**The Effectiveness of Bioethanol on the Reduction of Greenhouse Gas Emissions in the Transport Sector and the Marginal Cost of Such Reduction**

## 1. Introduction

Japan has set up the goal of achieving a 26% reduction in greenhouse gas emissions in fiscal 2030 from those in fiscal 2013, in "Japan's Intended Nationally Determined Contribution" (July 2015) (hereinafter referred to as the "INDC") of the Global Warming Prevention Headquarters.

To achieve this goal, the transport sector aims to reduce energy-originated CO2 emissions by 62 million t-CO2/year (27.6%), from 225 million t-CO2/year in fiscal 2013 to 163 million t-CO2/year in fiscal 2030, which serves only as a guide.

In "3. Measures which form the basis for the bottom-up calculation of the greenhouse gas emission reduction target" in the INDC, the following are listed as the measures that form the basis for the bottom-up calculation of the greenhouse gas emission reduction target for the transport sector.

(1) Improvement of fuel consumption;
(2) Penetration of next-generation automobiles;
(3) Other measures in the transport sector;
(4) Utilization of the special zones system for structural reform in the context of global warming countermeasures;
(5) Promotion of inter-ministry collaborative measures in a planned manner using a roadmap of global warming countermeasures, etc.

The present study focused on the measures mentioned in (1) and (2) above, which are directly involved in the introduction of bioethanol, and it analyzed the CO2 emission reduction targets of said measures as set forth in the Plans for Addressing Global Warming along with various ways of achieving said targets.

In the present report, a non-LCA-based value is used to refer to a CO2 emission coefficient because the CO2 emissions (emission coefficients) in the INDC and the Plans for Addressing Global Warming, which are discussed in the following section, are thought to be basically non-LCA-based.

For the electricity consumed by EVs and PHVs, the present report uses the CO2 emission coefficient (non-LCA-based) for electricity that is generally and widely used, taking into account the component corresponding to direct emissions from vehicles (zero) as well as that corresponding to indirect CO2 emissions from power generation.

The Plans for Addressing Global Warming (May 2016) aim to reduce CO2 emissions by 23.79 million t-CO2/year during the period from fiscal 2013 (fiscal 2012) to fiscal 2030 (20.89 million t-CO2/year, starting from fiscal 2017), as measures for penetration of next-generation automobiles, improvement of fuel consumption, etc.

Although this target value covers both passenger vehicles and cargo vehicles, "The Progress of the Plans for Addressing Global Warming as of Fiscal 2018" (March 2020) states, "There has been no progress in the improvement of fuel consumption for cargo vehicles so far." Meanwhile, it states, "Cargo vehicles will be subject to more stringent fuel consumption standards in and after fiscal 2022; it is anticipated that endeavors will be made to improve their fuel consumption from now onward and that energy saving and emission reductions will be promoted toward fiscal 2030." Nevertheless, the improvement of fuel consumption for cargo vehicles seems to have some aspects the feasibility of which is uncertain (or not practical).

Hence, the present report disregards the potential for reductions in CO2 emissions from cargo vehicles (mainly, diesel-powered vehicles) and discusses the subject matter with a focus on gasoline-powered passenger vehicles.

## 2. Choices of CO2 emission reduction measures for conventional vehicles

The choices for the CO2 emission reduction measures for conventional vehicles (i.e., conventional automobiles with gasoline engine) for achieving the aforementioned goal include the six approaches shown below. The present study calculated CO2 emission reduction amounts for these six approaches.

(1) Increasing the number of EVs (except PHVs);
(2) Increasing the number of HVs and PHVs;
(3) Increasing the number of FCVs (fuel-cell vehicles);
(4) Improving the fuel consumption of conventional vehicles;
(5) Increasing the use of bioethanol in the fuel for conventional vehicles (gasoline); and

(6) Increasing the use of bioethanol in the fuel for HVs and PHVs (gasoline).

The amount of $CO_2$ emissions reducible by these approaches was calculated with the following formula:

- Amount of CO2 emissions reducible by vehicles/fuel subjected to the measures (unit: 10,000 t-CO2/year) = annual CO2 emissions (unit: 10,000 t-CO2/year) from vehicles/fuel (not subjected to the measures) to be replaced by vehicles/fuel subjected to the measures in fiscal 2030 − annual CO2 emissions (unit: 10,000 t-CO2/year) in fiscal 2030 from vehicles/fuel subjected to the measures

**2-1. Amount of CO2 emission reductions by increasing the number of EVs**

Data necessary for calculating the amount of CO2 emission reductions by increasing the number of EVs was set as follows: however, this list omits the details of the individual numerical data items.

(1) Electricity consumption per distance (kWh/km) or fuel consumption per distance (L/km) for EVs, etc. (referring to EVs and conventional vehicles; the same applies hereinafter)
(2) Annual travel distance per vehicle (km/year·vehicle) for EVs, etc.
(3) The number of EVs, etc. in operation (owned) (unit: vehicle): The two cases shown below were set with respect to the outlook on the number of additional next-generation automobiles put in operation (limited to EVs. HVs, PHVs, and FCVs) (flow = the number of new vehicles sold: stock = the number of vehicles owned), and the number of EVs, etc. owned in fiscal 2030 was estimated for each case.
i) Base case: The number of additional next-generation automobiles put in operation was estimated on the assumption of realistic (conservative) penetration.
ii) Optimum case: The number of additional next-generation automobiles put in operation was estimated on the assumption of optimum penetration.
(4) CO2 emission coefficient for electricity (or fuel) (unit: g-CO2/kWh or g-CO2/L)

The result of calculating the amount of CO2 emissions reducible in fiscal 2030 by replacing conventional vehicles with EVs on the basis of the above formula and data was 84.6 × 10,000 t-CO2/year (base case) or 256.2 × 10,000 t-CO2/year (optimum case).

