FCEV Technology: Stack Technology

Technology developments to enable FCEV manufacturing at scale?

2016.9.27

Toyota Motor Corporation

1. Toyota Environmental Challenge
2. MIRAI Technologies
3. Future challenge
   - 3-1. New FCEV technologies
   - 3-2. Hydrogen Infrastructure
   - 3-3. Customer first

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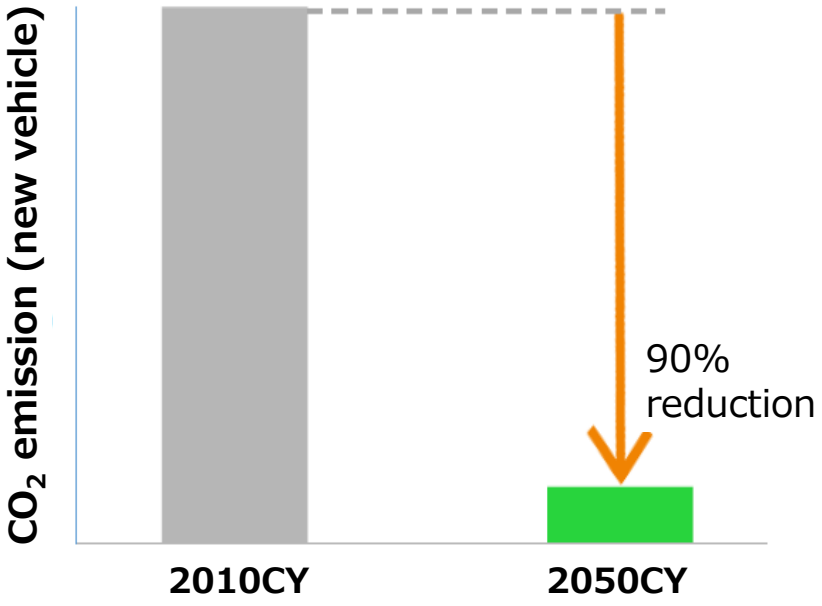
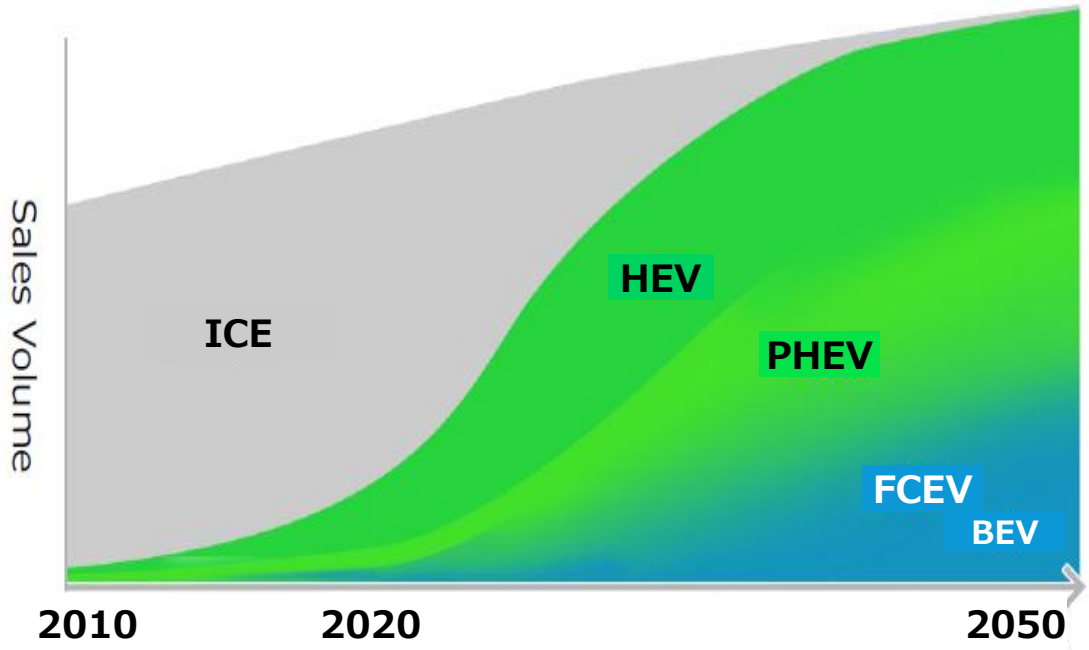
Toyota Environmental Challenge 2050 (Oct. 2015)

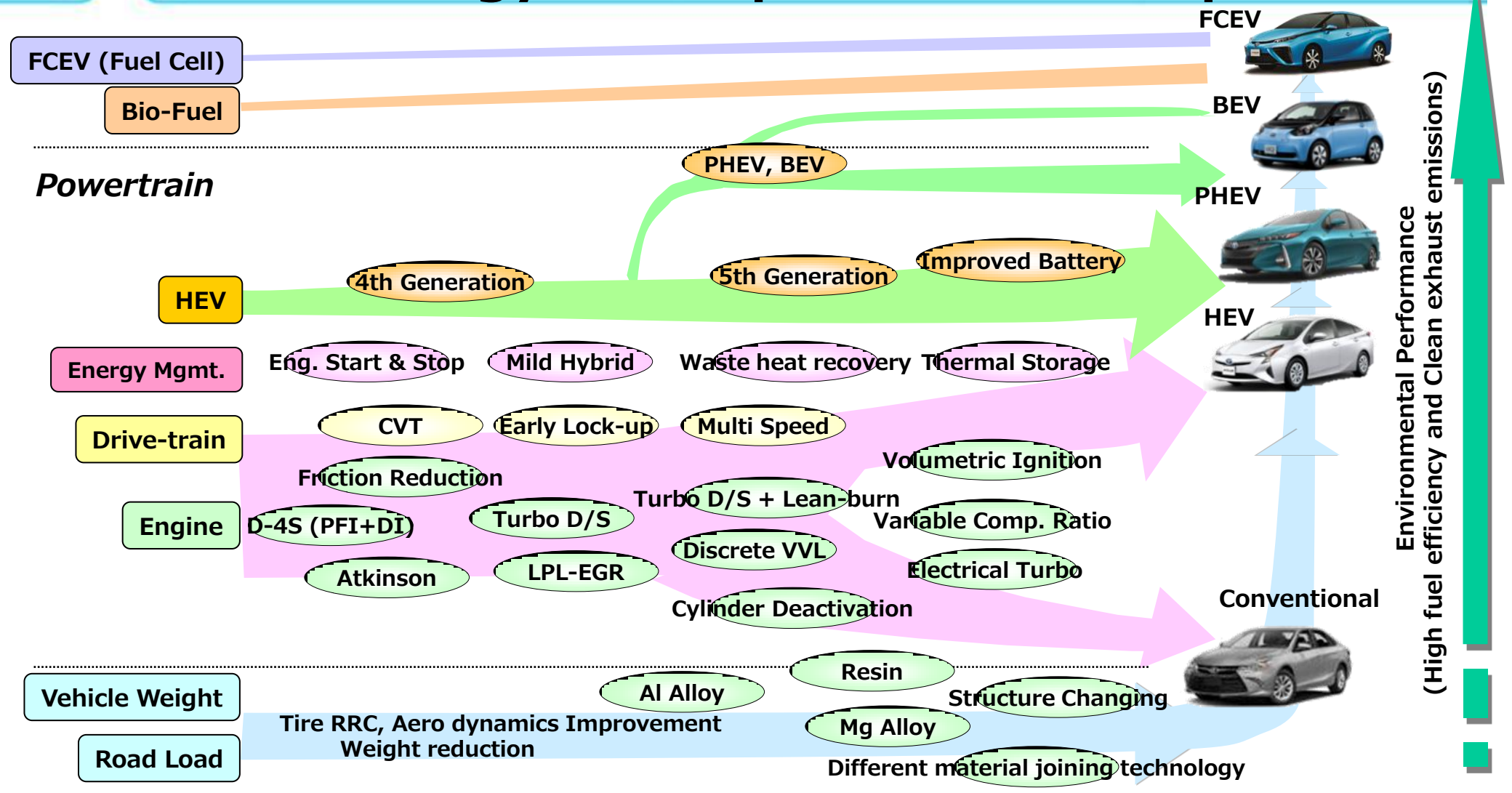
Powertrain mix for challenge 2050





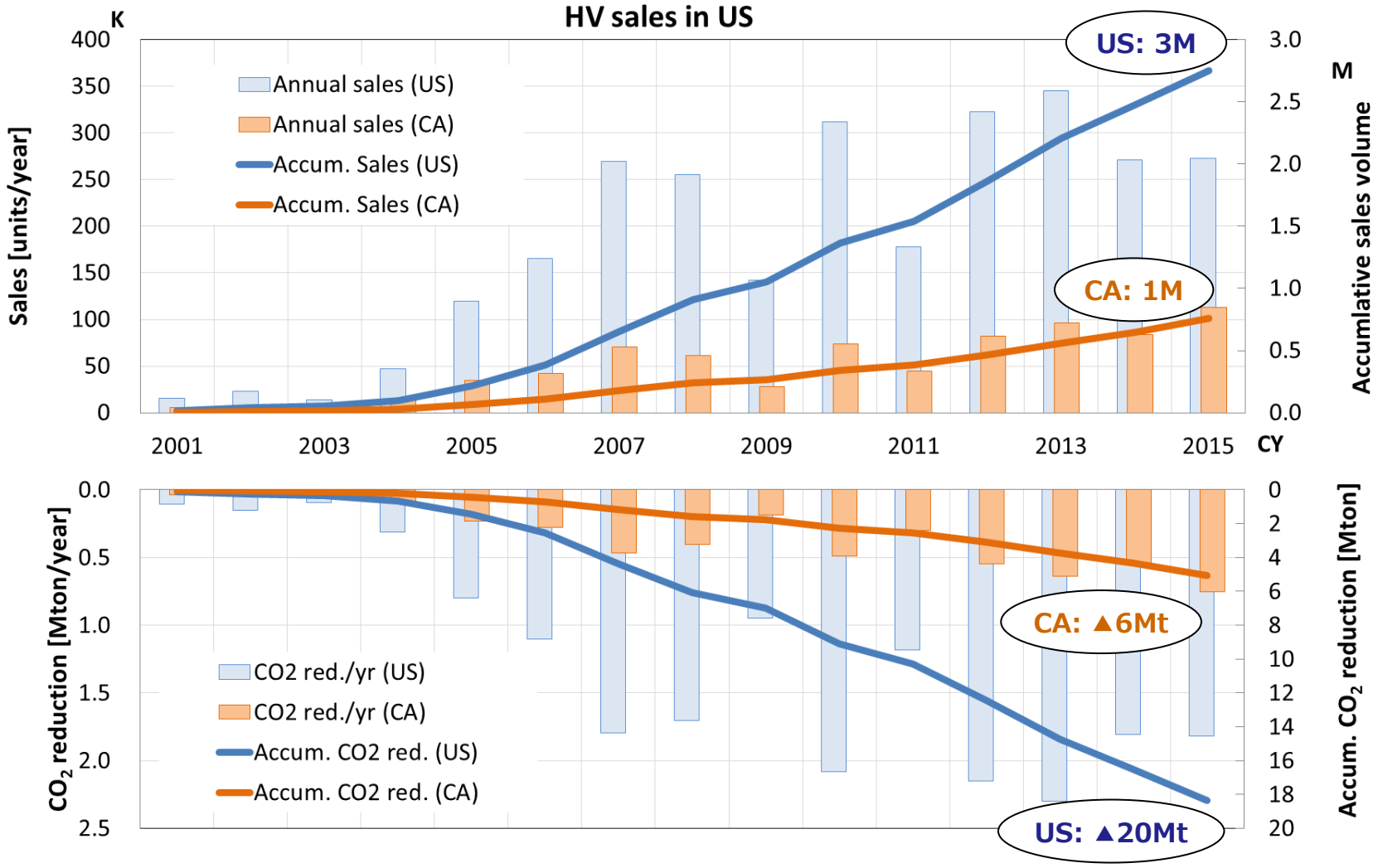
Electrification would increase dramatically after 2020.

