Progress and Challenges for TOYOTA's Fuel Cell Vehicle Development

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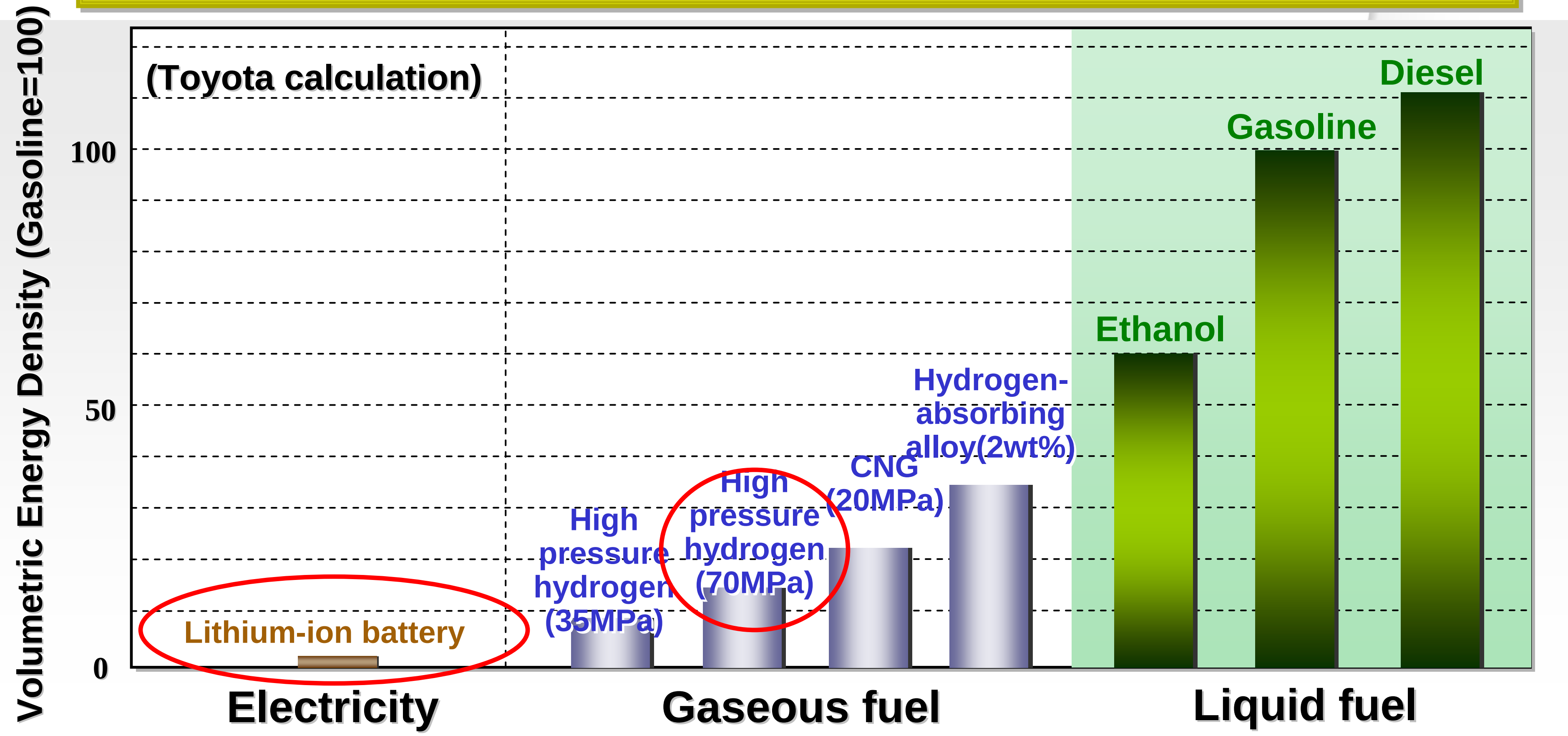
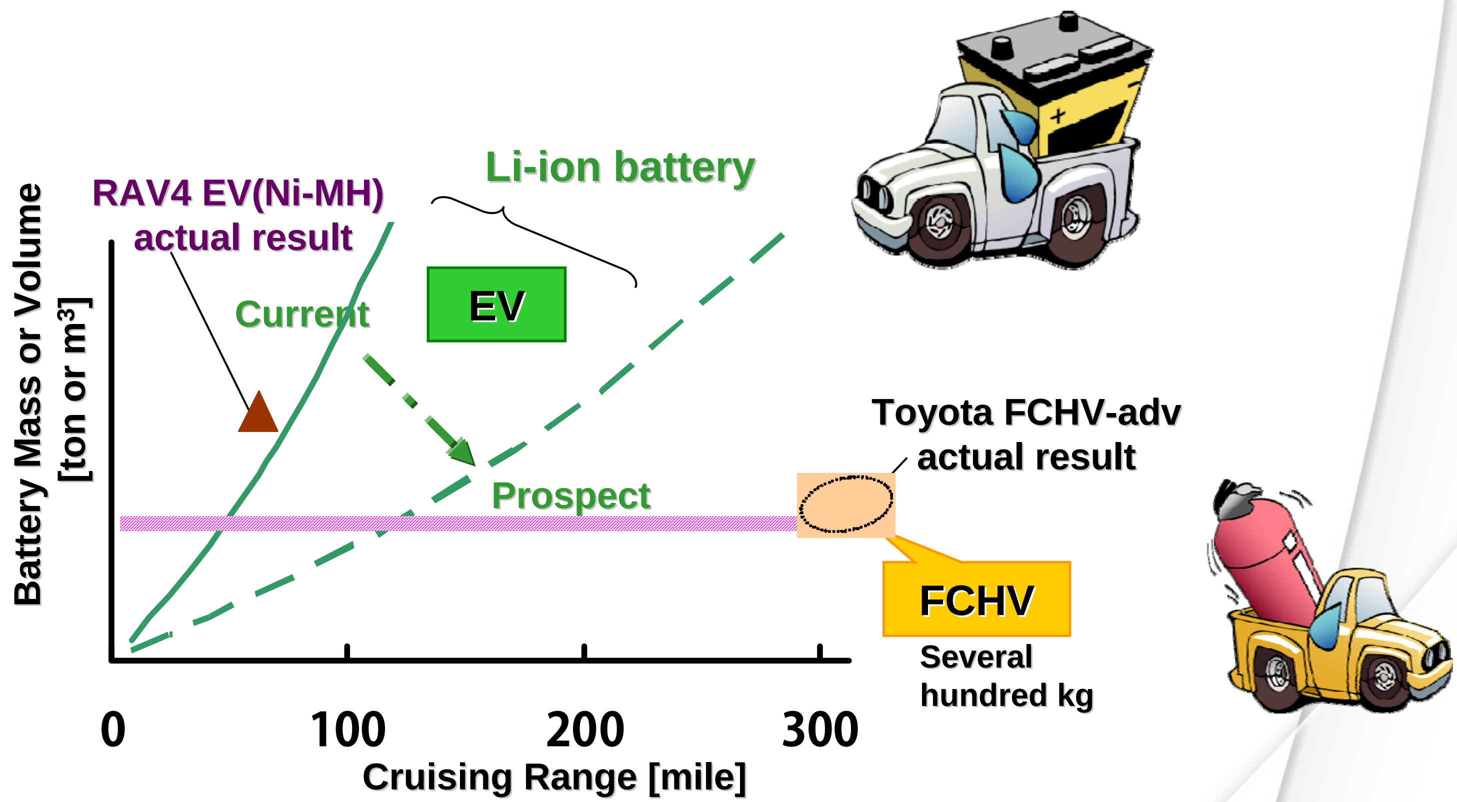
Comparison: Electricity and Hydrogen

