Electrocatalysts for Automotive Fuel Cells: *Status and Challenges*

Catalyst WG Meeting May 15th 2013

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05/15/2013

Outline

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1. Current Status of FCEV Development

2. FC Electrocatalyst: *Status and challenges*

3. Summary

Zero Emission

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Potential Global Warming Scenario

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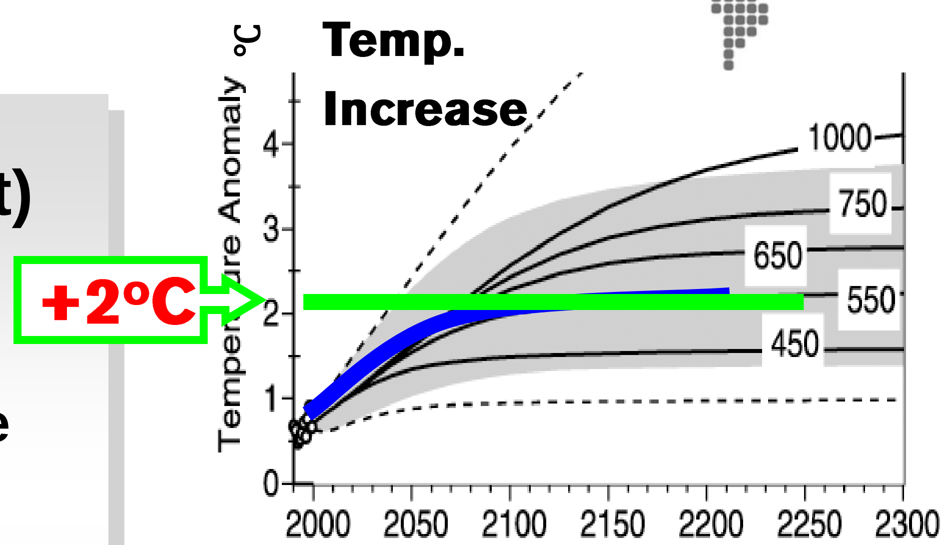
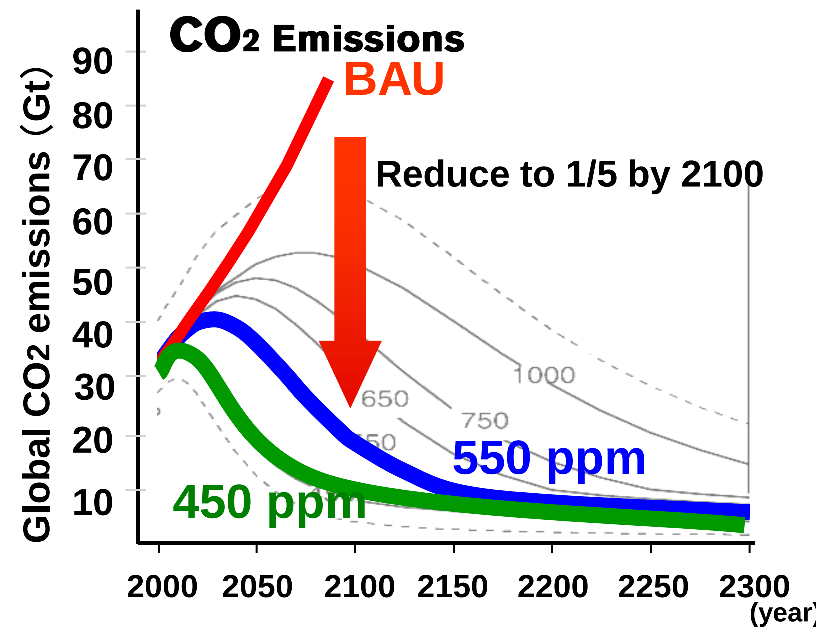
Theory (from IPCC 3rd report)

Average global temperature will increase up to +2 ºC on the basis of BAU*

↓

Atmospheric CO_2 concentration must be stabilized under 550 ppm level (450 ppm in 4th report)





Source) IPCC 3rd and 4th Assessment Report

*BAU (Business as Usual): Scenario in which global warming continues without countermeasures being taken

