Transitioning to Carbon Neutrality by 2050: A Scenario-Based Analysis

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1.0 Overview

Note: This study is based on hypothetical scenarios and does not represent a forecast, sales targets, or a policy of or commitment by the Japan Automobile Manufacturers Association (JAMA). This is a sensitivity analysis comparing CO_2 emissions when powertrain mix, energy mix, and carbon-neutral fuel supply volume values are varied; further, the commercial vehicle (trucks and buses) powertrain mix ratio was assumed for modeling convenience on a vehicle-count basis (see the “Trucks & Buses” segment on page 15 herein for a more detailed explanation).

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1.1 Overview of Study

■ Purpose of using scenarios

To understand, based on quantitative assessments, possible pathways to be pursued towards carbon neutrality (CN) in automotive transport by 2050.

■ Data applied

New-vehicle sales data, in-use vehicle fleet data, vehicle fuel/energy efficiency data, energy mix data, etc. (see pages 10-20).

■ Scenario parameters (partial)

Scenario Designation & Assumptions/Projections for 2050			BEV/FCEV Shares of New Passenger Vehicle Sales			2050 Projected CNF Share in Automotive Fuel Mix [2023 FC[6] -Based]
			Worldwide	Advanced economies[4]	Emerging economies[5]	
BAU[1]		: No new measures introduced	BAU	←	←	←
Hypothetical Scenario	CNF	: Wide use of CNF[2]	40%	50%	25%	30%[7]
	CNF+	: Assuming that approximately half of sustainable aviation fuel is produced via FT synthesis	See note 2 on page 20 for scenario definition.			35%[7]
	BEV75	: Widespread electrified vehicle adoption	75%	100%	50%	22%[7]
	NZE	: 100% BEVs/FCEVs (IEA-NZE[3] scenario)	100%	100%	100%	4%[7] (biofuel only)

[1]BAU: "Business as usual"; [2]CNF: Carbon-neutral fuel; [3]The International Energy Agency (IEA)'s NZE scenario: "Net Zero Emissions by 2050"; [4]Advanced economies: Japan, advanced European countries, North America, etc.; [5]Emerging economies: China, ASEAN member countries, India, Africa, etc. (for [4] and [5], see IEEJ Outlook 2026 Table A1, Annex); [6]FC: Total automotive fuel consumption; [7]Percentage figure represents the ratio to total automotive fuel consumption in 2023.

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1.2 Summary of Study Findings

Context	CO_2 Emission Levels in 2050
Worldwide	• **Findings show that all scenarios (excluding the BAU scenario) demonstrate the potential for global CO_2 emissions reduction in automotive transport to be in line with the IPCC's 1.5°C climate scenarios in 2050.** IPCC: Intergovernmental Panel on Climate Change (see note) • The IEA's NZE scenario is premised on one pathway towards carbon neutrality, but the JAMA study confirms that there are other pathways, comprising a wide variety of electrified vehicles including HEVs and PHEVs and the use of carbon-neutral fuel (CNF).
Advanced economies	• **The all scenarios (excluding the BAU scenario) demonstrate the potential in advanced economies for carbon neutrality in automotive transport by 2050.** • To that end, however, in addition to decarbonized electricity, the supply of carbon-neutral fuels for in-use vehicle fleets will be necessary.
Emerging economies	• In many emerging economies, vehicle sales volumes are expected to rise significantly. • **If the potential supply of CNF can be effectively utilized (→ CNF+ scenario), it will be possible for CO_2 emissions in emerging economies to be in line with the IPCC's 1.5°C climate scenarios in 2050, despite the challenge of achieving CO2 emissions reduction.**

Note: The IPCC's 2050 1.5°C climate scenarios are the basis of the goal adopted under the Paris Agreement in 2015 to limit increases in the global average temperature to within 1.5°C above pre-industrial levels (approximately 1850-1900).

JAMA member companies, together with their global stakeholders, will make maximum efforts towards carbon neutrality by 2050 by developing technologies to further reduce automotive CO_2 emissions so that they can provide optimal choices for consumers in countries/regions worldwide.

