Electromobility

ENERGY Management SYSTEM

Japan and the Future of Automobile Industry

14th Dec., 2017

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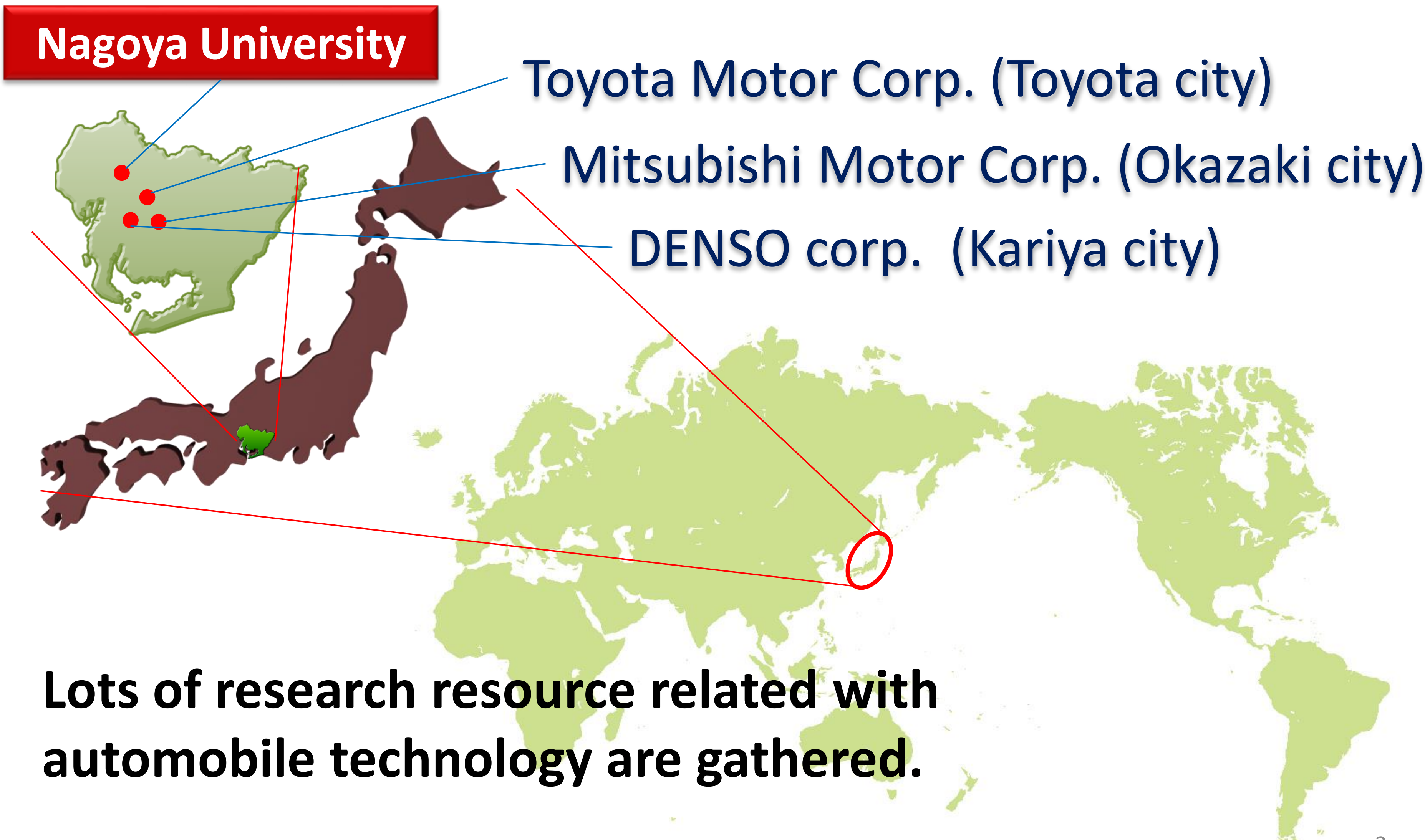
Where is Nagoya ?



Lots of research resource related with automobile technology are gathered.

Outline

1. Overview of trend of electrified mobility in JAPAN
   - Categorization of vehicle and prediction
   - What type of vehicle is promising in 2030?

2. Integration of smart grid and mobility by using EV and PHV (JST, CREST project)
   - Technical challenges

Categorization of electrified vehicle

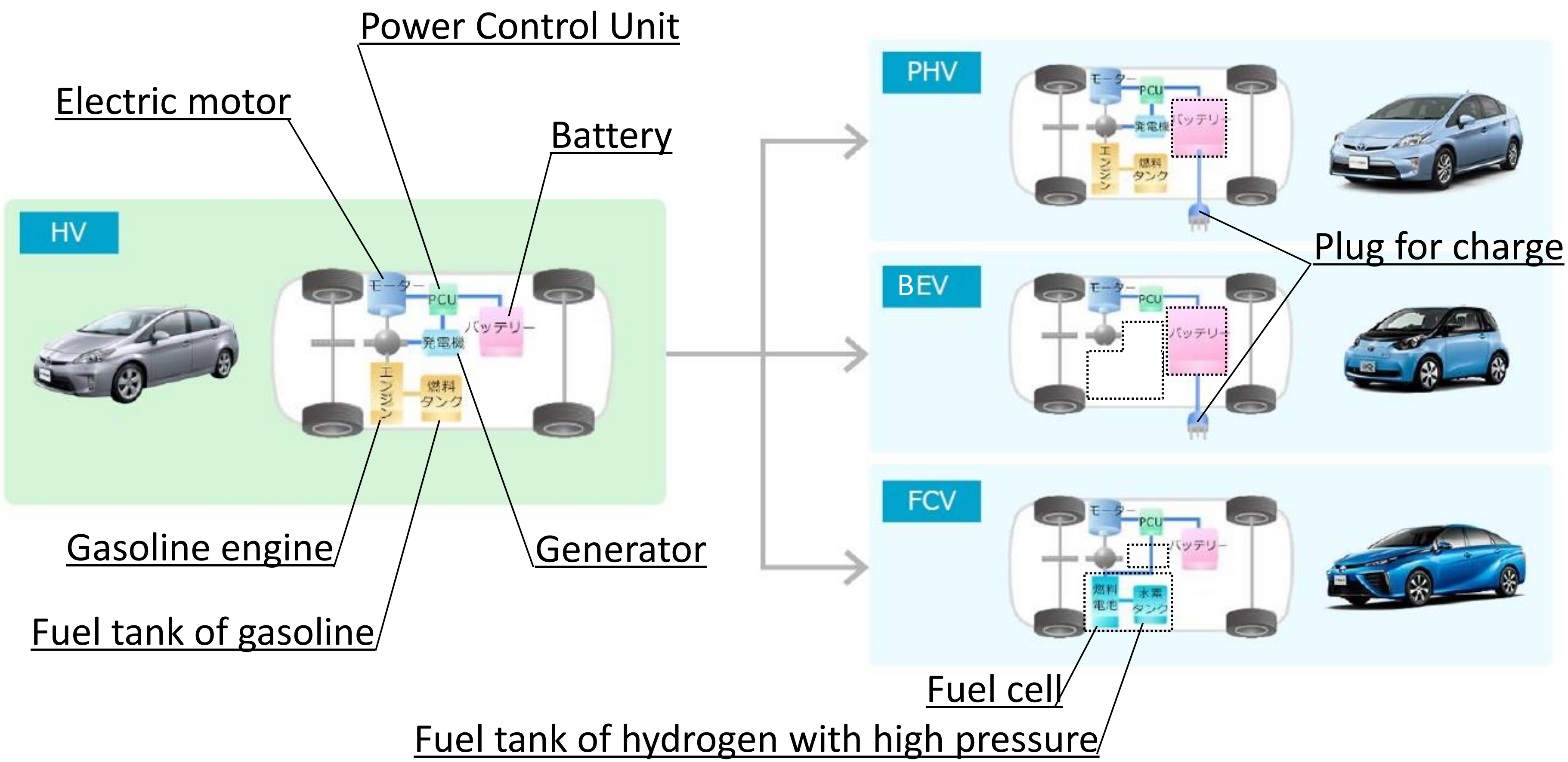
	HV	PHV	BEV	BEV with RE	FCV
Driving force	Engine, Motor	Engine, Motor	Motor	Motor,	Motor
fuel source	Gasoline	Gasoline, Electricity	Electricity	Electricity, Gasoline	Hydrogen
Price	◎	△	○	△	×
Distance	◎	◎	△	◎	◎
CO2 emission (not considering CFP)	△	○	◎	○	◎

HV: Hybrid Vehicle
PHV: Plug-in Hybrid Vehicle
BEV: Battery Electric Vehicle
BEV with RE: Battery Electric Vehicle with Range Extender
FCV: Fuel Cell Vehicle