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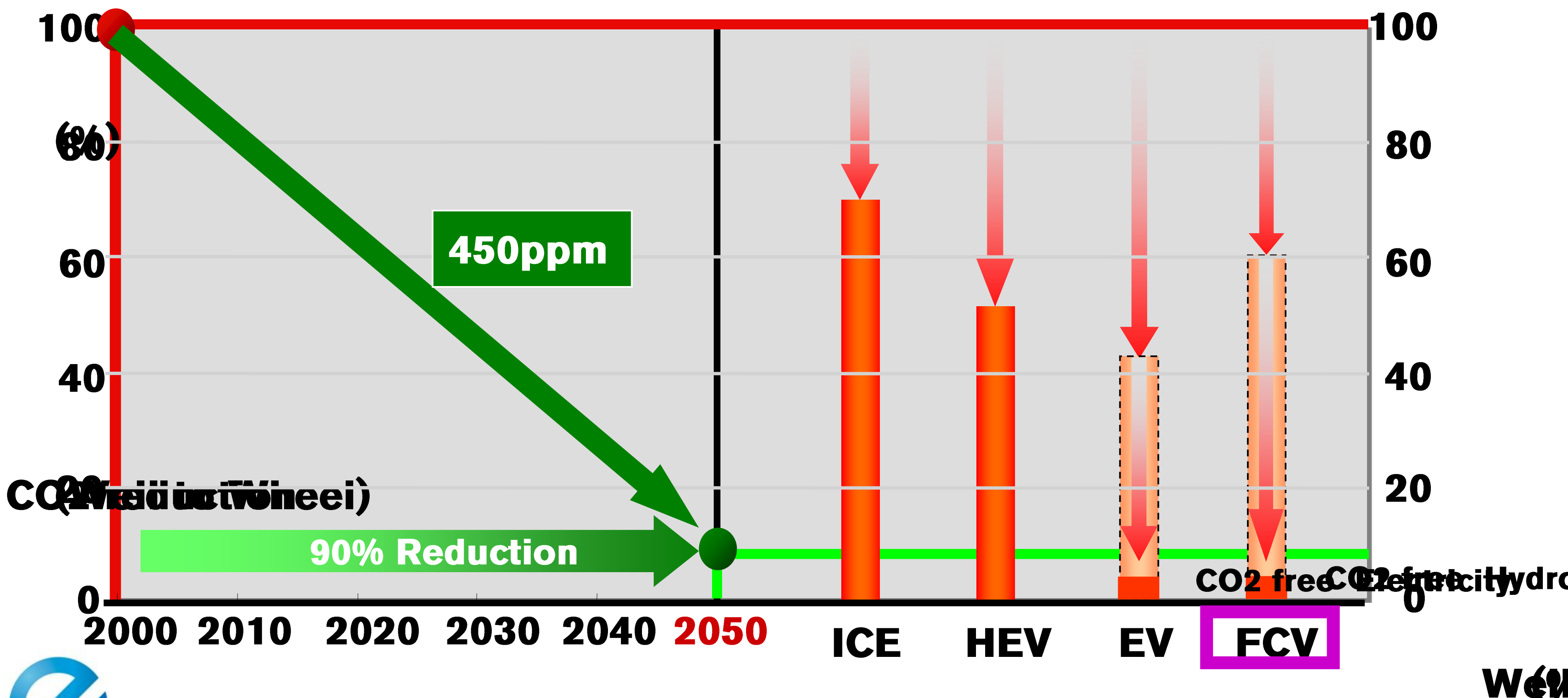
Long Term Goal for CO2 Reduction

- To reduce CO_2 emissions from all new vehicles by 90%,
  - Short & mid term : Internal Combustion Engine (ICE) efficiency
  - Long term : Electric Powertrains, CO_2 free energy



Nissan FCEV Development History

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- Developing the technologies to introduce FCEVs into market as early as 2017*.

2001	2002	2003	2005	2008	2010	201X
X-terra	X-Trail					
						
					Leaf	
Cruising Range						
160 km	200 km	350 km	500 km	Sub-Zero Start-able	200 km	
Accel. 0-100 kmph						
25 sec	20 sec	18 sec	ICE Competitive 14 sec		12 sec	
Fuel Cell Stack						
Outsourced	Outsourced	Co-Developed	In-House Gen-1	In-House Gen-2		In-house Gen-3

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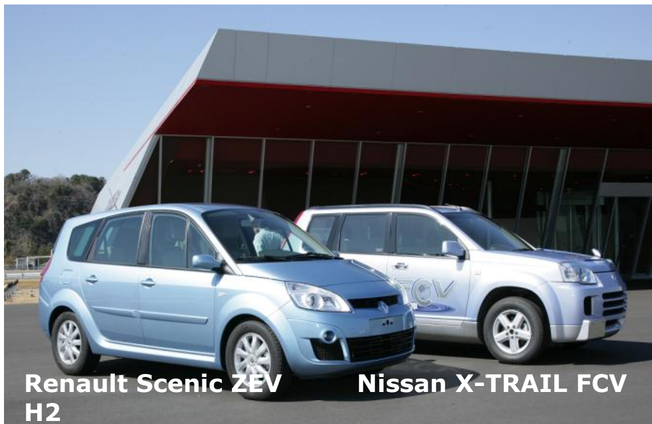
*Nissan Press Release:January 28,2013. http://www.nissan-global.com/EN/NEWS/2013/_STORY/130128-02-e.html

Current FCEV and Stack Technologies

- Performance level similar to ICE vehicles
- Downsized FC stack with high power density

X-TRAIL FCV (2005) Spec.	
Max. Speed	150 km/h
Cruising Range	370 km (500 km)
Max. Power	90 kW
Volume	90 L
Weight	120 kg



FC STACK Spec.	
Max. Power	85 kW
Volume	34 L
Weight	43 kg

New FC Stack (April, 2011)

FCV practicability being verified through domestic and international demonstration programs.