**2-2. Amount of CO2 emission reductions by increasing the number of HVs and PHVs**

Data necessary for the calculations for HVs and PHVs was set as follows:

(1) Fuel/electric power consumption per distance (L/km, kWh/km) for HVs/PHVs (fiscal 2030)
(2) Annual travel distance per vehicle (km/year·vehicle) for HVs/PHVs (fiscal 2030)
(3) The number of HVs/PHVs in operation (owned) (fiscal 2030)
(4) CO2 emission coefficient for fuel (fuel and electric power for PHVs) (g-CO2/L, g-CO2/kWh) (fiscal 2030)
(5) Numerical values for conventional vehicles to be replaced by HVs/PHVs (fiscal 2030)

The amount of CO2 emissions reducible in fiscal 2030 by replacing conventional vehicles with HVs/PHVs (unit: 10,000 t-CO2/year) based on the aforementioned data was as follows:

-HVs: 832.4 × 10,000 t-CO2/year (base case) or 968.2 × 10,000 t-CO2/year (optimum case)
-PHVs: 49.8 × 10,000 t-CO2/year (base case) or 150.6 × 10,000 t-CO2/year (optimum case)

**2-3. Amount of CO2 emission reductions by increasing the number of FCVs**

The amount of CO2 emissions reducible by fiscal 2030 that would be enabled by increasing the number of FCVs was calculated on the basis of the below data.

(1) Hydrogen consumption per distance (kg/km) for FCVs (fiscal 2030)
(2) Annual travel distance per vehicle (km/year·vehicle) for FCVs (fiscal 2030)
(3) The number of FCVs owned (fiscal 2030)
(4) CO2 emission coefficient for hydrogen (g-CO2/Nm3) (fiscal 2030)
(5) Numerical values for conventional vehicles to be replaced by FCVs (fiscal 2030)

The amount of CO2 emissions reducible in fiscal 2030 by replacing conventional vehicles with FCVs (unit: 10,000 t-CO2/year) based on the aforementioned data was 17.2 × 10,000 t-CO2/year (base case) or 50.8 × 10,000 t-CO2/year (optimum case).

**2-4. Amount of $CO_2$ emission reductions by improving the fuel consumption of conventional vehicles (vehicles other than EVs, HVs, PHVs, and FCVs)**

(1) Fuel consumption per distance (L/km) for conventional vehicles with improved fuel consumption (fiscal 2030)
(2) Annual travel distance per vehicle (km/year·vehicle) for conventional vehicles with improved fuel consumption (fiscal 2030)
(3) The number of conventional vehicles owned (unit: vehicle) (fiscal 2030), vehicles other than EVs, HVs, PHVs, and FCVs
(4) CO2 emission coefficient for fuel (g-CO2/L) (fiscal 2030)
(5) Numerical values of conventional vehicles for control (if there were no measures) (fiscal 2030)

The result of calculating the amount of CO2 emission reductions (unit: 10,000 t-CO2/year) in fiscal 2030 that would be enabled by improving the fuel consumption of conventional vehicles (vehicles other than EVs, HVs, PHVs, and FCVs) on the basis of the above-shown data was 641.7 × 10,000 t-CO2/year (base case) or 479.9 × 10,000 t-CO2/year (optimum case).

**2-5. Amount of CO2 emission reductions by increasing the use of bioethanol in conventional vehicles**

On the assumption that the use of bioethanol (E10) will have started for all conventional vehicles by fiscal 2030, the amount of CO2 emission reductions that would be achieved was calculated with the following formula:

Annual bioethanol consumption for bioethanol vehicles (L/year) = bioethanol consumption per distance (L/km) for bioethanol vehicles × annual travel distance per vehicle (km/year·vehicle) × the number of bioethanol vehicles owned (unit: vehicle).

The resultant amount of CO2 emissions reducible in fiscal 2030 by bioethanol vehicles (unit: 10,000 t-CO2/year) was 289.2 × 10,000 t-CO2/year (base case) or 216.3 × 10,000 t-CO2/year (optimum case).

**2-6. Amount of CO2 emission reductions by using bioethanol in HVs and PHVs**

Bioethanol can be introduced into HVs and PHVs as well. The amount of CO2 emissions reducible by introducing bioethanol (E10) into the fuel for HVs and PHVs (unit: 10,000 t-CO2/year) was 110 × 10,000 t-CO2 (base case) or 128 × 10,000 t-CO2 (optimum case) (with fractions less than 10,000 t rounded off for both cases) for HVs, and 6.2 × 10,000 t-CO2 (base case) or 18.9 × 10,000 t-CO2 (optimum case) (with fractions less than 10,000 t rounded off for both cases) for PHVs.