- Liquid fuel: Most appropriate for automotive use
- Electricity: Difficult to extend cruising range
- Hydrogen: Can achieve quick charge and long cruising range like conventional vehicles



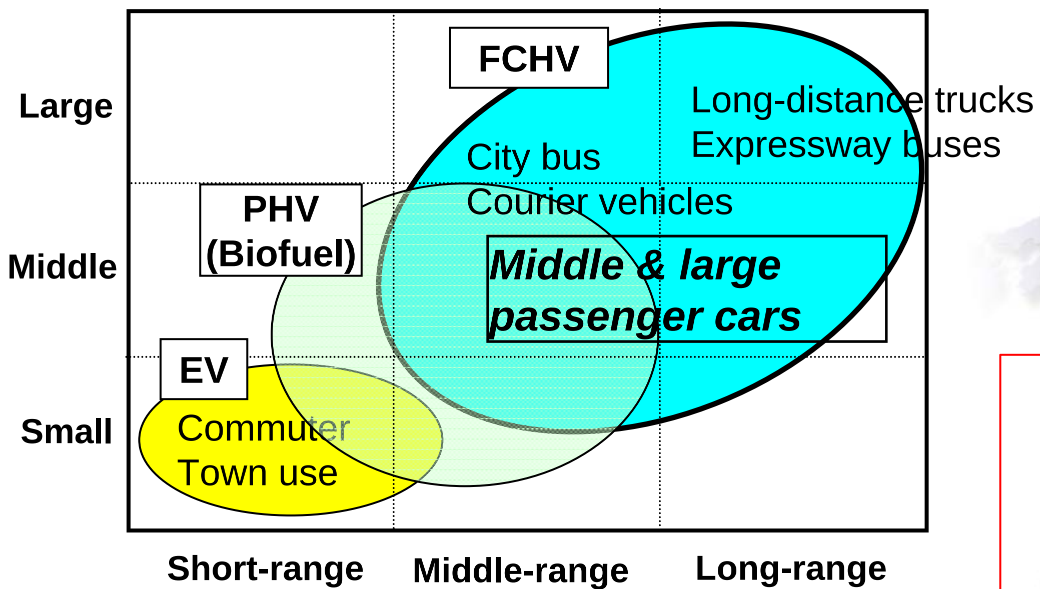
Comparison: Fuel Cell and Battery

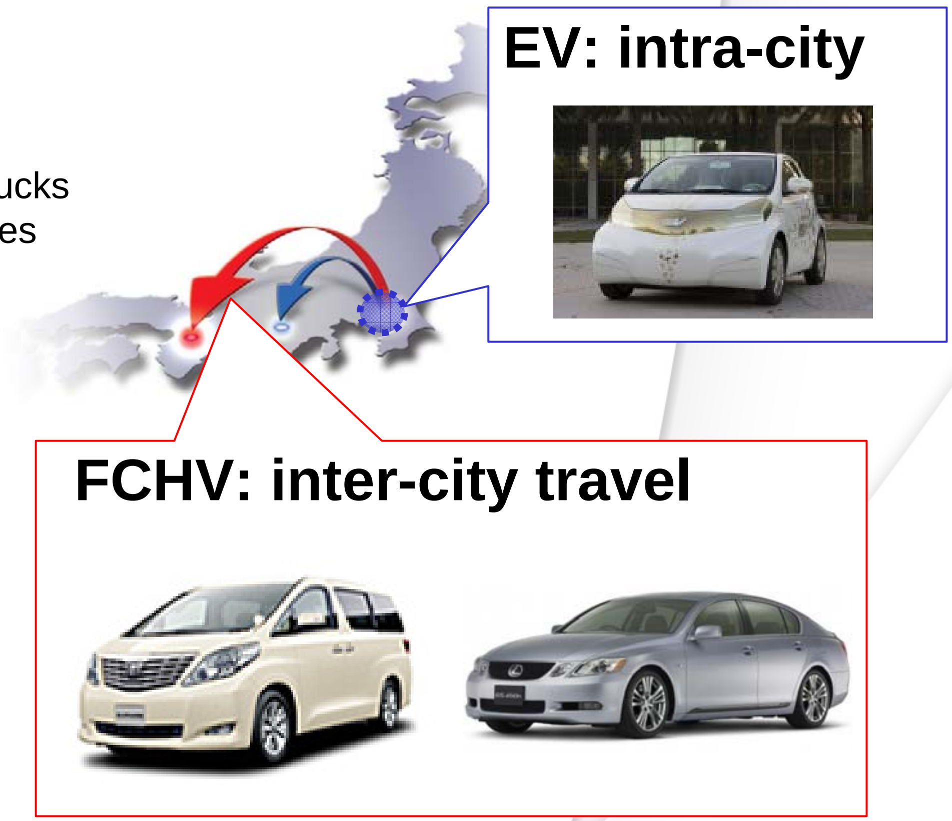
Mass (calculation) required to achieve an practical cruising range of 300 miles



[Vehicle weight (excluding battery) : 1.4t] Toyota calculation

Cover Area of FCHV and EV





As personal mobility, EV is viable for intra-city travel, and FCHV for inter-city travel.

Comparison of Total Efficiency

	Energy pathway	Well-to-Tank (50%)	Tank-to-Wheel *1 (50%)	Well-to-Wheel *1 (20% / 40%)
FCHV-adv	Natural gas ↓ Membrane separation reform → Hydrogen (70MPa)	67% *2	59%	40%
EV	Natural gas ↓ Gas-fired Power generation → Electricity	39%	85%	33%
Gasoline HV (Prius)	Crude oil ↓ Refine → Gasoline	84%	40%	34%
Gasoline ICE	Crude oil ↓ Refine → Gasoline	84%	23%	19%

*1 Tank-to-Wheel efficiency: measured in the Japanese 10-15 test cycle

*2 Efficiency difference between 35MPa and 70MPa: approx. 2%

(Toyota Calculation)

FCHV-adv has great advantage in the Well-to-Wheel efficiency.

Evolution of TOYOTA FCHV

	Dec. 2002 ~	Jul. 2005 ~	▼ Present	2015 ▼ FCCJ* Target on starting commercialization (Decision making)
Vehicle	 '02 FCHV (lease model)	 '05 FCHV (lease model)	 '08 FCHV-adv (lease model)	
Technical Challenges				
1. Cold Start / Driving Capability	0degC	0degC	-30degC	
2. Practical Cruising Range	130mile	145mile	300mile or more	
3. FC Stack Durability	→	→	→	15 years or more
4. Cost reduction	→	→	→	1/10 or less (design / materials)

* FCCJ: Fuel Cell Commercialization Conference of Japan

- Actual cruising range and cold start / driving capability has been significantly improved.
- Toyota continues efforts especially on FC stack durability and FC system cost reduction targeting commercialization in 2015.

