by 2050



Fuel Cell Technology for Aviation

1. Ban of Short Distance Domestic Flights: France and Austria

2. Extreme Technical Requirements: High Power Density, High Energy Density, High Temperature Operation

3. Airbus Targets to Mass Produce 100 Passenger Fuel Cell Aircraft by 2035
   (Required Power: 8~12MW)

4. RefuelEU Aviation active from Jan. 2025, submission starting in Jan. 2025
   → Regulating mixed portion of SAF (2025 2%, 2030 20%, 2025 70%)

IMO Net Zero Framework (2025. 04. 11)

Good Intentions and
Guidances do not work.
The Answer is Penalty!!

- Defined GHG Fuel Intensity (GFI)
- Determined Base Target and Direct Appliance Target GFI_T 책정

$$GFI_{attained} = \frac{\sum_{j=1}^{J} EI_j \times Energy_j}{Energy_{total}}$$

$GFI_T = (1 - Z_T/100) \cdot GFI_{2008}$ $GFI_{2008} = 93.3\ gCO_2eq/MJ$

Tier 1 compliance deficit =
(Direct compliance target annual GFI – Attained annual GFI) × $Energy_{total}$,

Tier 1 compliance deficit =
(Direct compliance target annual GFI – Base target annual GFI) × $Energy_{total}$

And

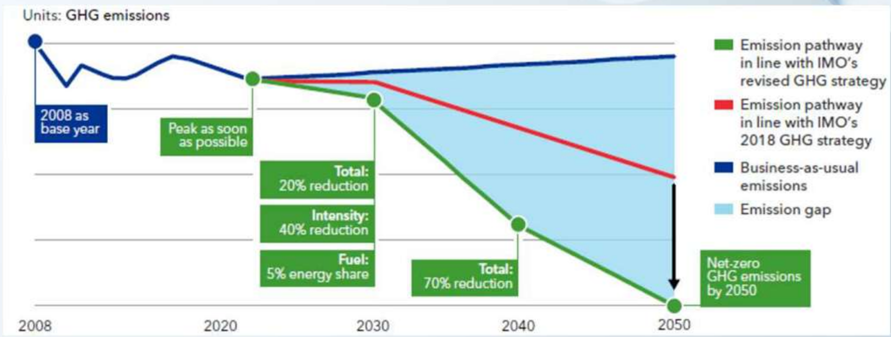
Tier 2 compliance deficit =
(Base target annual GFI – Attained annual GFI) × $Energy_{total}$

- Pena;lty ('28~'30): Penalty of '31 will be decided in '28

1) not meeting Direct compliance target : \$100/Ton CO2

2) not meeting Base target: \$380/Ton CO2

What does this mean to the operators:
Price of HFO: ≒ \$600/tonHFO
CO2 production: 3.11ton/tonHFO
Max. Penalty: **\$1,182 per ton HFO**