**2-7. Summary of CO2 emission reduction amounts**

We summed up the amounts of CO2 emissions that would be reduced by the respective measures, i.e., increasing the number of next-generation automobiles (EVs/HVs/PHVs/FCVs), improving the fuel consumption of conventional vehicles, and using bioethanol (E10) in conventional vehicles/HVs/PHVs, as calculated in the present study, and compared the total value with the additional CO2 emission reduction amounts that should be achieved by fiscal 2030, as calculated in Chapter 1, thereby calculating the CO2 emission reduction amounts that those respective measures alone would not be able to achieve. The calculation results are given in the below table.

The base case will result in the amounts of CO2 emissions reduced by increasing the number of EVs/HVs/PHVs/FCVs, improving the fuel consumption of conventional vehicles, and using bioethanol (E10) in conventional vehicles/HVs/PHVs being less than the target amounts in the Plans for Addressing Global Warming by 58 × 10,000 t-CO2/year.

In contrast, the optimum case, which anticipates large-scale penetration of next-generation automobiles, will result in the amounts of CO2 emissions reduced by these measures exceeding the target amounts in the Plans for Addressing Global Warming by 180 × 10,000 t-CO2/year.

From the simulation conducted to reduce the amount in excess of the target value of this optimum case to exactly zero, it can be concluded that the CO2 emission reduction targets can be achieved if it is possible to use E10 in 50.5% of all conventional vehicles, HVs, and PHVs owned.

Table: Calculations of CO2 emission reduction amounts for fiscal 2030 toward the achievement of the goals of the Plans for Addressing Global Warming (base case)

| Amounts of CO2 emission reductions | | | | vs Target |
|---|---|---|---|---|
| Target amounts | | 2,089 | $10^4$t-CO2/year | 100% |
| Increasing the number of next-generation automobiles | EV | 85 | $10^4$t-CO2/year | 4% |
| | HV | 832 | $10^4$t-CO2/year | 40% |
| | PHV | 50 | $10^4$t-CO2/year | 2% |
| | FCV | 17 | $10^4$t-CO2/year | 1% |
| | Subtotal | 984 | $10^4$t-CO2/year | 47% |
| Improving the fuel consumption of conventional vehicles | | 642 | $10^4$t-CO2/year | 31% |
| Introduction of bioethanol (E10) | Conventional vehicles | 289 | $10^4$t-CO2/year | 14% |
| | HV | 110 | $10^4$t-CO2/year | 5% |
| | PHV | 6 | $10^4$t-CO2/year | 0% |
| | Subtotal | 406 | $10^4$t-CO2/year | 19% |
| Subtotal | | 2,031 | $10^4$t-CO2/year | 97% |
| Deficient amounts | | 58 | $10^4$t-CO2/year | 3% |

Table: Calculations of CO2 emission reduction amounts for fiscal 2030 toward the achievement of the goals of the Plans for Addressing Global Warming (optimum case)

| Amounts of CO2 emission reductions | | | | vs Target |
|---|---|---|---|---|
| Target amounts | | 2,089 | $10^4$t-CO2/year | 100% |
| Increasing the number of next-generation automobiles | EV | 256 | $10^4$t-CO2/year | 12% |
| | HV | 968 | $10^4$t-CO2/year | 46% |
| | PHV | 151 | $10^4$t-CO2/year | 7% |
| | FCV | 51 | $10^4$t-CO2/year | 2% |
| | Subtotal | 1,426 | $10^4$t-CO2/year | 68% |
| Improving the fuel consumption of conventional vehicles | | 480 | $10^4$t-CO2/year | 23% |
| Introduction of bioethanol (E10) | Conventional vehicles | 216 | $10^4$t-CO2/year | 10% |
| | HV | 128 | $10^4$t-CO2/year | 6% |
| | PHV | 19 | $10^4$t-CO2/year | 1% |
| | Subtotal | 363 | $10^4$t-CO2/year | 17% |
| Subtotal | | 2,269 | $10^4$t-CO2/year | 109% |
| Deficient amounts | | -180 | $10^4$t-CO2/year | -9% |

## Japan's CO2 Emission Reduction Target (INDC) (unit: million t-CO2)

| | Estimated emission amount in fiscal 2030 | fiscal 2013 (fiscal 2005) |
|---|---|---|
| Energy-derived CO2 | 927 | 1,235 (1219) |
| Industrial sector | 401 | 429 (457) |
| Business and other sector | 168 | 279 (239) |
| Household sector | 122 | 201 (180) |
| Transportation sector | 163 | 225 (240) |
| Energy conversion sector | 73 | 101 (104) |

◆ Emissions from the transportation sector: Reduction of 62 million t-CO2 is required by fiscal 2030

## Penetration of next-generation automobiles and improvement of fuel consumption (Plans for Addressing Global Warming)

| | Unit | | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Evaluation index of measures Ratio of next-generation automobiles in new vehicle sales | % | Actual achievement | 23.2 | 25.6 | 32.3 | 35.8 | 36.7 | | | | | | | | | | | | | |
| | | Prospect (Upper) | | | | | | | | 50 | | | | | | | | | | 70 |
| | | Prospect (Lower) | | | | | | | | 20 | | | | | | | | | | 50 |
| Evaluation index of measures Average fuel consumption | km/L | Actual achievement | 14.7 | 15.3 | 16.0 | 16.6 | 17.2 | | | | | | | | | | | | | |
| | | Prospect | | | | | | | | 18.5 | | | | | | | | | | 24.8 |
| Energy saving amount | $10^4$kL | Actual achievement | 19.9 | 49.2 | 85.1 | 89.7 | 128.6 | | | | | | | | | | | | | |
| | | Prospect | | | | | | | | 283.4 | | | | | | | | | | 938.9 |
| Emission reduction amount | $10^4$t-CO2 | Actual achievement | 53.3 | 131.5 | 227.5 | 239.8 | 343.0 | | | | | | | | | | | | | |
| | | Prospect | | | | | | | | 702.5 | | | | | | | | | | 2,379 |

