Niobium Technology for Clean Energy
9th-14th, November, 2021, Web. Meeting

Highly Durable and Active Cathode Catalysts using Niobium for Polymer Electrolyte Fuel Cells

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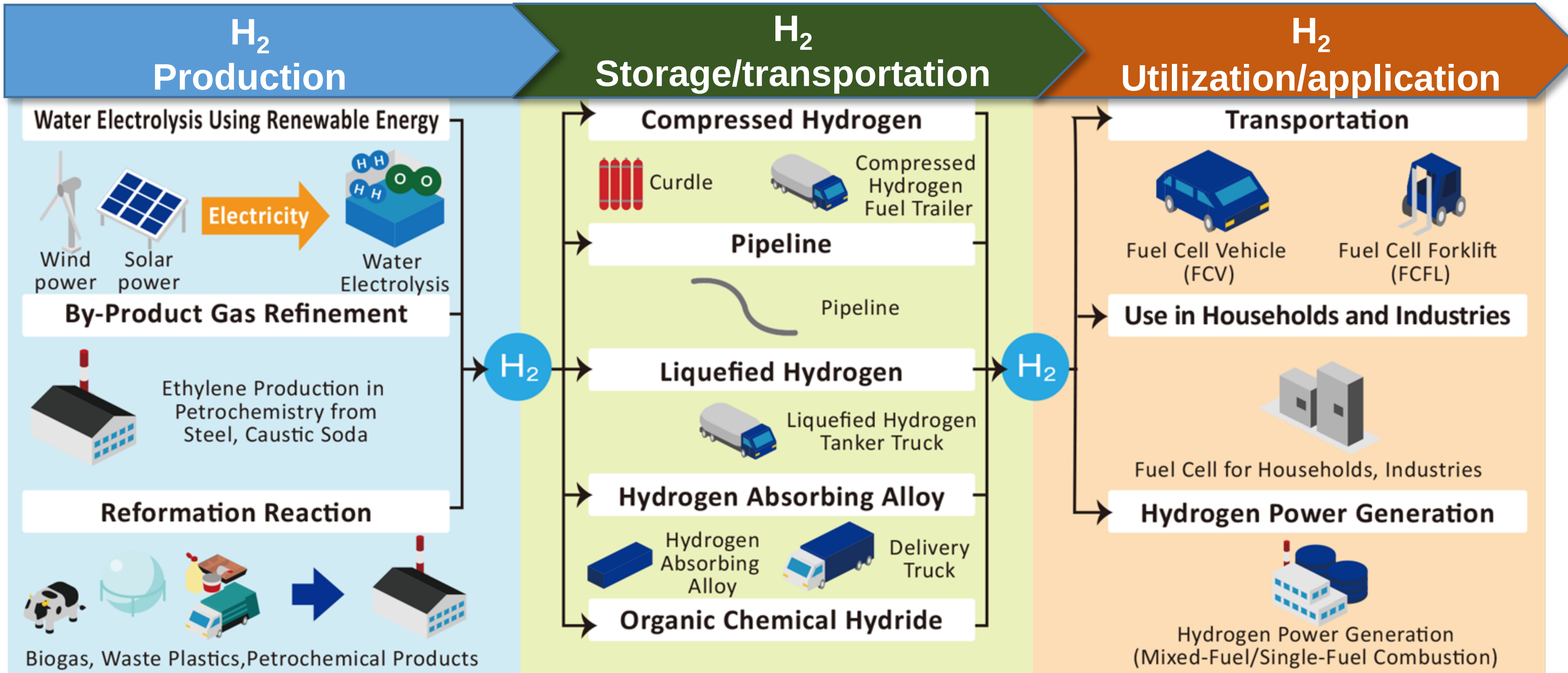
Hydrogen supply chain toward the achievement of decarbonization



https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/en/demonstration-business/index.html