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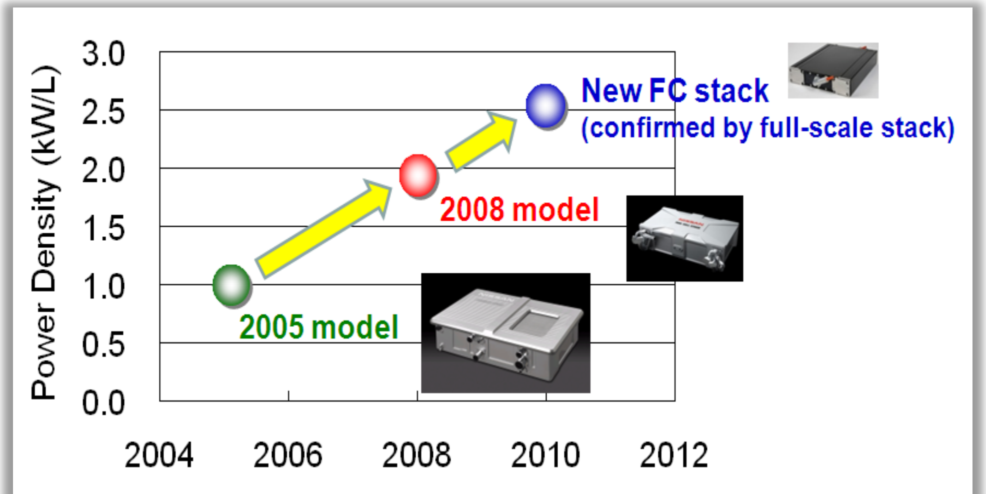
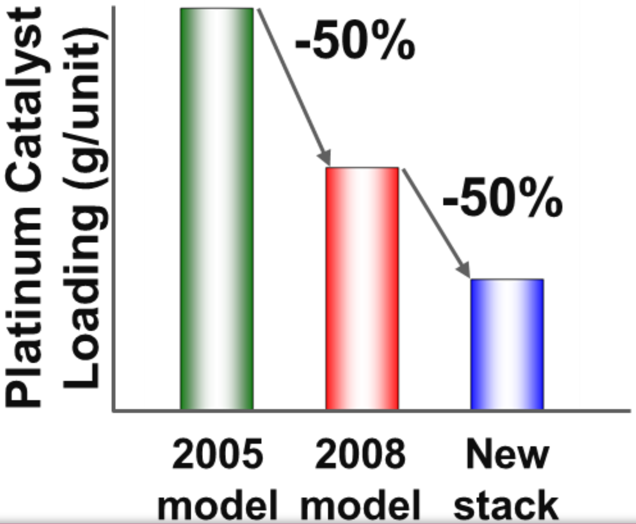
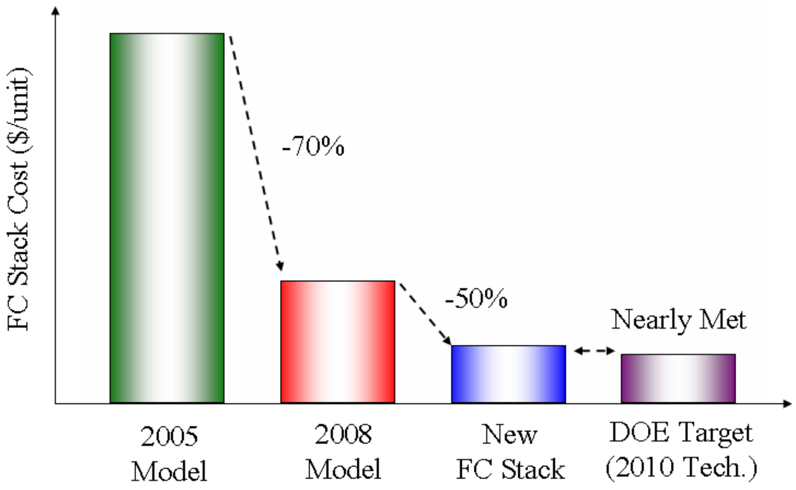
Current Status of Stack Technology



Evolution of Nissan FC Stacks in Rated Power Density

- **Increased power density :- improved separator and MEA**
- **Lower cost: Reduced Pt loading**





Further downsizing/cost reduction is necessary for successful commercialization

FCEV Commercialization Challenges

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Vehicle

Affordable FCEV

- **Cost Reduction**
  - Reduction in precious group metal usage
  - System simplification
- **Performance improvement**
- **Durability Improvement**
- **Innovative hydrogen storage system**
  - Material performance and cost
- **Public awareness and Acceptance**

Infrastructure

- **Hydrogen stations**
  - Safety, Codes and Std
  - Accuracy of H_2 meters, etc..
  - Govt. and state laws for safety, etc..
- **Hydrogen cost :**
  - $2-$4/gge (dispensed and untaxed)*
- **Public awareness and Acceptance**

* E L Miller DOE AMR 2012

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Current Status

- Nissan-Daimler-Ford Strategic partnership*

YOKOHAMA, Japan (Jan. 28, 2013)— Daimler AG, Ford Motor Company and Nissan Motor Co., Ltd., have signed a unique three-way agreement to accelerate the commercialization of fuel cell electric vehicle (FCEV) technology.
The goal of the collaboration is to jointly develop a common fuel cell electric vehicle system while reducing investment costs associated with the engineering of the technology. Each company will invest equally towards the project. The strategy to maximize design commonality, leverage volume and derive efficiencies through economies of scale will help to launch the world's first affordable, mass-market FCEVs as early as 2017.