Technology development road-map



Toyota has developed all the technologies not only conventional vehicles but also Zero Emission Vehicles.

HEV expansion and CO_2 reduction in US

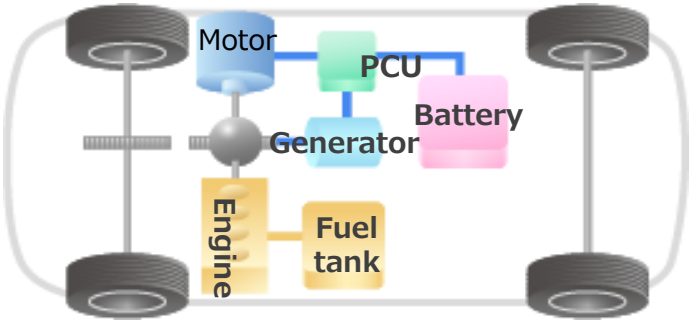


3.0M* HEVs in 15 years in US, resulting in 20M ton CO_2 reduction.

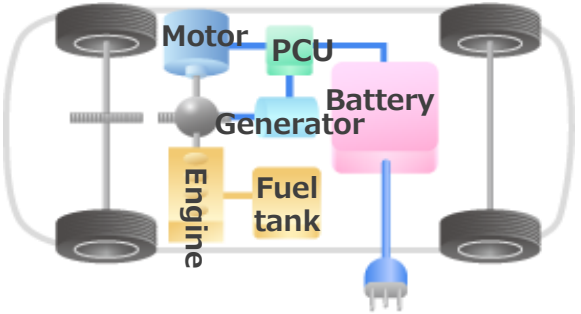
*achieved 9.0M HEVs in global

Development of Hybrid Technology

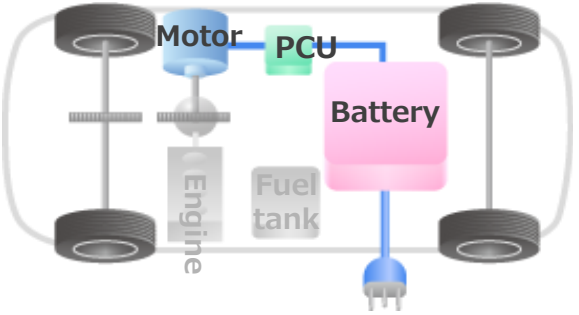
HEV



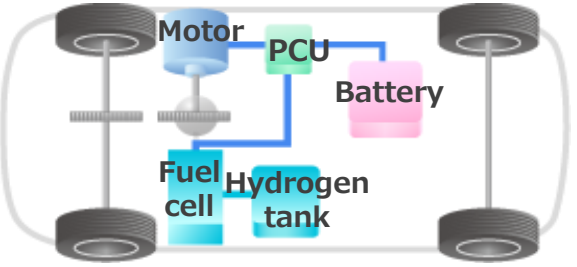
PHEV



BEV



FCEV



Hybrid technology as core, common crossover technology for PHEV, BEV and FCEV

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MIRAI debut

FCEV “MIRAI” was launched in US, October 2015
(Volume production started in Japan, 2014)

Newly developed components

FC stack

- Innovative flow channel structure and Electrodes of cells for higher output
- **Output/volume: 3.1kW/L**

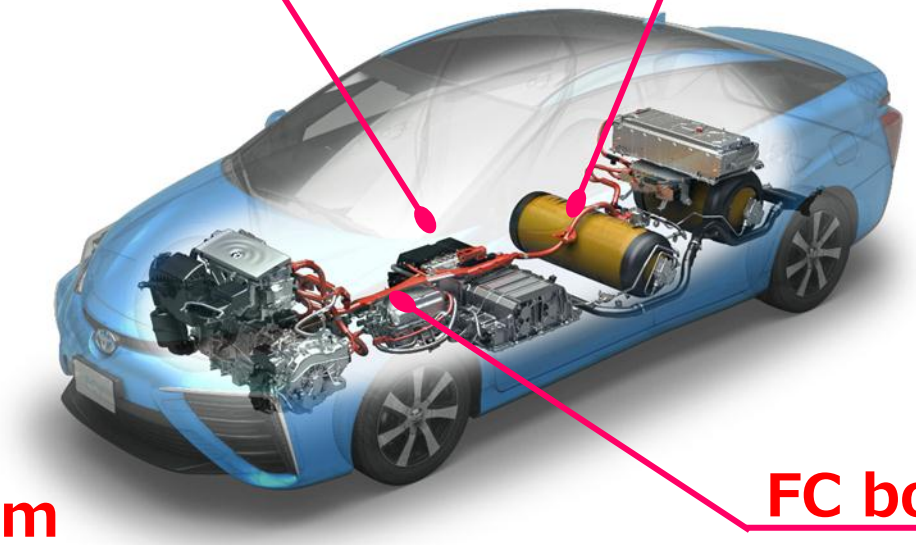
World top level

High pressure H_2 tank

- The light weight structure of carbon fiber reinforced plastic enabled
- **Storage: 5.7wt%***