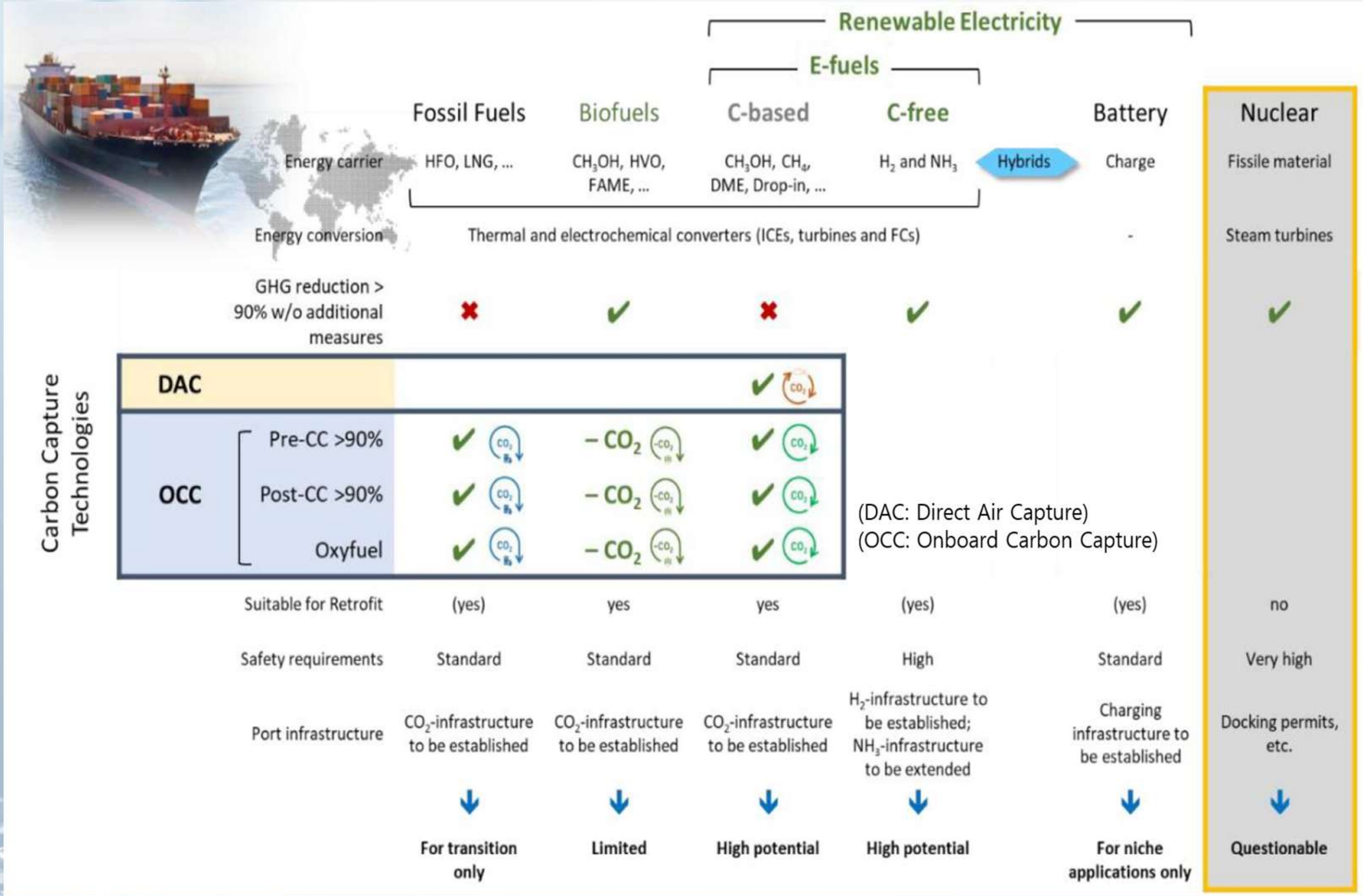
$Year_T$	Z_T for Base target	Z_T for Direct compliance target
2028	4.0%	17.0%
2029	6.0%	19.0%
2030	8.0%	21.0%
2031	12.4%	25.4%
2032	16.8%	29.8%
2033	21.2%	34.2%
2034	25.6%	38.6%
2035	30.0%	43.0%

Base target of '40 is finalized to 65%

Additional penalties for EU

1. FuelEU maritime : The penalty is based on the amount and cost of renewable and low-carbon fuels the ship should have used to meet the requirements. It is set at **€2400 per ton of VLSFO (Very Low Sulfur Fuel Oil) equivalent** exceeding the limit.(e.g., 2% reduction by 2025, 80% by 2050 compared to a 2022 baseline)
2. EU Emissions Trading System (ETS) : The primary penalty is **€100 for each tonne of excess CO2 equivalent emitted + Operation restrictions**