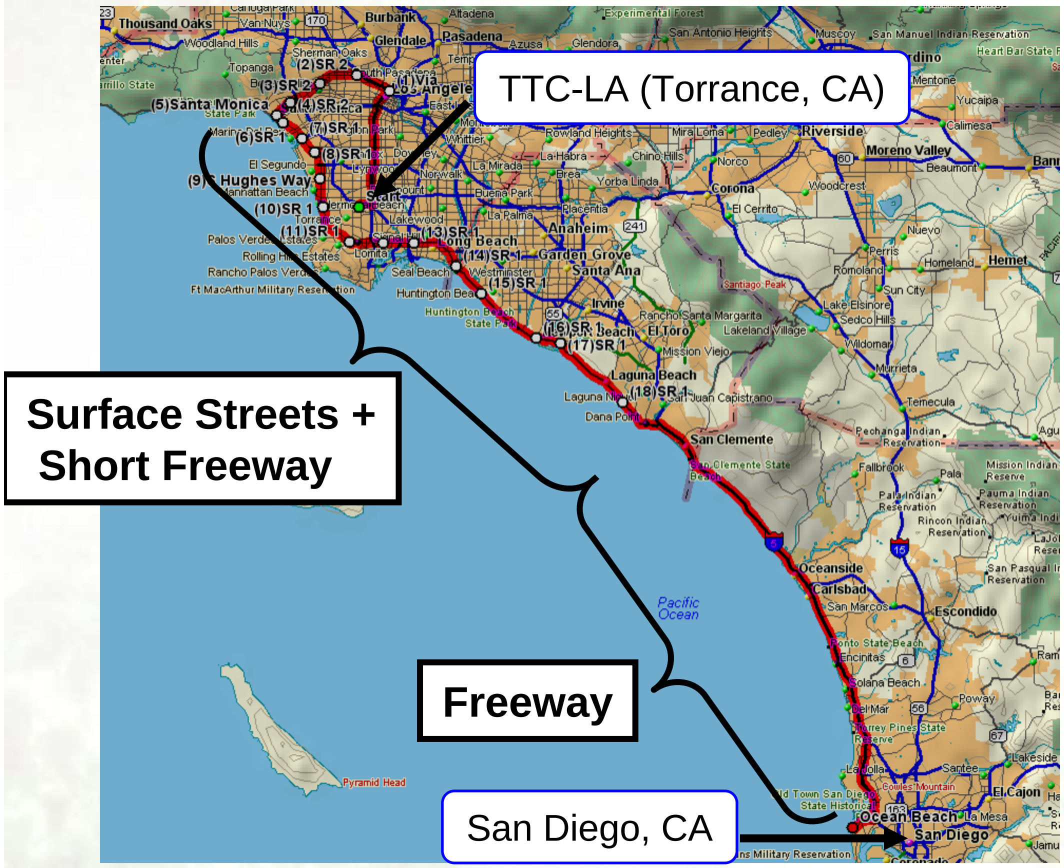
TOYOTA FCHV-adv

*1: in LA#4 cycle

Vehicle	Overall length/ width/ height (mm)	4,735/ 1,815/ 1,685	Fuel	Type	Pure hydrogen
	Max. speed (mph)	96		Storage system	High-press. H_2 tank
	Cruising range (mile)	455 *1		Max. storage pressure (MPa)	70
	Fuel economy (mile/kg H_2)	72.4 *1		Tank capacity (kg H_2)	6.29 (15 degC)
	Seating capacity	5	Curb weight		4145 lbs

Actual on-road range evaluation of Toyota's FCHV with DOE, NREL and SRNL

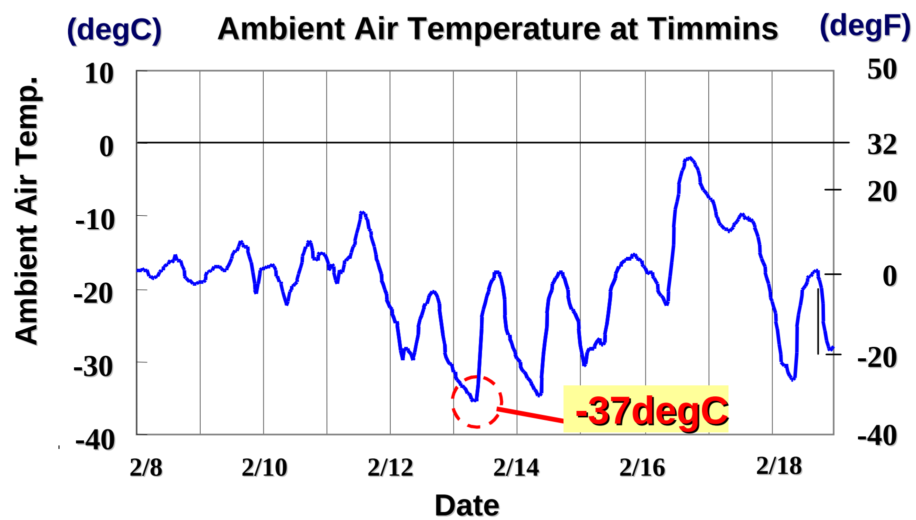
Joint evaluation of FCHV-adv was performed on June 30th, 2009 on mixed traffic condition in Southern California



Trip distance: 331.5 miles
Fuel Economy : 68.3mile/kgH_2
Calculated full-tank range : <u>431miles</u>