◎ Very good
○ Good
△ Fair
× Poor

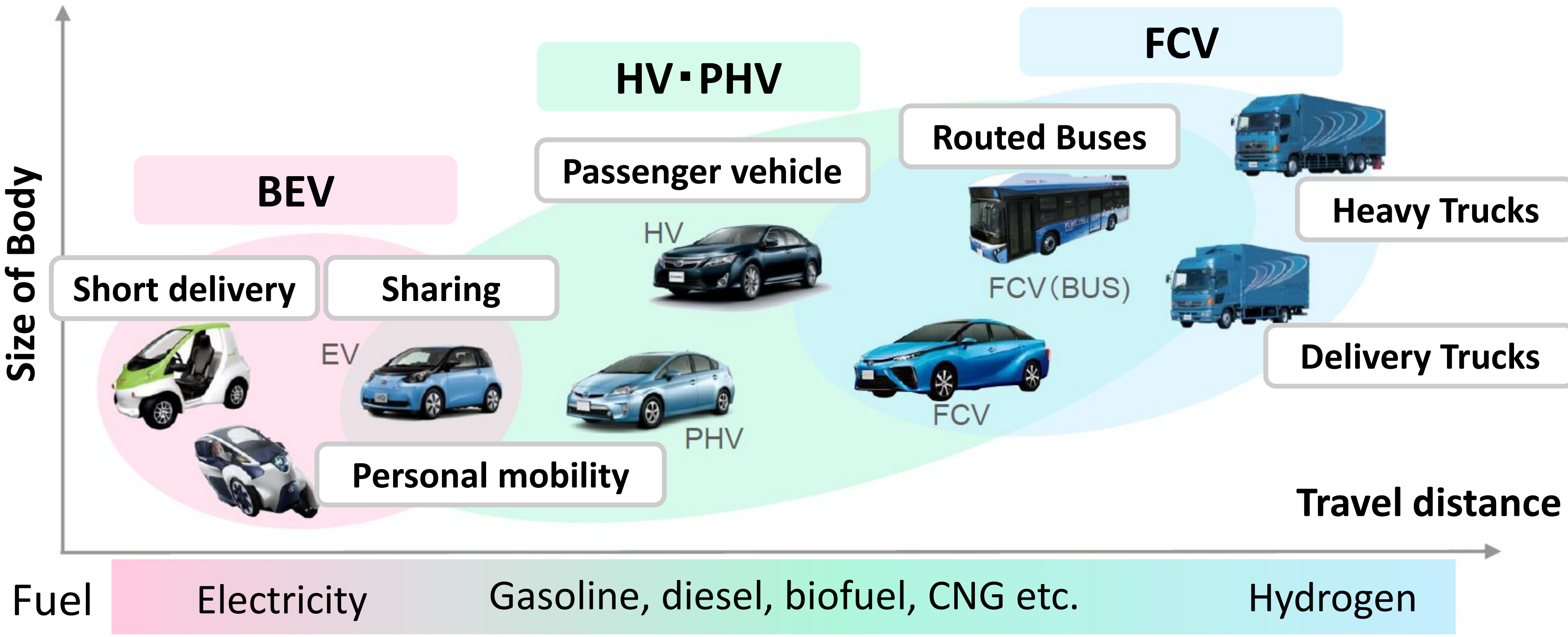
Comparison of structure

Technology in the Hybrid Vehicle can be transferred to other type (by TOYOTA)



Purpose of each type (by TOYOTA)

TOYOTA promotes to use various type of electrified vehicle according to size of body and travel distance.

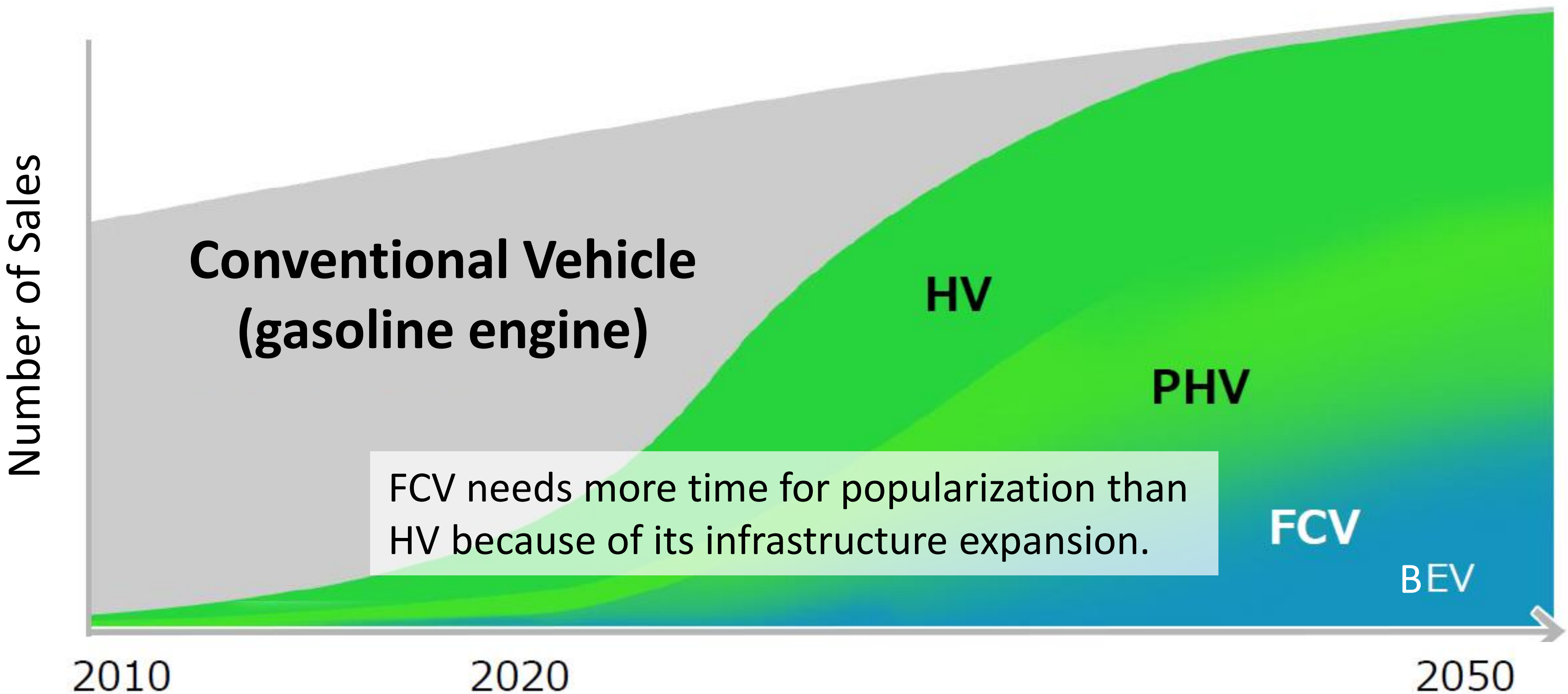


Target number of electrified vehicle by Japanese government

	HV	PHV+BEV	FCV	Clean Diesel	Total of low emission vehicle	Others
～ 2020	25%	20%	1%	5%	50%	50%
～ 2030	35%	30%	3%	10%	70%	30%
～ 2050	?	?	?	?	More than 95%	5%