*Nissan Press Release:January 28,2013. http://www.nissan-global.com/EN/NEWS/2013/_STORY/130128-02-e.html

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FC Electrocatalyst Criteria*

- ✓ Beginning of Life (BoL) performance at required power
- ✓ Acceptable end of life (EoL) performance after 5000 Hrs or 10 years of operation
- ✓ Reduction in Pt/PGM loading ($<0.125\ mg_{PGM}/cm^2$) without sacrificing performance and durability
- ✓ Resistance to Pt dissolution under vehicle load cycling conditions
- ✓ Resistance to support corrosion under start-up / shut down conditions
- ✓ Cold start capabilities and freeze tolerance

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* Mark Debe, June 2012, Nature vol 486

FC Electrocatalyst Targets

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Table 5. Technical Targets: Electrocatalysts

Characteristic	Units	2010 Target	2017 Target
Platinum group metal total content[a]	g/kW rated	0.15	0.125
Platinum group metal total loading [a]	mg PGM/cm^2 electrode area	0.15	0.125
Loss in Catalytic (mass) activity [b]	%	<40% loss of initial	<40% loss of initial
Catalyst support stability [c]	%	<10% mass loss	<10% mass loss
Mass Activity [d]	A/mgPGM @900mV$_{iR\text{-}free}$	0.44	0.44
Non-Pt Catalyst Activity per volume of supported catalyst [d, e]	A/cm^3 @800mV$_{iR\text{-}free}$	>130	300

US Drive Fuel Cell Technical Team Technical Targets
Revised Jan 25, 2012

OEM Specific targets

Items	2015	Final Target
ORR Mass-specific Activity	10X vs Ref*	-
Start-Stop Cycling 1.0V-1.5V	-	5000 Hrs (60,000 cycles)
Load Cycling 0.6V- 1.0 V	-	5000 Hrs (400K cycles/year)
Cost (Pt amount per unit kW)	0.1 g_{Pt}/kW	0

***Ref: TEC10E50E (50 wt% Pt on HSAC)**

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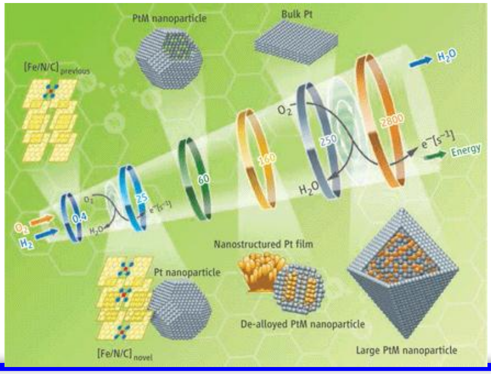
FC Electrocatalyst: Status
Available materials

Current state-of-the art electrocatalysts: Pt and Pt-alloy/C

Future candidate electrocatalysts:

- Core shell nanoparticles: Pt monolayer with cores containing Pd, Au-Ni, Pd-Co,Pd_3Co, Pd-Au,$AuNi_{0.5}Fe$, etc…
- Pt binary, ternary alloys
- Extended surface area catalysts: NSTF, Pt skins, ETFECS etc…
- Pt, Pt-alloy on various stable carbons
- Pt on stable non-carbon supports
- Non-PGM catalysts



❖ Some of these candidate materials have demonstrated very high activities in RDE. Can they have similar high activity and durability in MEA?

Material innovation is essential to improve the ORR activity while maintaining durability

* H. Gasteiger, N. Markovic, Science Vol 324, 2009

FC Electrocatalyst: Lab to Vehicle

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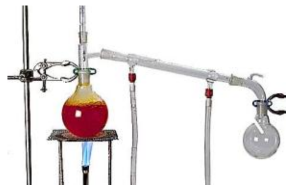
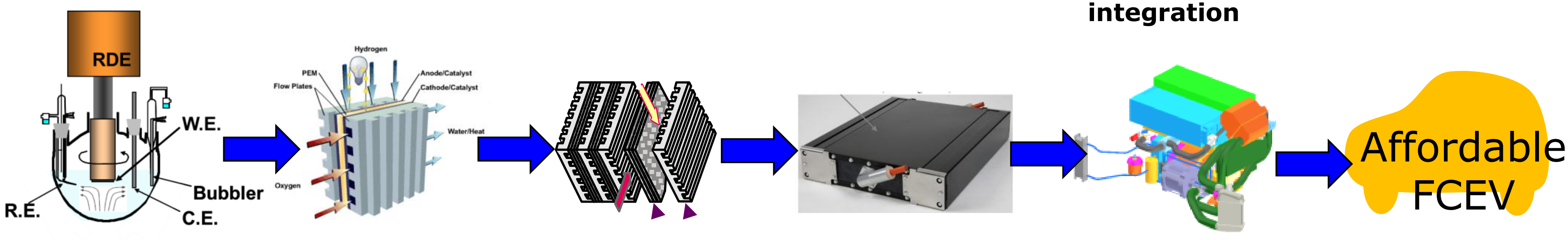
- **Understanding of development steps and timeline would help speed up the commercialization**



Catalyst synthesis and readiness

RDE Evaluation | **Single Cell** | **Short Stack** | **Full Stack** | **System integration**