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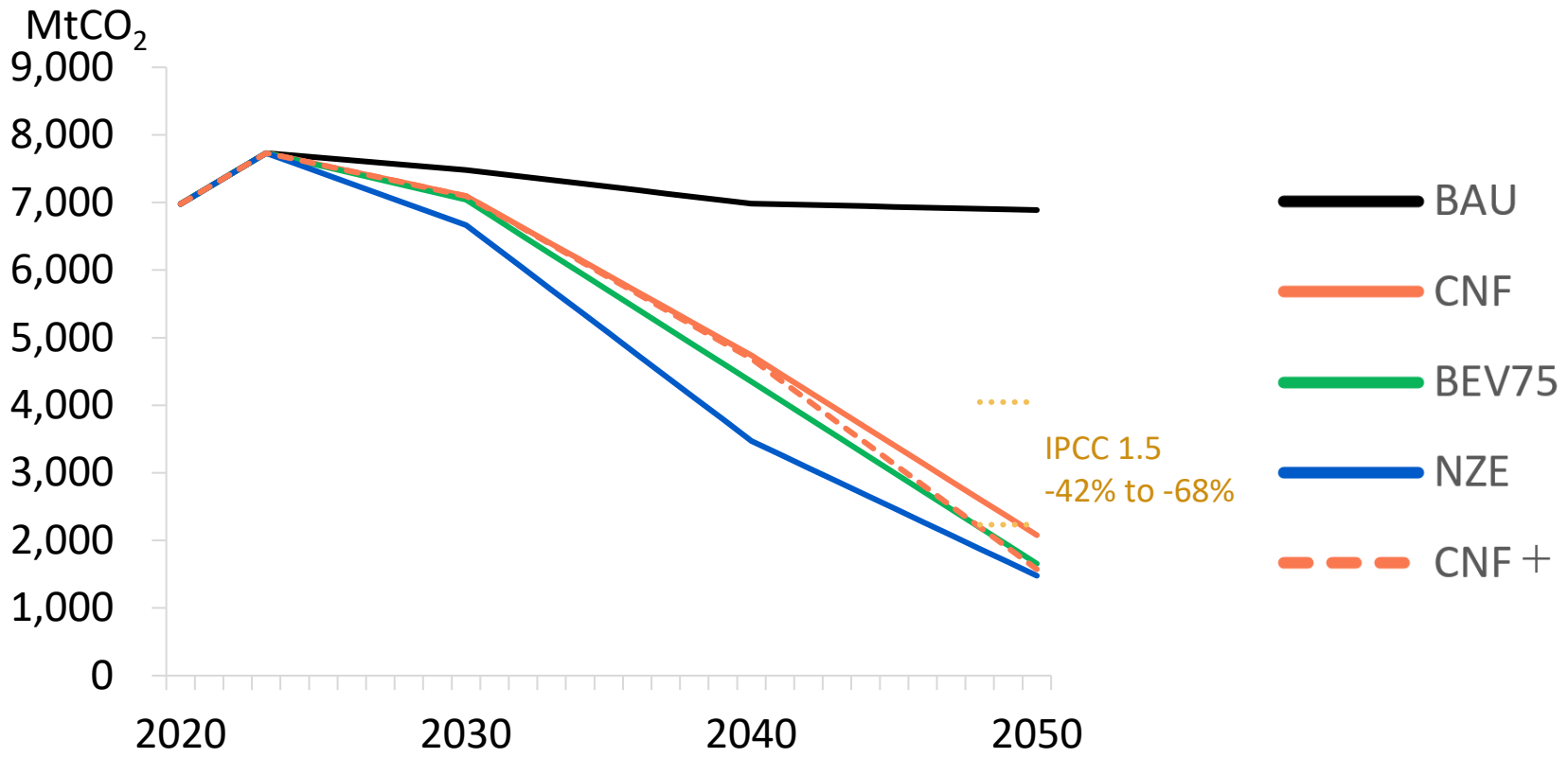
1.3 CO_2 Emissions Worldwide 2020-2050, by Scenario



Note: "IPCC 1.5 (-42% to -68%)" denotes the interquartile range of scenarios presented in Chapter 10 of the IPCC WGIII Sixth Assessment Report, under which global transport-sector CO_2 emissions decline by approximately 42% to 68% by 2050 relative to 2020 levels while limiting warming to 1.5°C with no or limited overshoot. Values within or below this range can be regarded as consistent with the IPCC 1.5°C pathway.