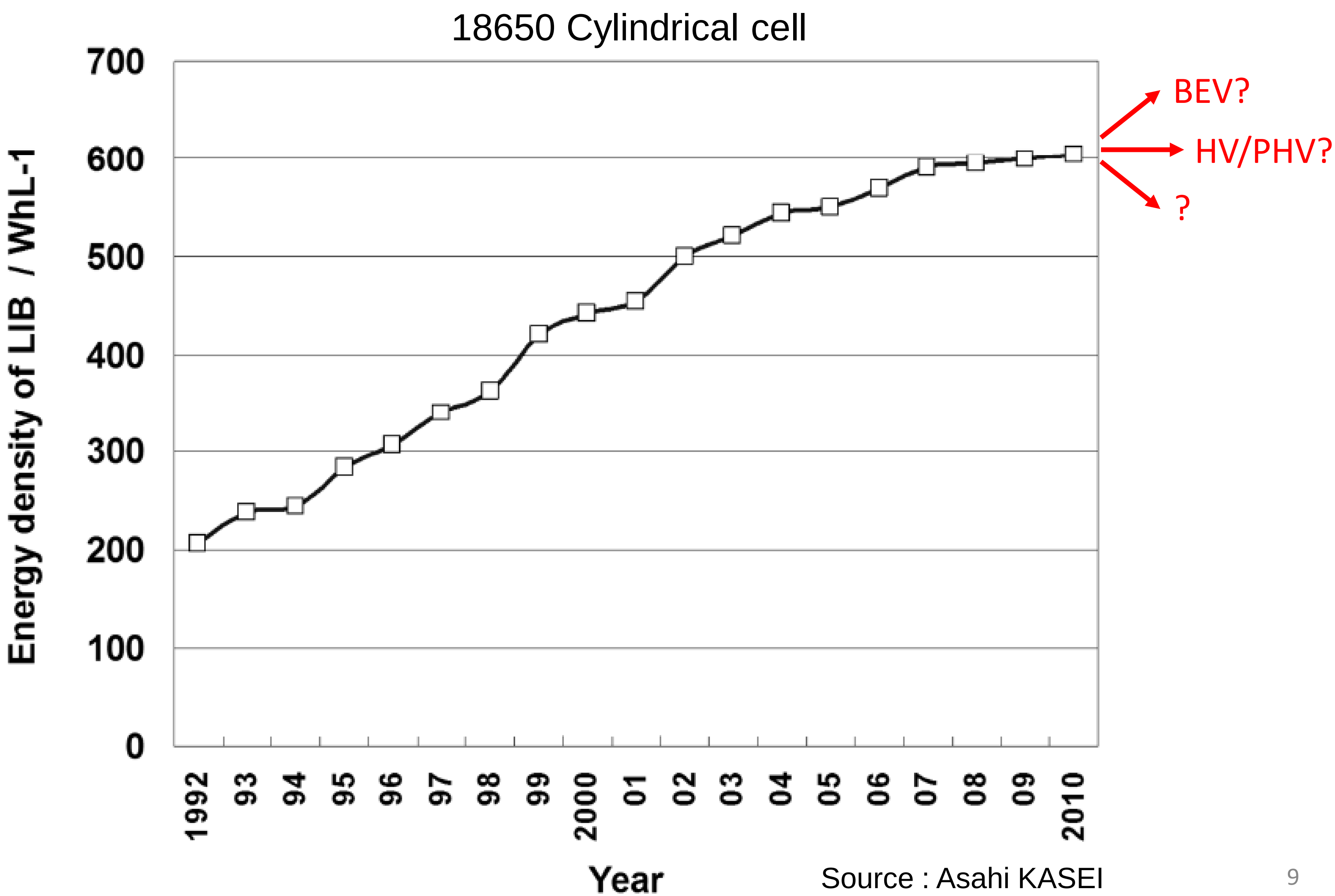
Prediction by TOYOTA

Target by 2050： "No vehicle travels only in a gasoline engine"



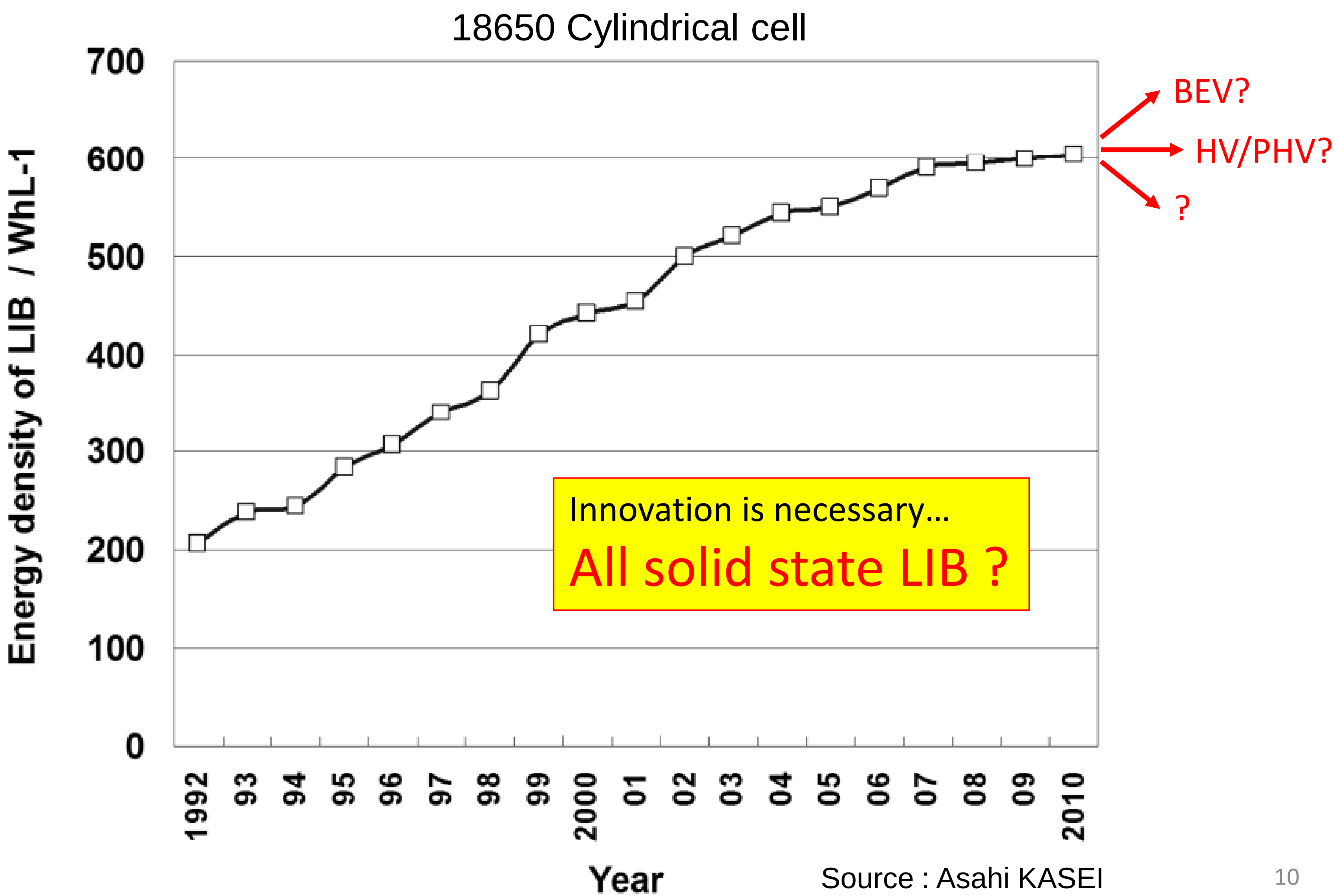
- Promotes hydrogen energy not only for vehicle and also for life.
- Contribute in energy security in Japan.

Growth of energy density in LIB



Source : Asahi KASEI

Growth of energy density in LIB



Source : Asahi KASEI

Why HV in Japan?

TOYOTA Hybrid vehicles (HVs) Prius was released in 1999. 50% of new car sales are HV in Japan. HV are prompted more than BEV from view point of structure of automobile industry.

- Number of components in vehicles

Hybrid vehicle (HV): 33,000

http://toyota.jp/prius

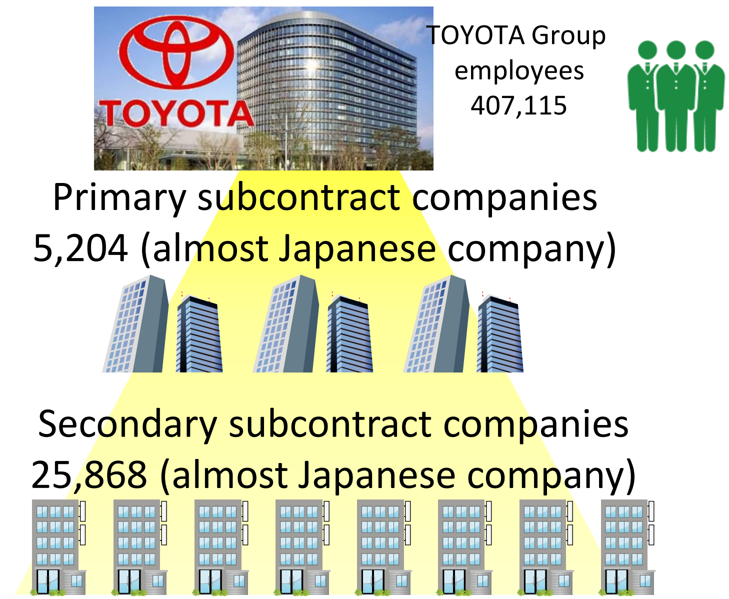
Gasoline car: 30,000

http://toyota.jp/corollafielder

Battery Electric vehicle (BEV): 10,000~20,000

http://ev.nissan.co.jp/LEAF

- Structure of automobile industry: (TOYOTA)