Academia/Labs/Supplier | **OEM**

Approx 5~10 years

Lab to vehicle journey of material need to be shorter

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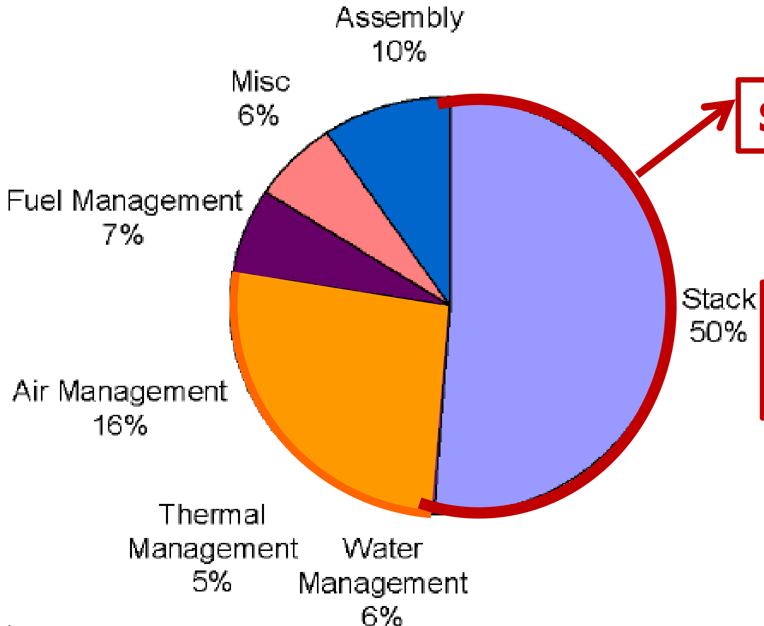
FC Electrocatalyst : Challenges

❑ **Cost is a major challenge for FCV commercialization**



(U.S. DOE Hydrogen Program Review 2009)

Stack 50% → **Pt Electrode ~25%**

Cost → **Catalyst Material** → **Performance** / **Durability**

Performance
- ✓ Improve ORR activity
- ✓ Improve mass transport

Durability
- ✓ Improve Pt diss resistance
- ✓ Improve support corrosion resistance

Reduction of Pt /PGM loadings is essential without sacrificing MEA performance/durability

FC Electrocatalyst : Challenges

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Catalyst Layers

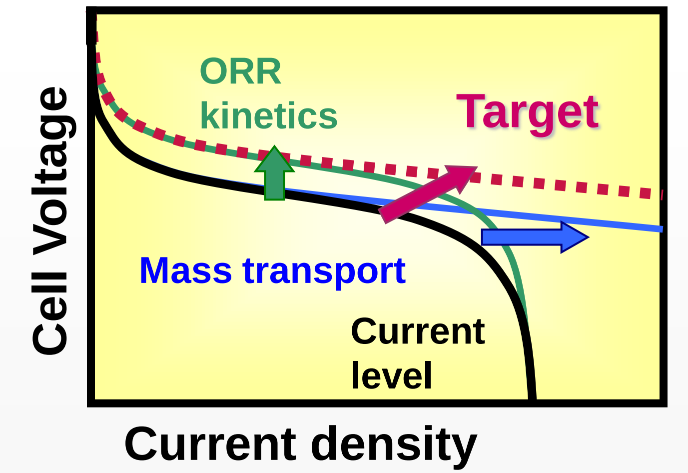
Performance

Reduce Pt Usage

- Improve ORR area-specific activity
- Increase effective site on Pt for ORR (high Pt utilization)
- Enhance mass transport in CLs (high Pt effectiveness)
- Enhance mass transport in other components (GDL, Membrane etc.)

ORR kinetics

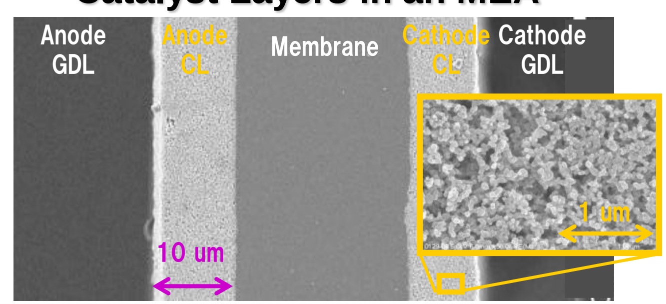
mass transport, IR



Targets in MEA:

- 0.65 V at 2 A/cm2
- ORR > 5X vs Ref (Pt/C)
- Mass transport > 2X Ref

Catalyst Layers in an MEA



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Catalyst layer is a key component

FC Electrocatalyst : Challenges

Catalyst Layer Design Scheme Approach*

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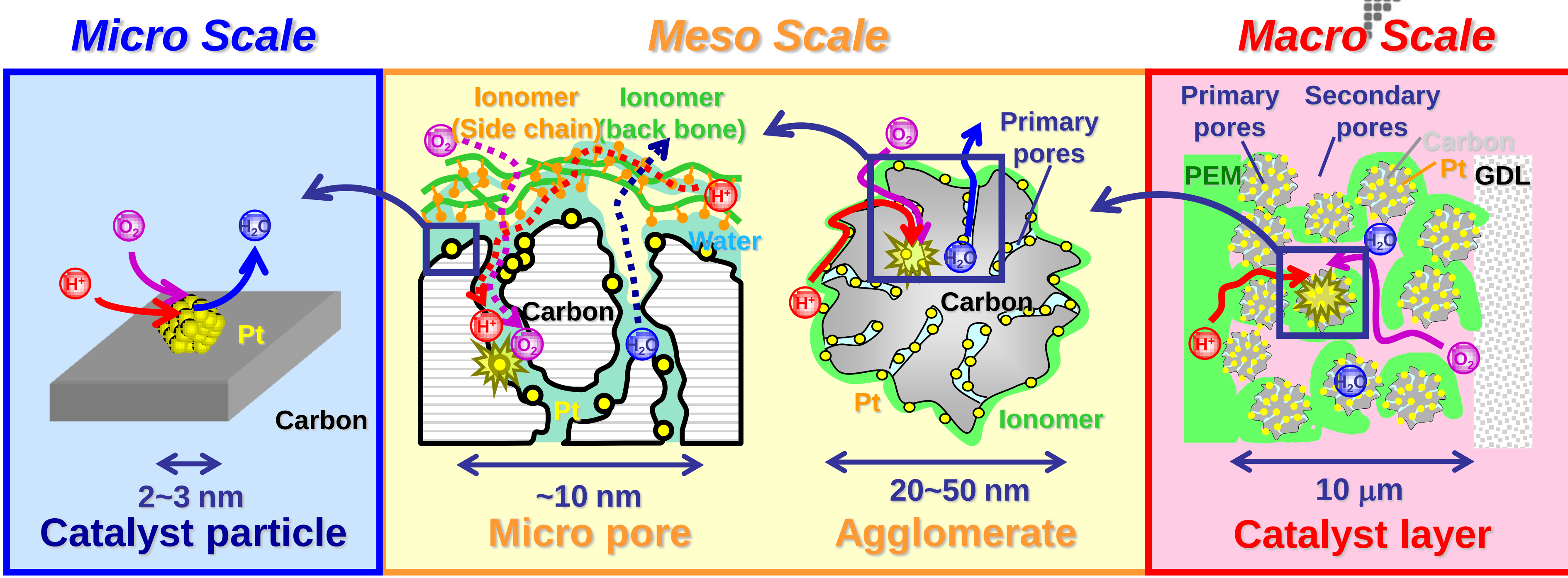