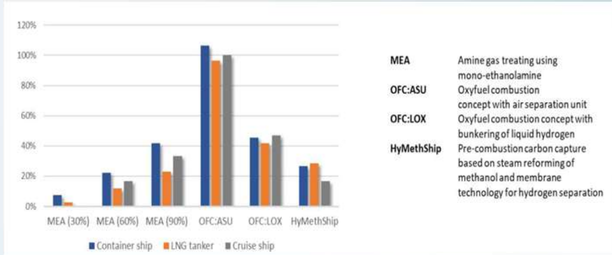
Decarbonization pathways for ocean-going vessels (Graz Uni, International Vienna Motor Symposium 2025)


Renewable Electricity

E-fuels

	Fossil Fuels	Biofuels	C-based	C-free		Battery	Nuclear
Energy carrier	HFO, LNG, ...	CH_3OH, HVO, FAME, ...	CH_3OH, CH_4, DME, Drop-in, ...	H_2 and NH_3	Hybrids	Charge	Fissile material
Energy conversion	Thermal and electrochemical converters (ICEs, turbines and FCs)					-	Steam turbines
GHG reduction > 90% w/o additional measures	✘	✔	✘	✔		✔	✔
Carbon Capture Technologies: DAC			✔				
Carbon Capture Technologies: OCC – Pre-CC >90%	✔	$-CO_2$	✔				
Carbon Capture Technologies: OCC – Post-CC >90%	✔	$-CO_2$	✔				
Carbon Capture Technologies: OCC – Oxyfuel	✔	$-CO_2$	✔				
Suitable for Retrofit	(yes)	yes	yes	(yes)		(yes)	no
Safety requirements	Standard	Standard	Standard	High		Standard	Very high
Port infrastructure	CO_2-infrastructure to be established	CO_2-infrastructure to be established	CO_2-infrastructure to be established	H_2-infrastructure to be established; NH_3-infrastructure to be extended		Charging infrastructure to be established	Docking permits, etc.
	For transition only	Limited	High potential	High potential		For niche applications only	Questionable

(DAC: Direct Air Capture)
(OCC: Onboard Carbon Capture)



Increase in fuel consumption using Carbon Capture technologies

- Produces more CO2 → more fuel cost
- Engergy needed mainly for liquifacion of CO2
- Additional 3 times size of fuel tank to store liquid CO2
- What if the country of the port cannot store CO2?
  Like Korea and Japan etc. → Export CO2 to middle east?

C-based E-fuels vs. C –free (E-NH3)

1st Produce renewable H2: Already expensive

2nd Direct Carbon Capture from Air : CO2 concentration 0.045%

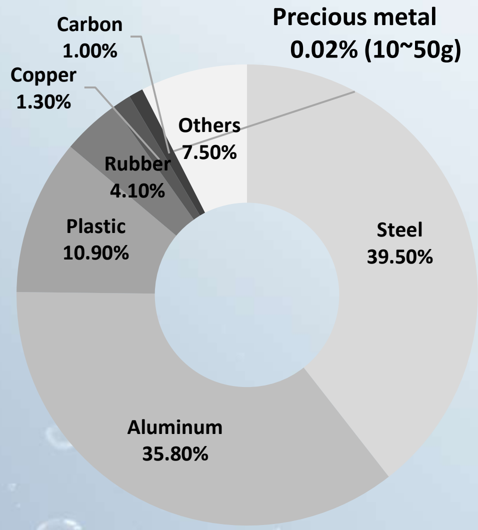
2nd N2 capture from Air: N2 concentration 78%

3rd Additional Chemical Processing

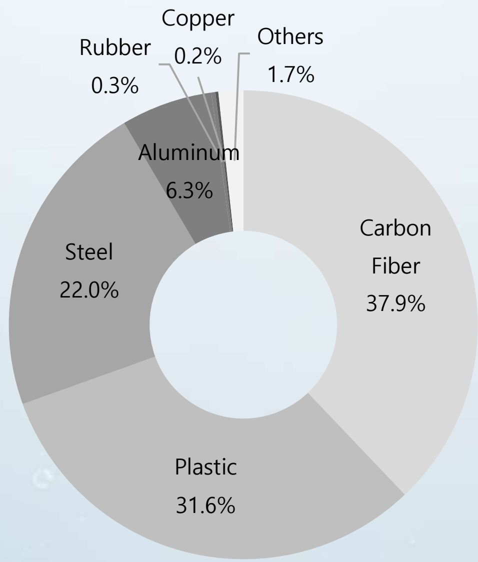
Weight Portion of Raw materials: (Fuel Cell System + H2 Storage) vs. Battery Pack