◆ Target to reduce emissions of 23.79 million t-CO2/year (20.89 million t-CO2/year from 2017) by fiscal 2030

## Measures to achieve the target

(1) Increasing the number of EVs
(2) Increasing the number of HVs and PHVs
(3) Increasing the number of FCVs
(4) Improving fuel consumption of conventional vehicles
(5) Introduction of bioethanol as fuel (gasoline) of conventional vehicles
(6) Introduction of bioethanol as fuel (gasoline) of HVs and PHVs

◆ Base case: Realistic scenario

◆ Optimum case: Scenario for accelerated introduction of next-generation automobiles

### Scenarios for the number of next-generation automobiles and conventional vehicles owned

| Case | Vehicles | Owned number | | Composition ratio |
|---|---|---|---|---|
| Base Case | EV | 137 | ×$10^4$ | 2% |
| | HV | 2,297 | ×$10^4$ | 35% |
| | PHV | 137 | ×$10^4$ | 2% |
| | FCV | 28 | ×$10^4$ | 0% |
| | Conventional | 3,902 | ×$10^4$ | 60% |
| | Total | 6,500 | ×$10^4$ | 100% |
| Optimum case | EV | 414 | ×$10^4$ | 6% |
| | HV | 2,672 | ×$10^4$ | 41% |
| | PHV | 414 | ×$10^4$ | 6% |
| | FCV | 83 | ×$10^4$ | 1% |
| | Conventional | 2,918 | ×$10^4$ | 45% |
| | Total | 6,500 | ×$10^4$ | 100% |

| Amounts of CO2 emission reductions | | | | vs Target |
|---|---|---|---|---|
| Target amounts | | 2,089 | $10^4$t-CO2/year | 100% |
| Increasing the number of next-generation automobiles | EV | 85 | $10^4$t-CO2/year | 4% |
| | HV | 832 | $10^4$t-CO2/year | 40% |
| | PHV | 50 | $10^4$t-CO2/year | 2% |
| | FCV | 17 | $10^4$t-CO2/year | 1% |
| | Subtotal | 984 | $10^4$t-CO2/year | 47% |
| Improving the fuel consumption of conventional vehicles | | 642 | $10^4$t-CO2/year | 31% |
| Subtotal | | 1,626 | $10^4$t-CO2/year | 78% |
| Deficient amounts | | 464 | $10^4$t-CO2/year | 22% |

| Amounts of CO2 emission reductions | | | | vs Target |
|---|---|---|---|---|
| Target amounts | | 2,089 | $10^4$t-CO2/year | 100% |
| Increasing the number of next-generation automobiles | EV | 256 | $10^4$t-CO2/year | 12% |
| | HV | 968 | $10^4$t-CO2/year | 46% |
| | PHV | 151 | $10^4$t-CO2/year | 7% |
| | FCV | 51 | $10^4$t-CO2/year | 2% |
| | 小計 | 1,426 | $10^4$t-CO2/year | 68% |
| Improving the fuel consumption of conventional vehicles | | 480 | $10^4$t-CO2/year | 23% |
| Subtotal | | 1,906 | $10^4$t-CO2/year | 91% |
| Deficient amounts | | 183 | $10^4$t-CO2/year | 9% |

◆ It is difficult to achieve the government target only by increasing the number of next-generation automobiles and improving the fuel consumtion of conventional vehicles.

## Reduction of CO2 emissions in fiscal 2030 (left: basic, right: optimum case*)

| Amounts of CO2 emission reductions | | | | vs Target |
|---|---|---|---|---|
| Target amounts | | 2,089 | $10^4$t-CO2/year | 100% |
| Increasing the number of next-generation automobiles | EV | 85 | $10^4$t-CO2/year | 4% |
| | HV | 832 | $10^4$t-CO2/year | 40% |
| | PHV | 50 | $10^4$t-CO2/year | 2% |
| | FCV | 17 | $10^4$t-CO2/year | 1% |
| | Subtotal | 984 | $10^4$t-CO2/year | 47% |
| Improving the fuel consumption of conventional vehicles | | 642 | $10^4$t-CO2/year | 31% |
| Introduction of bioethanol (E10) | Conventional vehicles | 289 | $10^4$t-CO2/year | 14% |
| | HV | 110 | $10^4$t-CO2/year | 5% |
| | PHV | 6 | $10^4$t-CO2/year | 0% |
| | Subtotal | 406 | $10^4$t-CO2/year | 19% |
| Subtotal | | 2,031 | $10^4$t-CO2/year | 97% |
| Deficient amounts | | 58 | $10^4$t-CO2/year | 3% |