World top level

*H_2 mass/Tank mass



No external Humidifier system

- Internal water circulation

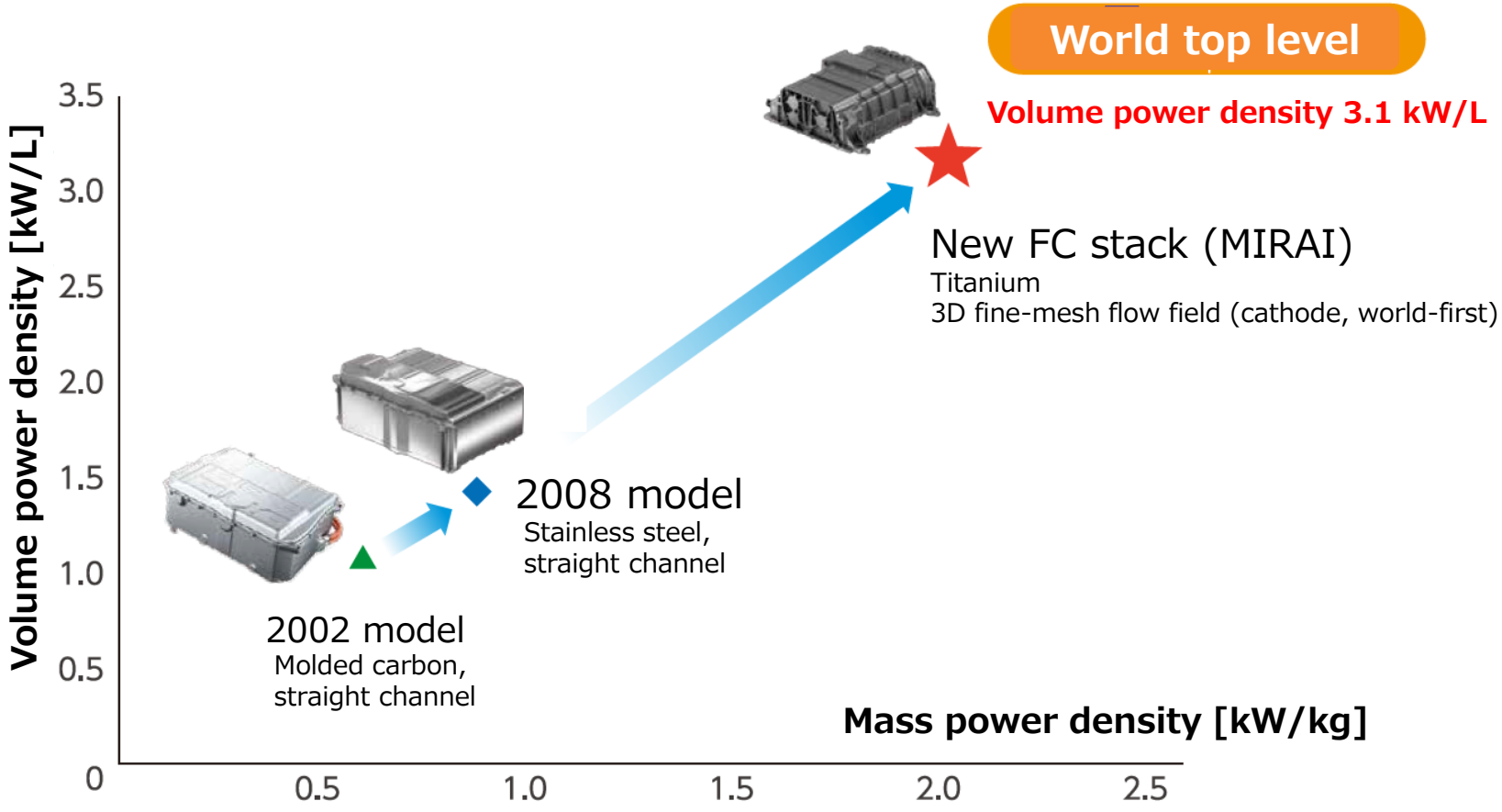
FC boost converter

- Reduced number of cells in FC stack
- Common use of hybrid units

In-house development of FC main components to achieve world leading performance

FC Stack with high power density

- Higher performance, smaller size -

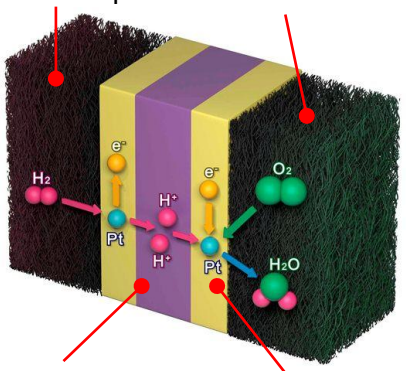


Achieved 2.2 times higher power density from previous (2008) model

High Performance of New Cells

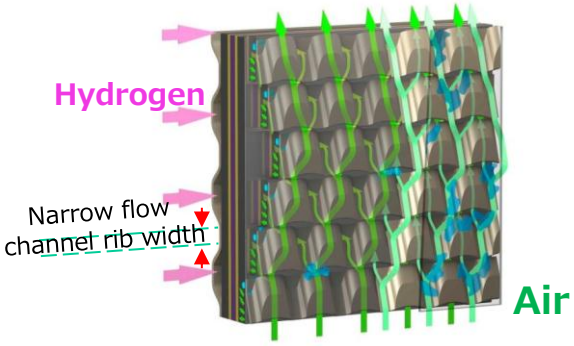
- Electrode and membrane and flow field innovations -

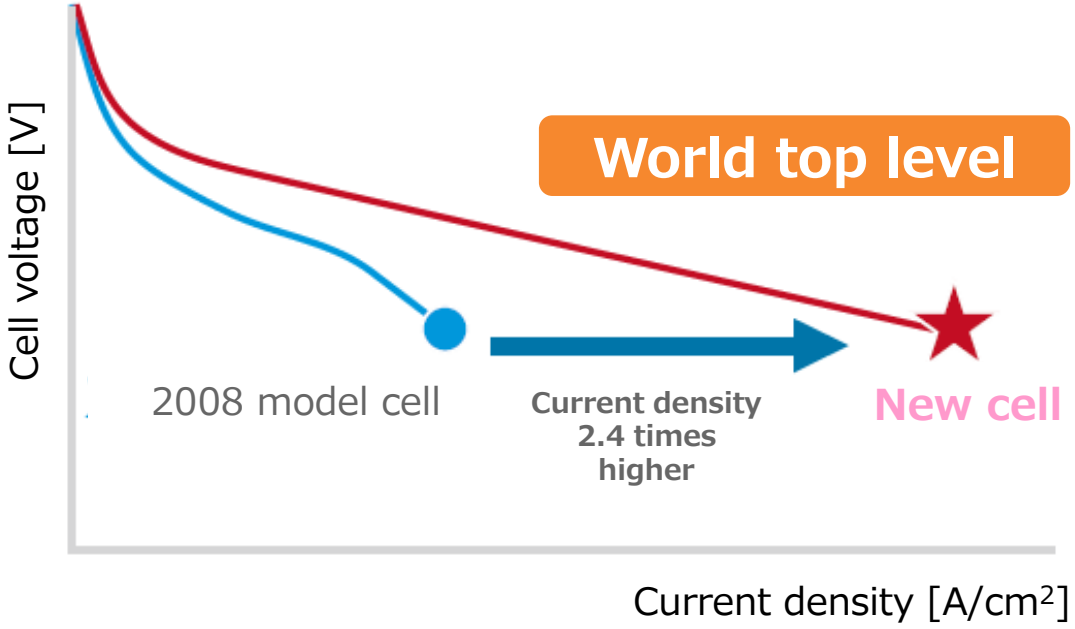
Gas diffusion layer:
Lower density and thinner base material
Gas diffusion performance more than doubled



Electrolyte membrane:
Thinned to one-third Proton conductivity increased by 3 times

Catalyst layer:
Highly reactive Pt/Co alloy catalyst. Activity increased by 1.8 times



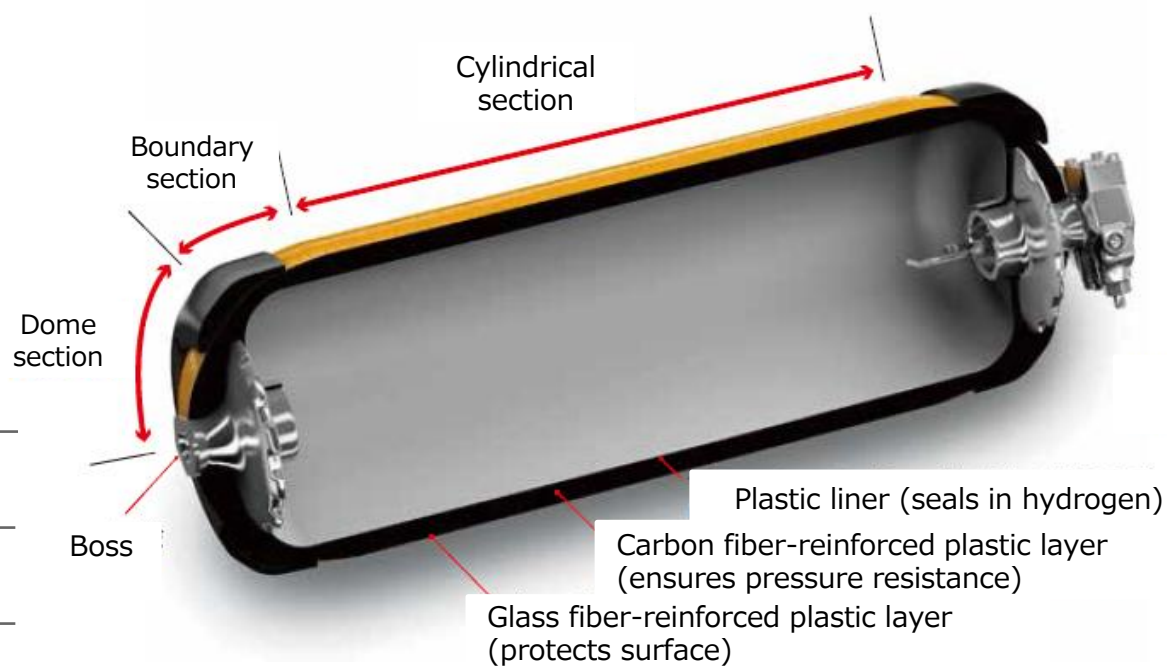


High performance FC with thinner electrolyte membrane and high-activity catalyst. They provided humidifier-less system.

High pressure hydrogen tank

Main specification

Nominal working pressure	70 MPa (approx. 700 bar)
Tank storage density	**5.7 wt%** (world top level)
Tank internal volume	122.4 L (front: 60.0 L, rear: 62.4 L)
Hydrogen storage mass	Approx. 5.0 kg



Weight is reduced by innovation of carbon fiber-reinforced plastic layer structure. Tank storage density of 5.7wt% achieved, a world top level

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Uncertainties

Vehicle Technology
- Cost/benefit improvements
- Deployment rates
- Fleet sales mix

Fuels
- Price
- Availability
- Quality/Specs
- Infrastructure

Govt Policies
- Incentives
- Flexibilities
- Other regulations (safety, fuels, etc.)
- State mandates

Customers
- Preference
- Affordability
- Awareness of FE Technologies
- Acceptance of Technologies
- Investment payback

Economic Conditions
- GDP
- Unemployment rate
- Income levels
- Health of Auto Industry

There are many uncertainties for the future expansion

Key point of further FCEV expansion

Technology development

- Cost reduction
- Downsizing
- Cruising range (Fuel efficiency)

Infrastructure

- Easy access
- High reliability

Customer first

- Fuel price
- Incentives

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Future challenges of FCEV

FCEV volume target (around 2020 and later):

Global: More than 30,000/year

Japan: Approx. 1,000/month, plus 100 buses in total

Environmental challenge 2050, Oct. 2015

Cost Reduction

- *High performance and downsizing*
- *High cost materials*
  Platinum, PEM, CFRP etc.
- *Production Volume Efficiency*

Downsizing

- *FC and BOP*
- *Hydrogen Storage*

High Spd&Volume Manufacturing

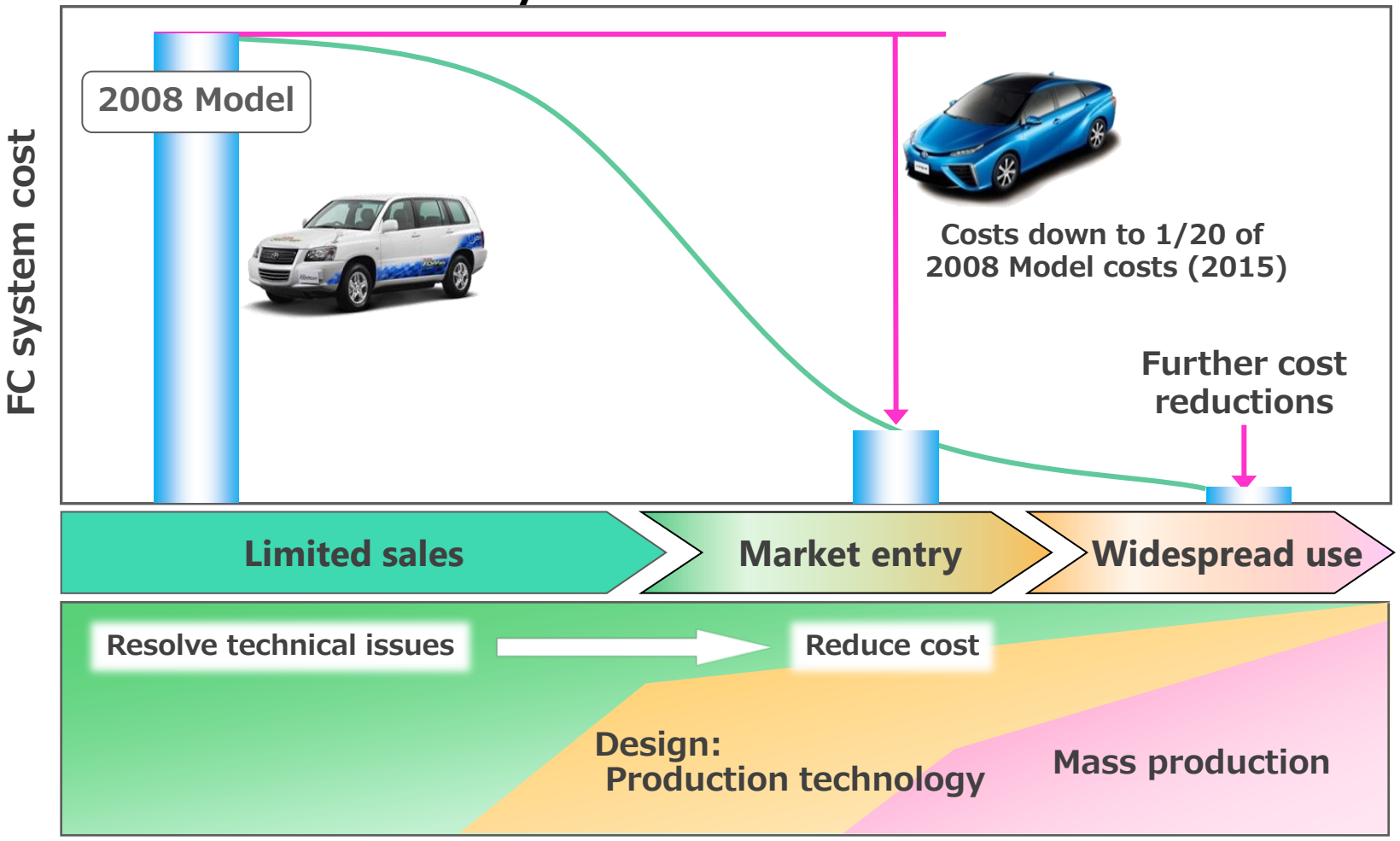
- *FC cell production*
- *Hydrogen Tank production*