Cold Start / Driving Capability Performance Test Results in Canada

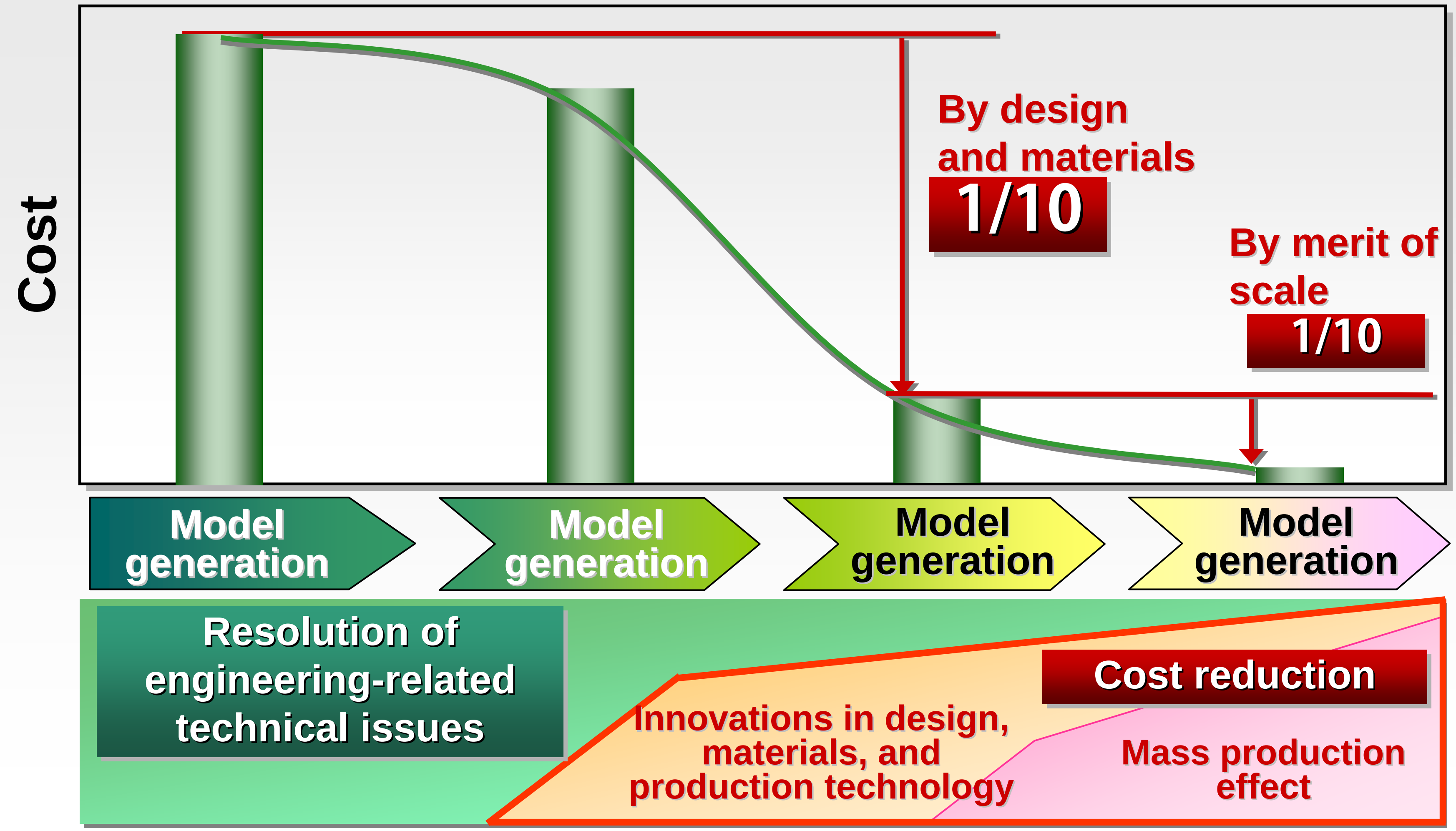
Timmins, Canada



Yellowknife, Canada

Cold start and driving performance of the TOYOTA FCHV-adv was verified to be equivalent to gasoline-ICE vehicles.

Cost Reduction for FCHV



First, we aim to reduce the cost to 1/10 of the current level by design and materials improvement.

Approaches to FCHV Cost Reduction toward 1/10

TOYOTA FCHV-adv

(1) Design:

1. System simplification

- FC system, H_2 tank system, etc.

2. FC stack

- Simplifying design
- Downsizing & downweighting, Reducing Pt amount (to reduce the materials used)

(2) Materials:

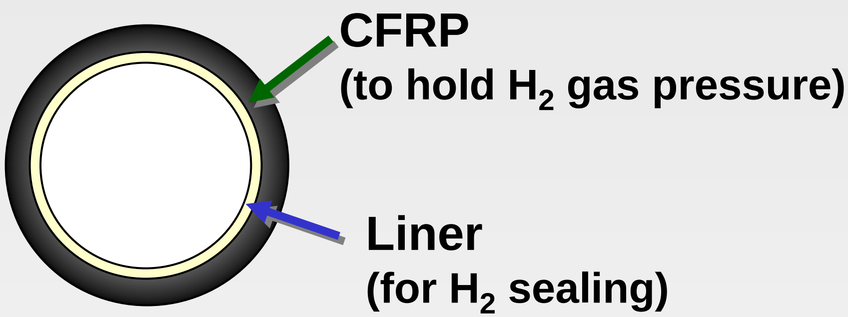
Reducing the cost of FC-system-specific materials

→ Important to cooperate with materials manufactures

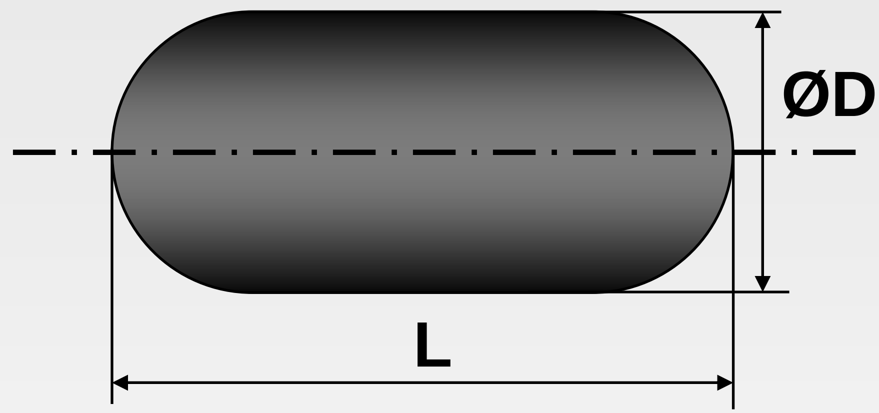
(3) Mass Production technology

- FC stack, H_2 tank, etc.