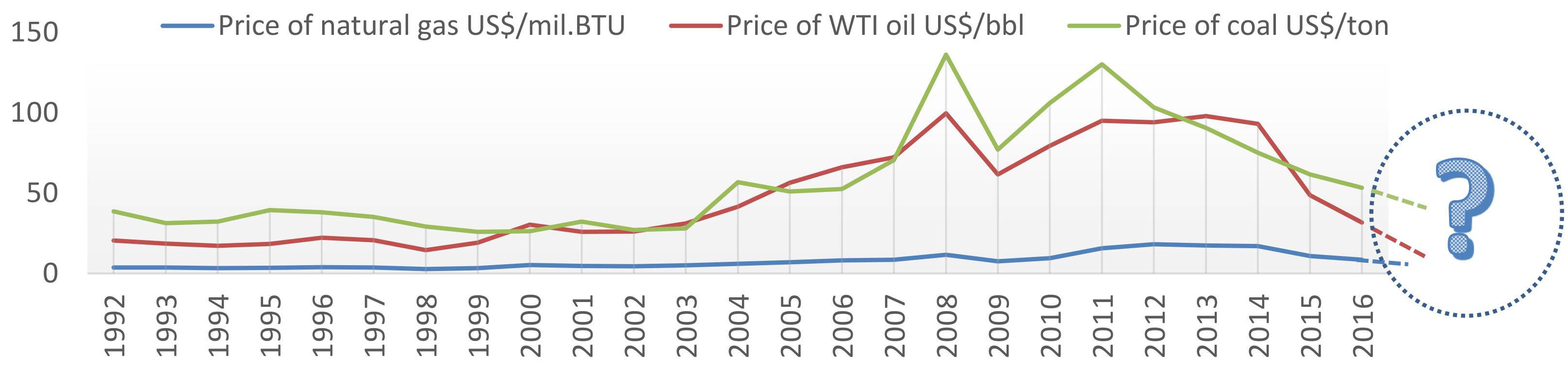


Total number of employees in subcontract companies 1,436,124

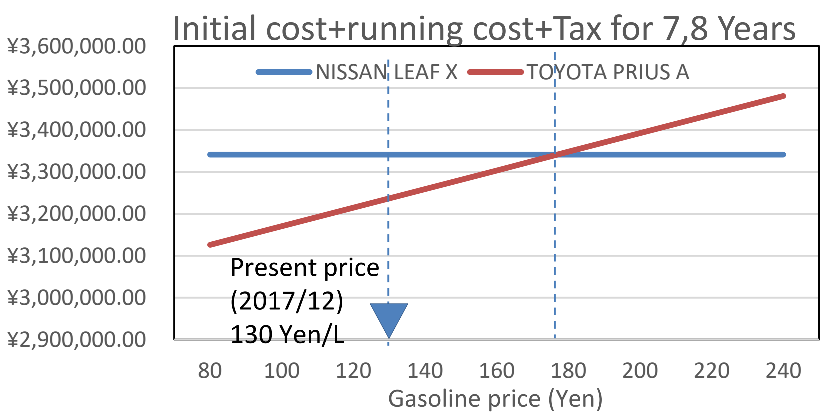
Worker population in Japan 2015: 63,990,000

Which is cost effective in Japan BEV or HV ?

- Energy price is declining and is difficult to predict.



- EV is unlikely to defeat HV from viewpoint of total cost.



http://ev.nissan.co.jp/LEAF

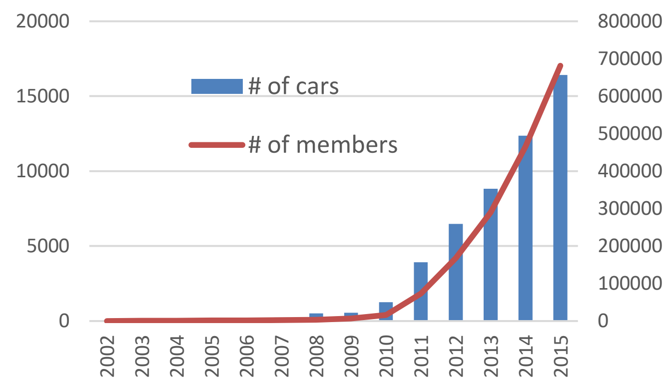
http://toyota.jp/prius

	NISSAN LEAF X	TOYOTA PRIUS A
Body price	¥3,648,240	¥2,777,563
Fuel consumption rate	9.3km/kWh	37.2km/L
Electricity price (midnight plan of TEPCO)	¥12.16/kWh	-
TAX for 7.8 years (+Tax bonus)	¥-224,400	¥341,100
Ave. running distance	10,575km/year	
Upgrade cycle (in 2015)	7,8 years	

From Date of Agency of natural resources and energy http://www.enecho.meti.go.jp/

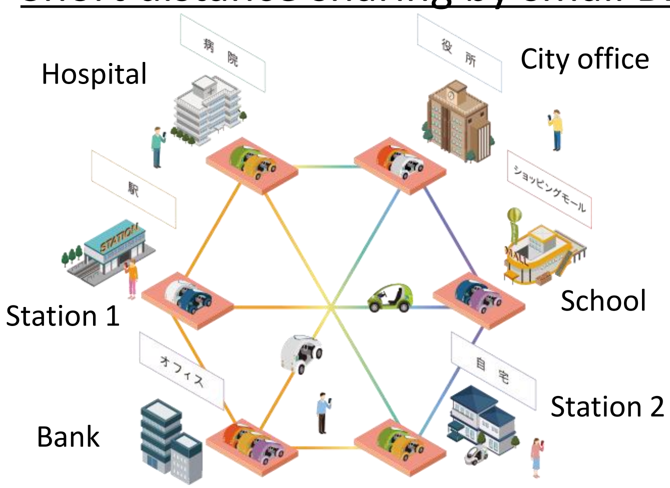
Small BEVs and car sharing in Japan

- Progress of car sharing service in Japan



From Foundation for Promoting Personal Mobility and Ecological Transportation

- Short distance sharing by small BEV



- Field tests of one-way type small BEV car sharing service (in progress)

NISSAN New Mobility Concept

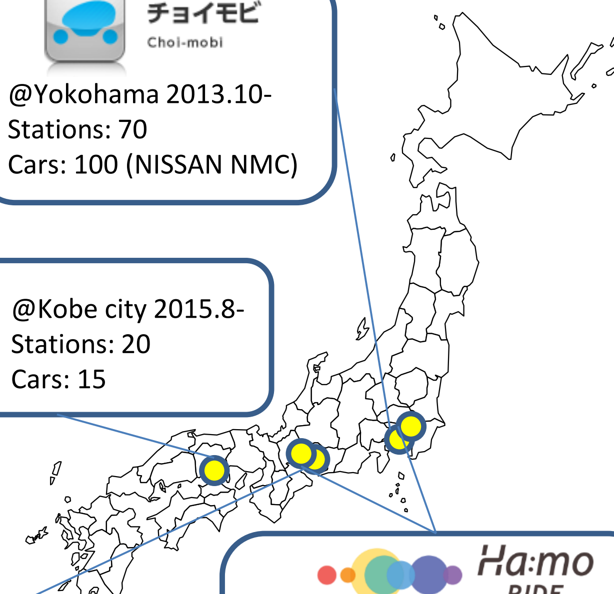
チョイモビ Choi-mobi

@Yokohama 2013.10-
Stations: 70
Cars: 100 (NISSAN NMC)

i-MiEV (Mistubishi)

sea:mo

@Kobe city 2015.8-
Stations: 20
Cars: 15



COMS (TOYOTA BODY)

kii mobi き～☆モビ Anjo

@Anjo city 2014.12-
Stations: 35
Cars: 30 (COMS)

Ha:mo RIDE

@Toyota city 2012.10-
@Tokyo 2015.4-
Stations: 46@Toyota, 30@Tokyo
Cars: 103 (COMS, i-ROAD)

TOYOTA i-ROAD

Concept: Providing daily short range drive using small BEV

Categorization of battery charger

	Normal	Double-speed	Semi-rapid	Rapid	Super-rapid
Charging time	16 hour	8 hour	40min – 2hour	30min	5min
Power rating	1.5kW	3kW	10 - 30kW	50kW	200kW
AC/DC	AC	AC	DC	DC	DC

