Analysis of CO2 Emissions to Consider Future Technologies and Integrated Approaches in the Road Transport Sector

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   (Model Structure, Analysis Target)

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   (Demand of Road Transport Sector, Automotive Technologies)

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   (Number of Automobiles, Fuel Economy, CO2 Emissions)

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※CEAMAT: Energy Analysis model for the long term in the transport sector
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Increasing concerns about energy security and global climate change

Necessity of energy saving, fuel diversification and reduction of greenhouse gas

Not enough evaluation of long term technical scenarios in the road transport sector

- Not considering cost-effectiveness and realizing fuel economy improvement technologies
- Restriction of analysis vehicle target (e.g. only Passenger cars)
Purpose of this Research

Development of long term CO2 reduction scenarios to consider future automotive technologies and integrated approaches in the Japanese automotive sector.

1. Construction of a database with demand of the road transport sector and future automotive technologies
2. Development of cost-effectiveness tools for future automotive technologies
3. Scenario analysis
4. Analysis of CO2 reduction with integrated approaches
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What is CEAMAT?

CEAMAT is an analysis energy model for the road transport sector for the long-term.
- CEAMAT links with the IEEJ2050 model that is an energy analysis model for all sectors worldwide, developed by The Institute of Energy Economics, JAPAN.

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**IEEJ 2050 model (World)**

- Estimation of Economy/Energy/No. of Vehicles
  - World population
  - Each country/region GDP
  - Energy consumption of each sector
  - Primary energy consumption
  - Cost of fuel and electricity
  - Vehicle demand
  - No. of new vehicle sales/in use

**CEAMAT (Japan)**

- Estimation of Fuel Economy and Vehicle Number by Each Technology
  - Gasoline/Diesel Vehicle
  - Biofuel Vehicle
  - HEV, PHEV, EV
  - FCV
  - NGV, LPG
  - Other

- Estimation of Fuel Demand
  - Oil (Gasoline/Diesel)
  - Biofuel
  - Electricity
  - Hydrogen
  - CNG, LPG
  - Synthetic fuel
  - Other

- Integrated Approaches
  - Improving Traffic flow
  - Eco-driving

- Social Cost
  - Emission of GHG
  - Vehicle cost/fuel cost
  - Social cost (infrastructure, tax, etc.)

**Output**

- Energy consumption
- CO2 emissions
- Annual total cost

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**Analysis Scenario**
### Target Vehicle Type and Class

Vehicle section, focus on the Japanese automotive market

<table>
<thead>
<tr>
<th>Passenger car</th>
<th>Truck</th>
<th>Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle (＞ 2000cc)</td>
<td>Large (GVW ＞ 8t)</td>
<td>Large (GVW ＞ 8t)</td>
</tr>
<tr>
<td>Small (≦ 2000cc)</td>
<td>Middle (3.5t＜GVW ≤ 8t)</td>
<td>Small (GVW ≤ 8t)</td>
</tr>
<tr>
<td>Mini (≦ 660cc)</td>
<td>Small (GVW ≤ 3.5t)</td>
<td>Mini (≦ 660cc)</td>
</tr>
</tbody>
</table>

**Passenger car**

**Truck**

**Bus**
<table>
<thead>
<tr>
<th>Technology</th>
<th>Fuel path</th>
</tr>
</thead>
<tbody>
<tr>
<td>GICEV</td>
<td>Gasoline/Ethanol</td>
</tr>
<tr>
<td>GICEHEV</td>
<td>Gasoline Internal Combustion Engine Hybrid Vehicle</td>
</tr>
<tr>
<td>DICEV</td>
<td>Diesel Internal Combustion Engine Vehicle</td>
</tr>
<tr>
<td>DICEHEV</td>
<td>Diesel Internal Combustion Engine Hybrid Vehicle</td>
</tr>
<tr>
<td>HICEV</td>
<td>Hydrogen Internal Combustion Engine Vehicle</td>
</tr>
<tr>
<td>HICEHEV</td>
<td>Hydrogen Internal Combustion Engine Hybrid Vehicle</td>
</tr>
<tr>
<td>CNGV</td>
<td>CNG</td>
</tr>
<tr>
<td>DMEV</td>
<td>DME</td>
</tr>
<tr>
<td>LPGV</td>
<td>LPG</td>
</tr>
<tr>
<td>EV</td>
<td>Electricity</td>
</tr>
<tr>
<td>HFCV</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>GICEPHEV</td>
<td>Gasoline/Electricity</td>
</tr>
<tr>
<td>DICEPHEV</td>
<td>Diesel oil/Electricity</td>
</tr>
<tr>
<td>HFPCPHEV</td>
<td>Hydrogen/Electricity</td>
</tr>
</tbody>
</table>