Cost Reduction of High-pressure Hydrogen Tank Body



Cross-section of tank body



Tank dimension

(1) Reduce CFRP by reducing the wall thickness

- Optimize laminar structure (hoop winding / helical winding)
- Selection of tank type (type III, IV)
- Optimize L/D
- Optimize boss size

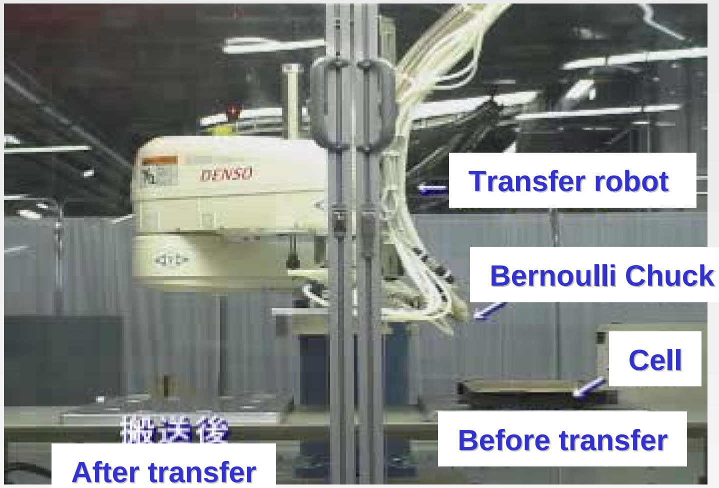
（2） Reduce cost of CFRP

- Aviation grade → general-purpose grade
- Develop low-cost CFRP for high-pressure tank

Development of Mass Production Technology

(1) Web handling technology

(2) One-by-one handling technology



(3) High speed winding of 70 MPa hydrogen tank

Conditions for FCV's mass introduction

Self-sustaining increase of FCV sales together with H_2 supply network

Customers
Purchase and drive FCV

Green-conscious
+ economic advantage
(Vehicle cost, fuel cost)

Auto OEMs
Manufacture & sell FCV

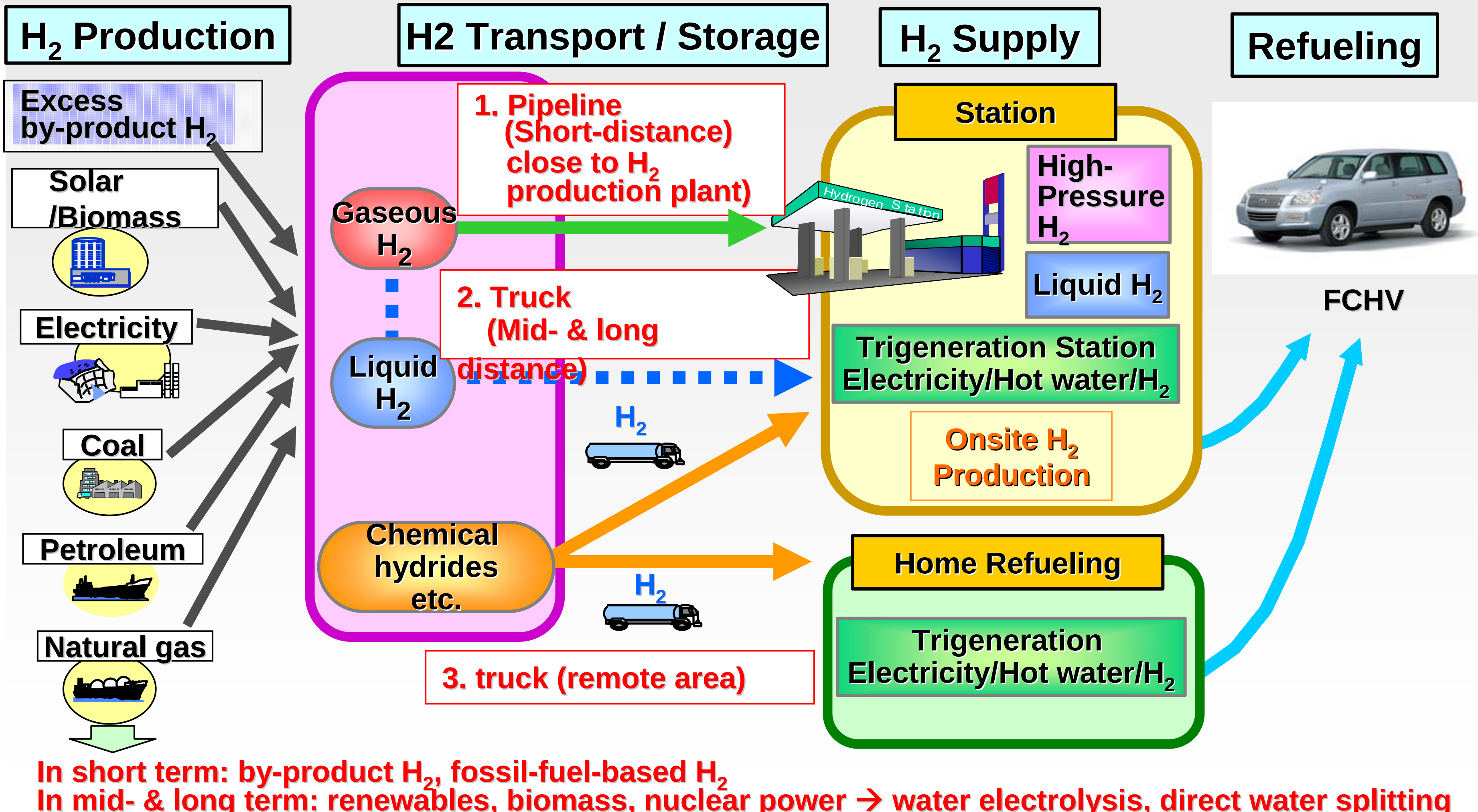
Profitability
(vehicle manufacturing & sales)

Energy suppliers
Produce & sell H_2

Profitability

For mass introduction of FCVs, profitability of every stakeholder is essential.

