# Regional Energy Modeling for Long-term $CO_2$ Emission Reduction in Japan

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# Background and Purpose

- It is necessary to draw alternative energy system with large-scale $CO_2$ emission in Japan toward 2050.

- We should consider regional differences in user-side energy technologies for it.

We develop the Japanese Regional Energy Model (J-REM), which divided energy demand sectors of Japan into several regions by municipality considering climate, population density, and availability of city gas infrastructure and energy demand and energy service demand in each region are estimated.

# Standard for Over Coefficient of Heat Loss and Heating Degree Days
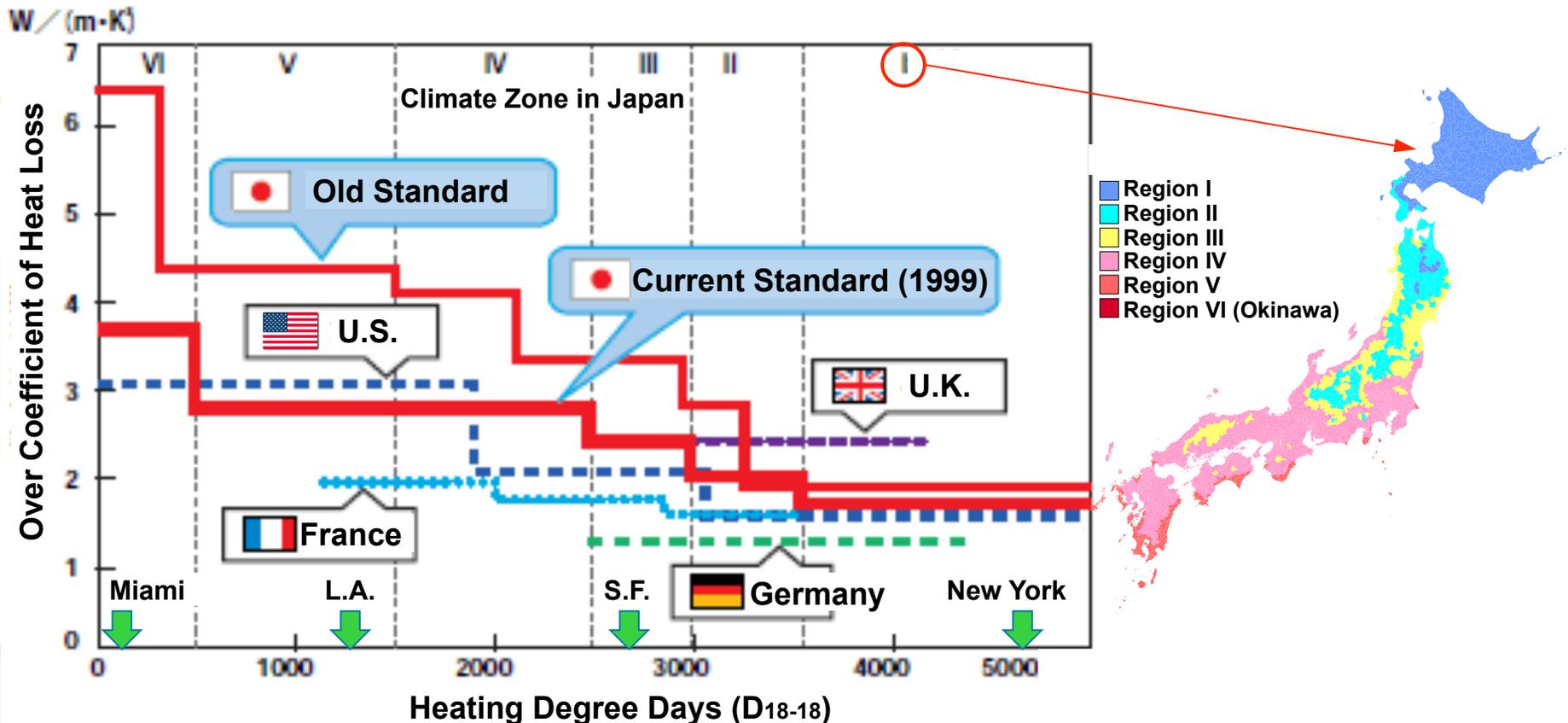
**Climate of Japan has wide variation and the range of HDDs is almost comparable with that of lower 48 states of U.S.**

# Points for Regional Division

**Considering particular situations of Japan**

- **Wide climate variation**
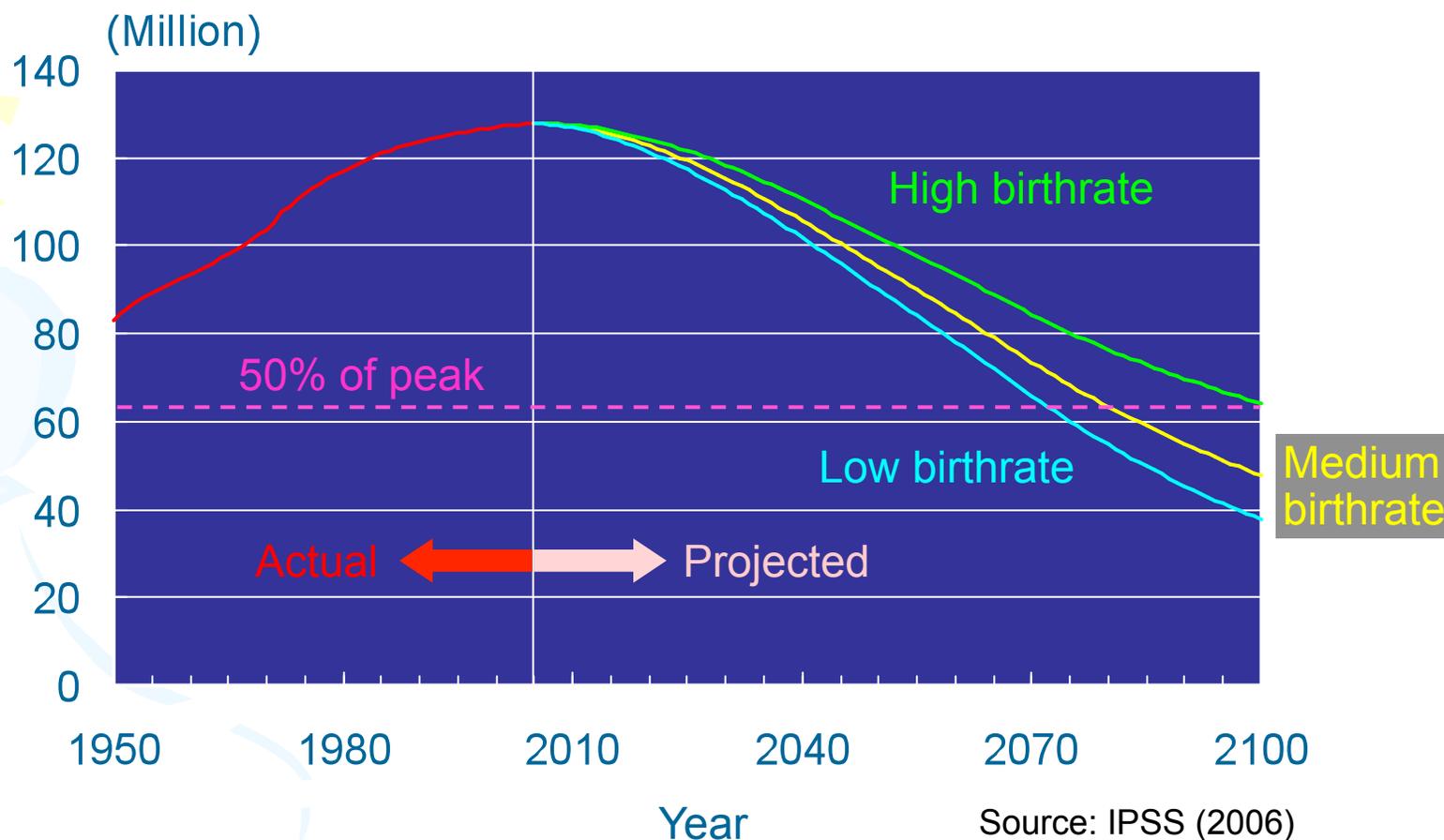  - ➔ Energy demand and appliances vary by region