Cruising Range, Fuel Efficiency

- *Further Cruising Range*
- *Fuel Efficiency Improvement*

Cost reduction

FC System cost reduction



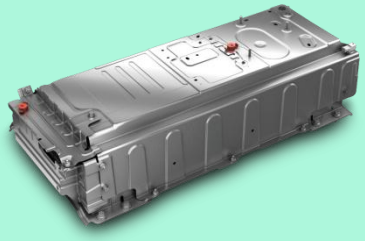
Fuel cell system costs have been reduced significantly.
Effort of cost reductions has continued

Toyota's approach

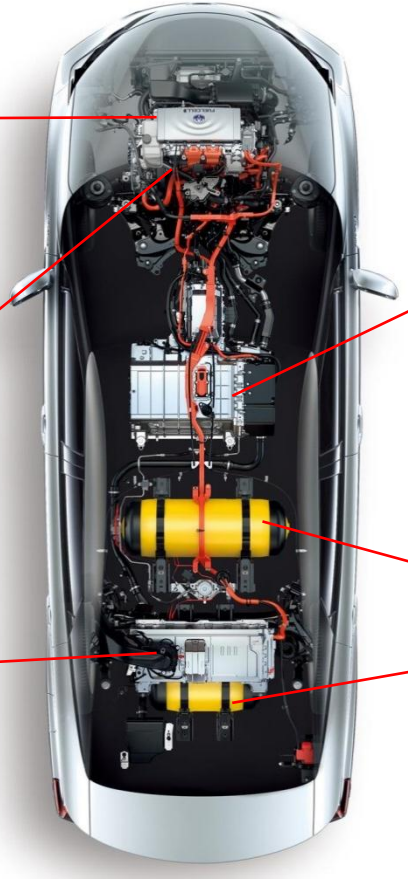
HEV Technology

Power Control Unit

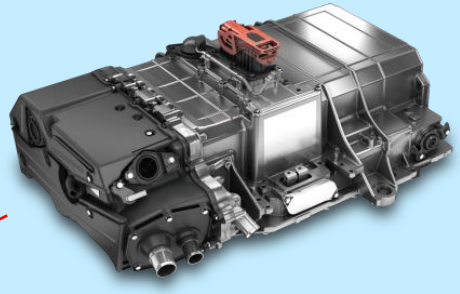
Motor



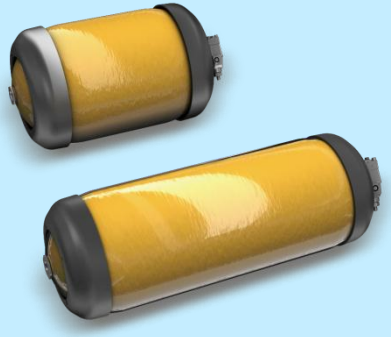
Battery



FCEV Technology



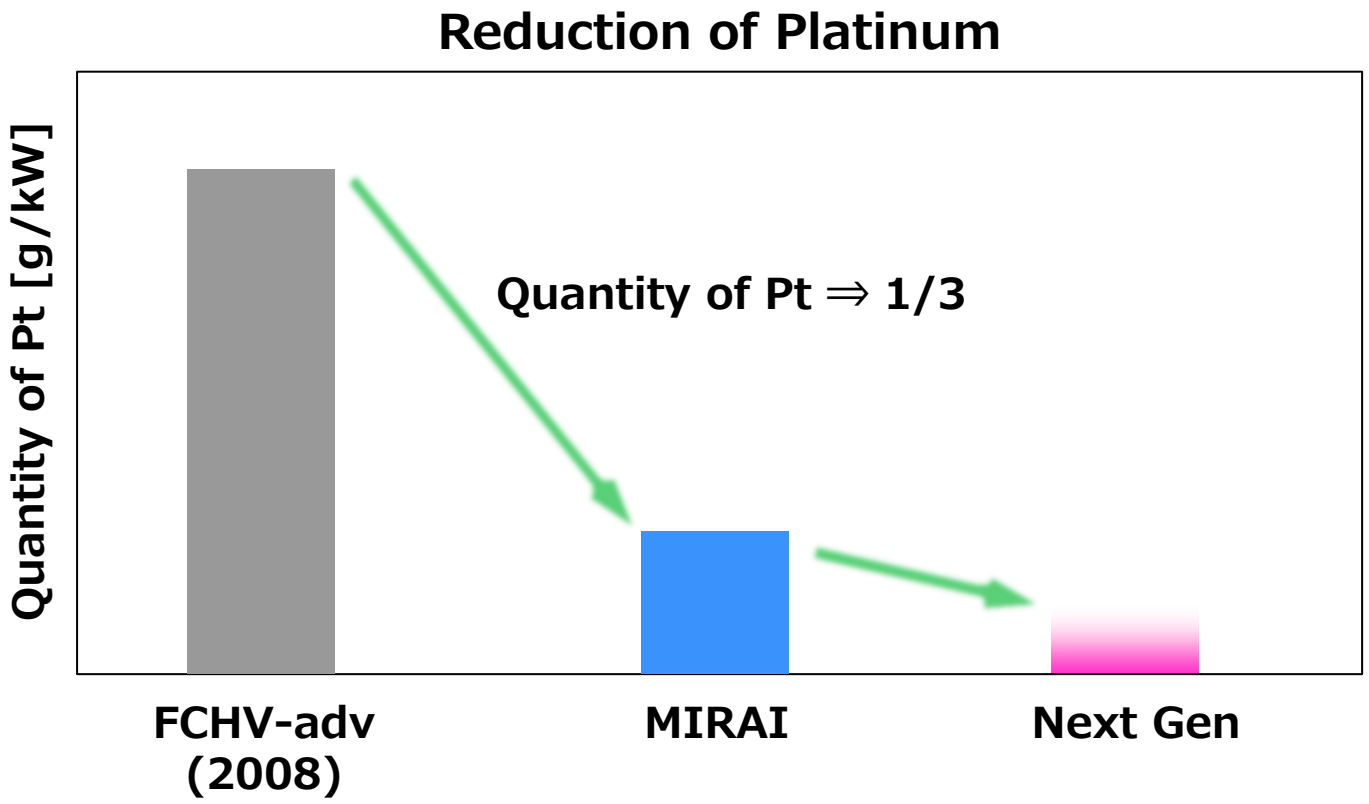
FC Stack
(electrolyte membrane, separator)



High pressure hydrogen tank
(Carbon fiber)