- For a Fuel Cell System, **Cost Reduction Potential is high** due to the **Low Portion of Precious Materials**
- Fuel cell system precious metals (Pt, Ir, etc.) ~0.02% / battery pack major materials (Ni, Co, Mn, Li) ~19%

[Fuel cell system]

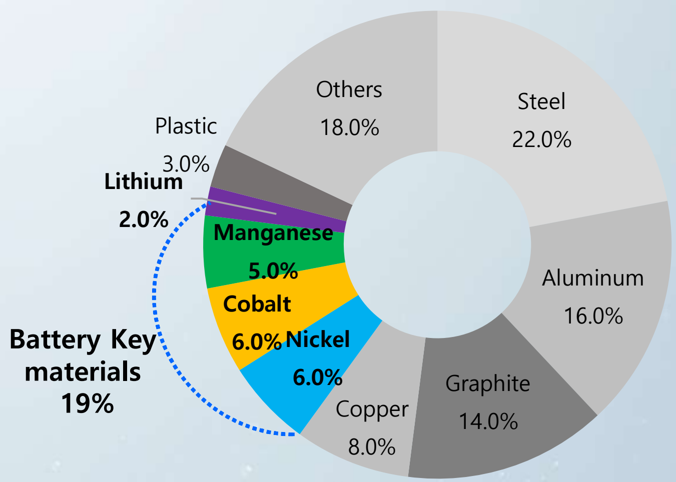


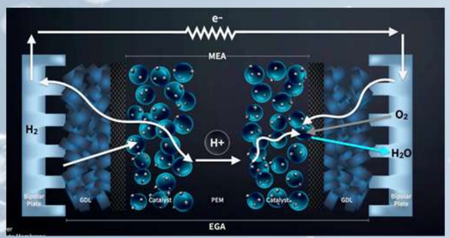
[Hydrogen storage]



[Battery Pack]

* Sources: ICCT (International Council on Clean Transportation)





Fuel Cell (Electrolysis) Technology: Complexity ↑, Degree of Difficulty ↑

- Vertically Integrated Conglomerate Companies have benefit on developing the systems such as Hyundai and Toyota

Fuel Cell System + **H2 Storage System**

Stack (array of cells)

- Ionomer (Fluro-carbon/Hydro-carbon)
- Expanded polymer
- Anti-Oxidant
- Adhesive
- Sub-gasket
- Gasket (Sealing)
- Separator
- Gas Diffusion Layer
- Catalyst Support
- Catalyst Manufacturing
- Electrode Binder
- Current Collector
- Pressure-Plate
- Fastening system
- Enclosure
- Terminal Block
- Cell Monitoring System
- Busbar
- Waterproof
- Vibration Resistance

Balance of Plant

- Air Compressor
- Inter-cooler
- Air Flow Meter
- ~~Humidifier~~
- Pressure / Temp. Sensor
- Insulation Resistance Sensor
- H2 Pressure Regulator
- H2 Supply / Cut-Off Valve
- H2 Ejector / Injector
- H2 Recirculation Blower
- Water Drain Valve
- H2 Purge Valve
- Gas-Liquid Separator
- H2 Sensor
- Coolant Pump
- Multi-Way Valve
- Electric Resistance
- De-ionizer
- Non-Conducting Coolant
- Air Cut-Off Valve
- Air Pressure Regulator
- DC/DC Converter / Inverter
- LDC + 12V Battery