Hydrogen Energy Ministerial Meeting

METI Ministry of Economy, Trade and Industry

NEDO New Energy and Industrial Technology Development Organization

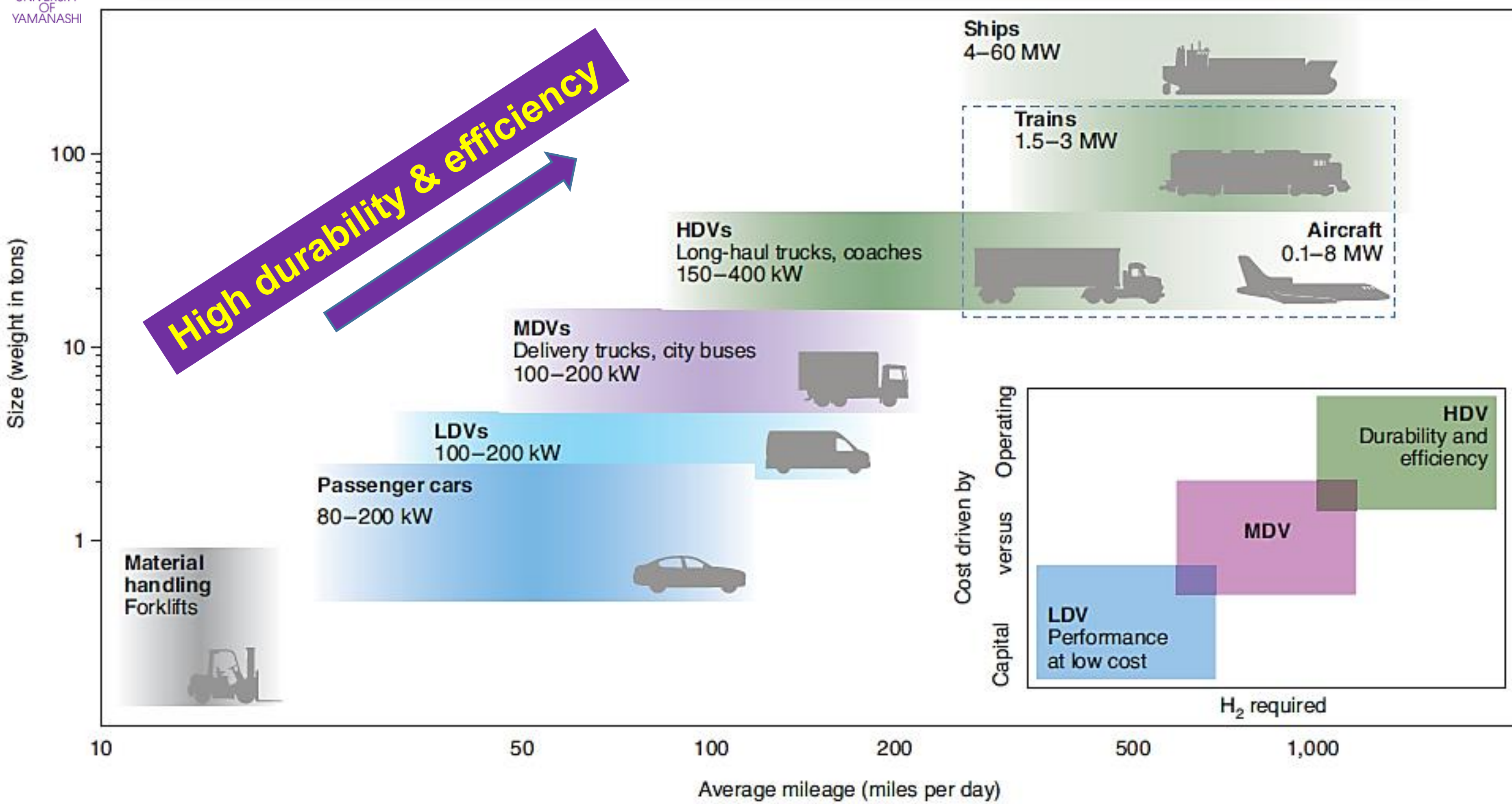
https://hem-2021.nedo.go.jp/_en/

International Partnership for Hydrogen and Fuel Cells in the Economy

IPHE

https://www.iphe.net

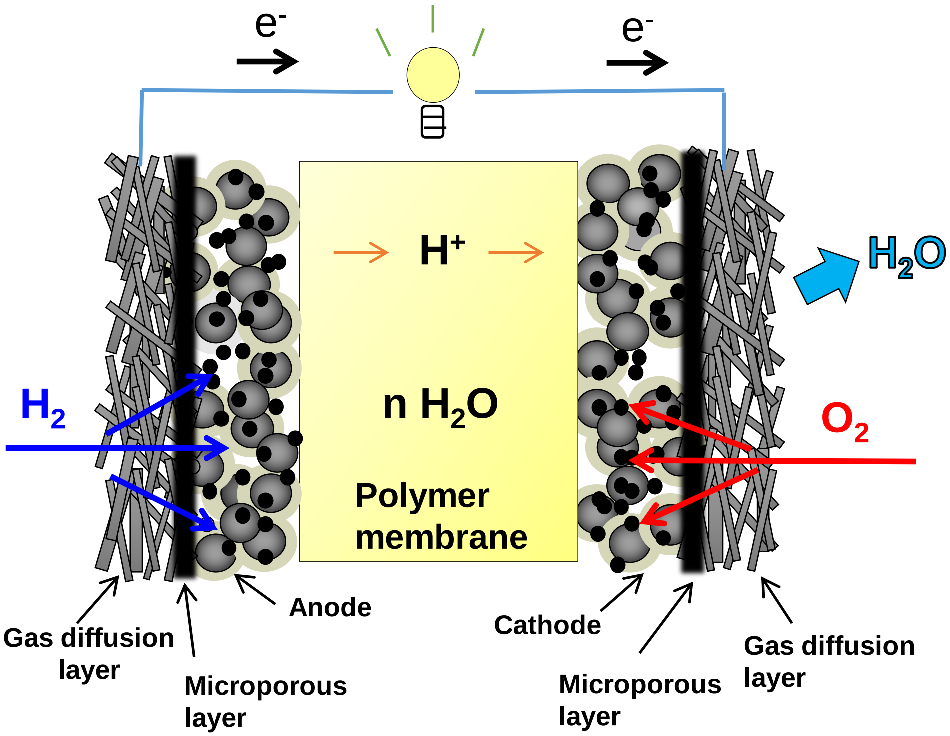
Trend of fuel cells technologies for transportation



D.A. Cullen, K.C. Neyerlin, R.K. Ahluwalia, R. Mukundan, K.L. More, R.L. Borup, A.Z. Weber, D.J. Myers, A. Kusoglu, Nature Energy 6 (2021) 462-474.

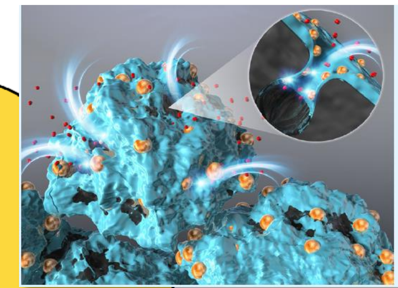
PEFCs will be developed to meet the requirements of the heavy-duty vehicle market (in transportation) with the higher efficiency and durability.

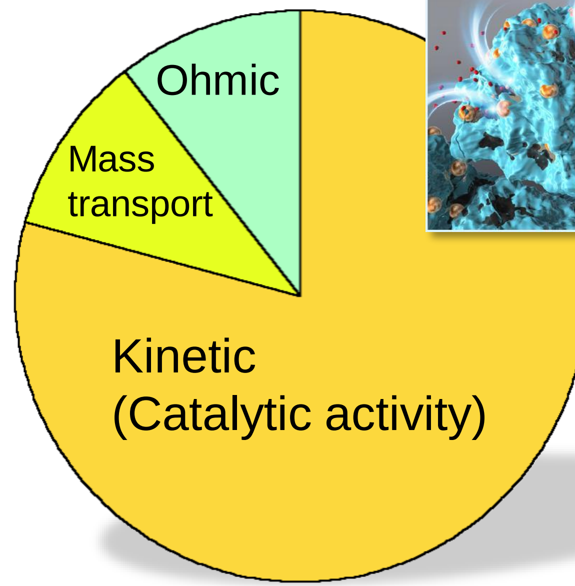
Essential factor toward the improvement of fuel cell performance