Maximum HEV technology application yields cost reduction

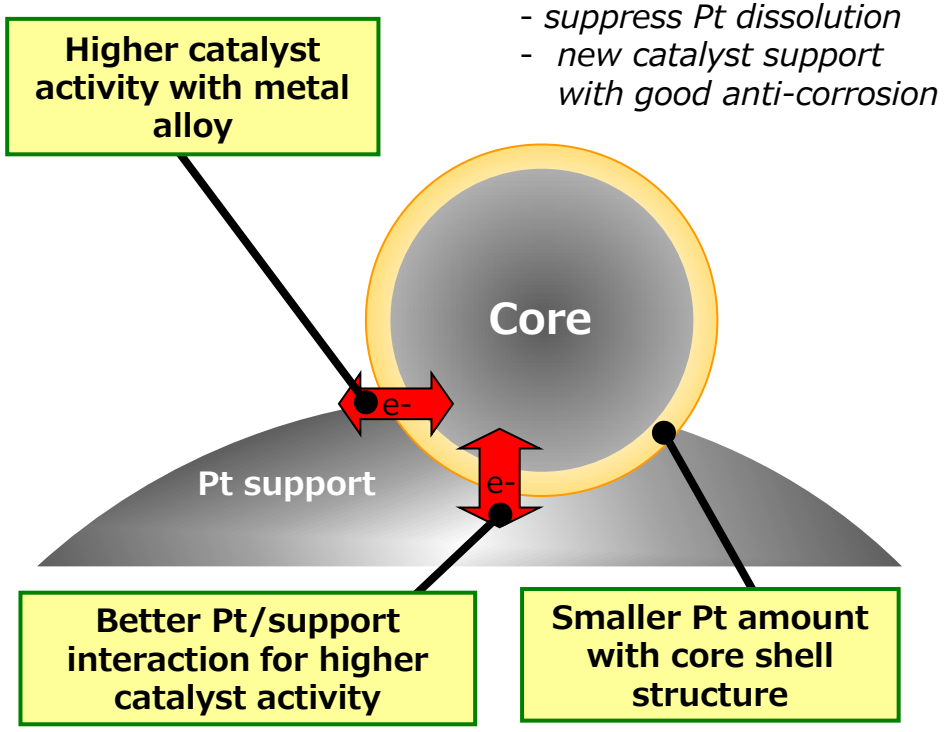
High cost material reduction



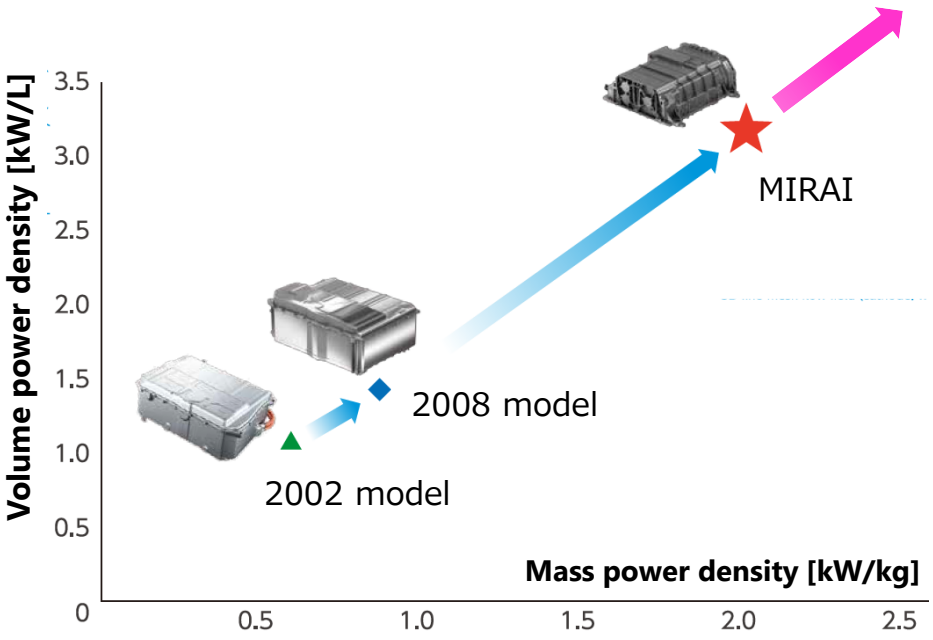
Reduction of high cost materials may achieve both higher FC power density and cost reduction

Multi-approaches for material reduction

Precious metal reduction ex.: Core Shell Catalyst



Development for higher performance and downsizing

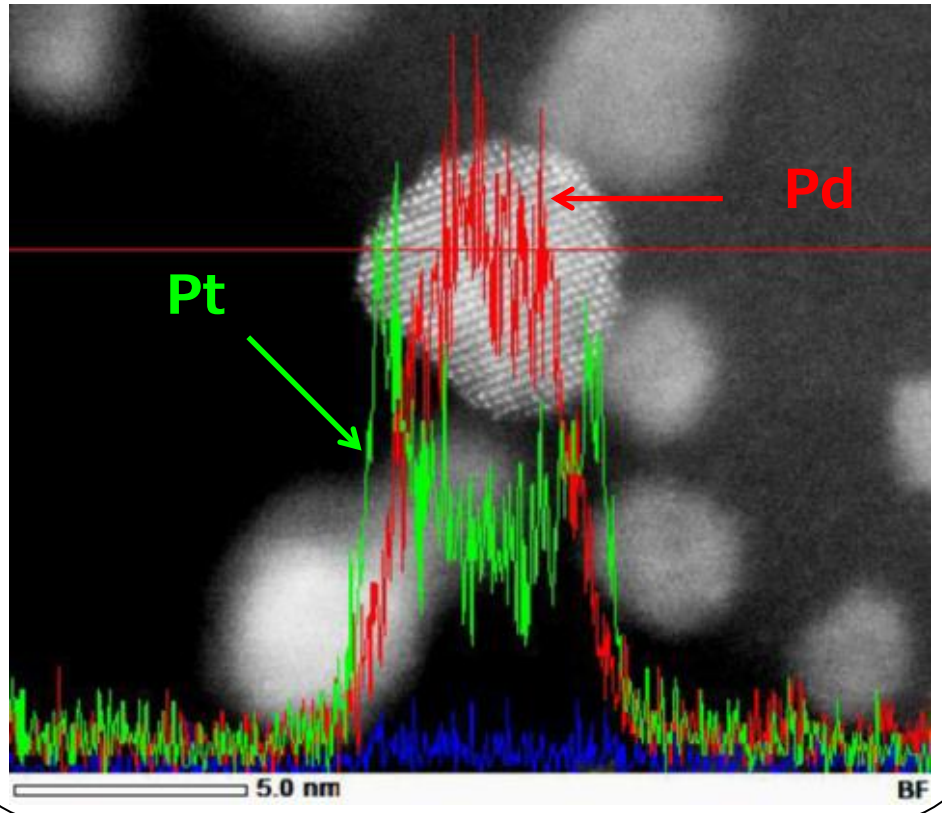


1) Material development:
ex) alloy, core shell structure catalyst
2) Performance improvement and downsizing

Material/cost reduction

Multi-approaches for material reduction

Precious metal reduction ex.: Core Shell Catalyst



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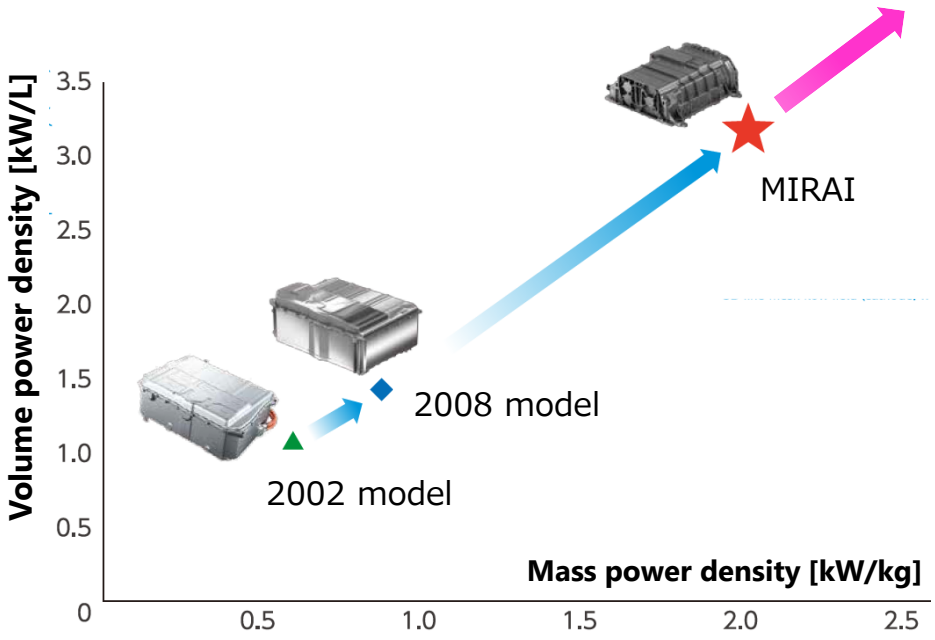
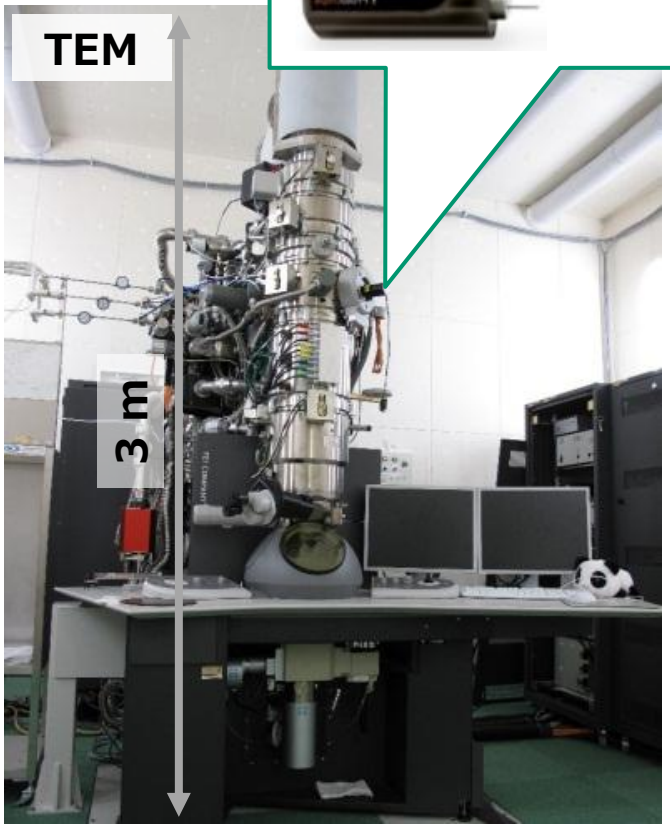


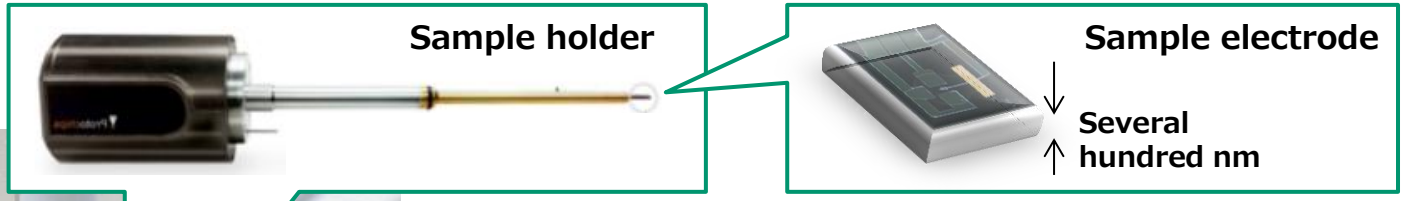
1) Material development:
ex) alloy, core shell structure catalyst
2) Performance improvement and downsizing