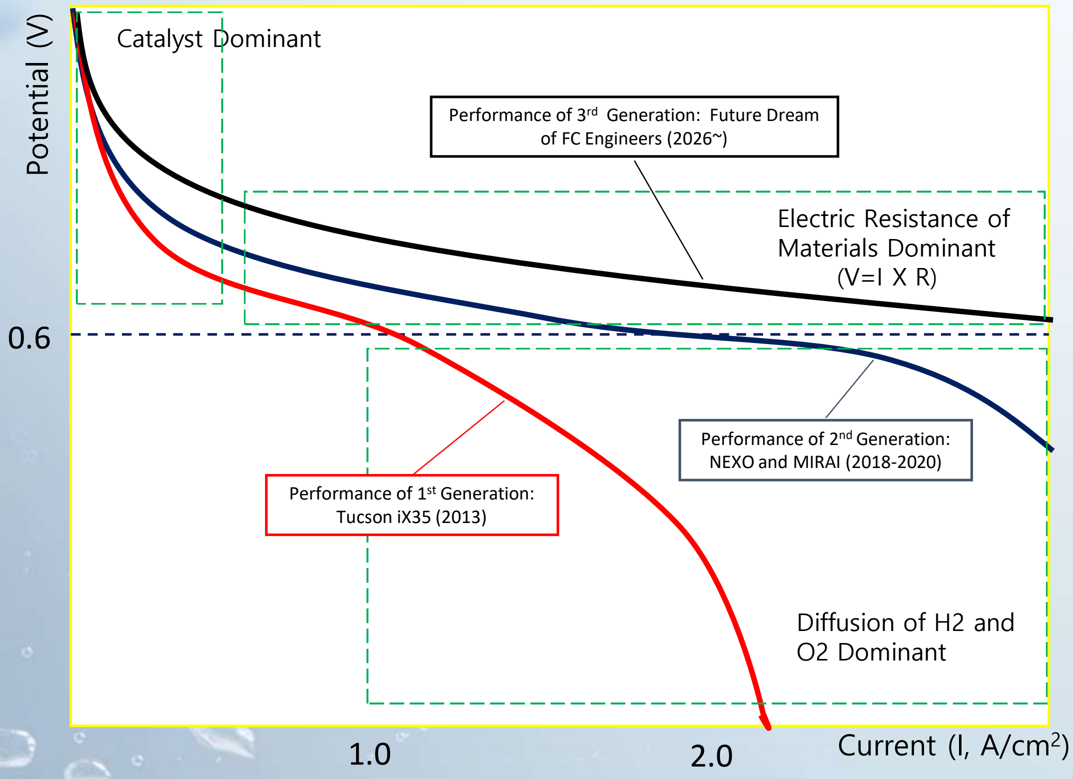
Control

- Air Flow and Pressure Control
- H2 Concentration Control
- Coolant Temperature Control
- Humidity Control
- Idle Stop Operation
- Start-Up Process
- Shut Down Process
- Cold Start Process
- Power Control
- Voltage Control
- Cell Health Management

↓

- Power Net Control for Hybrid Operation
- Customized Interface Design
- H2 Tank Valve Control

Innovation in Fuel Cell Technology



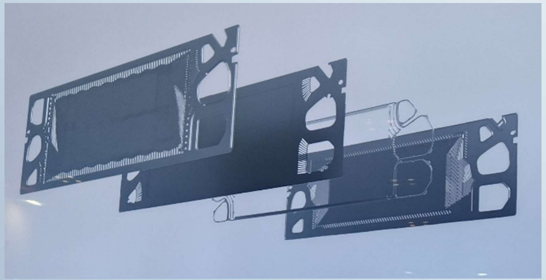
- Catalyst / Electrode (200g/100kW →30→10 Target)
  - Improve carbon support structure
  - New technology for doping Pt to carbon support
  - High permeable binder
  - Better antioxidant
- Proton Exchange Membrane (15um →10 →5)
  - Thinner Membrane
  - Lower permeable ionomer
  - Stronger reinforcement membrane
  - Better antioxidant
- Gas Diffusion Layer
  - Thinner and Stronger
  - Higher electric conductivity
  - Hydrophobic treatment
  - Better porosity control of microporous layer and base material
- Bipolar Plate
  - Finer flow channel
  - High corrosion resistance coating
  - High electric conductivity coating
  - Hydrophilic surface coating