| Amounts of CO2 emission reductions | | | | vs Target |
|---|---|---|---|---|
| Target amounts | | 2,089 | $10^4$t-CO2/year | 100% |
| Increasing the number of next-generation automobiles | EV | 256 | $10^4$t-CO2/year | 12% |
| | HV | 968 | $10^4$t-CO2/year | 46% |
| | PHV | 151 | $10^4$t-CO2/year | 7% |
| | FCV | 51 | $10^4$t-CO2/year | 2% |
| | Subtotal | 1,426 | $10^4$t-CO2/year | 68% |
| Improving the fuel consumption of conventional vehicles | | 480 | $10^4$t-CO2/year | 23% |
| Introduction of bioethanol (E10) | Conventional vehicles | 109 | $10^4$t-CO2/year | 5% |
| | HV | 65 | $10^4$t-CO2/year | 3% |
| | PHV | 10 | $10^4$t-CO2/year | 0% |
| | Subtotal | 183 | $10^4$t-CO2/year | 9% |
| Subtotal | | 2,089 | $10^4$t-CO2/year | 100% |
| Deficient amounts | | 0 | $10^4$t-CO2/year | 0% |

*The right table shows the case where the introduction of bioethanol accounts for about 50% of the total number in the optimum case.

◆ The target can be achieved by introducing bioethanol (E10) into conventional vehicles, HVs and PHVs.

## 3. Trial calculation of CO2 marginal abatement cost

The definition of CO2 marginal abatement cost and other conditions are as follows, and are the same as in many other documents. In this connection, the calculated value of the marginal cost of CO2 reduction substantially varies depending on the preconditions and individual settings. In the present report, the following conditions are used to calculate said value.

(1) Definition of CO2 marginal abatement cost (yen/t-CO2): Marginal cost (expenses) necessary for additionally reducing 1 t of CO2 in comparison with the control

(2) Target country: Japan

(3) Target vehicles and years:

- Vehicles subject to the calculations of CO2 emission reduction amounts in Chapter 2
- Target years: Fiscal 2030 (single year)

Note: Like the calculations of CO2 emissions/emission reduction amounts in Chapter 2, this calculation targets a single year, namely, fiscal 2030, not calculating a cumulative CO2 marginal abatement cost for the period of time from now up to fiscal 2030.

(4) Controls:

- Current conventional vehicles that only use gasoline as fuel
- For HVs and PHVs in which bioethanol will be used, however, their respective controls are ordinary HVs and PHVs that only use gasoline as fuel, which are the same as the controls used for the calculations of CO2 emission reduction amounts in Chapter 2.

### 3-1. Formula for calculating CO2 marginal abatement cost

Formula:

CO2 marginal abatement cost (yen/t-CO2) = (cost for vehicles subject to the calculations in fiscal 2030 − cost for conventional vehicles, etc. (yen/year)) ⁄ (CO2 emissions from conventional vehicles, etc. − CO2 emissions from vehicles subject to the calculations in fiscal 2030 (t-CO2/year))

### 3-2. Calculation of CO2 marginal abatement cost associated with EVs

The following are set to calculate the cost of marginal CO2 reduction by EVs:

(1) Difference in initial cost (expenses for purchasing vehicles) (yen/year)

(2) Annual operating expenses (yen/year): Fuel cost = difference in end sales price of fuel (yen/L) (or electric power rate (yen/kWh)) × annual consumption of fuel/electric power (L/year or kWh/year)

(3) Infrastructure development expenses (yen/year): Expenses for constructing new charging stations (does not include expenses for maintenance of charging stations nor those for renewal of the same)

The result of calculating the CO2 marginal abatement cost associated with the replacement of conventional vehicles with EVs (yen/t-CO2) on the basis of the above data was 292,010 yen/t-CO2 (base case) and 282,221 yen/t-CO2 (optimum case).

### 3-3. Calculations of CO2 marginal abatement costs associated with HVs, PHVs, and FCVs

The CO2 marginal abatement costs associated with HVs, PHVs, and FCVs were calculated in the same manner. The results were as given below:

(1) CO2 marginal abatement costs for HVs (yen/t-CO2): 2,626 yen/t-CO2 (base case) and −998 yen/t-CO2 (optimum case)

(2) CO2 marginal abatement costs for PHVs (yen/t-CO2): 399,023 yen/t-CO2 (base case) and 261,456 yen/t-CO2 (optimum case)

(3) CO2 marginal abatement costs for FCVs (yen/t-CO2): 325,630 yen/t-CO2 (base case) and 277,423 yen/t-CO2 (optimum case)

### 3-4. CO2 marginal abatement costs associated with the use of bioethanol in conventional vehicles, HVs, and PHVs

CO2 marginal abatement costs associated with the use of bioethanol in conventional vehicles, HVs, and PHVs (yen/t-CO2):

34,748 yen/t-CO2 (base case) and 35,577 yen/t-CO2 (optimum case)

### 3-5. CO2 marginal abatement cost associated with the improvement of the fuel consumption of conventional vehicles

CO2 marginal abatement costs (yen/t-CO2) associated with improvements in the fuel consumption of conventional vehicles, which require no additional cost, are used as control values: −53,621 yen/t-CO2 (base case) and −53,621 yen/t-CO2 (optimum case)

### 3-6. Summary of CO2 marginal abatement costs

It was found that the CO2 marginal abatement cost associated with the use of bioethanol (E10) in conventional vehicles/HVs/PHVs was 3.47–3.56 × 10,000 yen/t-CO2, which is higher than that associated with the increased use of HVs (0.26–−0.10 × 10,000 yen/t-CO2) and that associated with improving the fuel consumption of conventional vehicles (−5.36 × 10,000 yen/t-CO2) but substantially lower than the CO2 marginal abatement cost associated with the increased use of EVs (29.2–28.2 × 10,000 yen/t-CO2), PHVs (39.9–26.1× 10,000 yen/t-CO2), and FCVs (32.6–27.7 × 10,000 yen/t-CO2).