Polymer electrolyte fuel cell

A. Kobayashi et al.
ACS Appl. Energy Mater. 4 (2021) 2307.





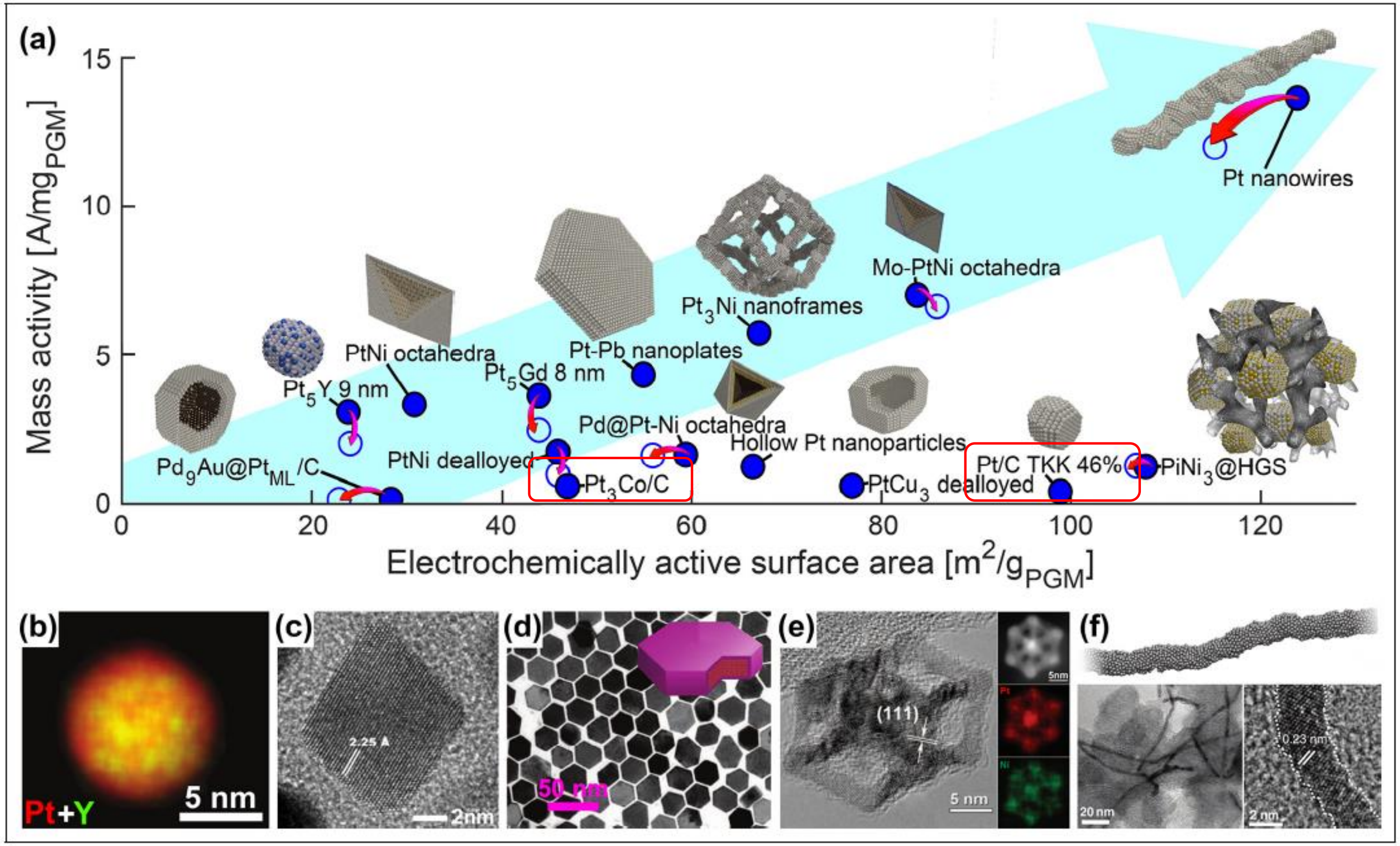
Overpotential (@1.0 A cm^{-2} 80^{o}C)

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

Cathode : $2H^+ + 1/2O_2 + 2e^- \rightarrow H_2O$

The new electrocatalysts with higher activity and durability are required.

Improvement of catalytic activity



M. Escudero-Escribano, K.D. Jensen, A.W. Jensen Current Opinion Electrochem., 8 (2018) 135-146.
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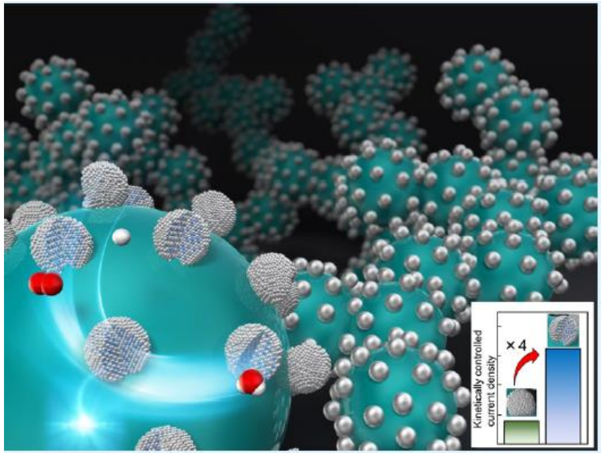
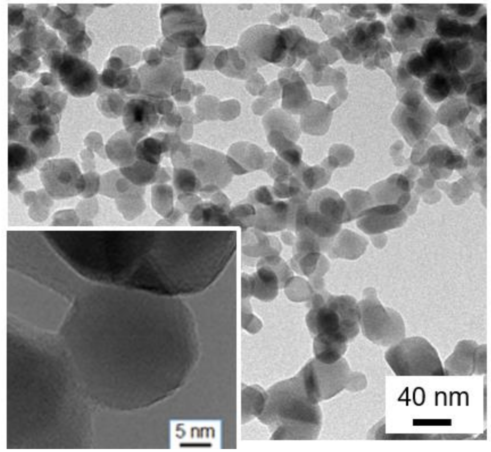
Pt alloys, nanorods and nanowires are one of the candidate electrocatalysts for fuel cells.

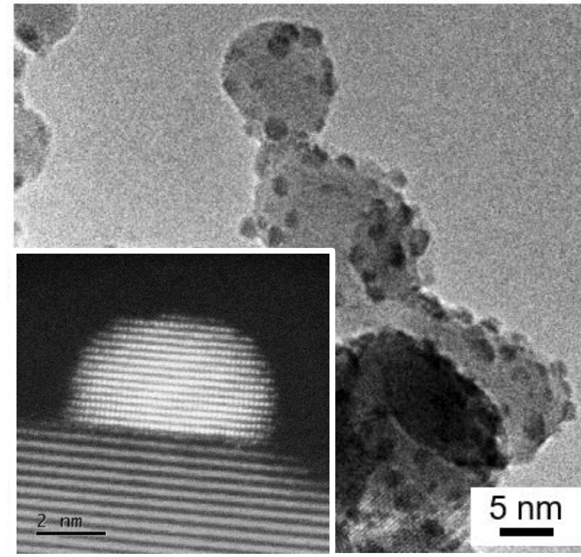
New cathode catalyst for fuel cells



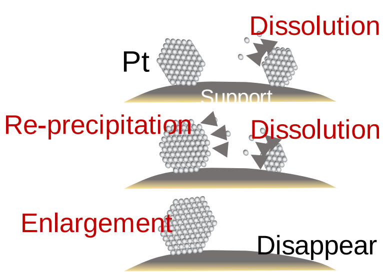
ACS Appl. Energy Mater. 2020, 3, 6922



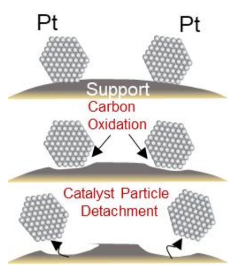
Electrochim. Acta, 2011, 56, 2881.