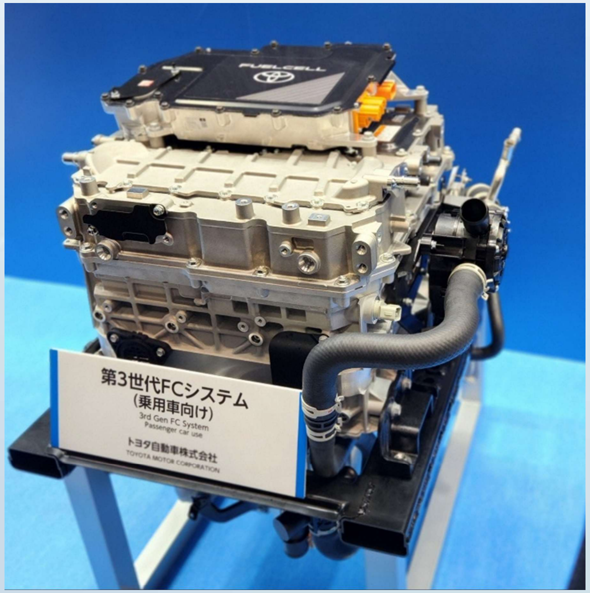
What Toyota achieved recently ('25. 2) in 3rd Generation FC: Better than ICE in all aspects only cost is left!!

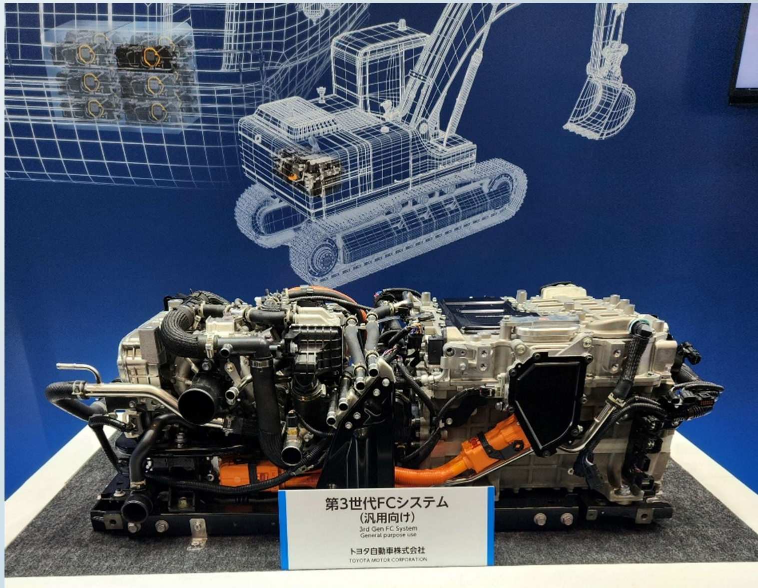
1. **Power Density**: 2 times Mirai 2, which means **smaller than Engine**
2. **Durability**: 2 times Mirai 2, which is **equivalent to Diesel Engine or better**
3. **Operation Temperature**: 85°C → 105°C, which means **cooling problem of FC stack is solved** (estimated from size of coolant pump)
4. **Efficiency**: 20% improved compared to Mirai2, which means the **system efficiency will be around 65%**
5. **Cost reduction** (not officially announced but good guess):

   ① Use SUS instead of Ti ② Thinner Membrane ③ remove Humidifier (same as Mirai 2) ④ Better Catalyst (probably reduced Pt)