- **Population decrease nationwide and growing some densely inhabited districts**
  - ➔ Differences in available public transportation and in driving distance of cars

- **Limitation of city gas availability**
  - ➔ Expansion of supply area for small-size customer will not be expected and it will affect future choice of energy technologies.

# Supply Region of City Gas
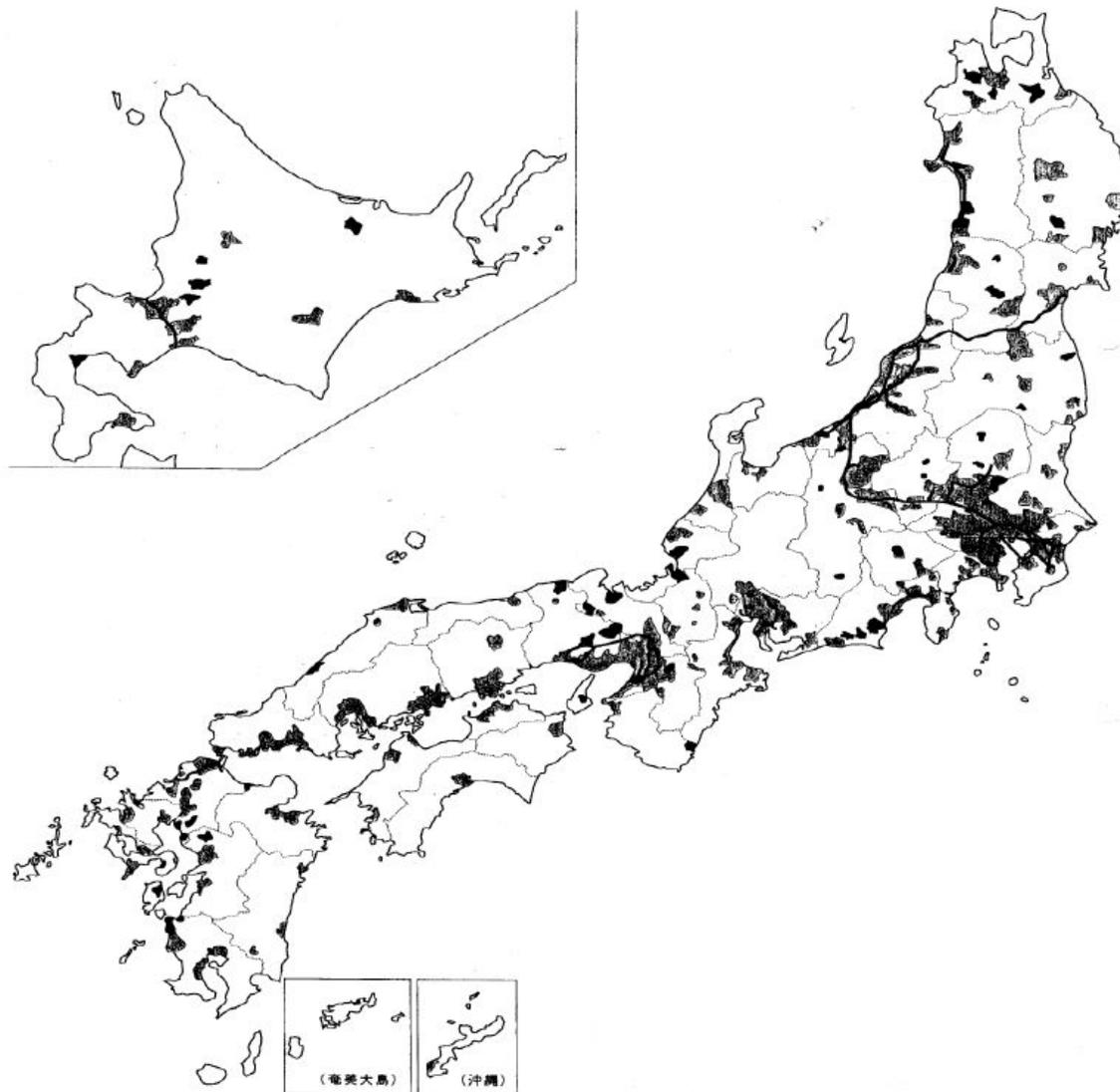


Unlike in other developed countries, supply region of city gas is **only 6% of total land area** and quite limited in Japan.
Enlarging supply region for small-size customers will not be expected because Japan is facing population decrease and cost recovery of preparing long-distance and low-pressure gas pipelines is quite difficult.