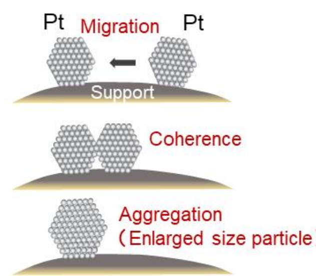
Dissolution and enlargement



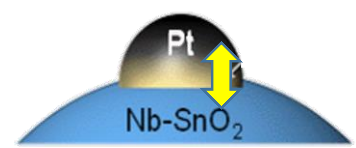
Catalyst particle detachment



Aggregation

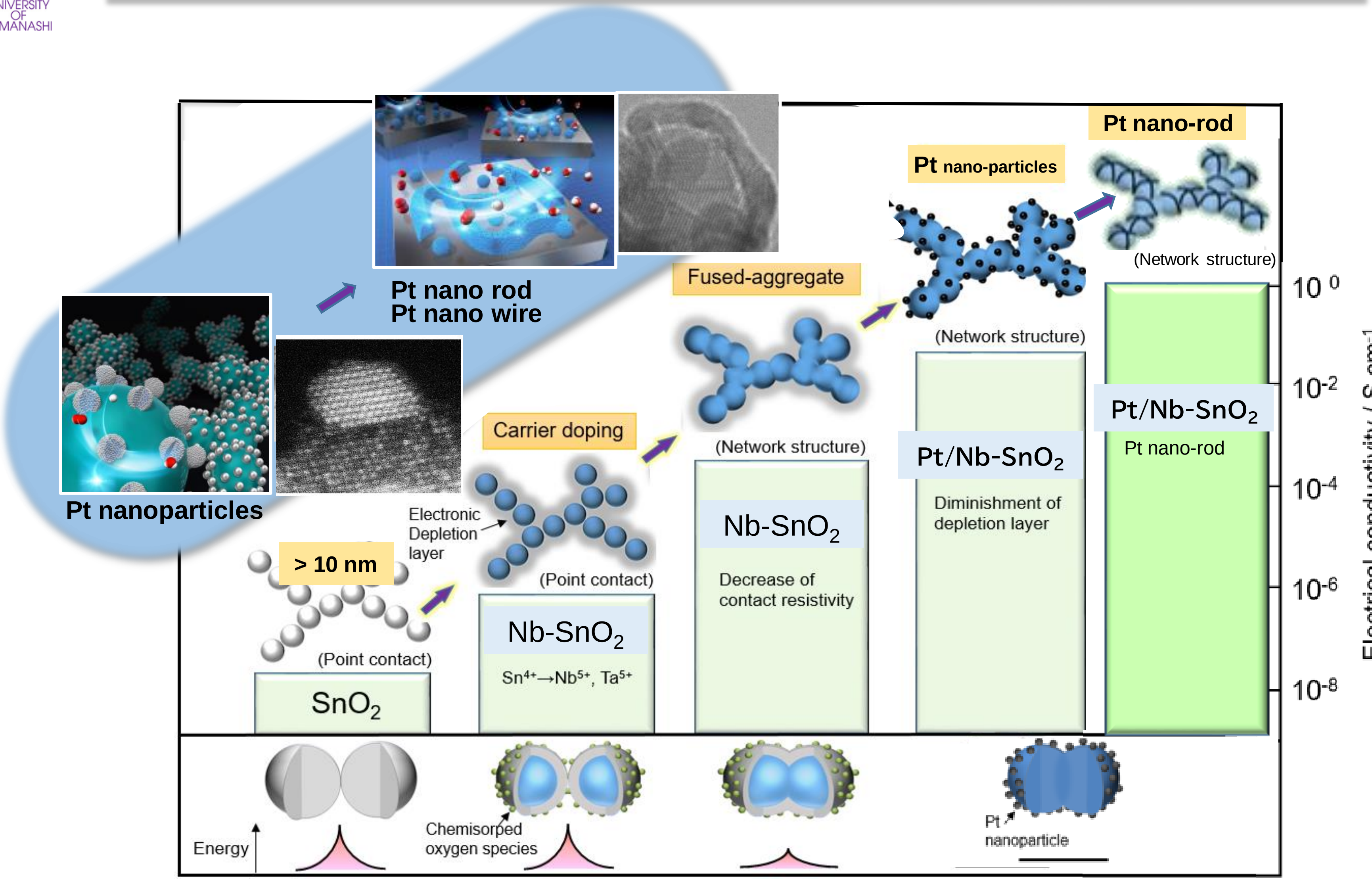


Metal - support interaction



Startup/shutdown & load cycle durability of Pt/Nb-SnO_2 is superior to that of Pt/GCB, which relies on the strong bonding between Pt and Nb-SnO_2 and well size control of Pt particle

Design concept of new cathode catalyst for fuel cells



K.Kakinuma, et al. ACS Appl. Mater & Interfaces 11 (2019) 34957
G. Shi, et al. ACS Catal.11 (2021) 5222.