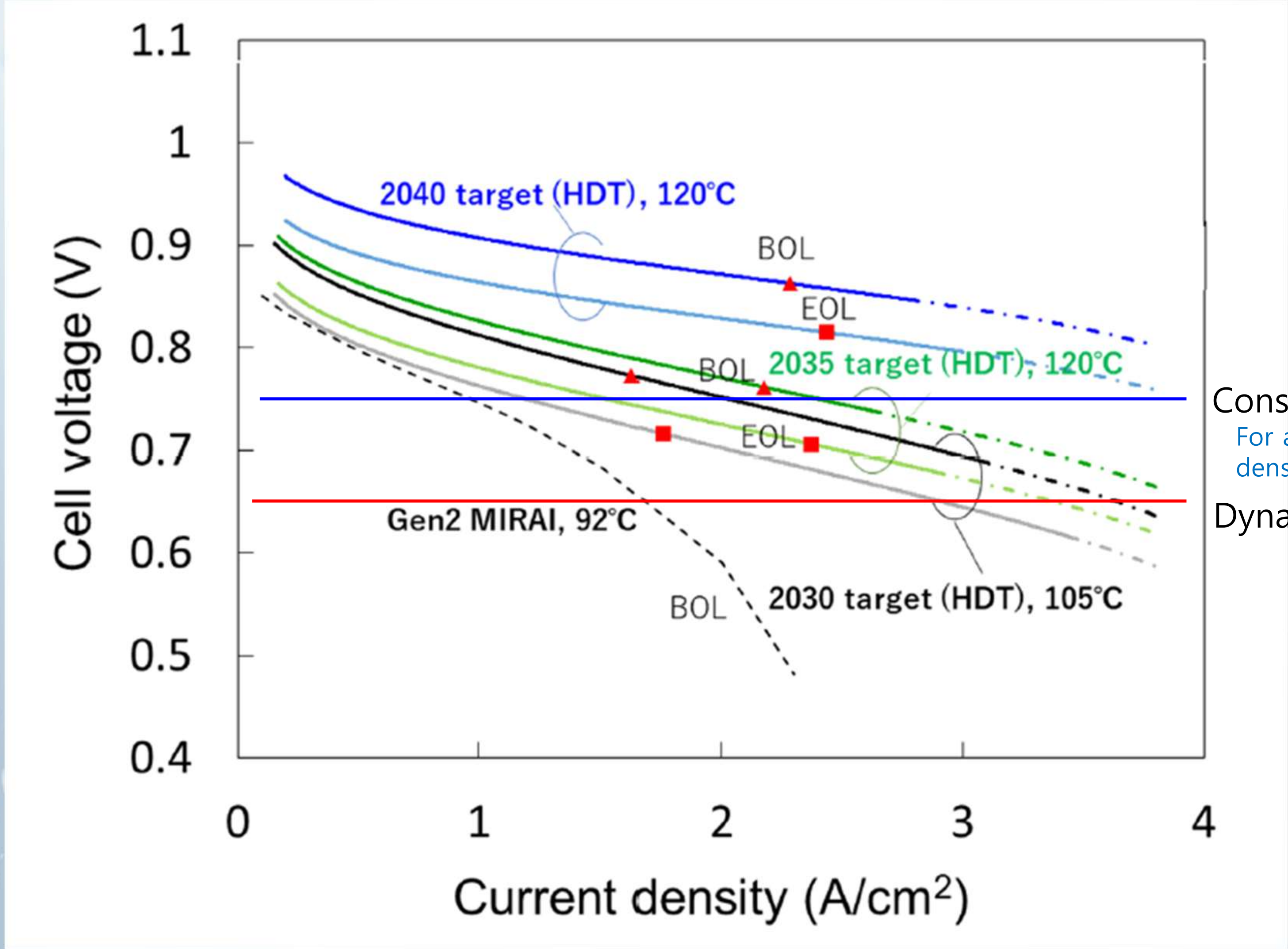
Serial production for passenger vehicle '26 → commercial vehicle '27 → marine application '28







What is beyond 3rd Generation: 4th and 5th will come! (NEDO Technology Roadmap, '24. 10)