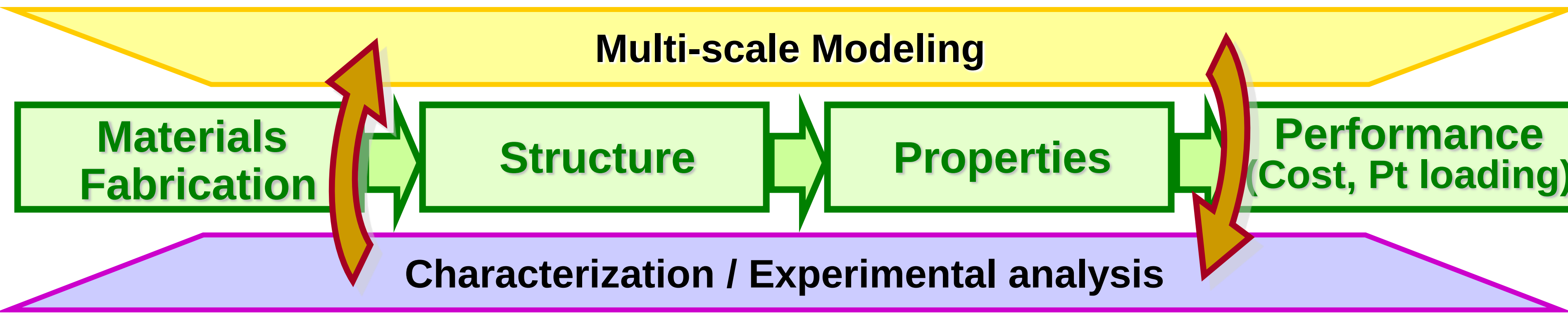

Reveal relationship from materials to performance via key mechanisms.

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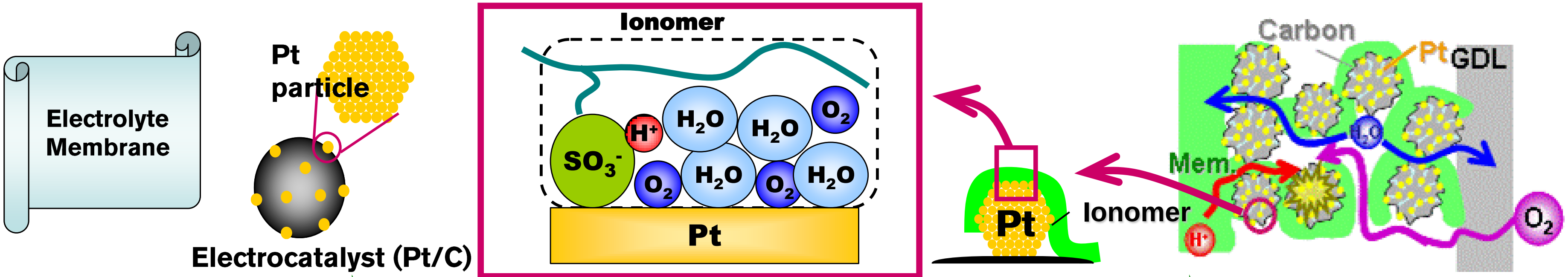
A. Ohma ,et al , Electricmica Acta , 56(2011) 10832-10841

FC Electrocatalyst : Challenges

Catalyst Layer Design Scheme Approach

❑ New Key Factor *Ionomer Coverage*



Materials Fabrication → **Structure** → **Properties** → **I-V Performance**

Structure
- Pt particle distribution across the thickness
- CL thickness
- **Ionomer coverage on Pt**
- Interfacial double layer structure
- Water morphology in ionomer

Properties
- Pt surface area
- Pt oxide coverage
- Effective H^+ transport resistance
- Effective O_2 transport resistance

We are trying to understand ionomer coverage on Pt and correlation with ORR kinetics, mass transport properties, and I-V performance.