Table: Results of CO2 marginal abatement cost calculations (summary)

Base case

| CO2 marginal abatement cost | | |
|---|---|---|
| Increasing the number of next-generation automobiles | EV | 292,010 yen/t-CO2 |
| | HV | 2,626 yen/t-CO2 |
| | PHV | 399,023 yen/t-CO2 |
| | FCV | 325,630 yen/t-CO2 |
| Improving the fuel consumption of conventional vehicles | | -53,621 yen/t-CO2 |
| Introducing bioethanol (E10) | Conventional vehicle | 34,748 yen/t-CO2 |
| | HV | 34,748 yen/t-CO2 |
| | PHV | 34,748 yen/t-CO2 |

Optimum case

| CO2 marginal abatement cost | | |
|---|---|---|
| Increasing the number of next-generation automobiles | EV | 282,221 yen/t-CO2 |
| | HV | -998 yen/t-CO2 |
| | PHV | 261,456 yen/t-CO2 |
| | FCV | 277,423 yen/t-CO2 |
| Improving the fuel consumption of conventional vehicles | | -53,621 yen/t-CO2 |
| Introducing bioethanol (E10) | Conventional vehicle | 35,577 yen/t-CO2 |
| | HV | 35,577 yen/t-CO2 |
| | PHV | 35,577 yen/t-CO2 |

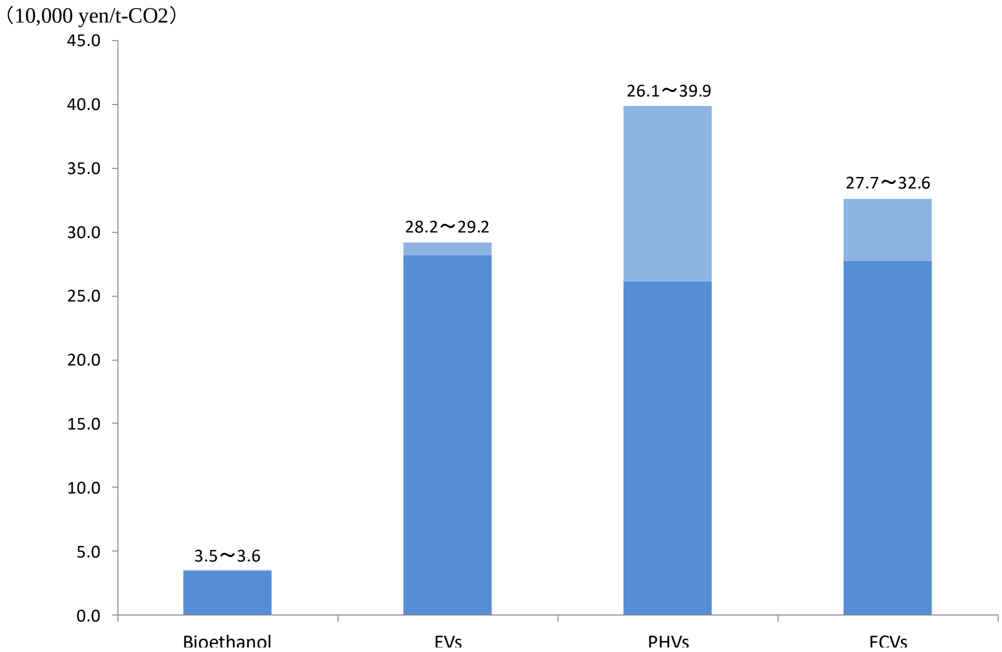



Figure: Results of CO2 marginal abatement cost calculations (abstract)

A summary of the results of CO2 marginal abatement cost calculations is given on the following page.

## Reduction of CO2 emissions in fiscal 2030 (left: basic, right: optimum case*)

| Amounts of CO2 emission reductions | | | | vs Target |
|---|---|---|---|---|
| Target amounts | | 2,089 | $10^4$t-CO2/year | 100% |
| Increasing the number of next-generation automobiles | EV | 85 | $10^4$t-CO2/year | 4% |
| | HV | 832 | $10^4$t-CO2/year | 40% |
| | PHV | 50 | $10^4$t-CO2/year | 2% |
| | FCV | 17 | $10^4$t-CO2/year | 1% |
| | Subtotal | 984 | $10^4$t-CO2/year | 47% |
| Improving the fuel consumption of conventional vehicles | | 642 | $10^4$t-CO2/year | 31% |
| Introduction of bioethanol (E10) | Conventional vehicles | 289 | $10^4$t-CO2/year | 14% |
| | HV | 110 | $10^4$t-CO2/year | 5% |
| | PHV | 6 | $10^4$t-CO2/year | 0% |
| | Subtotal | 406 | $10^4$t-CO2/year | 19% |
| Subtotal | | 2,031 | $10^4$t-CO2/year | 97% |
| Deficient amounts | | 58 | $10^4$t-CO2/year | 3% |