# Population Projection of Japan

(Million)

50% of peak

High birthrate

Low birthrate

Medium birthrate

Actual ← → Projected

Year

Source: IPSS (2006)

**Enlargement of city area will not be expected and how to design "energy-efficient compact cities" is an important issue for Japan.**
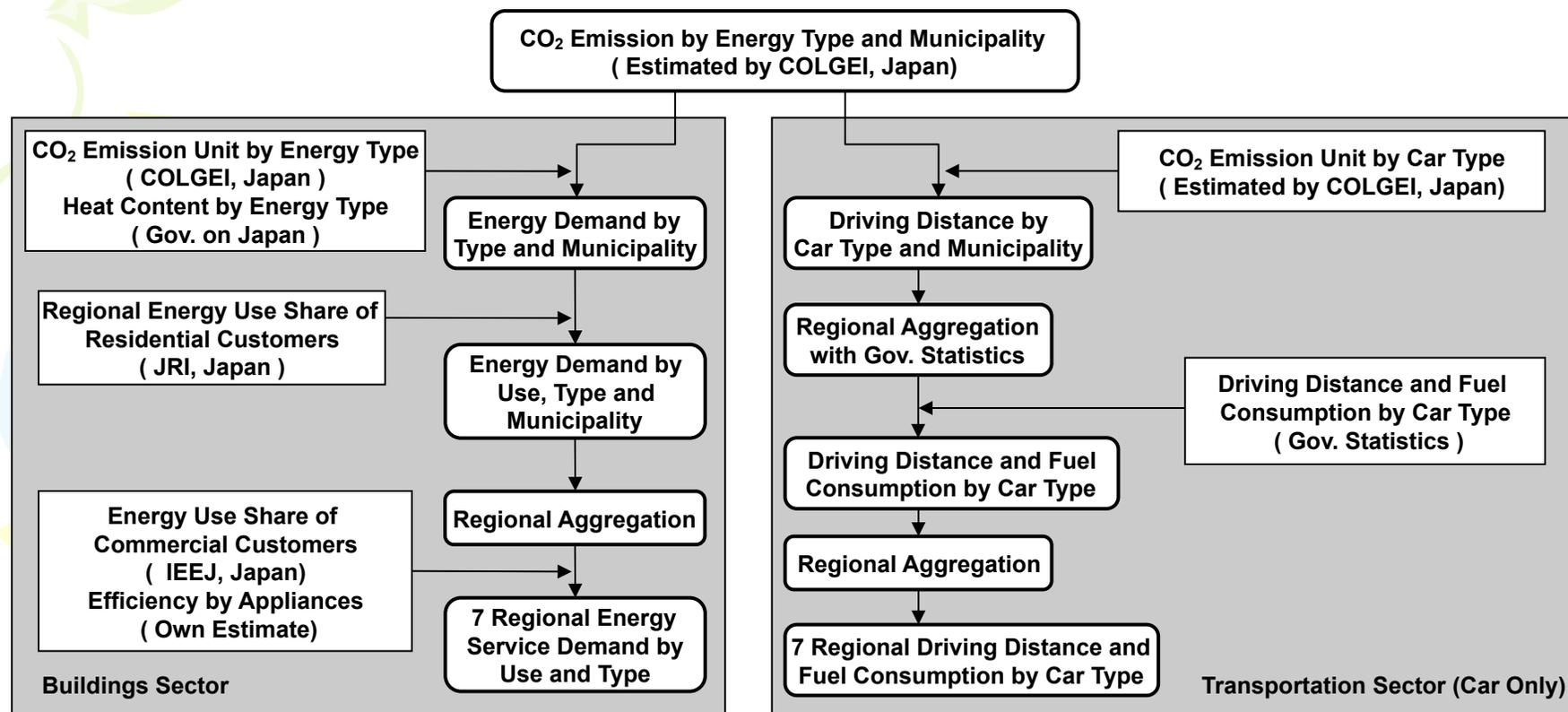
# Regional Division of J-REM

Region 1 (cold with city gas)
Region 2 (cold without city gas)
Region 3 (cool with city gas)
Region 4 (cool without city gas)
Region 5 (warm metropolitan)
Region 6 (warm with city gas)
Region 7 (warm without city gas)

| Region | No. of Municipality | Population (in 2000) |
|--------|---------------------|----------------------|
| 1 | 21 | 377 million |
| 2 | 188 | 167 million |
| 3 | 100 | 748 million |
| 4 | 667 | 713 million |
| 5 | 126 | 3,938 million |
| 6 | 516 | 4,536 million |
| 7 | 1,629 | 2,214 million |

- **Three climate zones (cold, cool and warm)**

- **There is strong correlation between population density and availability of city gas.**

- **In three metropolitans located in the warm region (Tokyo, Osaka, and Nagoya), subway network is available and they are treated separately.**

- **As a result, all 3,247 municipalities existed in 2000 are classified into seven regions.**
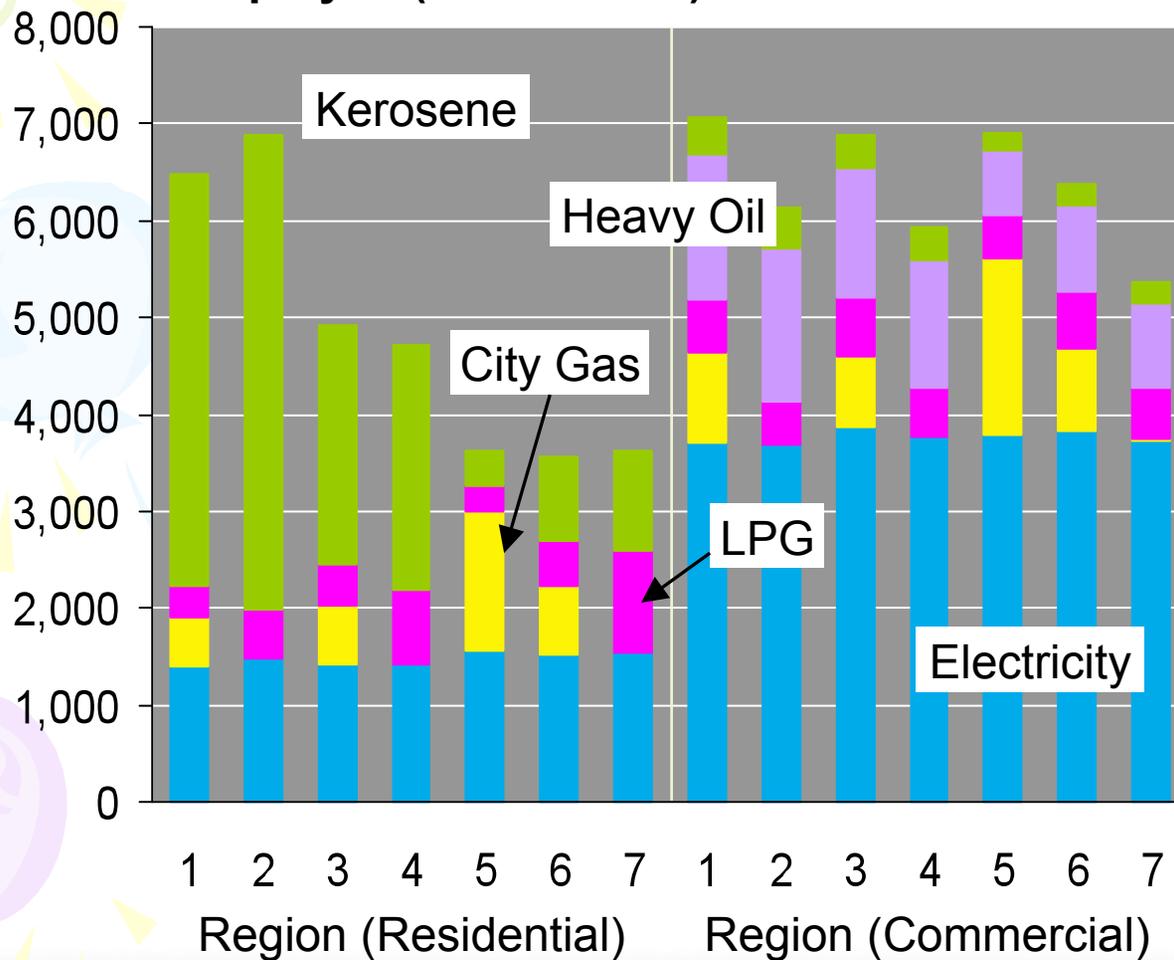
# Data Estimation