Constant (rated) Operation

For aerospace application, The current density should reach 2.0A/cm2 at 0.75V

Dynamic (max.) Operation

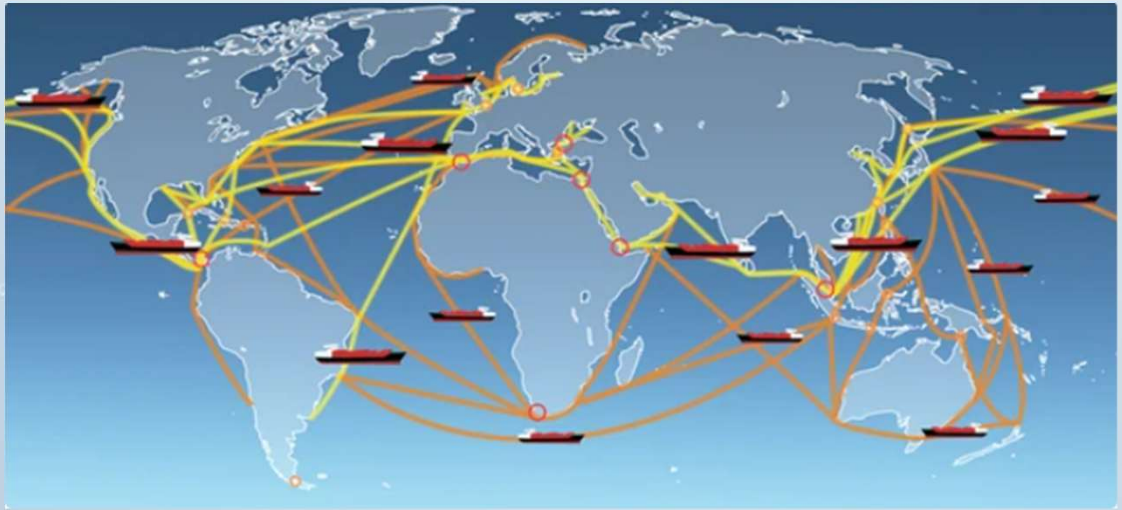
Remarks:

Hydrogen Industry Expected to Ramp Up by '28~'30

1. Legal Supporting Mechanism (Regulations) almost Finalized
2. 5~7 years before 2035 (automotive industry)
3. Technical Limitation with conventional technology for meeting the CO_2 regulation (maritime industry)
4. Strong Demand for H_2 Production: Curtailed Renewable

One thing we have to start now! Connect Globally local solution is not sufficient

1. Connect production and demand sites (Internationally planned project)
2. Harbors should be ready for H_2 and NH_3 infrastructure
3. High volume bunkering technology: cars refuel 5~10kg H_2 trucks 30~70kgH_2, ships 400~800tonH_2
4. Greater scale of Hydrogen Energy Supply Chain (HESC) Project needed (by Kawasaki etc. in 2022, 1ton H_2 delivered)



Curtailed Renewable Electricity in 2024 could of Produced 6 Million tonH2

- Germany: **30,304 GWh**
- UK: **8,300 GWh** (8.3 TWh)
- Spain: **1,700 GWh** (1.7 TWh)
- Poland: **731 GWh**
- Greece: **900 GWh**
- Austria: Average 5,800 MWh per month X 12 = **69,600 GWh** [6,044 MWh (October) + 41,282 MWh (Jan.~August)]
- Brazil: more than **14,600 GWh** (14.6 TWh)
- Chile: **5,909 GWh**
- Australia: **4,500GWh** 4.5 terawatt-hours (TWh)
- Japan: **2,120 GWh** 2.12 TWh (Terawatt-hours)
- California: **3,400 GWh** 3.4 million megawatthours (MWh)
- Texas: **5,300 GWh** 5.3 TWh
- China: 3~6% curtailed but no exact value. China installation of Renewable is 1.2TW (1,200GW) in 2024 and 1.53TW in 2025

  If average of 400GW (1/3 of 1.2TW) is used, curtail would be 18GW. So, 18GW X 365 X 24 = 157,680 GWh → 3,153,600 tonH2 (3Milion tonH2)

1GWh of electricity can produce 20ton of H2.

So, the curtailed renewable electricity of 147,364 GWh (China Excluded) could of produced 2,947,280 tonH2 (3Million tonH2)