Type of connector

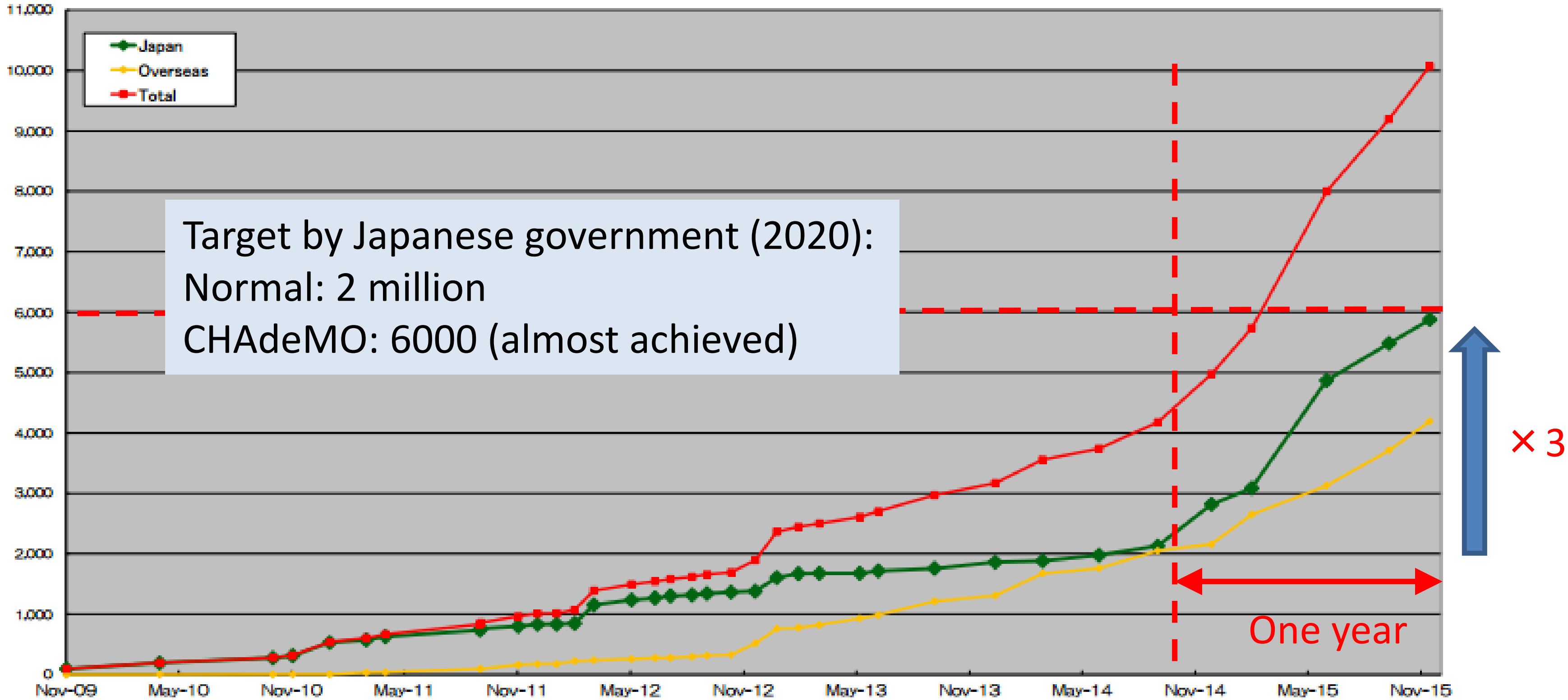
CHAdeMO's fast charging station in the world

Source : CHAdeMO Association (www.chademo.com)

The number of CHAdeMO DC Quick chargers installed up to today is 10377.
(Japan: 5960, Europe:2755, USA:1554, Others:108) (As of February 4, 2016)

Growth of the number of CHAdeMO fast charging station

Between November 2009 and November 2015



Source : CHAdeMO Association (www.chademo.com)

EV shifting in the world (?)

Europe — Norway: Electrify all vehicle by 2025
France, England: ICV will be prohibited before 2040

China — BYD: Symbolic Battery maker in China developing EV

Supported by government policy rather than technological evidence

Ex.) China wants to be a new leader in the automobile industry

Japan — Considering blending of the future vehicle types (ICV, HV, PHV, BEV, FCV,,,) logically and reasonably

(Generally speaking)

Choice of the vehicle type should not be made from single viewpoint (environment) but should be made based on multiple criteria such as cost, performance, usability, infrastructure…

PHV / BEV with range extender

(In my personal opinion,)

In Japan, **the most realistic solutions** in **coming 10 years** are, probably,

PHV (ex. TOYOTA: Prius) and
BEV with range extender (ex. Nissan: Note, Matsuda: Demio).

They have same characteristics as EV for short range, but achieve longer driving distance thanks to engine and generator.

They can be solution for wide variety of needs

Why is the shift to PHV is not so rapid in Japan?

High cost: more expensive than same class HV by 7,000 $
Heavy weight: may degrade the fuel consumption rate
For users, it is difficult to understand the benefit of PHV over the existing HV.
PHV is a hybrid of BEV and HV ? Need to charge both gasoline and electricity…
The strongest competitor of PHV is HV !

Potential of FCV

TOYOTA FCV `Mirai' was released in Dec.2014, since 1992

Will FCV be Post PHV?

○ **Diversification of energy of future society is important government policy**

Lots of energy sources are imported in Japan, oil, gas,…
Japan need more stable (economically) and secure energy source

△ **How to generate the hydrogen**

Huge amount of hydrogen is already generated in the process of petroleum refinement or iron refinement factories.
These factories already have hydrogen generator.

× **How to implement the enough number of hydrogen stations?**

We need promising business model.

What type of vehicle is promising?

What type of vehicle will be most dominant in future?

～2030 PHV and BEV with RE for possession vehicle
small size BEV for sharing service
～2050 ???
BEV, PHV, FCV will be used complementary

What are dominant factors to characterize future vehicle ?

1. Government energy policy
2. Cost of energy source; oil, gas, hydrogen,,,
3. Installation of energy stations (infrastructure)
4. Innovation in technology ; battery capacity, size and cost performance of motor

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Power policy reform in Japan

2011.3.11: The Great East Japan Earthquake

- Must promote the decentralization of power source.
  - not only fossil fuel, nuclear plant is not desirable
  - solar, hydrogen, biomass etc.

2016.4.1: The full liberalization of retail electricity sales

- Promote penetration of renewable energy.
  - any company can sell power, and customer have more choice.
  - accelerate popularization of PHV/BEV because of additional value as energy storages .

- Variety/diversity of fuel types is required for energy security.
- Automobiles must adapt to variety of fuel types.

2020: The power distribution and transmission lines will be open

After 2020: Various vehicle will be used for various purpose

- **For short range**: **BEV** Sharing
  - Car-sharing/park-and-ride services.
  - Small vehicle (**K-car**) will be replaced by BEV.
- **For long range**: HV, **PHV**, **BEV+RE,** **FCV** ? Possession

Experiments of Vehicle-to-Home with FCV (HONDA)

HONDA news release:
http://www.honda.co.jp/news/2013/4130409.html

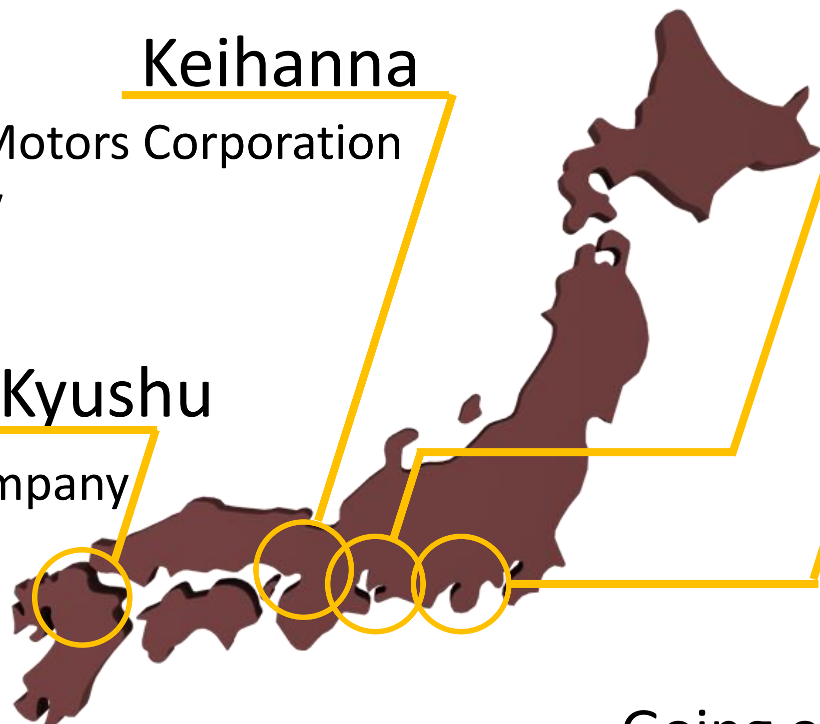
Integration of smart grid and mobility

Sharing — The services will be integrated with **regional EMS** because the vehicle use are controllable and distributed (like public transportation).

Possession — These vehicles will be exploited for **local EMSs** because of personalized use of vehicle.

Field test in Japan

Field test to integrate smart grid and mobility



Keihanna

MITSUBISHI Motors Corporation
- PHEV
- EV

Toyota

Toyota Motor Corporation
- PHV
- Small EV

Northern Kyushu

HONDA Motor Company
- FCV

Yokohama

NISSAN Motor Company
- EV

<u>Going on the Next Stage…</u>

Real-world field test in Toyota city

A. Toyota city real-world field test project (2011-)
- Target: 67 households, school, convenience store etc.
- Equipment:
  - All houses: electric power source, PV (3-5kW), home battery (5kWh) and a PHV.
  - About 30 houses: fuel cell, charging station for Vehicle to Home (V2H).