CO$_2$ Emission by Energy Type and Municipality
( Estimated by COLGEI, Japan)

**Buildings Sector**

CO$_2$ Emission Unit by Energy Type
( COLGEI, Japan )
Heat Content by Energy Type
( Gov. on Japan )

Regional Energy Use Share of
Residential Customers
( JRI, Japan )

Energy Use Share of
Commercial Customers
( IEEJ, Japan)
Efficiency by Appliances
( Own Estimate)

Energy Demand by
Type and Municipality

Energy Demand by
Use, Type and
Municipality

Regional Aggregation

7 Regional Energy
Service Demand by
Use and Type

**Transportation Sector (Car Only)**

CO$_2$ Emission Unit by Car Type
( Estimated by COLGEI, Japan)

Driving Distance by
Car Type and Municipality

Regional Aggregation
with Gov. Statistics

Driving Distance and Fuel
Consumption by Car Type
( Gov. Statistics )

Driving Distance and Fuel
Consumption by Car Type

Regional Aggregation

7 Regional Driving Distance and
Fuel Consumption by Car Type

**Regional energy service demand was estimated based on the CO$_2$ emission estimation by 3,247 municipality in 2000 (in 1999 for transportation sector) by COLGEI (The Coalition of Local Government for Environmental Initiative, Japan).**

# Regional Energy Demand



**Mcal/person (residential)**
**Mcal/employee (commercial)**

Chart labels: Kerosene, Heavy Oil, City Gas, LPG, Electricity

X-axis: Region (Residential) 1–7, Region (Commercial) 1–7
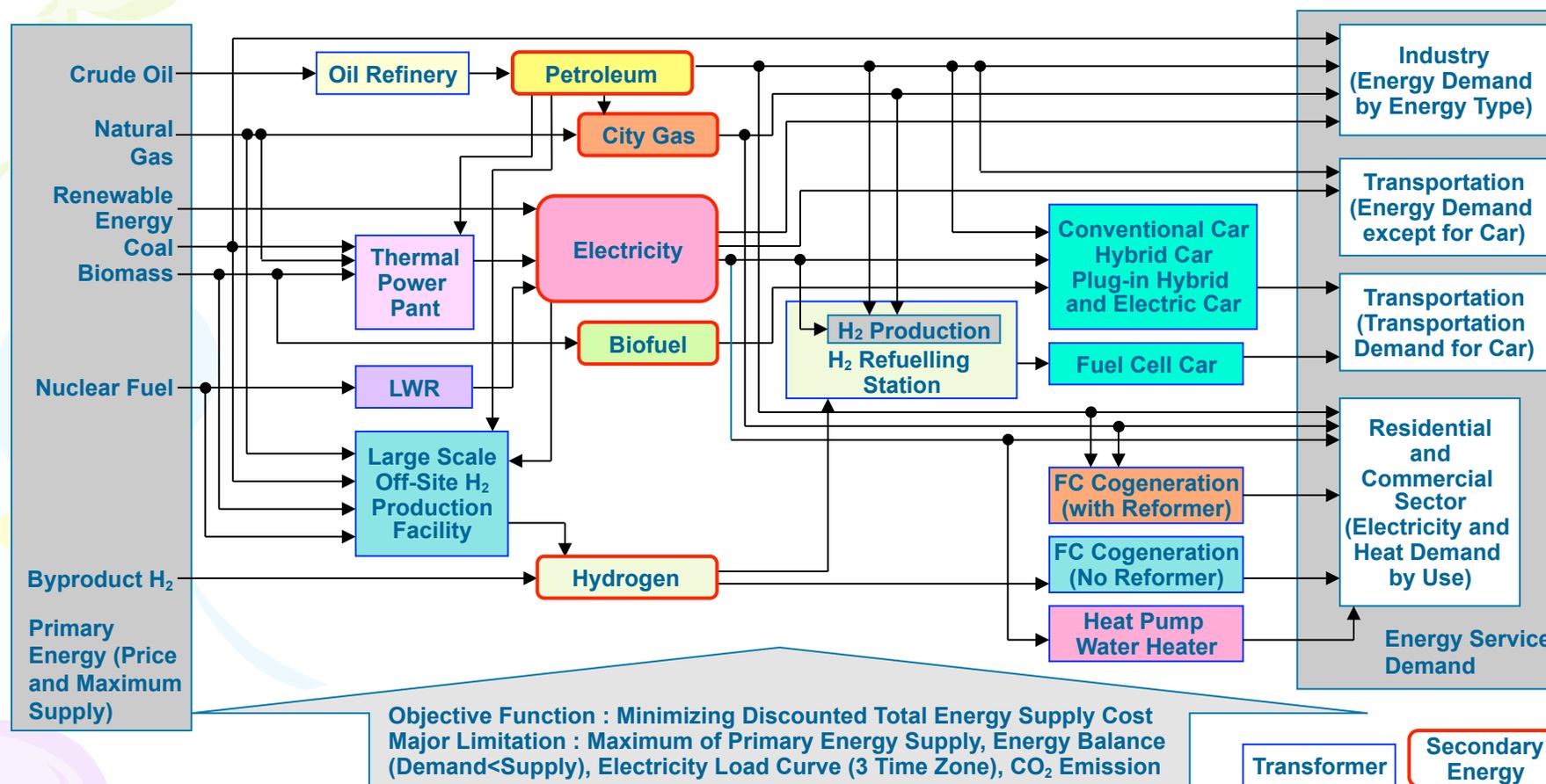
Y-axis: 0 to 8,000