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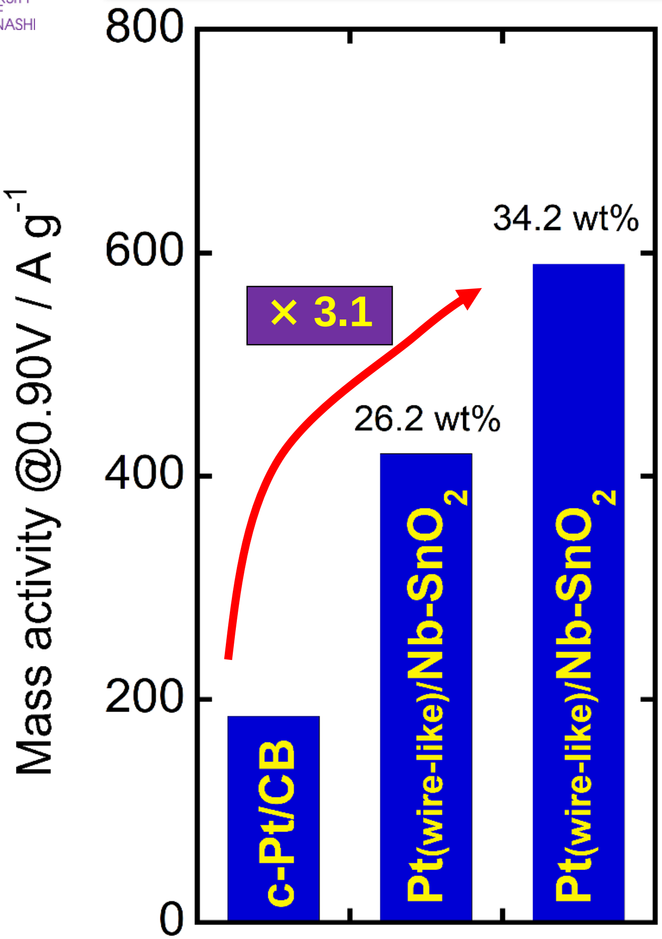
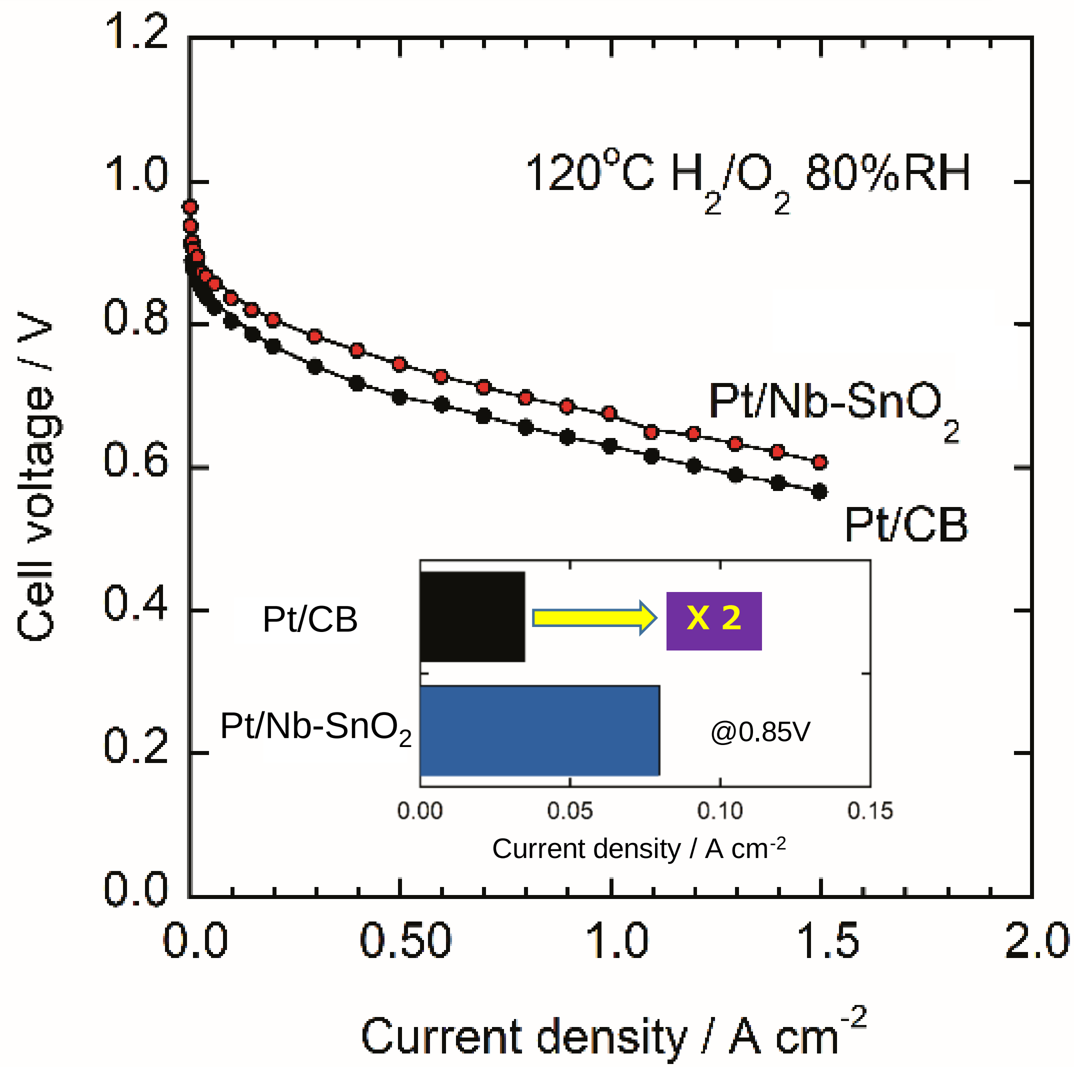
120°C operation by Pt/Nb-SnO_2 catalysts



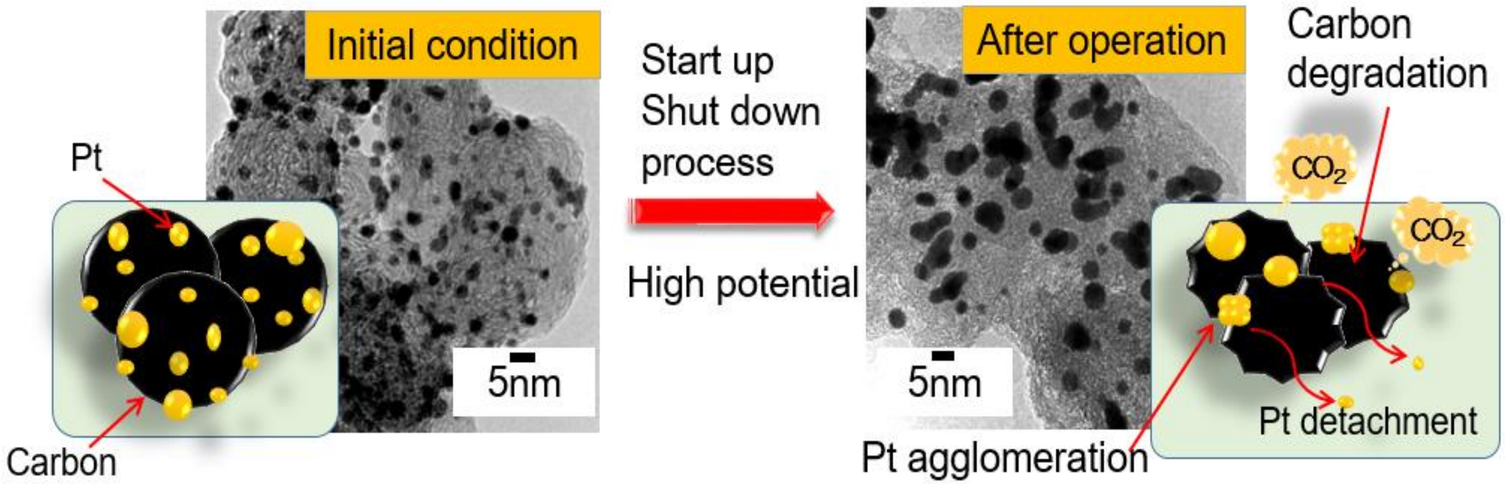
G. Shi, et al. ACS Catal.11 (2021) 5222.



Single cell performances (power/durability) using Pt/Nb-SnO_2 catalyst layers is superior to those using current Pt supported on carbon (Pt/CB).

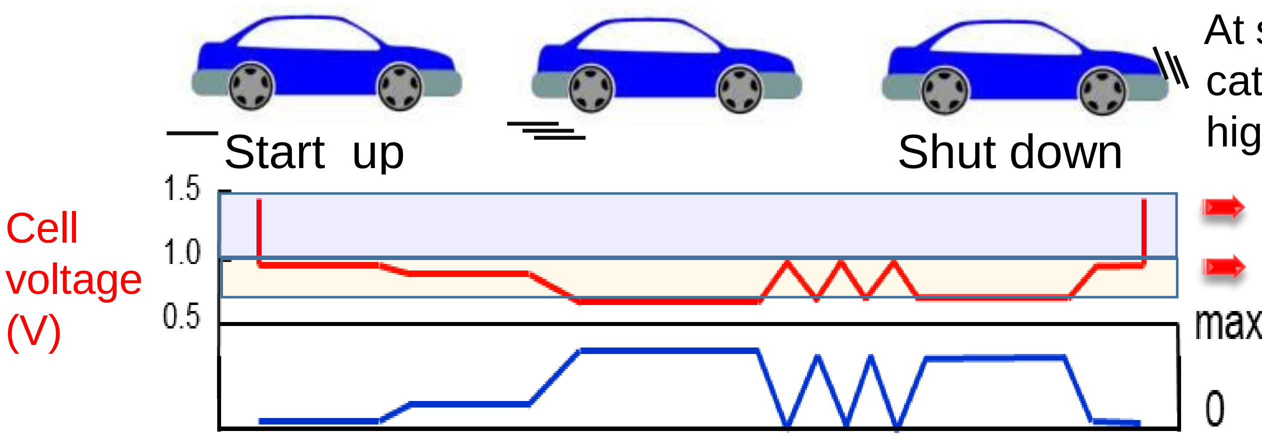
Durability of new cathode catalyst for fuel cells