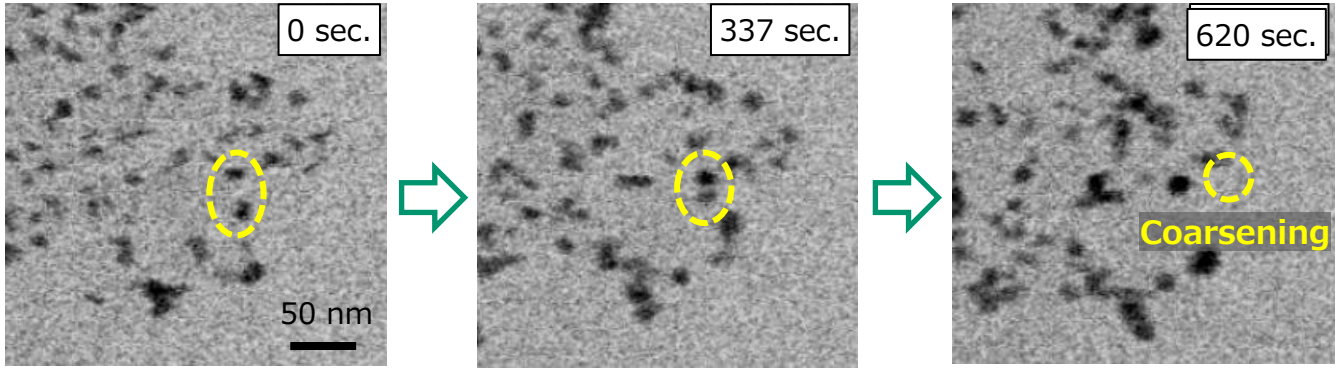
Material/cost reduction

Real time observation of Pt behavior

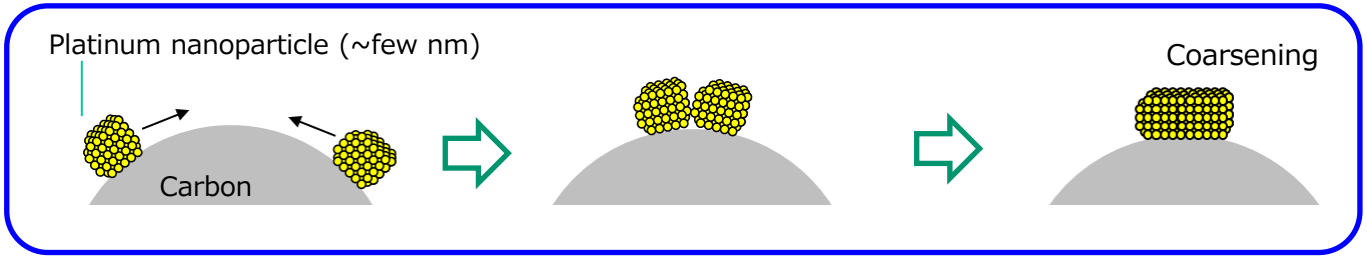
Direct reaction observation via transmission electron microscope (TEM)







Phenomenon observed (schematic diagram)



Recreate a fuel cell catalyst chemical reaction in a TEM and observe real-time catalyst coarsening

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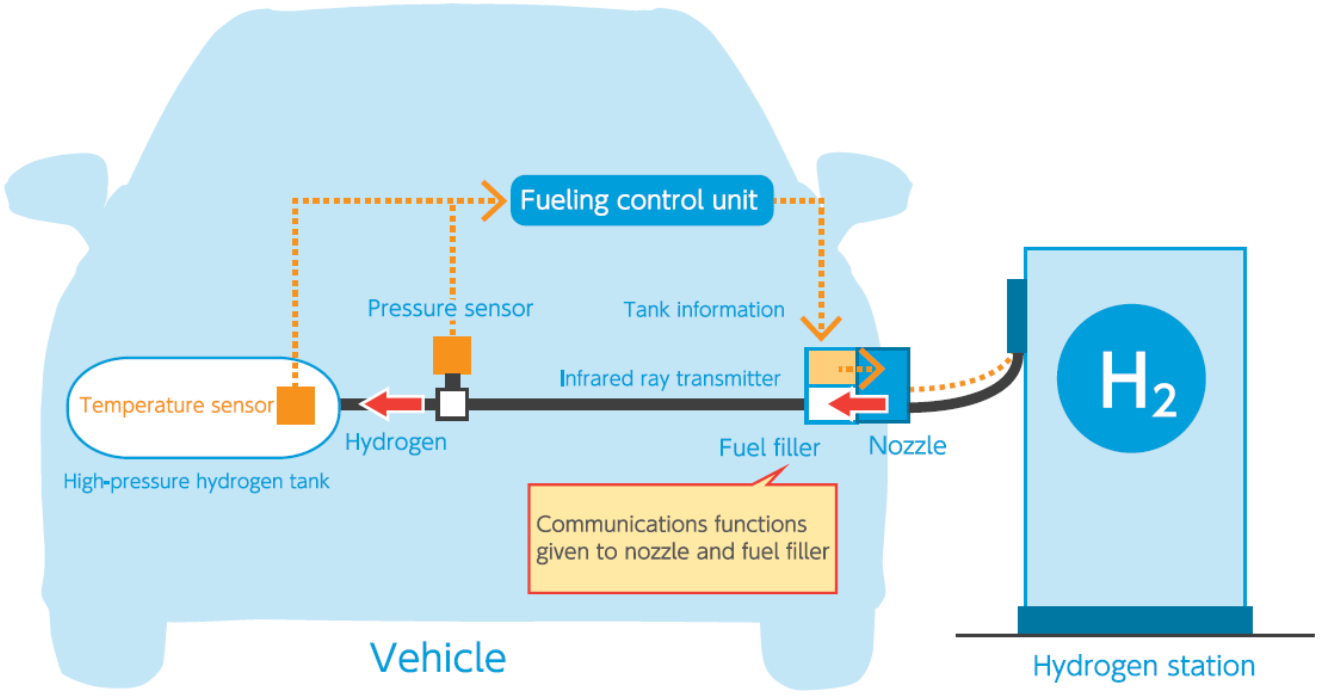
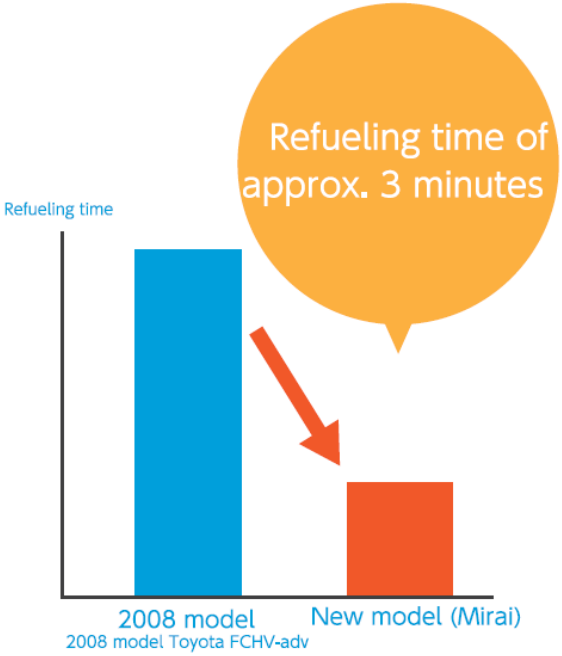
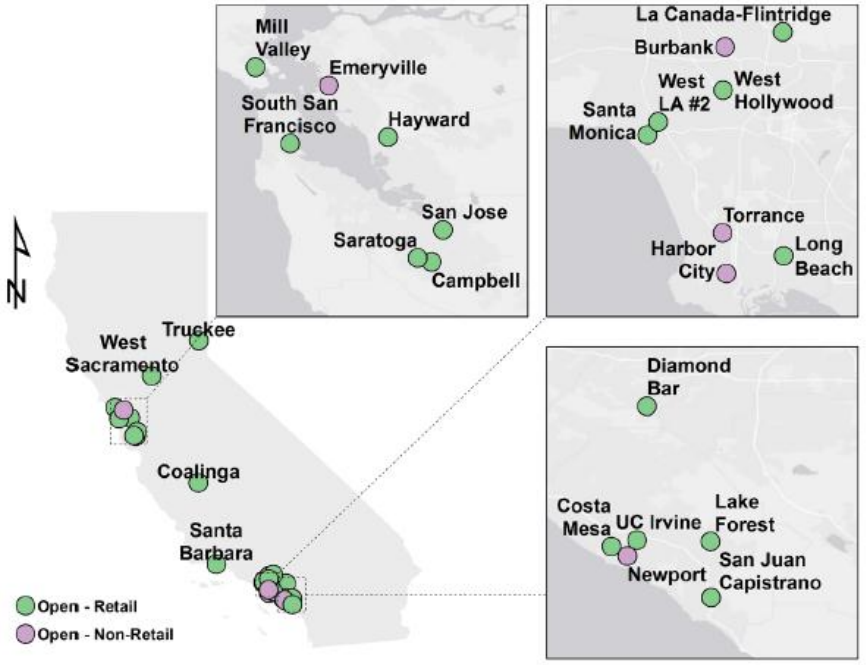
Hydrogen refueling

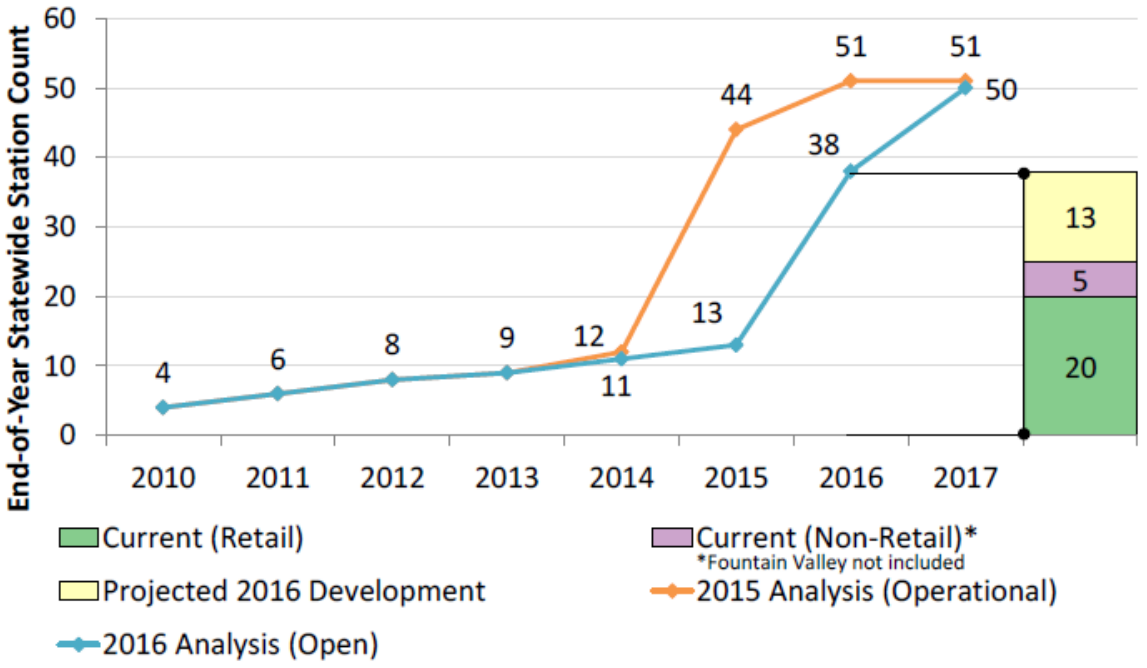




Fueling time of approximately 3 minutes has been achieved with new fueling standards (same in the US, Japan and Europe)