**Images:**
- CNGV (mixed Bio-ethanol)
- GICEV (mixed Bio-diesel)
- DICEV (mixed Bio-diesel)
- HICEV
- GICEHEV
- GICEPHEV
- HFCV
- EV
Related Probability of Technology Choice and Driving Distance (e.g. GICEV vs. GHEV)

- Probability of technology choice (Pr) is estimated by total cost in the depreciation period and Line-up number for each distance.

\[
Pr_k = \frac{M_k^{\theta_1} \cdot \exp(\theta_0 \cdot C_{Tk})}{\sum_{k' \in K} M_{k'}^{\theta_1} \cdot \exp(\theta_0 \cdot C_{Tk'})}
\]

- \(k\): Technology section
- \(K\): Assembly technology section
- \(C_{Tk}\): Total cost in usage period
- \(M_k\): Line-up number
- \(\theta_0, \theta_1\): Parameter (\(\theta_0=-6.46, \theta_1=0.94\))

![Graph showing probability of technology choice for different annual driving distances](image)
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Demand of the Road Transport Sector and Fuel Price in the IEEJ2050 Model

**Demand of Passenger car (Passenger car & Bus)**

- **Vehicle mileage traveled (VMT: billion person-km)**
  - Passenger car
  - Bus

**Number of Vehicles in Use**

- **Annual driving distance (km/year)**
  - Passenger car
  - Truck
  - Bus

**Demand of freight (Truck)**

- **Traffic volume (Billion ton·km)**

**Fuel Price**

- **Fuel price with tax: Yen/MJ**
  - Gasoline
  - Diesel oil
  - CNG
  - Electricity
  - Hydrogen
# Efficiency and Price of Future Technologies in ICE Vehicles

- **Base vehicle:** Standard vehicles in the year 2000
- **Choice of good cost-effectiveness technology combinations**
- **Determination of approximate curve to use good cost-effectiveness technology combinations**

## Improving FE Technology Grouping

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Improving FE Technology</th>
<th>Passenger car</th>
<th>Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Gasoline Direct Injection (Stoichimetric)</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Gasoline HCCI</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Cam Phasing</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Engine Downsizing</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Improved Engine Friction</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Improved firing chamber</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Other normal advance technologies</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>EGR</td>
<td>○</td>
<td>○</td>
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<tr>
<td></td>
<td>Turbo Compound</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Variable Compression Ratio</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Valuable Valve Timing</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>2 stages Turbo</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>After treatment Device</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Transmission</td>
<td>CVT</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>5AT</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>6AT</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Multiple Transmission</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>High Differential Gears Ratio</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Direct-connected maximum gear</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Dual Clutch</td>
<td>○</td>
<td>○</td>
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<tr>
<td></td>
<td>AMT</td>
<td>○</td>
<td>○</td>
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<tr>
<td>Accessories</td>
<td>Electric Power Steering</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Improved Alternator</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Electric Accessories</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

### Price curve (Passenger car)

- **Middle**
- **Small**
- **Mini**

### Price curve (Truck)

- **Large**
- **Middle**
- **Small**
- **Mini**
Scenario of Future Technological Factors with EV and HFCV

- Price and efficiency of battery and fuel cell systems in the future are based on government and private sector reports and interviews.
- Future scenarios are efficiency improvement and a lower price, considering advanced technologies and mass production.
- Trucks’ part prices are higher than passenger car parts’ prices, because system accessories are larger and more expensive.

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**Battery Weight**
- Passenger car and truck weights decrease over time.