Carbon support : Intrinsic thermodynamic instability



$C + 2H_2O \rightarrow CO_2 + 4H^+ + 4e^-$ E = 0.207 V SHE

FCV operation

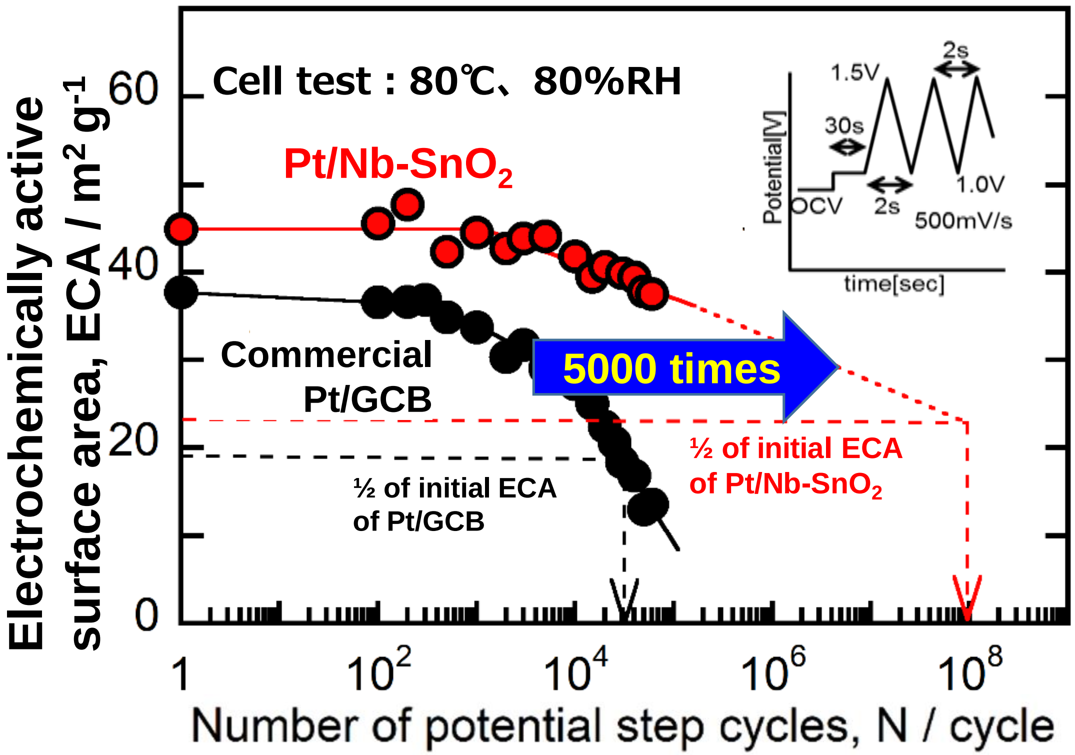


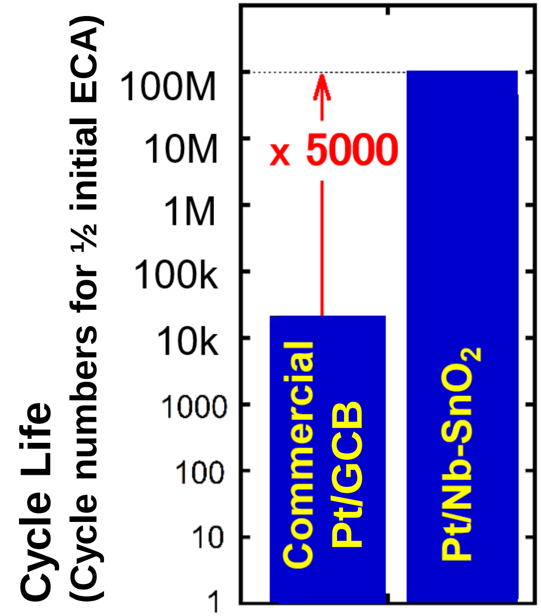
At start up / shut down operation, cathode catalysts are exposed to higher potential condition over 1.5V

- ➡ Carbon degradation
- ➡ Ostwald ripening

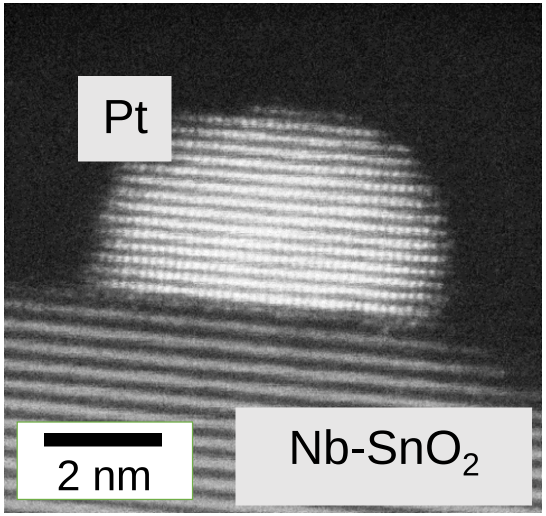
Power (kW)