**Small regional differences in electricity**

**Electricity is not a dominant fuel for heating. Instead, kerosene and heavy oil are mainly used and their demand vary seriously by region.**
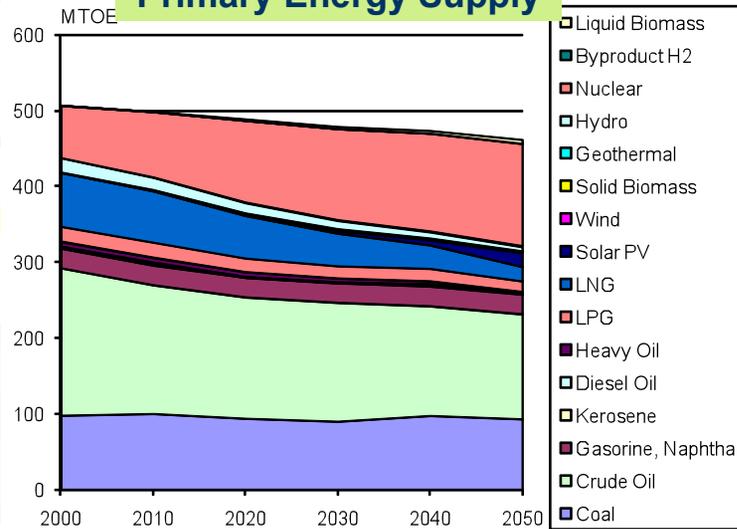
# Structure of J-REM

Crude Oil → Oil Refinery → Petroleum → City Gas → Industry (Energy Demand by Energy Type)

Natural Gas

Renewable Energy

Coal

Biomass

Thermal Power Pant

Electricity

Biofuel

LWR

Large Scale Off-Site $H_2$ Production Facility

Nuclear Fuel

Byproduct $H_2$

Hydrogen

Primary Energy (Price and Maximum Supply)

$H_2$ Production $H_2$ Refuelling Station

Conventional Car Hybrid Car Plug-in Hybrid and Electric Car

Fuel Cell Car

FC Cogeneration (with Reformer)

FC Cogeneration (No Reformer)

Heat Pump Water Heater

Transportation (Energy Demand except for Car)

Transportation (Transportation Demand for Car)

Residential and Commercial Sector (Electricity and Heat Demand by Use)

Energy Service Demand

Objective Function : Minimizing Discounted Total Energy Supply Cost
Major Limitation : Maximum of Primary Energy Supply, Energy Balance (Demand<Supply), Electricity Load Curve (3 Time Zone), $CO_2$ Emission

Transformer    Secondary Energy

- **Energy prices are exogenously given.**
- **Import limitation for fossil fuels are imposed.**
- **Renewables except for hydro and biomass are exogenously given.**
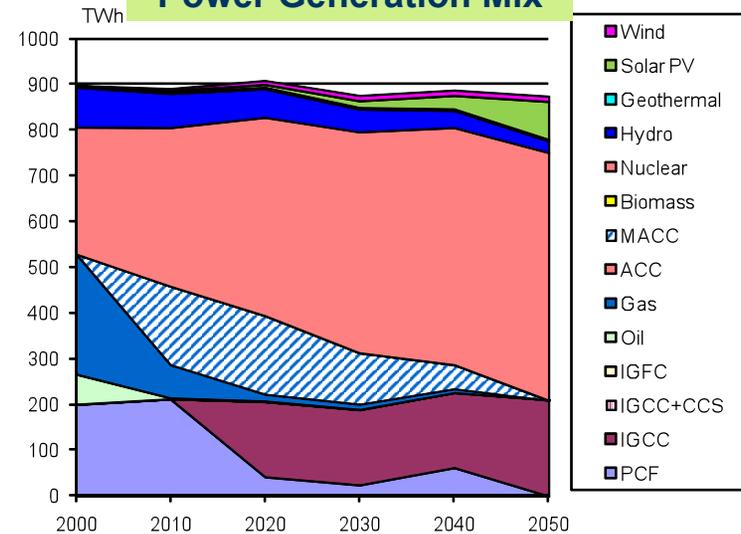
# Regional Differences in Assumption

- **Heating Appliance** : Heat-storage electric heaters are used in cold and cool regions and air-conditioners aren't because of technical reasons.

- **COP (coefficient of performance) of Heat Pump Water Heater** : 2.0 in cold regions, 3.0 in cool regions and 4.0 in warm regions

- **Increase in Energy Service Demand** : Relatively small in cold and cool regions than in warm regions, considering future decreasing rates of population. As for use, relatively high in cooling and warming, considering the low-sufficiency rate of whole house air conditioning.
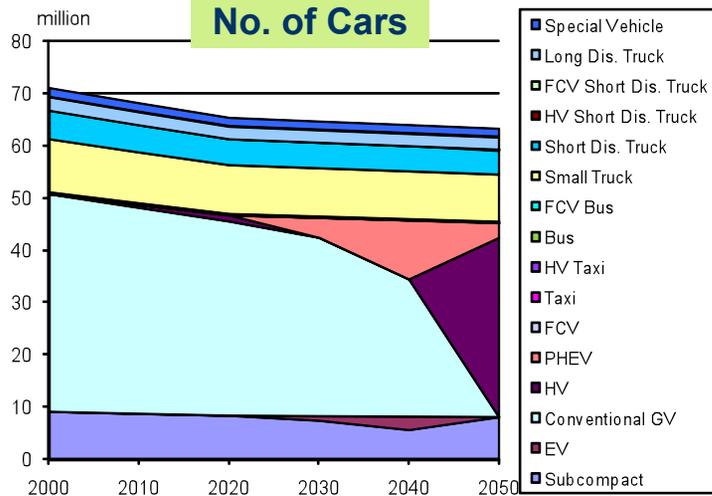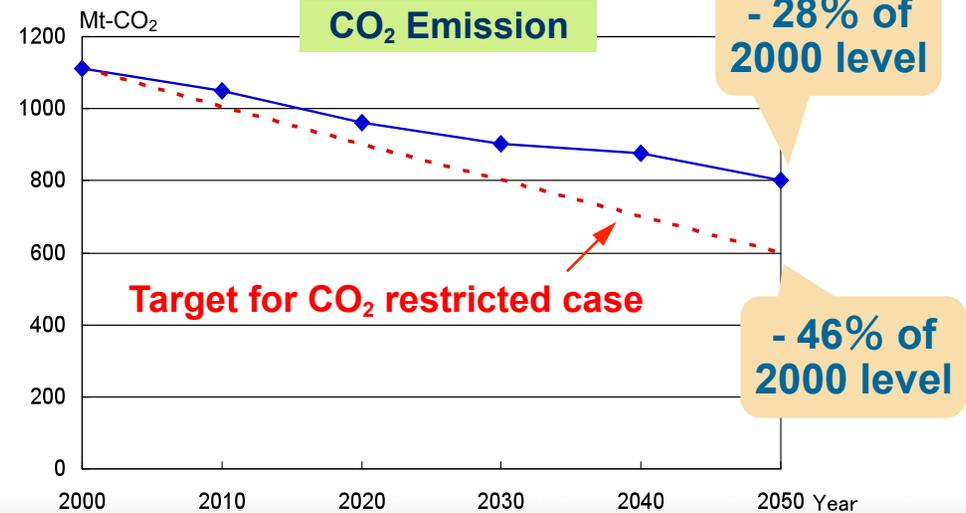
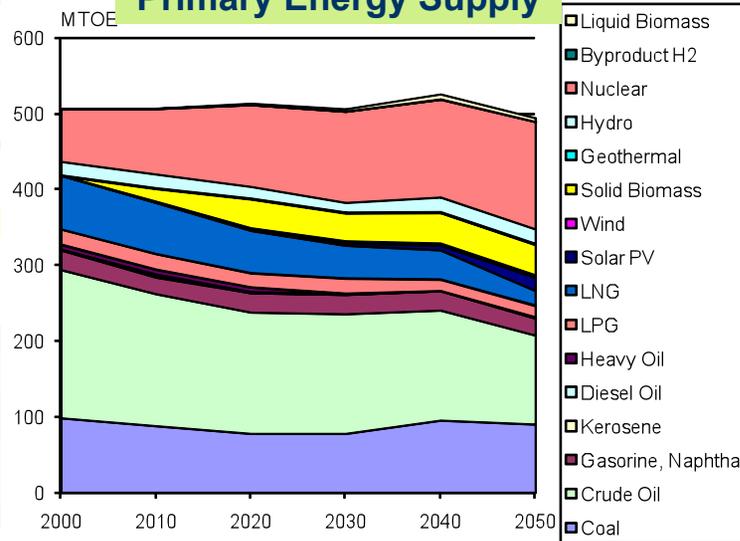# Result of BAU Case