Hydrogen infrastructure in CA

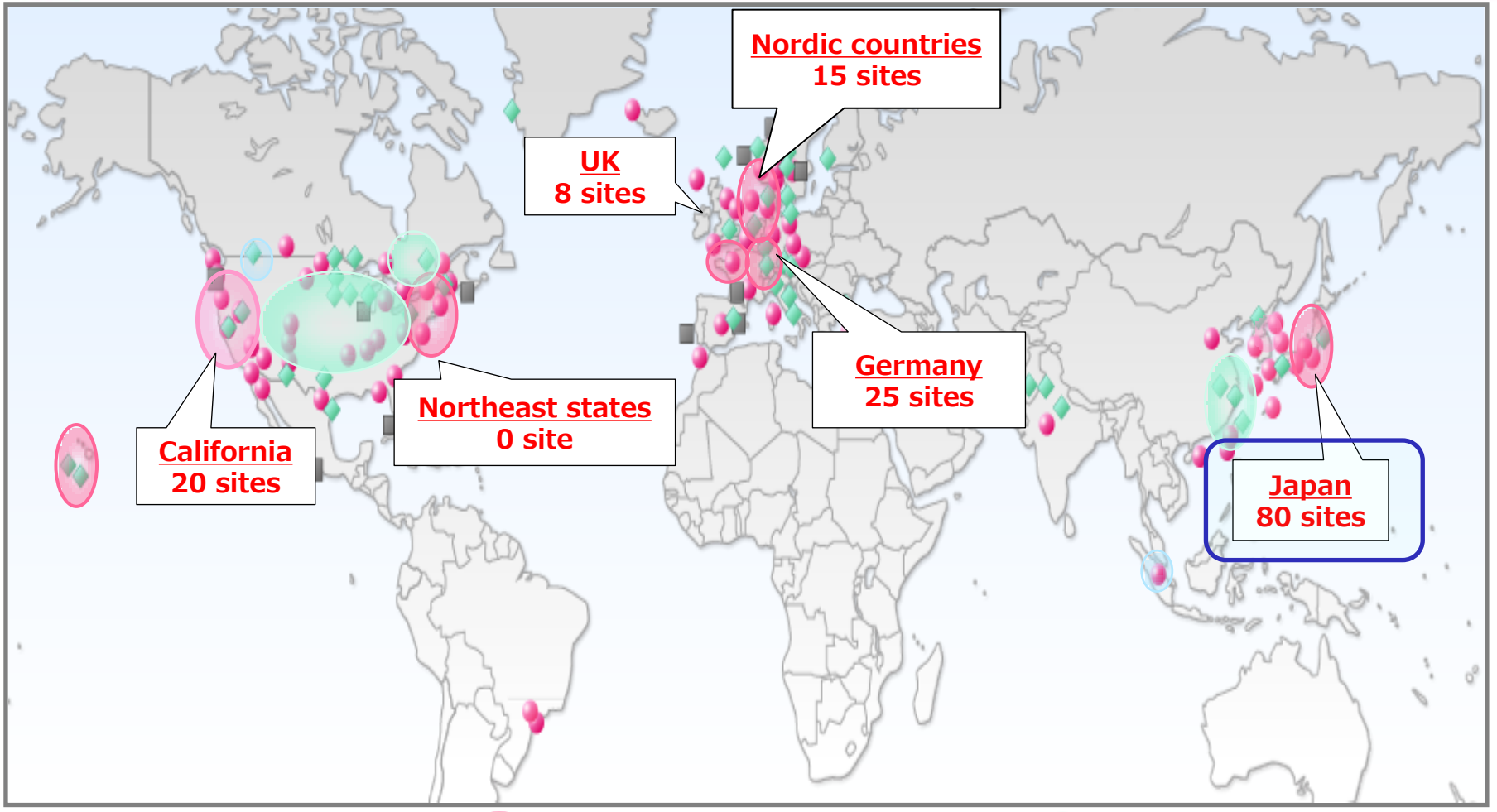




2016 CARB Annual Evaluation

Stations number is growing, forecasted 50 in 2017
Further deployment is necessary for wide FCEV expansion

Global deployment of hydrogen stations



In operation
Planned
Not in operation
Areas where infrastructure development can be expected from early 2016
Areas where infrastructure development can be expected after 2016

150+ public stations in global, deployment has just started

Approach in Japan

Strategic Roadmap for Hydrogen and Fuel Cells, 2016.3.22

	2015	2016 (present)	2020 (target)	2025 (target)	2030 (target)
FCEV number	-	-	40,000	200,000	800,000
Station number	84 sites	100 80 sites are open	160	320	900
Capex/Opex	$3.9M/$400k	-	half of 2014 level	same level as US/Europe	-
Fuel cost	same as HEV ($10/kg)	-	< $10/kg	-	-
Gross profit	-	-	-	$5/kg	-

H_2/FC roadmap was revised by METI* in March 2016 mid and long term targets were set under government leadership

*Ministry of Economy, Trade and Industry

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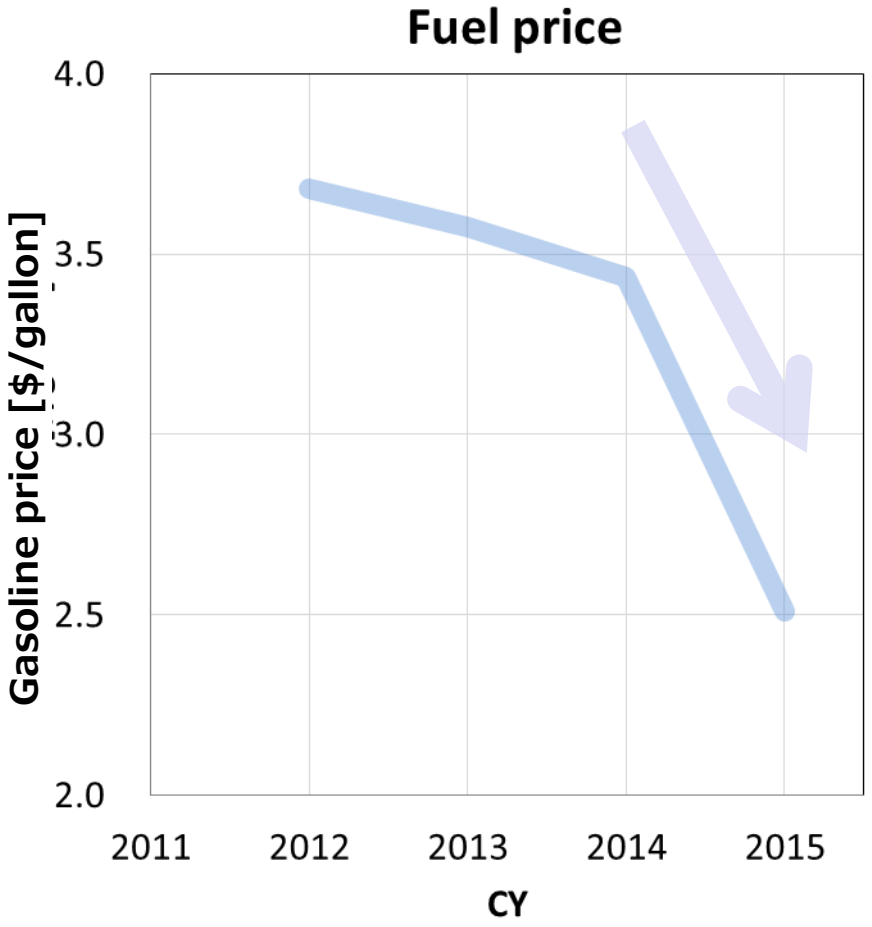
Gas prices impact ZEV