Start up / shut down durability of Pt/Nb-SnO_2



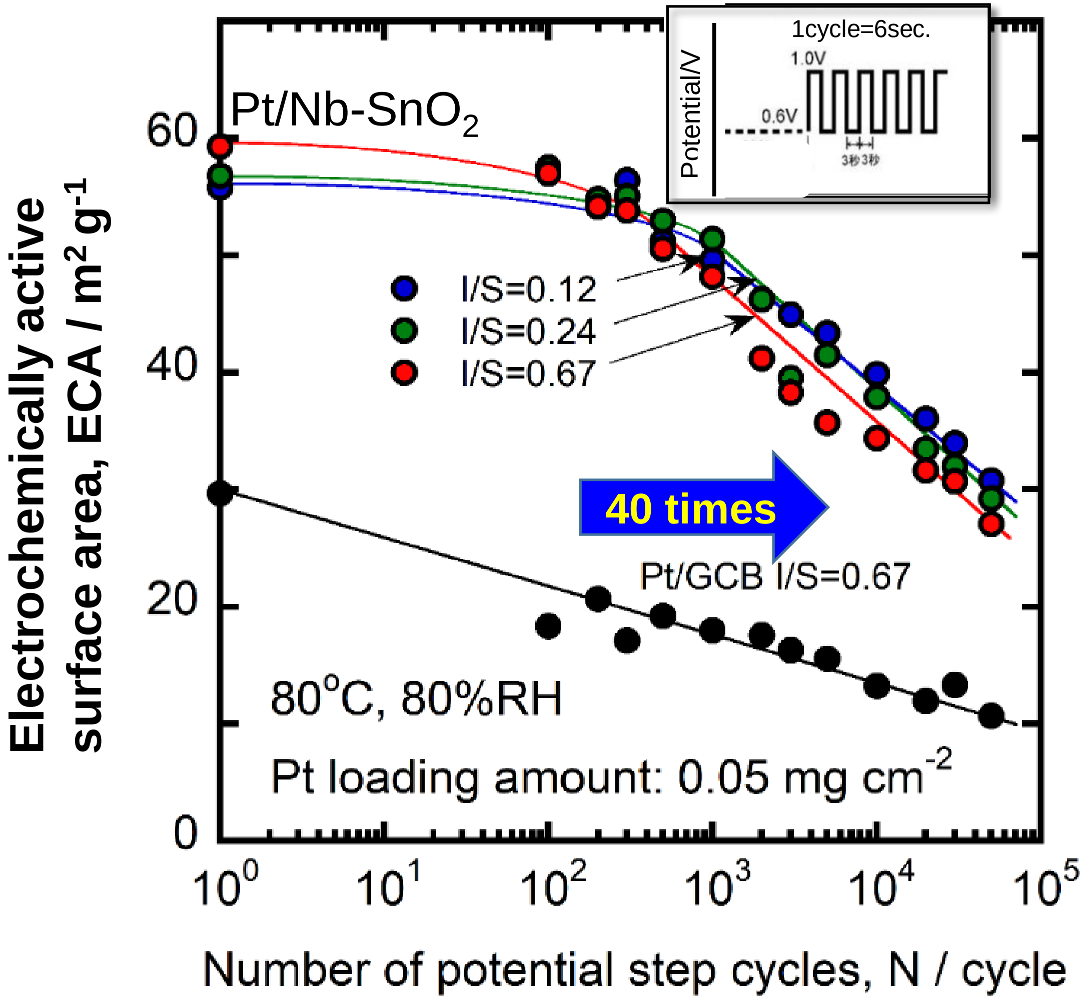


Y. Chino, K. Taniguchi, Y. Senoo, K. Kakinuma, M. Watanabe, M. Uchida, *J. Electrochem. Soc.* 162 (2015) 736.

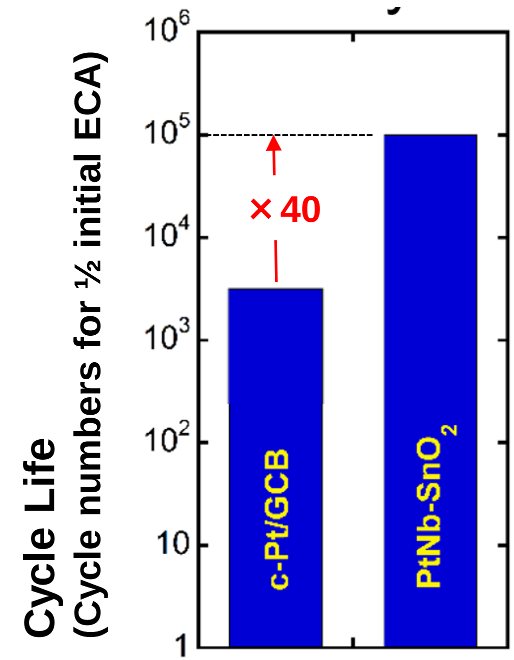


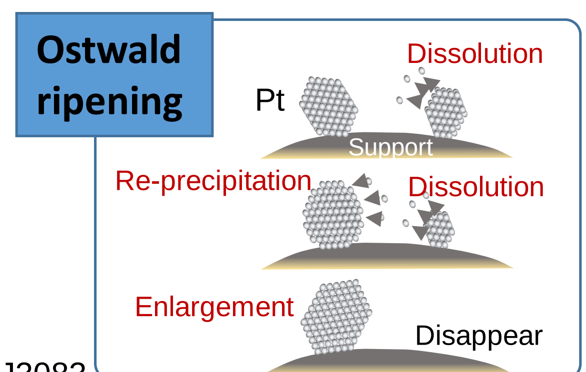
Startup / shutdown durability of Pt/Nb-SnO_2 catalyst layers is superior to that of Pt/GCB catalyst layers and relies on the strong bonding between Pt and Nb-SnO_2.

Load cycle durability of Pt/Nb-SnO_2



K. Kakinuma, R. Kobayashi, A. Iiyama, M. Uchida, *J. Electrochem. Soc.* 165 (2018) J3083.

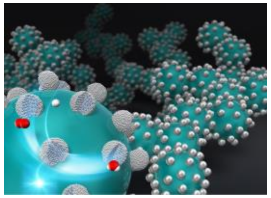


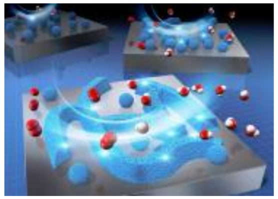


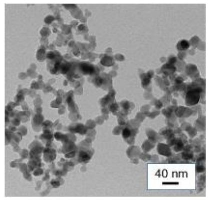
Load cycle durability of Pt/Nb-SnO_2 catalyst layers is also superior to that of Pt/GCB catalyst layers.

Performance comparison table

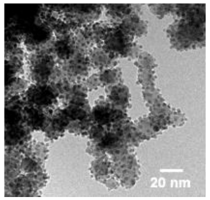
Candidate catalyst	Electronic Conductivity	Catalytic Activity	Durability	Cost
Commercial Pt/Carbon	✔	✔	✔	✔
Pt/Graphitized carbon	✔	✔	✔	✔
Pt/TiO_2 + Carbon nanotube	✔	✔	✔	/
Pt/TiO_2-RuO_2	✔	✔✔	✔✔	/
Pt/Nb-SnO_2	✔✔	✔✔✔	✔✔✔	✔
	×10 (vs. Pt/Carbon)	×3.2 (vs. Pt/Carbon)	×5000 (vs. Pt/Carbon)	