**Primary Energy Supply**

MTOE

Legend: Liquid Biomass, Byproduct H2, Nuclear, Hydro, Geothermal, Solid Biomass, Wind, Solar PV, LNG, LPG, Heavy Oil, Diesel Oil, Kerosene, Gasorine, Naphtha, Crude Oil, Coal



**Power Generation Mix**

TWh

Legend: Wind, Solar PV, Geothermal, Hydro, Nuclear, Biomass, MACC, ACC, Gas, Oil, IGFC, IGCC+CCS, IGCC, PCF



**No. of Cars**

million

Legend: Special Vehicle, Long Dis. Truck, FCV Short Dis. Truck, HV Short Dis. Truck, Short Dis. Truck, Small Truck, FCV Bus, Bus, HV Taxi, Taxi, FCV, PHEV, HV, Conventional GV, EV, Subcompact



**CO$_2$ Emission**

Mt-CO$_2$

**- 28% of 2000 level**

**Target for CO$_2$ restricted case**

**- 46% of 2000 level**

Year

# Result of CO$_2$ Restricted Case

**Primary Energy Supply**

MTOE

Legend:
- Liquid Biomass
- Byproduct H2
- Nuclear
- Hydro
- Geothermal
- Solid Biomass
- Wind
- Solar PV
- LNG
- LPG
- Heavy Oil
- Diesel Oil
- Kerosene
- Gasorine, Naphtha
- Crude Oil
- Coal

**Power Generation Mix**

TWh

Legend:
- Wind
- Solar PV
- Geothermal
- Hydro
- Nuclear
- Biomass
- MACC
- ACC
- Gas
- Oil
- IGFC
- IGCC+CCS
- IGCC
- PCF

**No. of Cars**

million

Legend:
- Special Vehicle
- Long Dis. Truck
- FCV Short Dis. Truck
- HV Short Dis. Truck
- Short Dis. Truck
- Small Truck
- FCV Bus
- Bus
- HV Taxi
- Taxi
- FCV
- PHEV
- HV
- Conventional GV
- EV
- Subcompact
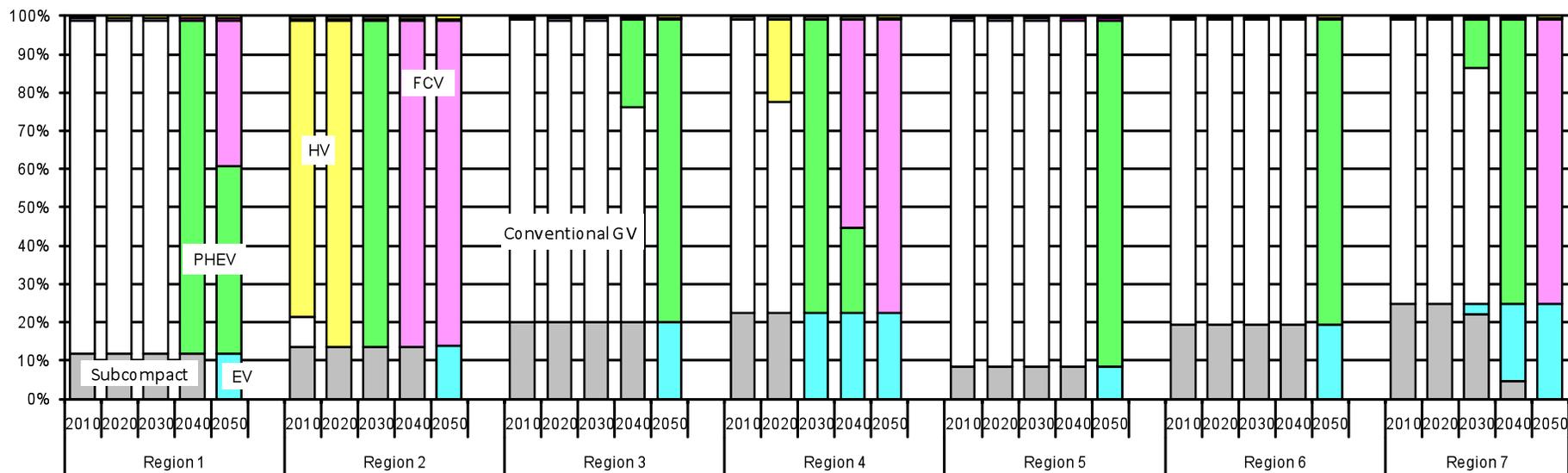
- **Electrification is the key for large-scale CO$_2$ reduction.**

- **PHEV and EV in transportation and HP and heat-storage electric heaters in residential sectors will be used.**

- **As a result, electricity demand will increase compared with BAU case.**

# Main Results of CO$_2$ Restricted Case

- All kinds of Energy-efficient technologies which are not introduced in the BAU Case will be introduced.

- Remarkable regional differences are found in **passenger car** and **residential hot water supply**.

- **Passenger car** : in the region 2, 4, and 7, next-generation vehicles will be introduced earlier because population densities of these regions are relatively small and travel distance of cars are longer.