ZEV sales and fuel price have strong correlation

Key point of FCEV expansion

1. **"Cool", "advanced" FCEV**
   Better price, better product

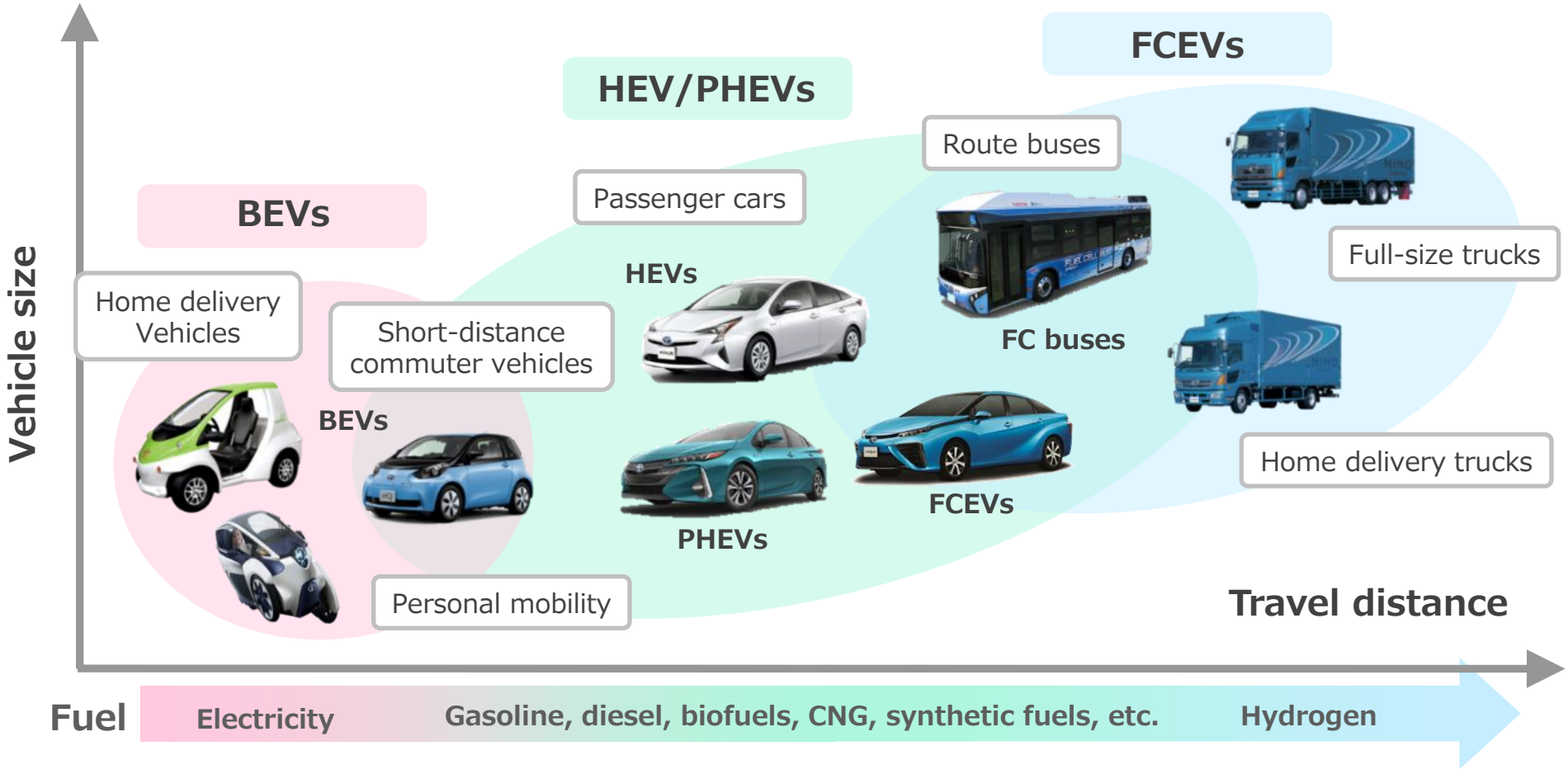
Responsible to auto industry

2. **Hydrogen station deployment for the customers**
   Access within 5-10min.

3. **Customer first**
   Equal or less fueling price as HEV incentive for ZEV affordable

Government, Energy Stakeholder ***corporation*** are necessary

Fuel diversity and uses



HEV & PHEV: Wide-use, BEV: Short-to-mid distance, FCEV: Medium-to-long distance

Fun to drive experience

Excellent usability

"The Toyota Mirai breaks 24-hour fuel-cell electric mileage record (1,438miles!) in California"

TrueZero, Green Car Congress 09/17/16

Refueling time:

Approx. 3 minutes

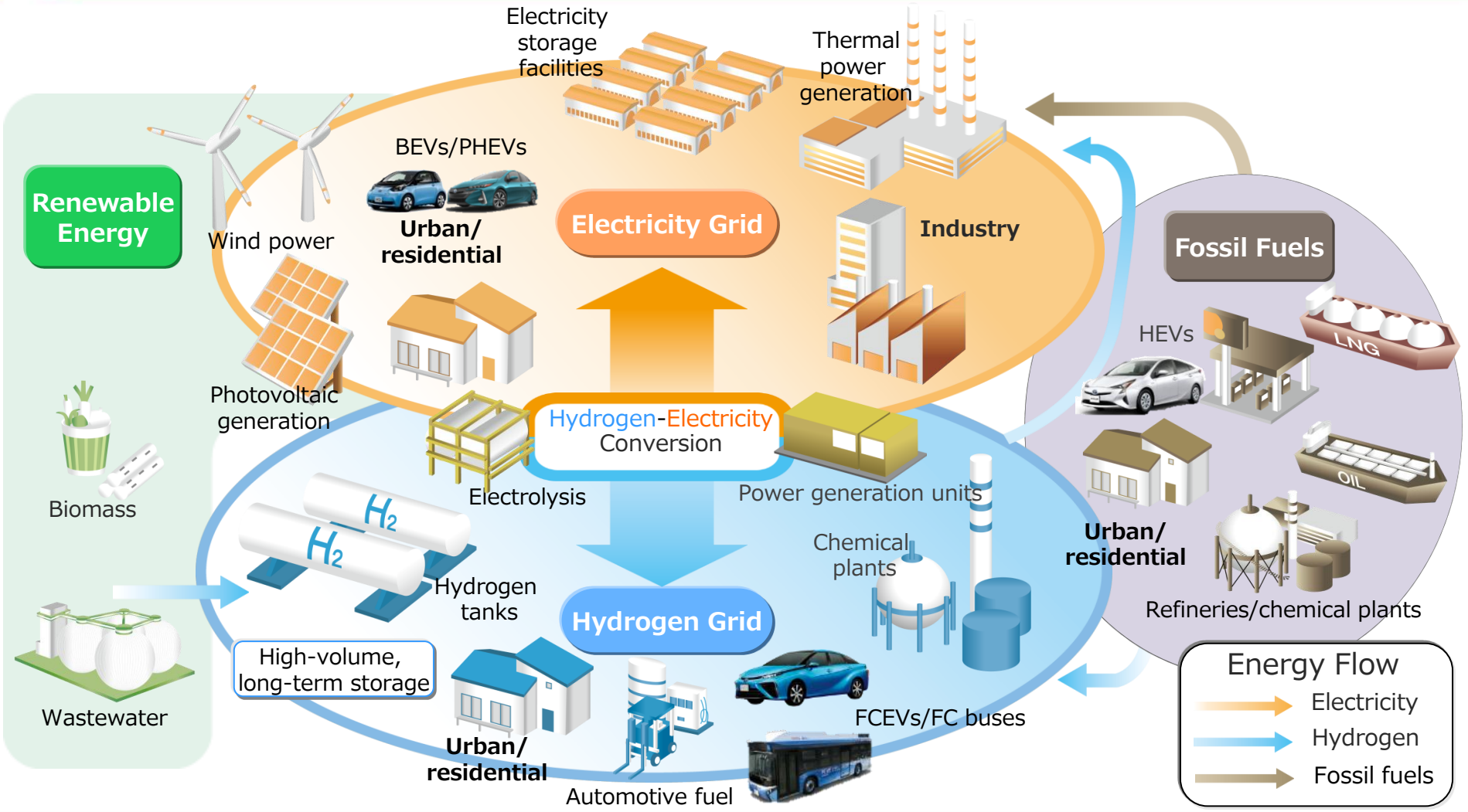
Cruising range:

312 miles

EPA-rated miles, world top level

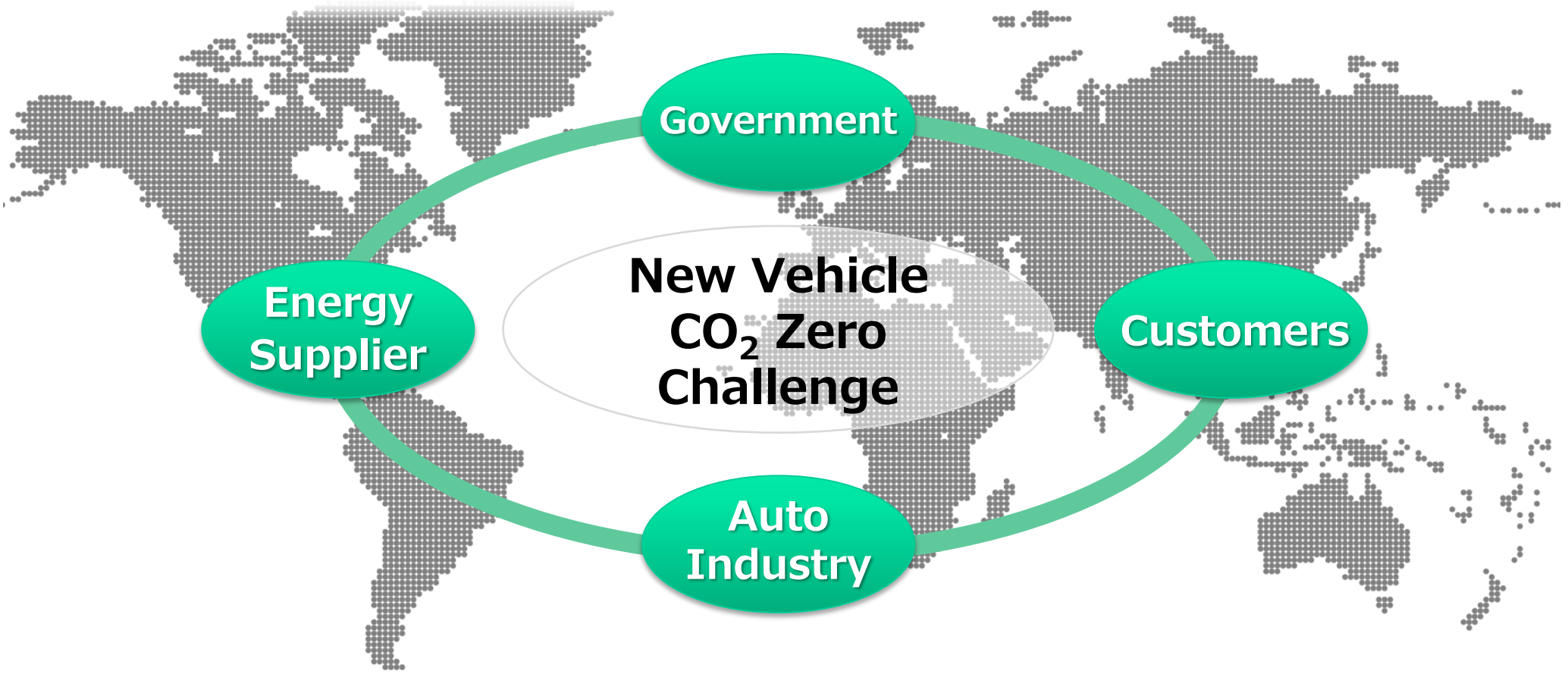
Short refueling time, long cruising range

Sustainable Mobility Society



New value-chain, new energy storage and sustainable society with hydrogen

Cooperation with all stakeholders



Cooperation with all stakeholders is required to reduce CO_2.

Summary

- TOYOTA will continue to ***develop all the technologies*** from conventional to zero emission vehicles against challenging global warming.
- TOYOTA launched FCEV "***MIRAI***" in US, October 2015, and keeps developing new technologies.
- ***Corporation with all stakeholders*** is necessary for the FCEV expansion and better future for our children.

Thank you