	Category	Contents
1	Purchasing Electricity	Current purchasing electricity [W]
2	Selling Electricity	Current selling electricity [W]
3	Total electricity consumption	Current total electricity consumption [W]
4	Electricity at each section in the house	Current electricity consumption at each section in the house [W]
5	Home battery	Current State-of-Charge (SOC) [%]
		Current charge/discharge electricity [W]
		Charging/discharging capacity [Wh]
6	PV generation	Current generated output [W]

	Category	Contents
7	PHV	Plug information [connected/disconnected]
		Information of charging [charging/finished]
		Current State-of-Charge (SOC) [%]
8	Eco Cute Heat pump	Amount of hot water in tank [L]
		Current electricity consumption [W]
9	Water supply	Total used amount [L]

Data is logged every 1minute

Energy consumption and vehicle use are observed simultaneously

Model predictive Home EMS (with EV and HPWH)

【Given】 $k \in [t, t+T-1]$

$\tilde{W}^{+}(k\|t)$	Power demand	$\tilde{W}^{-}(k\|t)$	PV generation	$\tilde{\gamma}(k\|t) \in \{0, 1\}$	Vehicle state
$f^{+}(t)$	Buying price	$f^{-}(t)$	Selling price	$\tilde{B}^{cons}(k\|t)$	Powes used by EV
$\tilde{T}_{air}(k)$	Air Temp.	$\tilde{T}_{water}(k)$	Water temp.	$\tilde{Q}_{use}(k)$	Heat demand

【Find】 $k \in [t, t+T-1]$

$p(k|t)$; Charge profile of EV battery [kW]

$\alpha_{65}(k|t) \in \{0, 1\}$; Command for HPWH (Set Temp. 65℃)

$\alpha_{90}(k|t) \in \{0, 1\}$; Command for HPWH (Set Temp. 90℃)

【Subject to】

- Use of power and vehicle
- HPWH and battery model
- Constraints on HPWH and battery

【Objective Function】

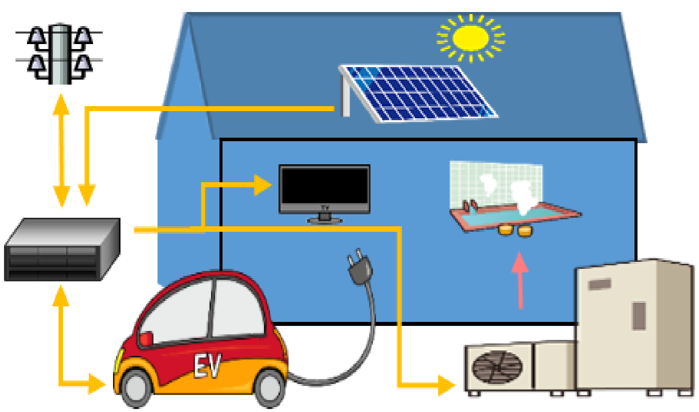
minimize:

$$Z = \sum_{\tau=t}^{t+T-1} F(\tau)W(\tau|t)\,\Delta t + \omega_1 \sum_{\tau=t}^{t+T-1} (\alpha_{65}^{on}(\tau|t) + \alpha_{90}^{on}(\tau|t))$$

Cost for 24 howers — **Number of ON/OFF**

$$+\omega_2 \sum_{\tau=t}^{t+T-1} |p(\tau|t) - p(\tau-1|t)| + \omega_3 \sum_{\tau=t}^{t+T-1} S(\tau|t)\Delta t$$

Smoothing effect — **Penalty for backfeed**



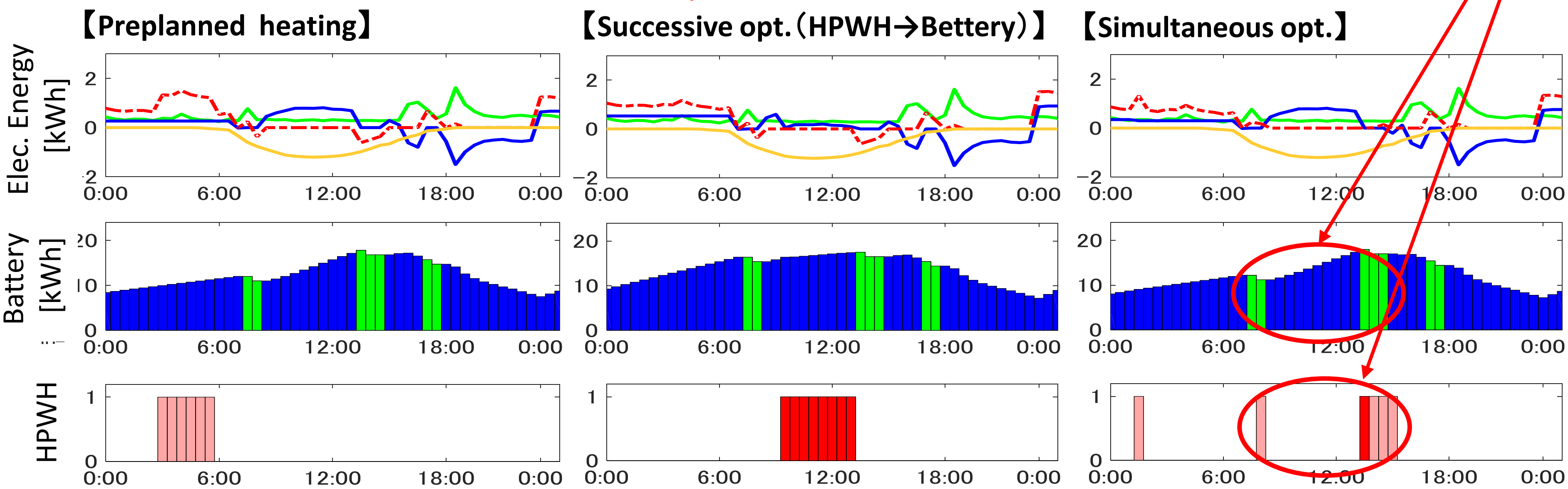
$$W(k|t) = \tilde{W}^{+}(k|t) + \tilde{W}^{-}(k|t) + p(k|t) + P_{HP}(k|t)$$

$$S(k|t) = \begin{cases} 0 & \text{if } W(k|t) \geq 0 \\ -W(k|t) & \text{if otherwise} \end{cases}$$

Model predictive Home EMS (with EV and HPWH)

- Simulation results

Point 1: When EV is available, it is used for saving power generated by PV, otherwise HPWH is used instead.



Point 2: Thanks to simultaneous optimization, excess (backfeeding) power is reduced.

	Preplanned	Succe. opt.	Simul. Opt.
Excess power [kWh/we.]	11.96	10.42	**4.69**
Fee [JPY/we.]	1857	1935	1814

- Power except EV and HPWH
- Charge/discharge of EV
- Total consumed power
- Generated power by PV

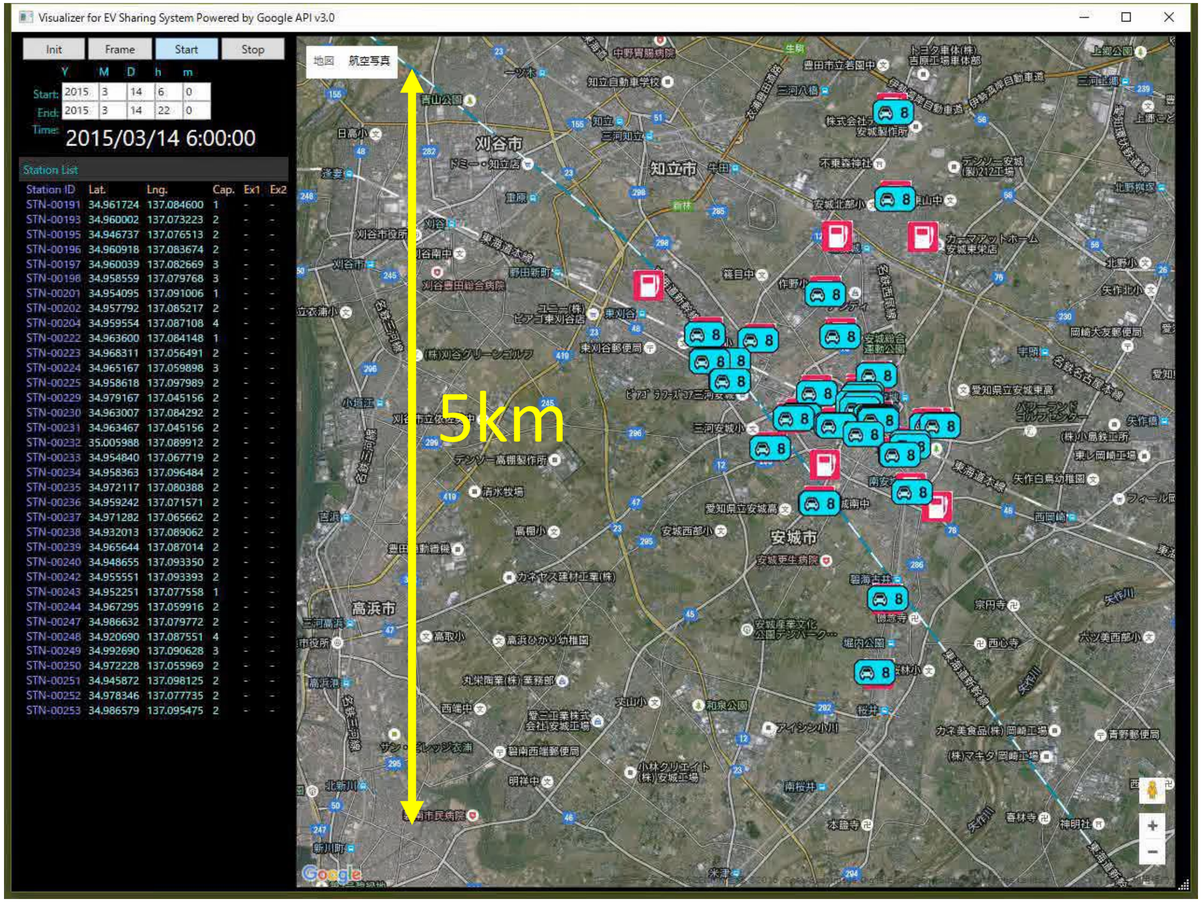
- EV is parked at home
- EV is used for travelling