In all scenarios (excluding the BAU scenario), CO_2 emissions worldwide can reach a level consistent with the IPCC's 1.5°C climate scenarios in 2050.

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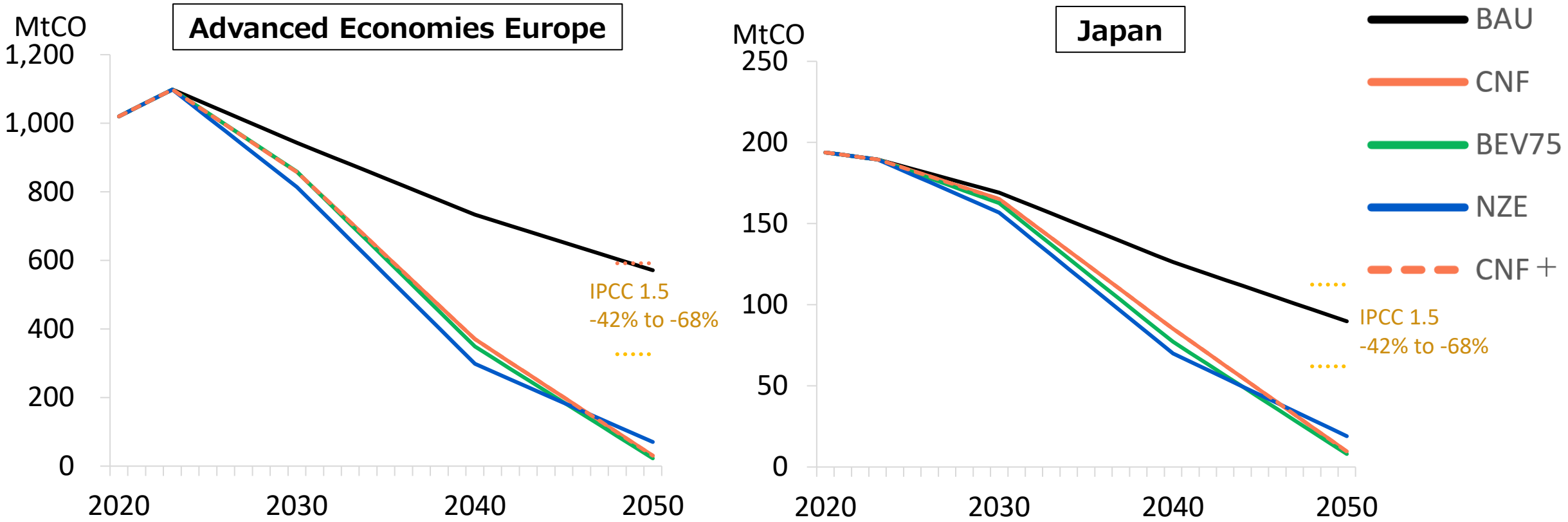
1.3 CO_2 Emissions in Advanced Economies 2020-2050, by Scenario



Note: Since the results for the CNF and CNF+ scenarios are identical for advanced economies in Europe and for Japan, the two lines overlap in both graphs. "IPCC 1.5 (-42% to -68%)" denotes the interquartile range of scenarios presented in Chapter 10 of the IPCC WGIII Sixth Assessment Report, under which global transport-sector CO_2 emissions decline by approximately 42% to 68% by 2050 relative to 2020 levels while limiting warming to 1.5°C with no or limited overshoot. Values within or below this range can be regarded as consistent with the IPCC 1.5°C pathway.

All scenarios (excluding the BAU scenario) demonstrate the potential in advanced economies for carbon neutrality in automotive transport by 2050.