Challenges of Infrastructure Development, Hydrogen Pathways



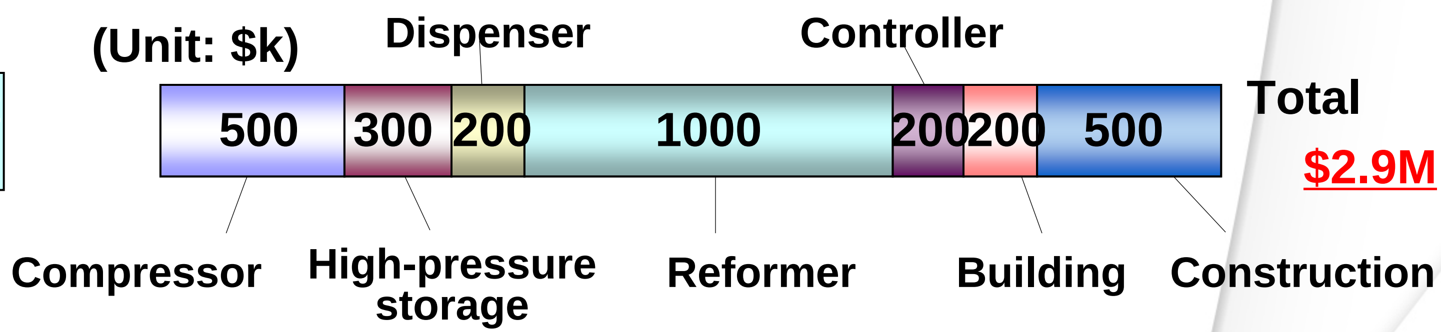
Optimum hydrogen infrastructure building from the perspective of right timing, right place, and right methods

Breakdown of Hydrogen Station Cost (Case of Japan)

(2005 results)

On-site NG reformation
100Nm³/h (96 vehicles/day), **35MPa**

H_2 station cost (Aichi Expo)



Total
$2.9M

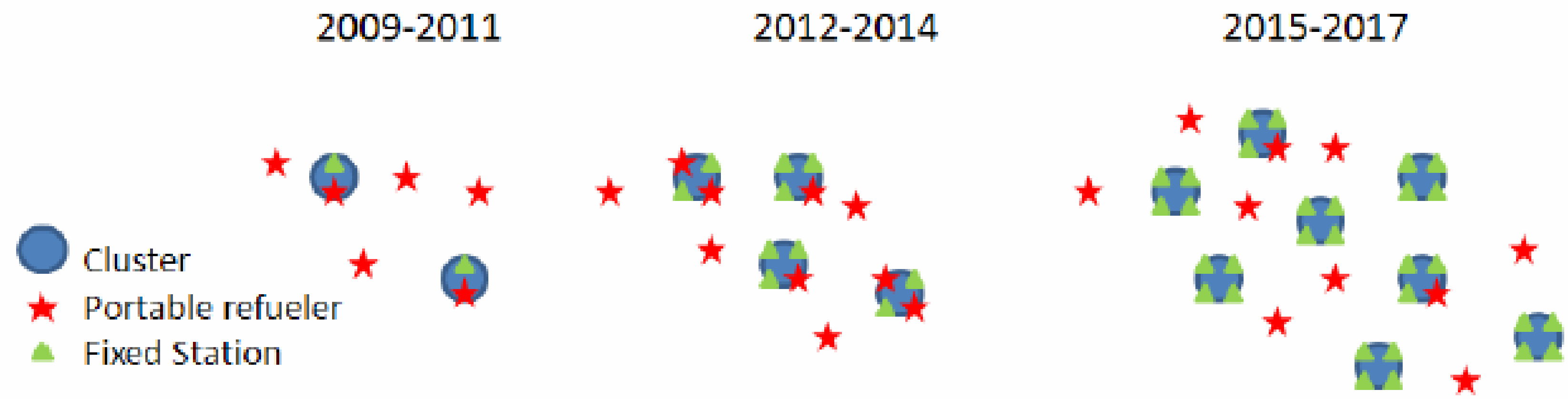
Gasoline station ave. building cost

Approx. $1M (8 nozzles)

$1 = 100 Yen based

For popularization, development of Hydrogen Station's cost reduction technology is essential.

Scenario studied by UC Davis Workshop
- California Hydrogen and Fuel Cell Vehicle Roadmap Study