- HPWH ON/OFF (65℃)
- HPWH ON/OFF (90℃)

- **EV and HPWH are used complementary**
- **Excess power is reduced → closer to island model**

EV Sharing (Anjo city)

(35stations, 30cars; 1day Behavior of EV and SOC)



Collected data: Location(GPS), Drive distance [m], Battery SOC [%], Reservation info. (1sec)

EV Sharing with PV car ports (1)

➢ One-Way EV Sharing Services

As the time progress, vehicles tend to gather in the same station.

New reservations are unlikely to be accepted

Customer:

"Oh!, there is no place to park!"

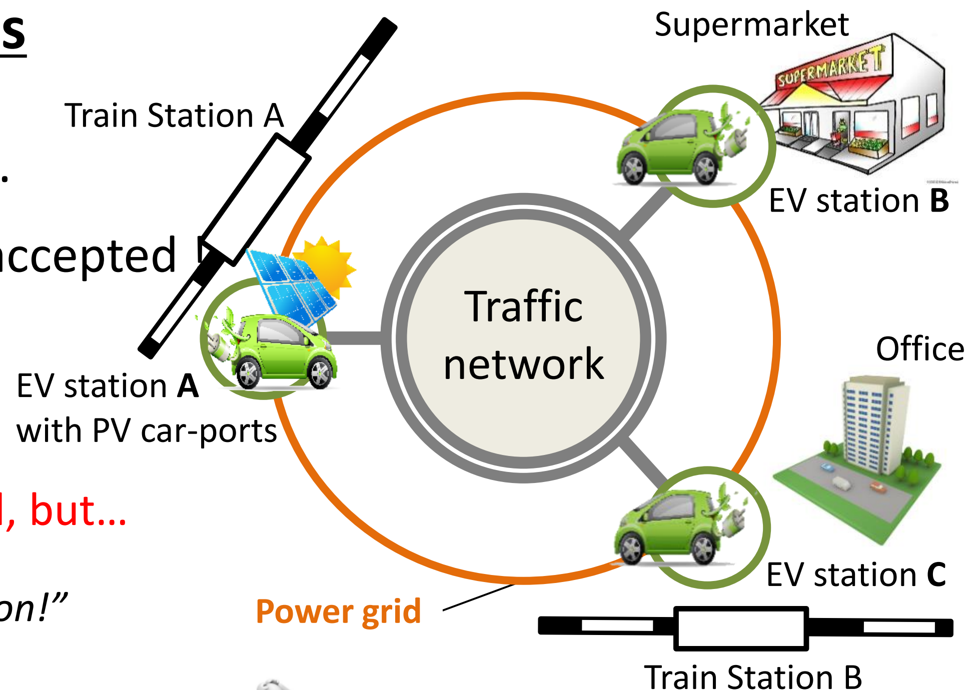
"Oh!, there is no EV for rent!"

Vehicle reallocation is required, but…

Operator:

"Oh!, it's hard to schedule reallocation!"

cost, optimality,,,



Requirements of the one-way EV sharing systems:

- Accept as much as possible reservations from customers.
- Reduce the number of reallocation.
- Reduce purchased power from grid (power distributor).
- Charge in-vehicle batteries from PV generation as much as possible.

How do we resolve these problems?

Formulate the optimization problem which minimizes cost for reallocation and electricity.

EV Sharing with PV car ports (2)

➢ Formulation as an Optimization

Parameters: the number of EVs V, stations S, reservations $R(t)$

Target time duration of optimization: $\tau \in \{t', \ldots, T\}$,

$$t' = \begin{cases} t^s \ (t < t^s) & \text{(out of service)} \\ t+1 \ (t \geq t^s) & \text{(under service)} \end{cases}$$

t^s :service start time

Given:

- Reservations $\{r_k(t)\}_{k \in \{1,\ldots,R(t)\}}$ consists of, departure time t_k^D, arrival time t_k^A, departure station s_k^D, arrival station s_k^A and estimated power consumption for movement $\hat{e}_k$
- Predicted generation of PV $\{\hat{g}_i(\tau|t)\}_{i \in \{1,\ldots,S\}}$
- Initial location of EVs $\{x_{i,j}(t)\}_{i \in \{1,\ldots,S+1\}, j \in \{1,\ldots,V\}}$
- Cost coefficients of reallocation $f_m(t)$, wasted power $f_w(t)$ and purchased power $f_l(t)$

Find:

$\{a_{j,k}(t)\}_{j \in \{1,\ldots,V\}, k \in \{1,\ldots,R(t)\}}$:assignments of vehicles to reservations.

$\{x_{i,j}(\tau|t)\}_{i \in \{1,\ldots,S+1\}, j \in \{1,\ldots,V\}, \tau \in \{t',\ldots,T\}}$:vehicle locations (which leads reallocation schedule)

$\{p_{i,j}(\tau|t)\}_{i \in \{1,\ldots,S+1\}, j \in \{1,\ldots,V\}, \tau \in \{t',\ldots,T\}}$:charging schedules

Which minimize:

Sum of three costs $A(\tau), W(\tau)$ and $L(\tau)$ in service for a day

$$E = \sum_{\tau=t'}^{T} f_m(\tau) M(\tau) + \sum_{\tau=t'}^{T} f_w(\tau) W(\tau) + \sum_{\tau=t'}^{T} f_l(\tau) L(\tau)$$

$M(\tau)$: number of reallocation

$W(\tau)$: wasted electricity

$L(\tau)$: purchased electricity

Subject to:

$\{y_{i,k}(t) \in \{0,1\}\}_{i \in \{1,\ldots,S+1\}, k \in \{1,\ldots,R(t)\}}$:requirement of vehicle existence for reservation

$x_{i,j}(\tau | t) \geq a_{j,k}(t)\, y_{i,k}(t)$:requirement of vehicle location from assigned reservation

$l_i(\tau | t) + g_i(\tau | t) - w_i(\tau | t) - \sum_{j=1}^{V} p_{i,j}(\tau | t) = 0$:power supply and demand balance for each station

$b_j(\tau | t) - b_j(\tau - 1 | t) = \sum_{i=1}^{S} p_{i,j}(\tau | t) \Delta t - \hat{e}_k(\tau | t) x_{S+1,j}(\tau | t)$:dynamics of State of Charge (SoC)

$l_i(\tau | t)$:purchased power

$w_i(\tau | t)$:wasted power

Constraint on available time duration for reallocation

Other constraints

EV Sharing with PV car ports (3)

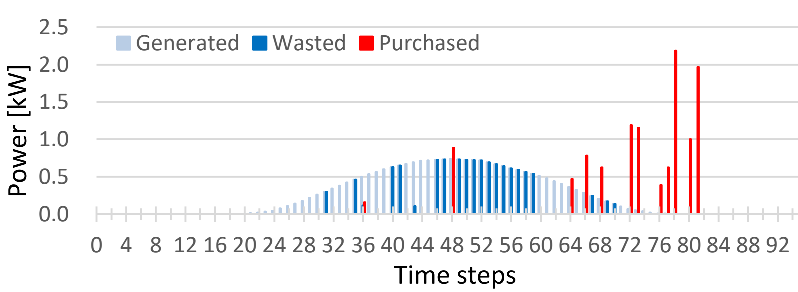
➢ Comparison in a test case

Number of accepted reservations depends on availability of reallocation.