- **Hot water** : in warm and no city gas regions, HP water heater will be introduced earlier because COP is larger and heat demand is smaller than in colder regions.
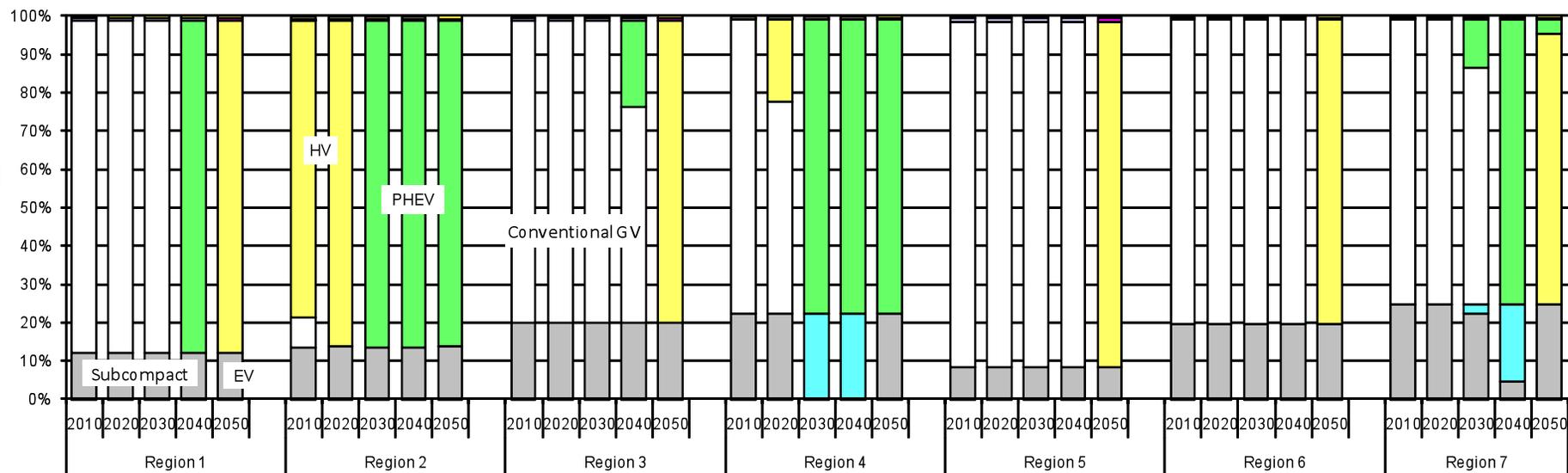
# No. of Passenger Car (CO$_2$ Restricted Case)

Chart labels: FCV, HV, PHEV, Conventional GV, Subcompact, EV

Regions 1–7, years 2010 2020 2030 2040 2050

| Region | Changes in Technology Choice | Dominant Vehicle Type in 2050 |
|---|---|---|
| 1 | GV → PHEV → FCV | PHEV |
| 2 | GV→HV→PHEV→FCV | FCV |
| 3 | GV → PHEV | PHEV |
| 4 | GV→HV→PHEV→FCV | FCV |
| 5 | GV → PHEV | PHEV |
| 6 | GV → PHEV | PHEV |
| 7 | GV → PHEV → FCV | FCV |

In the region 5 and 6, penetration of next-generation vehicles is slow because of short driving distance. On the other hand, various vehicles will penetrate in the region 2 and 4.

# No. of Passenger Car (BAU Case)

The chart shows percentage distribution (0%–100%) of passenger car technology types for Regions 1–7 across years 2010, 2020, 2030, 2040, 2050. Labels: HV, PHEV, Conventional GV, Subcompact, EV.

| Region | Changes in Technology Choice | Dominant Vehicle Type in 2050 |
|--------|------------------------------|-------------------------------|
| 1 | GV → PHEV → HV | HV |
| 2 | GV → HV → PHEV | PHEV |
| 3 | GV → HV | HV |
| 4 | GV → PHEV | PHEV |
| 5 | GV → HV | HV |
| 6 | GV → HV | HV |
| 7 | GV → PHEV → HV | HV |

**FCV is expensive and will be never used. PHEV or EV will be introduced, but they will return to HV or GV because of the changes in fuel prices.**
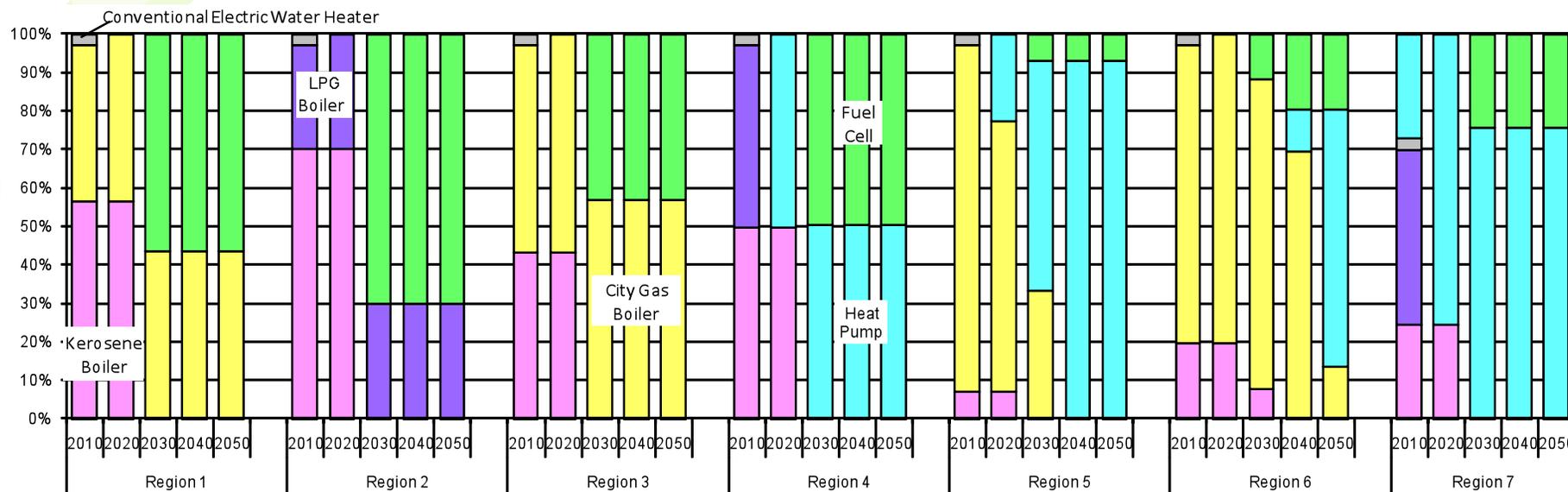
# Res. Hot Water Supply (CO₂ Restricted Case)
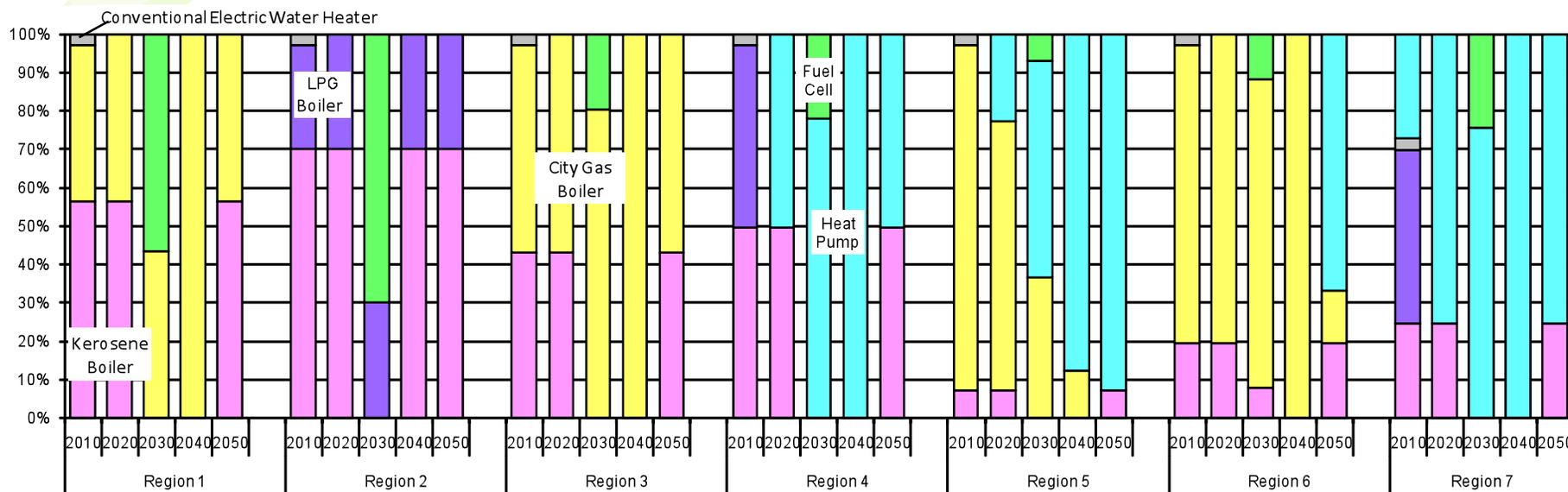
| Region | Changes in Technology Choice | Dominant Appliance (fuel) in 2050 |
|---|---|---|
| 1, 2 | Fuel cell will be used in 2030, but boiler (latent heat recovery type) is dominant | Boiler (Kerosene) |
| 3 | Boiler (latent heat recovery type) is dominant throughout the period | Boiler (Kerosene) |
| 4 | Boiler → Heat Pump | Boiler (Kerosene) and Heat Pump (Electricity) |
| 5 ~ 7 | Boiler → Heat Pump | Heat Pump (Electricity) |