| Amounts of CO2 emission reductions | | | | vs Target |
|---|---|---|---|---|
| Target amounts | | 2,089 | $10^4$t-CO2/year | 100% |
| Increasing the number of next-generation automobiles | EV | 256 | $10^4$t-CO2/year | 12% |
| | HV | 968 | $10^4$t-CO2/year | 46% |
| | PHV | 151 | $10^4$t-CO2/year | 7% |
| | FCV | 51 | $10^4$t-CO2/year | 2% |
| | Subtotal | 1,426 | $10^4$t-CO2/year | 68% |
| Improving the fuel consumption of conventional vehicles | | 480 | $10^4$t-CO2/year | 23% |
| Introduction of bioethanol (E10) | Conventional vehicles | 109 | $10^4$t-CO2/year | 5% |
| | HV | 65 | $10^4$t-CO2/year | 3% |
| | PHV | 10 | $10^4$t-CO2/year | 0% |
| | Subtotal | 183 | $10^4$t-CO2/year | 9% |
| Subtotal | | 2,089 | $10^4$t-CO2/year | 100% |
| Deficient amounts | | 0 | $10^4$t-CO2/year | 0% |

*The right table shows the case where the introduction of bioethanol accounts for about 50% of the total number in the optimum case.

## Calculation of CO2 marginal abatement cost

**CO2 marginal abatement cost** =

Difference of (Vehicle purchase expenses + Fuel/Electricity expenses + Infrastructure construction expenses)

―――――――――――――――――――――――――――――

Amount of CO2 emission reduction

### Preconditions for calculating CO2 marginal abatement cost

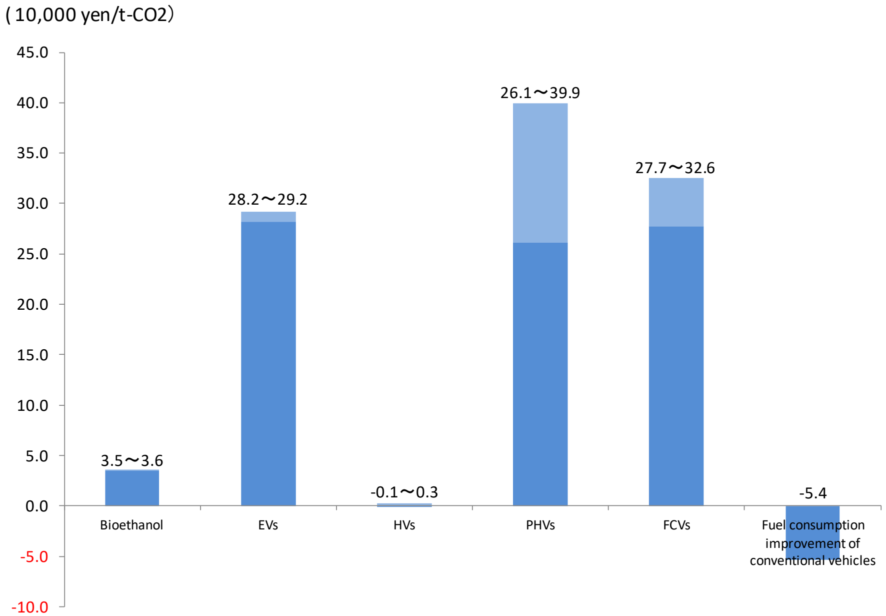
- ✓ Calculation year: Fiscal 2030 (1 year)
- ✓ Controls (comparison target): Current conventional vehicles, except introduction of bioethanol into HVs/PHVs of which comparison target is the normal HVs/PHVs (fiscal 2030). This is the same method as calculating the CO2 emission reduction amount, in order to prevent double counting.
- ✓ Numerator of CO2 marginal abatement cost (cost): Difference of total of vehicle purchase cost, fuel cost (including electricity cost), and infrastructure construction cost in fiscal 2030 (1 year)
- ✓ Denominator of CO2 reduction cost (CO2 emission reduction amount): CO2 emission reduction amount in fiscal 2030 (1 year) calculated in this study as above (non-LCA basis)

### Base case

| CO2 marginal abatement cost | | |
|---|---|---|
| Increasing the number of next-generation automobiles | EV | 292,010 yen/t-CO2 |
| | HV | 2,626 yen/t-CO2 |
| | PHV | 399,023 yen/t-CO2 |
| | FCV | 325,630 yen/t-CO2 |
| Improving the fuel consumption of conventional vehicles | | -53,621 yen/t-CO2 |
| Introducing bioethanol (E10) | Conventional vehicle | 34,748 yen/t-CO2 |
| | HV | 34,748 yen/t-CO2 |
| | PHV | 34,748 yen/t-CO2 |

### Optimum case

| CO2 marginal abatement cost | | |
|---|---|---|
| Increasing the number of next-generation automobiles | EV | 282,221 yen/t-CO2 |
| | HV | -998 yen/t-CO2 |
| | PHV | 261,456 yen/t-CO2 |
| | FCV | 277,423 yen/t-CO2 |
| Improving the fuel consumption of conventional vehicles | | -53,621 yen/t-CO2 |
| Introducing bioethanol (E10) | Conventional vehicle | 35,577 yen/t-CO2 |
| | HV | 35,577 yen/t-CO2 |
| | PHV | 35,577 yen/t-CO2 |