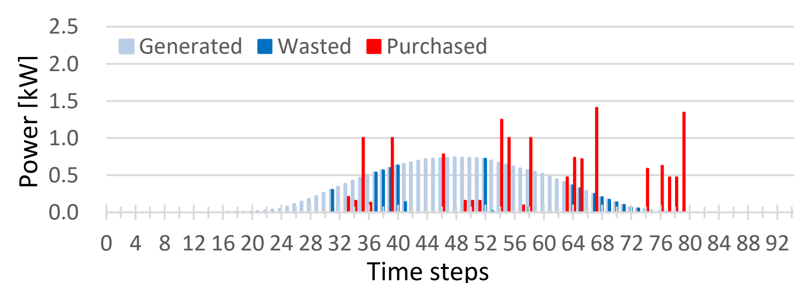
Time duration available for reallocation	No time	9:00-12:30 & 16:00-18:00	Any time
Number of reallocation	0	51	58
Accepted reservations	68	95	**100**
Rejected reservations	32	5	**0**
Wasted electricity [kWh]	**2.87**	2.45	**1.31**
Purchased electricity [kWh]	2.86	4.00	3.48

- ✓ Number of Station: 35
- ✓ Number of Vehicles: 30
- ✓ Number of reservation: 100
- ✓ Service time: 8:00 to 20:00 (12 hours)
- ✓ Battery capacity: 5.2kWh, initial: 2.6kWh
- ✓ PV car-port is equipped only at Sta.1
- ✓ Generation capacity (PV): 1kW
- ✓ Total electricity generated by PV: 5.64kWh
- ✓ Cost coefficient $f_i(t)$: 11.0 JPY/kWh
- ✓ Cost coefficient : 24.3 円/kWh

Reallocation is **not allowed** at any time.



Reallocation is **allowed** at any time **and optimized**.



By optimization of vehicle assignment, reallocation and charging,

- Acceptance of reservation is increased.
- Peak of the purchased power is suppressed.
- Wasted power is reduced

Reallocation has crucial effect!

Effect on Distribution Voltage

◆ Continuum Model of Distribution Voltage

$$\frac{d\theta}{d\ell} = \frac{s}{v^2}, \quad \frac{dv}{d\ell} = w,$$
$$\frac{ds}{d\ell} = -\frac{p(\ell,t)b - q(\ell,t)g}{g^2+b^2}$$
$$\frac{dw}{d\ell} = \frac{s^2}{v^3} - \frac{p(\ell,t)g + q(\ell,t)b}{v(g^2+b^2)}$$

Ref.) DistFlow ODE

$\ell \in \Sigma$

Distribution Grid

Bank

Inclusion

Active−Power Density Function along a feeder

$$p(\ell,t) = p_{\mathrm{L}}(\ell,t) + p_{\mathrm{G}}(\ell,t) + p_{\mathrm{EV}}(\ell,t,\rho_{\mathrm{EV}})$$

Consumption | Generation (DER) | Charging/Discharging of EVs

$$p_{\mathrm{EV}}(\ell,t,\rho_{\mathrm{EV}}) = \int_D \rho_{\mathrm{EV}}(\xi,t) \times P \times \phi_{\mathrm{chargin.point}}(\xi,\ell)d\xi$$

Density Representation of EV Movement

$$\rho_{\mathrm{EV}}(\boldsymbol{x},t)$$

$$\boldsymbol{x} \in D$$

Area of EV−Sharing

Coarse−Graining

Measured or Predicted Data

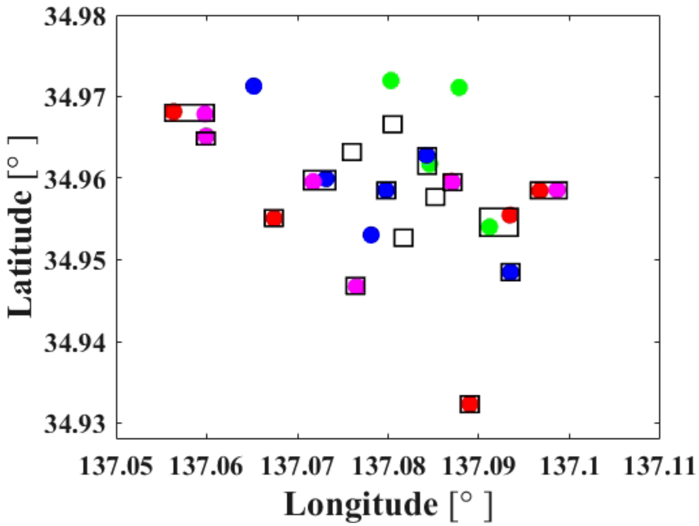
Procedure of analysis:

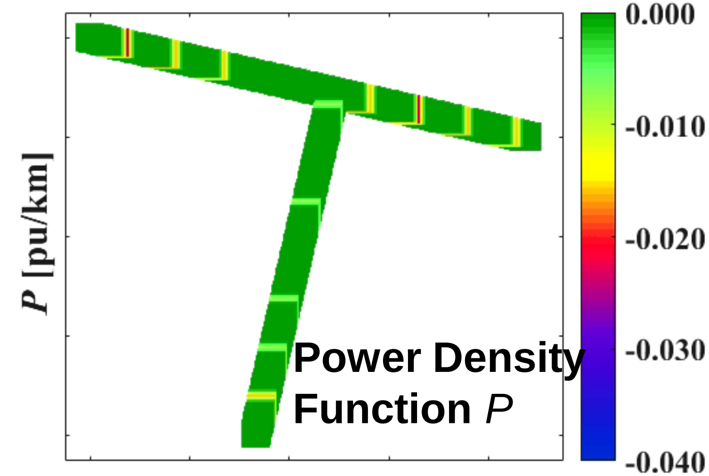
- Superimpose the distribution feeder on the geometrical map in Anjo city.
- Apply the Data in EV sharing operation
- Spatiotemporal distribution of EV is substituted in the analytical model of distribution voltage assessment

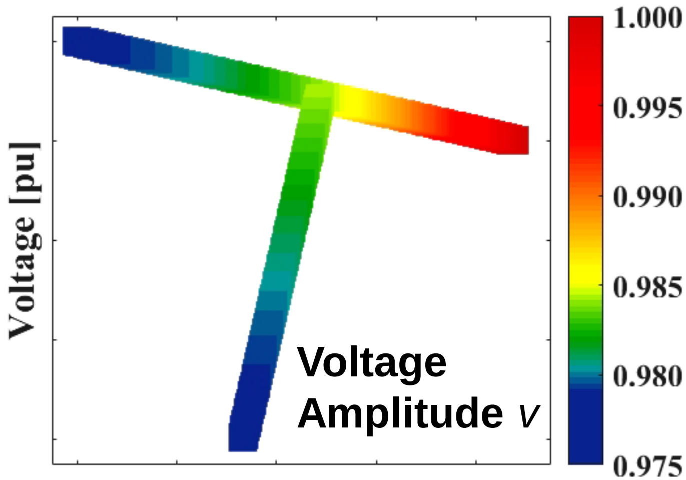
Numerical analysis

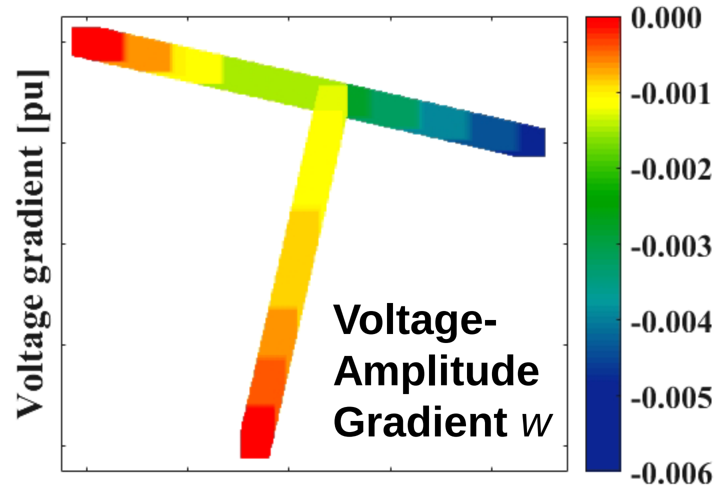
10月23日 11時0分

Allocation ov EVs and stations









Summary (Overview in Japan)

1. In Japan, electrification of vehicle will be accelerated because of government energy policy and increase of number of charging stations.

2. In Japan, PHV and BEV with range extender are likely to be popular as a possesion car in 2030

3. Small BEV will be exploited for short range sharing service

Summary (Integration with s.g.)

1. In Japan, power policy reform (initiating from 2016) will may bring strong influence on the power market, and market of electrified vehicle.

2. Electrified vehicle will be a key player in smart grid system of both local and regional. Integration of the smart grid and mobility will lead to a new generation smart city.