For FCEV Commercialization

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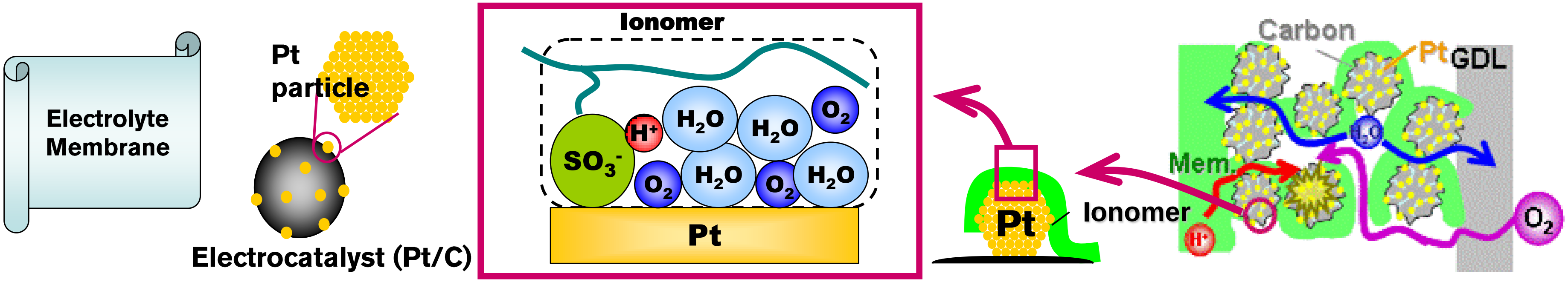
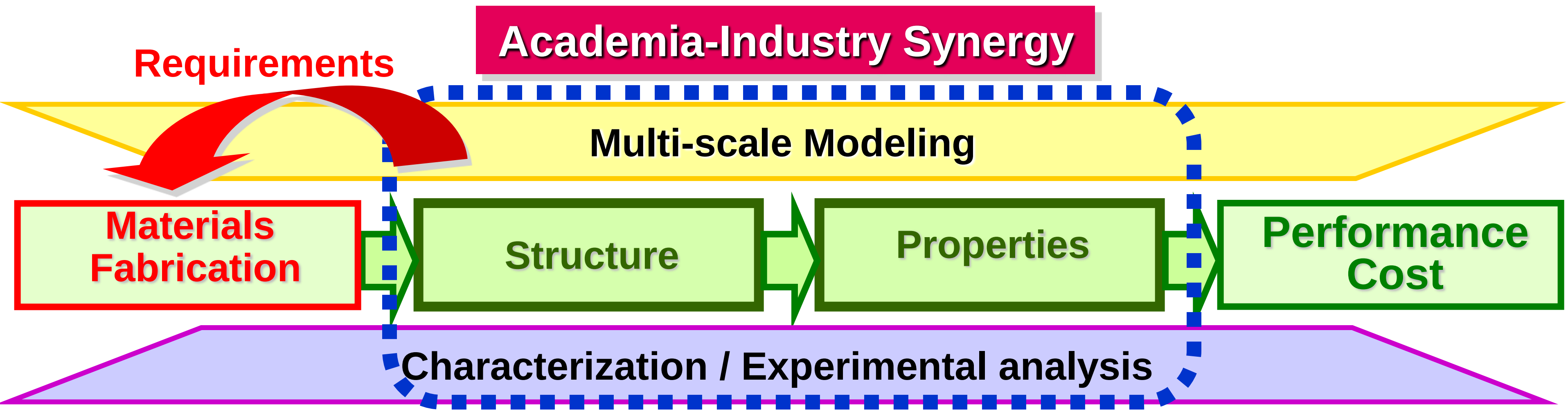
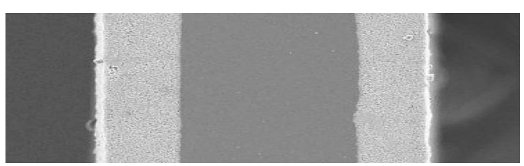
❑ Academia-Industry Synergy for Material Innovation







Low cost MEA

FCEV Commercializaiton

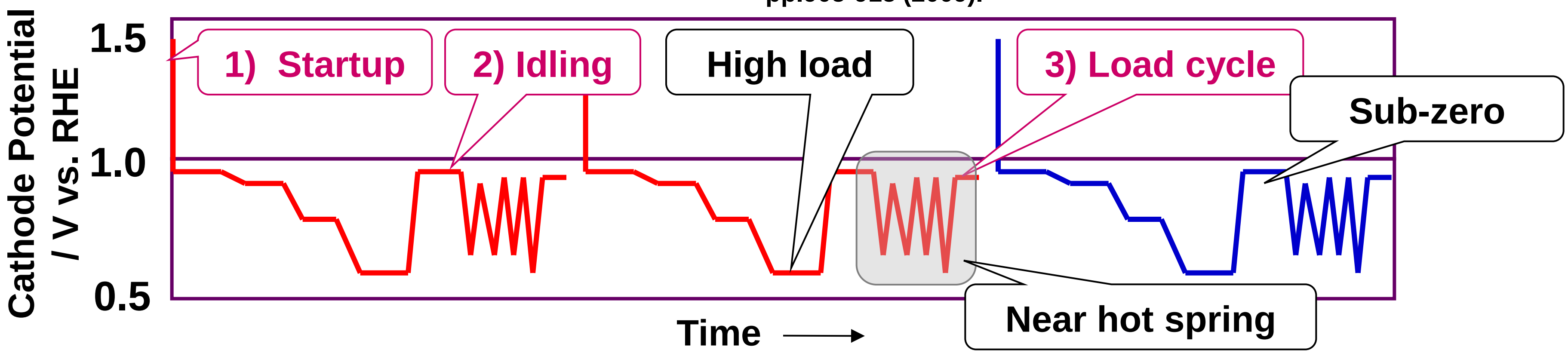
Material innovation by understanding "Structure" and "Properties" is essential for FCEV commercialization