CO2 marginal abatement cost of next-generation automobiles and bioethanol introduction

- ➢ The CO2 marginal abatement cost of introducing bioethanol (E10) to conventional vehicles, HVs, and PHVs is 3.47-3.56 × 10,000 yen/t-CO2.
- ➢ This value is much lower than CO2 marginal abatement cost of EVs (28.2-29.2 × 10,000,000 yen/t-CO2), PHVs (26.1-39.9 × 10,000 yen/t-CO2), and FCVs (27.7-32.6 × 10,000 yen/t-CO2).

(Points to note)

The results of CO2 marginal abatement cost calculations vary greatly depending on the calculation method, formulas used, years included in the calculations, control product/technology, calculation ranges of numerators (e.g., expenses for purchasing vehicles, fuel expenses, infrastructure development expenses) and individual set values (e.g., vehicle purchase price/introduction quantity, fuel price, infrastructure price/introduction quantity, serviceable life), and calculation range of the denominator (CO2 emission reduction amount) and individual set values (e.g., fuel consumption/electricity consumption, CO2 emission coefficient, whether or not the coefficient is based on LCA, introduction quantity, travel distance, serviceable life).

For example, in a scenario in which the gasoline price of 124.4 yen/L used in the present study is raised or lowered, an increase in the gasoline price will cause an increase in the advantage in terms of fuel cost over the control conventional vehicles that use gasoline as fuel and cause a reduction in CO2 marginal abatement cost as well.

The figure below shows a graph in which the calculated values are compared with the values in certain documents of the Agency for Natural Resources and Energy selected from data in various pieces of literature.

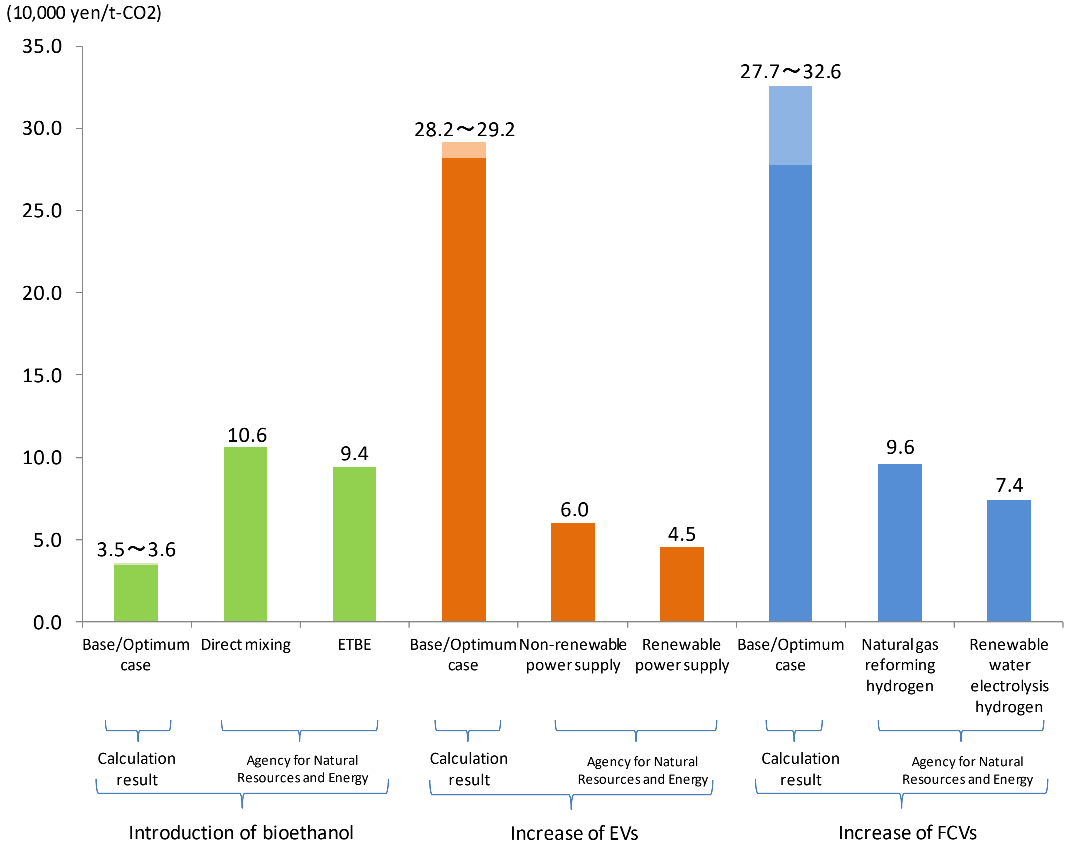



Figure: Comparison of the calculated values shown in the present report with the values in certain documents of the Agency for Natural Resources and Energy

The CO2 marginal abatement costs associated with vehicles in which bioethanol is introduced, as shown here, are less than the values in the documents of the Agency for Natural Resources and Energy. Meanwhile, the CO2 marginal abatement costs associated with EVs and FCVs, as shown here, are greater than the values in the documents of the Agency.