Pt nanoparticle

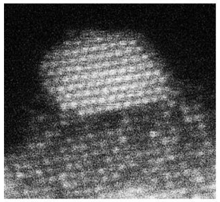

Pt nanorod



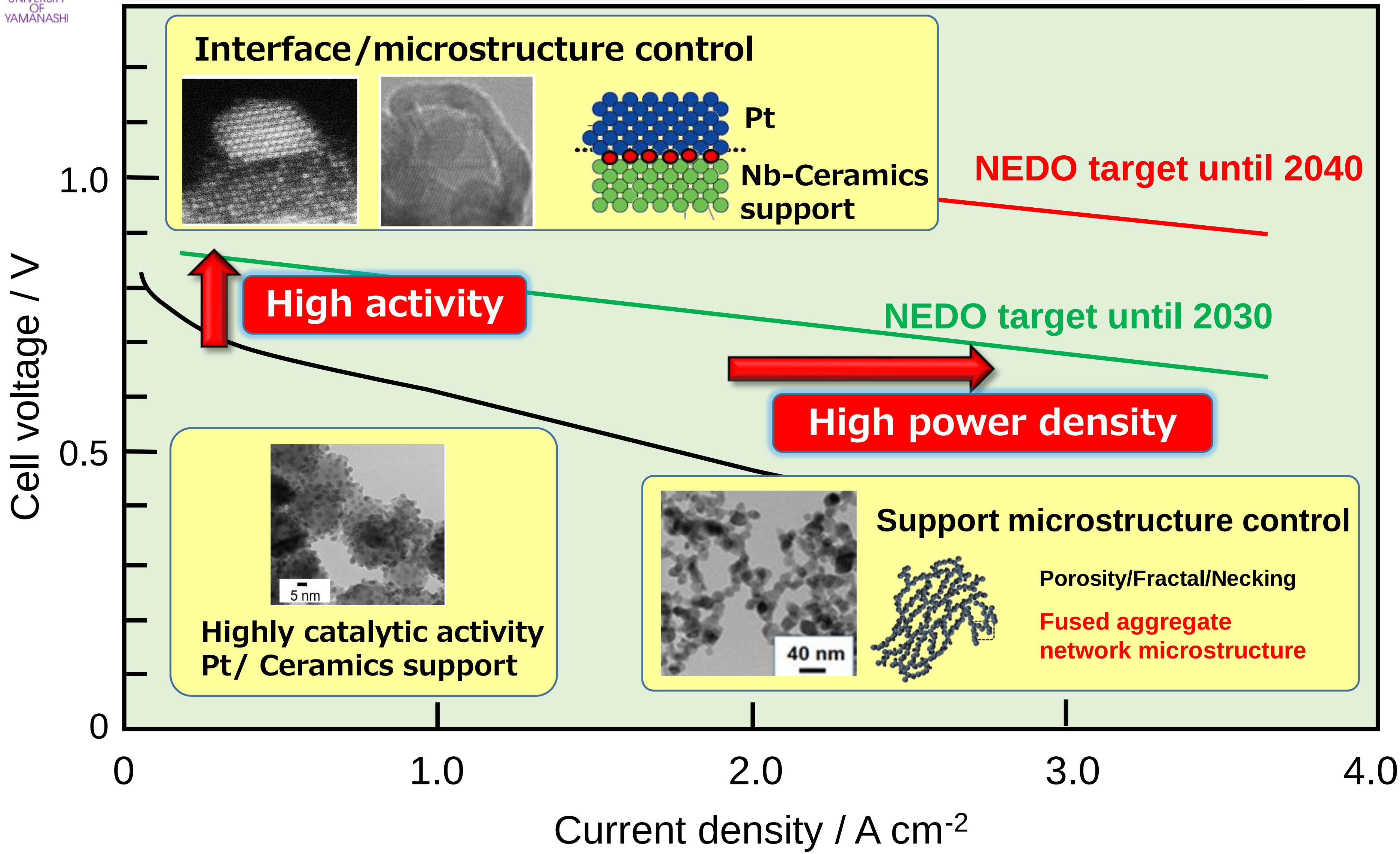
Nb support



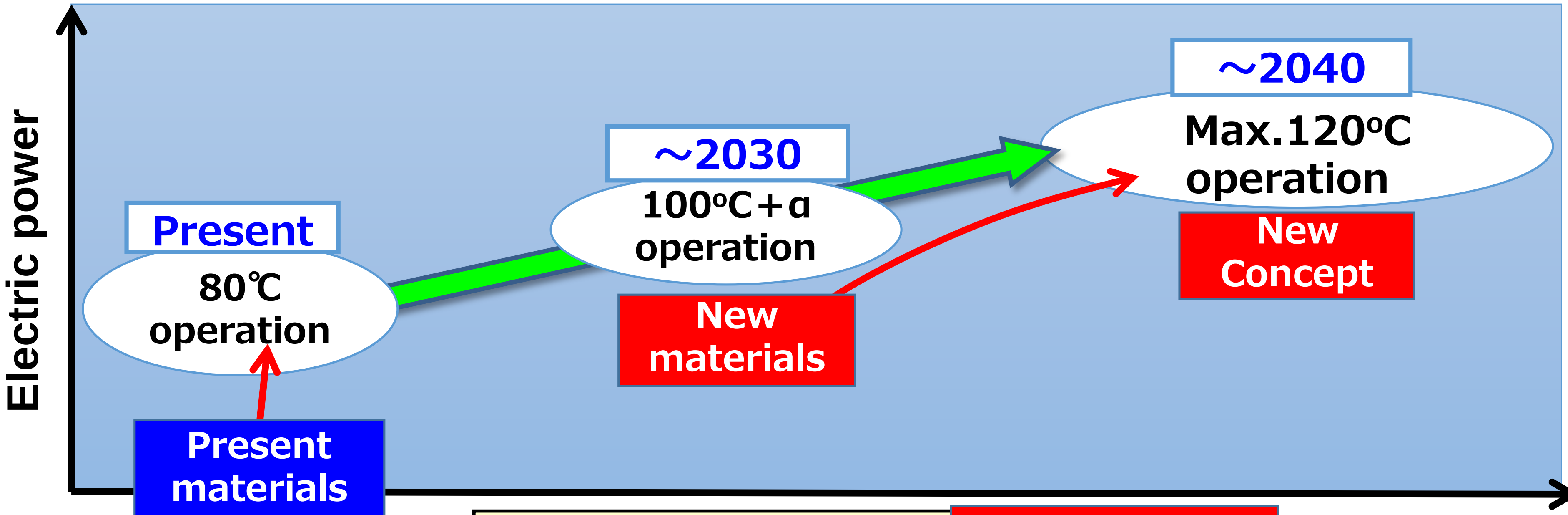
High dispersion


Pt orientation

Future plan


Interface/microstructure control
Pt
Nb-Ceramics support
NEDO target until 2040
High activity
NEDO target until 2030
High power density
5 nm
Highly catalytic activity Pt/ Ceramics support
40 nm
Support microstructure control
Porosity/Fractal/Necking
Fused aggregate network microstructure
Cell voltage / V
1.0
0.5
0
0
1.0
2.0
3.0
4.0
Current density / A cm-2

Conclusion
Toward the high power and durable PEFC

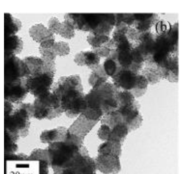


Present concept

Pt alloy
Skin
Core-shell
Carbon
Nafion

New materials
Pt nanowire
Fused-aggregated network nanoparticles
Aromatic membrane with reinforcement

New concept
Pt/ceramic/ionomer harmonized interface
Platinum anti-dissolution mechanism (PADM)
Atmospheric resistive switching mechanism (ARSM)



Nb

Key materials
Pt Catalysts using Niobium supports

Acknowledgement

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Thank you very much
for your kind attention !