**Battery Price**
- Passenger car and truck prices decrease over time.

**Fuel cell system efficiency improving Ratio**
- Efficiency improves significantly over time for both passenger cars and trucks.

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**Fuel cell system Price**
- Passenger car and truck prices decrease over time, showing improvements in efficiency and cost.
All technologies improved energy economy, considering advance technology factors such as ICE technologies, battery and fuel cost.

Improvement technologies price of improvement are added to ICEV’s vehicle price.

Other new automobiles come down in price to reflect mass production of technology factors (Battery and fuel cell system, etc.).
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</tr>
</tbody>
</table>
**Number of New Vehicles and Vehicles in Use (Passenger Car)**

- **Number of new vehicles**
  - Share of next generation vehicles※: 48% (2050)

- **Number of vehicles in use**
  - Share of next generation vehicles: 43% (2050)

※Next generation vehicles are HEV, EV, PHEV, FCV and CNGV. This definition is from a report by METI, “Diffusion report of next generation vehicles 2010” written in Japanese.
Fuel Economy of Vehicles in Use and TtW CO₂ Emissions in the Passenger Car Sector

- CO₂ emissions in 2050: -55% (Based on 2005)
CO2 Emissions (Road Transport Sector)

- CO2 emissions in 2050: -47% (Based on 2005)

![Graph showing CO2 emissions for different modes of transport over the years 2005 to 2050. The graph indicates a significant decrease in emissions by 2050, with a comparison to 2005 emissions. The legend includes symbols for Passenger car, Truck, and Bus, with the Truck emissions line showing the largest decrease.]
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
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</table>
Analysis Process of CO2 Reduction for Eco-driving

CO2 reduction of eco-driving per unit
Passenger car: 13%
Truck: 9%

Popularization ratio of eco-driving in 2050
Passenger car & Truck: 70%

CO2 weighting factor in 2050
(Based on vehicle mileage traveled)
Passenger car: 65%
Truck: 35%

Each CO2 reduction for eco-driving
Passenger car: 9%
Truck: 6%

CO2 reduction for eco-driving
Total: 8%

9 organizations of evaluating eco-driving:
NIES, Libertas terra Co.Ltd, HONDA R&D CO.Ltd
IID.Inc. NTSEL, LEVO, etc
Analysis Process of CO2 Reduction to Improving Traffic Flow

GDP in Japan → Road project cost in Japan → Changing average speed in Japan

Speed vs. CO2 emissions

Speed distribution (all vehicle categories)

Energy ITS research meeting report

CO2 reduction to road improvement
Total: 4%

<table>
<thead>
<tr>
<th>Item</th>
<th>CO2 Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platoonning</td>
<td>0.2%</td>
</tr>
<tr>
<td>Traffic light control (Only vehicle)</td>
<td>0.04%</td>
</tr>
<tr>
<td>Traffic light control (link up with infrastructure)</td>
<td>2%</td>
</tr>
<tr>
<td>Full route information</td>
<td>1.4%</td>
</tr>
<tr>
<td>Predicting optimal starting time</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

CO2 reduction to implement technologies
Total: 4%

CO2 reduction to improving traffic flow
Total: 7%
CO2 Reduction for Integrated Approaches (Road Transport Sector)

- Technological composition is assumed to be the same as the Baseline case, that is without an integrated approach.
- CO2 Reduction in 2050: 55% based on 2005 (Baseline case: 47%)
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Cost-effectiveness analysis tools including an automotive database with advanced technologies were developed, and future scenarios were analyzed. In addition, integrated approaches were researched and calculated for their potential to reduce CO2 emission.

1. From the result of this scenario analysis, CO2 reduction potential of the road transport sector with next generation automobiles is calculated as 47% (based on 2005) in 2050.

2. CO2 reduction potential from next generation automobiles and integrated approaches (Improving traffic flow and Eco-driving) is calculated as 55% (based on 2005) in 2050.

From the result of CO2 reduction potential from improving traffic flow and eco-driving, we’ve shown it is necessary to popularize next generation automobiles and integrated approaches.
Thank you for your attention!