Fuel cell will use kerosene as its fuel and will disappear in the latter period when the costraint of CO₂ emission will become severer.

# Res. Hot Water Supply (BAU Case)



| Region | Changes in Technology Choice | Dominant Appliance (fuel) in 2050 |
|--------|------------------------------|-----------------------------------|
| 1, 2 | Boiler → Fuel cell | Fuel cell (Kerosene) |
| 3 | Fuel cell will be used after 2030, but boiler (latent heat recovery type) is dominant | Boiler (Kerosene) |
| 4 | Boiler→Heat Pump→Heat Pump · Fuel cell | Fuel cell (Kerosene) and Heat Pump (Electricity) |
| 5 ~ 7 | Boiler → Heat Pump | Heat Pump (Electricity) |

**Mainly because of economic reason, fuel cell will be introduced in the cold and cool regions compared with the $CO_2$ restricted case.**

# Results

- This study has analyzed the cost and effectiveness of various advanced energy supply and utilizing technologies in reducing $CO_2$ emissions by the year 2050 by employing the Japanese Regional Energy Model (J-REM).

- The results of test-run shows two remarkable differences in regional technology choices will happen to decrease $CO_2$ emission considerably and confirmed the importance of regional consideration.

- We will analyze the $CO_2$ reduction more precisely by checking various presuppositions and revise the model including the various changes happened after the 3.11 Fukushima I Nuclear Accident.

# Scope of the J-REM model

| Item | Scope |
|---|---|
| Region | Japan (7 regions for residential, commercial, and transportation sectors) |
| Time range | 2000-2050, 6 points (every 10 years) |
| Energy demand | Exogenous (service demand for transportation and buildings sectors) |
| Primary energy type | 15 types (coal, oil (6 types), gas, renewable (5 types), nuclear, $H_2$) |
| Final energy type | 12 types (coal, oil (5 types), gas (2 types), electricity, heat, $H_2$, biofuels) |
| Vehicle technologies | 5 types (conventional, HV, PHEV, EV, and FCV) |
| Power generation technologies | 9 types (coal-fired (4 types, one of them has a CCS option), oil-fired, gas-fired (3 types), nuclear) |
| On-site energy utilization technologies | Conventional system, stationary fuel cell cogeneration (building sector only, and heat pump water heater (residential sector only) |
| Supply of renewable energy | Exogenous for geothermal, PV, and wind power generation Endogenous for hydropower and biomass power generation |
| Load duration curve of electricity | Considered (approximation by 3 time patterns function) |
| Energy conservation | Considered (demand changed by using assumed price elasticity) |

# Assumptions for Main Variables

| Item | | Unit | Year | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
| Energy Price | Crude oil | $/bbl | 28.0 | 52.2 | 80.1 | 89.0 | 93.9 | 99.1 |
| | Petroleum products | $/TOE | 193.0 | 360.0 | 551.8 | 613.1 | 647.0 | 682.8 |
| | LNG | $/TOE | 187.7 | 315.1 | 430.0 | 478.2 | 504.6 | 532.5 |
| | Coal | $/TOE | 52.7 | 123.9 | 129.4 | 134.4 | 141.8 | 149.7 |
| Energy Service | Industry | MTOE/y | 193.0 | 192.4 | 191.7 | 190.7 | 189.7 | 188.8 |
| | Residential | MTOE/y | 48.4 | 49.7 | 51.2 | 53.9 | 57.0 | 60.3 |
| | Commercial | MTOE/y | 40.0 | 44.7 | 49.9 | 50.0 | 50.2 | 50.6 |
| | Transportation | MTOE/y | 98.9 | 94.9 | 90.9 | 90.0 | 89.0 | 88.0 |
| Nuclear Power | Capacity | GW | 45.08 | 50.38 | 61.50 | 68.13 | 73.10 | 76.41 |
| | Capacity factor | % | 81.0 | 81.0 | 81.0 | 81.0 | 81.0 | 81.0 |
| PV Capacity | | GW | 0.33 | 3.0 | 6.0 | 14.0 | 28.0 | 79.0 |
| Upper limits of ownership rate of next generation cars | | Owner% | 0.0 | 3.0 | 3.0 | 10.0 | 30.0 | 100.0 |