FC Electrocatalyst : Challenges

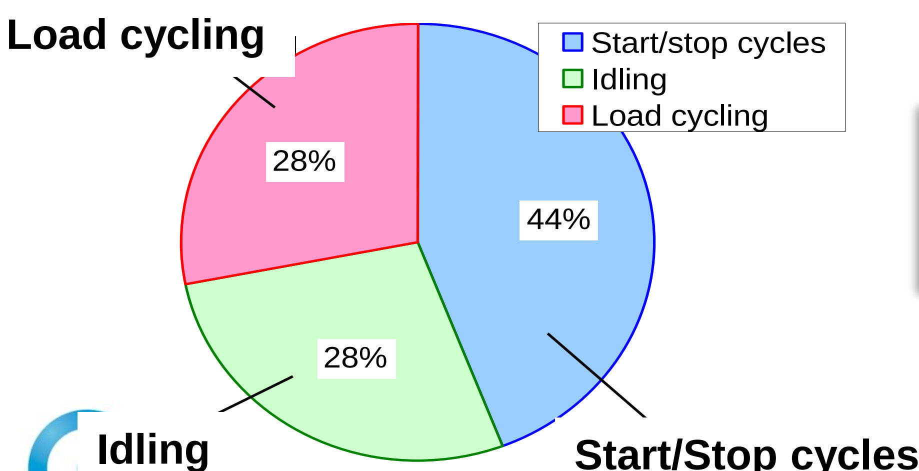
Durability

❑ Operating Mode in FCEV

A. Iiyama et al., Handbook of Fuel Cells - Fundamentals, Technology and Applications, Vol.6, Chap.61, Wiley, New York, pp.905-915 (2009).



❑ Impact of Operating Mode on Degradation



R. Shimoi et al., SAE 2009-01-1014 (2009).

Start/Stop: 44%

Load cycle/Idling: 56%

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FC Electrocatalyst : Challenges

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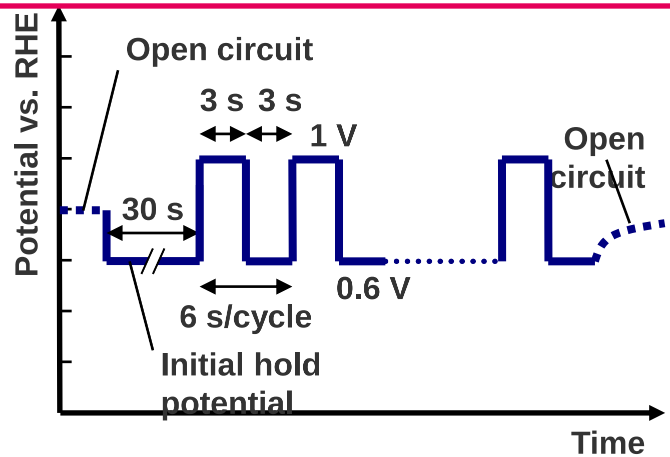
Durability

Catalyst Durability:-Load Cycling

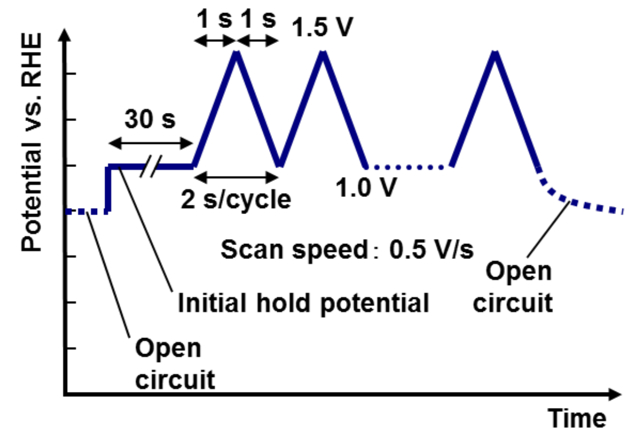


➢ **Target for Load cycles in FCEV**

Up to 400K cycles/year

Assuming 5000 Hrs in 10 year Life

Support Durability:-Start-Stop



➢ **Target for S/S cycles in FCEV**

60,000 cycles

5000 Hrs Total Life

Avg. 12 cycles/ hour

- ❑ **Load cycle operation degrades the stack significantly**
- ❑ **0.6 V-1.0 V covers almost all load cycles**
- ❑ **Start/stop operation degrades the stack most**
- ❑ **Target 60,000 cycles include all the FCV start-stop operations**

Pt dissolution resistance need to be improved

Start-stop can be mitigated by system level controls, but need to be mitigated at material level for system cost reduction

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Summary

- Cost, Performance and Durability still remain the challenges for FCV commercialization
- Improvement in electrocatalyst ORR activity is necessary by material innovations
- Better performance in MEA is indispensable and catalyst layer design can help to fully utilize the high catalyst material activity
- Load cycling and start-stop durability need to be improved and mitigated at material level
- "Academia-Industry Synergy" is needed to understand "structure" and "properties" to correlate from material to performance for design

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Thanks

Special Thanks to.....

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Thank you for your kind attention!