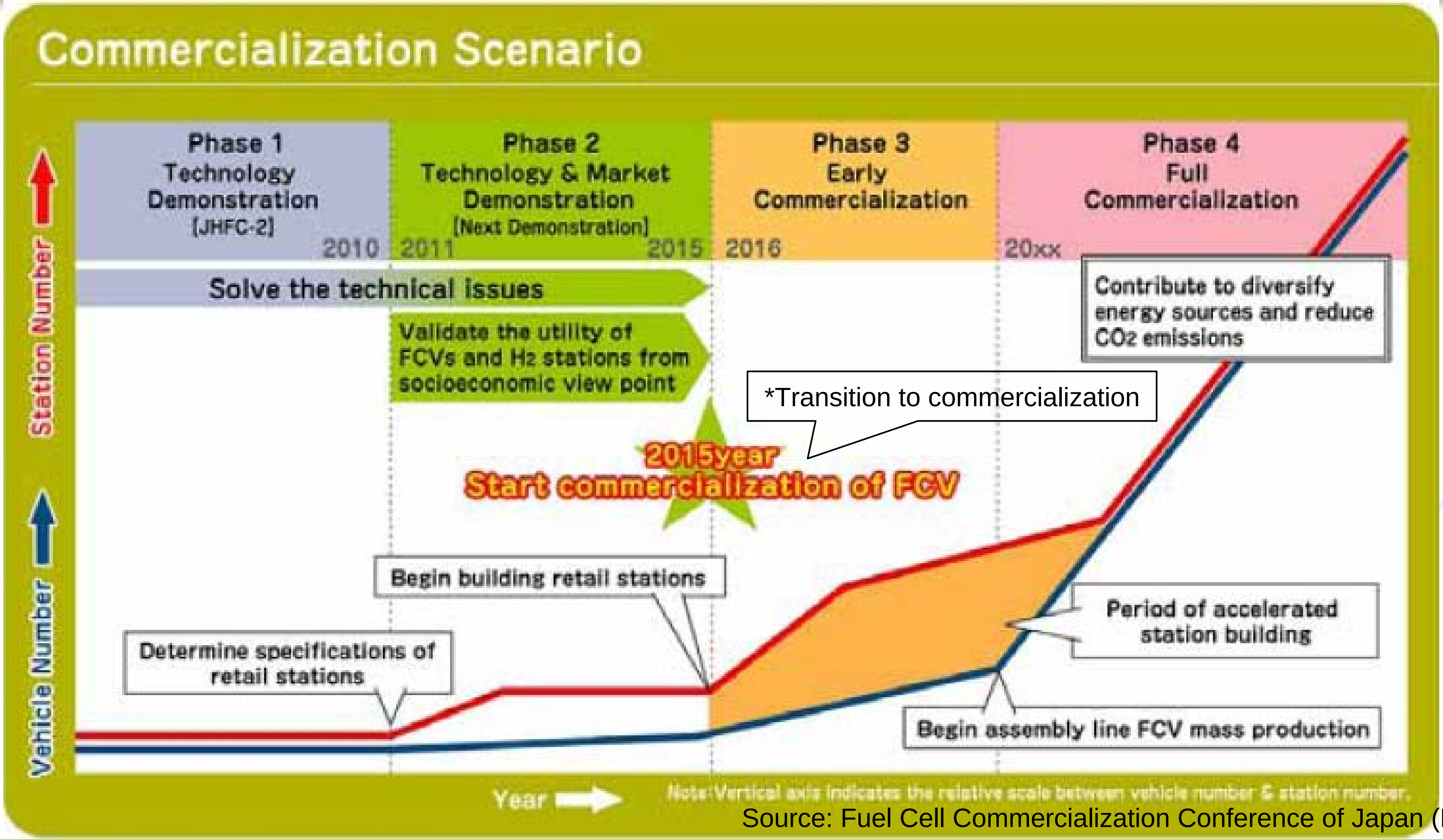


	600 FCVs	5000 FCVs	25,000 FCVs
# Stations	8	20	40
# clusters	2 (2 sta/cluster)	4 (4 sta/cluster)	8 (4 sta/cluster)
# connect.sta	4	4	8
Station Mix	6 Portable refuelers 2 SMRs (100 kg/d)	10 Portable Refuelers 10 SMRS (400 kg/d)	10 Portable refuelers 10 SMRs (400 kg/d) 20 SMRs (1000 kg/d)

Table 1: Transition Pathway for Building an Early H2 Infrastructure in Southern California

Infrastructure building needs to be coordinated with vehicle placements.

Fuel Cell Commercialization Scenario in Japan



Source: Fuel Cell Commercialization Conference of Japan (FCCJ)

Auto OEMs and Energy Suppliers are working in line toward expected start of 2015 FCV commercialization in Japan.

Toward future mass introduction of FCVs

<Conditions for mass introduction>

- Profitable Business cases for Customers, Auto OEMs and Hydrogen suppliers is important. In other words, low-cost FC vehicle and sufficient supply of low priced hydrogen should be available.
- Both Fuel Cell vehicles and Hydrogen infrastructure should be durable and reliable in practical use. (Durability, safety, etc. must be proven in the real world.)
- It took seven years even for “successful” HV vehicles to reach 100k/year global sales.

<Request to CARB in regards to Fuel Cell Vehicles>

- Close observation of technology progress and surrounding condition to determine potential ZEV Phase 4 regulation. (Just a large number of mandate will not work to realize mass introduction.)
- Variety of Incentives for real mass introduction of Fuel Cell vehicles together with Hydrogen supply network.
- To enhance study of Low-cost supply network of Hydrogen by Energy Companies.

Summary

1. Fuel Cell vehicle is more suitable for longer-range, larger vehicle applications compared to EVs.
2. Toyota's FCHV technology has been steadily moving forward including more than 300miles of practical range and –30degC freeze start capability.
3. Toward 2015 target of larger scale introduction, Toyota is making maximum efforts to overcome remaining technical challenges of FCHV such as Cost reduction and Durability improvement.
4. **Conditions for FCV's Mass Introduction**
   - Low-cost and easy-access H_2 supply network are a must. Further technical development and study of profitable business case are necessary.
   - Variety of governmental incentives are critical to form initial market beginning around 2015-2020.
5. **Request to CARB/Government**
   - Align ZEV requirement with technical, infrastructure and market readiness.
   - Study of various potential governmental incentives.


Today for Tomorrow