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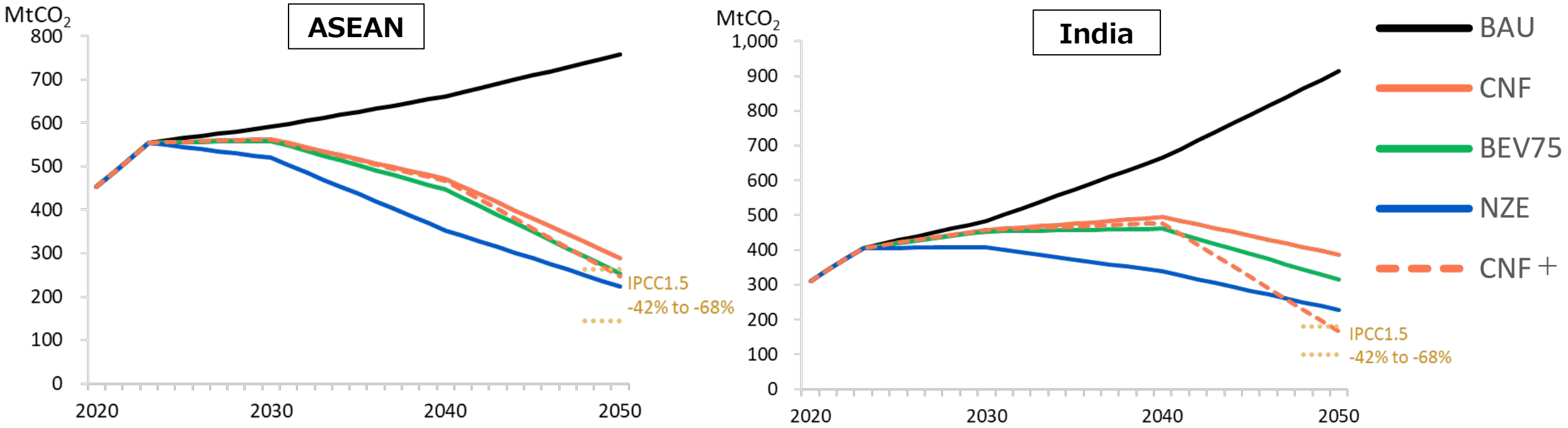
1.3 CO_2 Emissions in Emerging Economies 2020-2050, by Scenario

In many emerging economies, new vehicle sales will increase, leading to a significant rise in BAU CO_2 emissions.



Note: In the CNF+ scenario CNF supply is approximately 1.2 times greater than in the CNF scenario, assuming that about half of the sustainable aviation fuel supply in 2050 is produced via FT synthesis (see page 20 for details). The additional supply is preferentially allocated to Africa, the Middle East, India, and ASEAN, where decarbonization of the power sector is relatively difficult. "IPCC 1.5 (-42% to -68%)" refers to the interquartile range of scenarios presented in Chapter 10 of the IPCC WGIII Sixth Assessment Report, under which global transport-sector CO_2 emissions decline by approximately 42% to 68% by 2050 relative to 2020 levels while limiting warming to 1.5°C with no or limited overshoot. Values within or below this range can be regarded as consistent with the IPCC 1.5°C pathway.

CNF+ levels of CNF supply could achieve emission reductions consistent with the IPCC 1.5°C target.

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2.0 Details of Study

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2.1 Details of Study (Summary)

Scenario Designation & Assumptions for 2050[1]			Projections for 2050
BAU		**: No new measures introduced**	Source: Reference scenario (IEEJ_REF) from *IEEJ Outlook 2026**
Hypothetical Scenario	**CNF**	**: Wide use of carbon-neutral fuel (CNF)[2]**	• BEVs/FCEVs account for 50% of new passenger car sales in advanced economies and about 30% in emerging economies. • Wide use of CNF; share in liquid fuel mix: 30%.[3]
	CNF+	**: Assuming that approximately half of sustainable aviation fuel is produced via FT synthesis**	• See note 2 on page 20 for more detailed scenario definition. • Share of CNF in liquid fuel mix: 35%.[3]
	BEV75	**: Widespread electrified vehicle adoption**	• BEVs/FCEVs account for 100% of new passenger car sales in advanced economies and 50% in emerging economies (75% worldwide). • Growing use of CNF; share in liquid fuel mix: 22%.[3]
	NZE	**: 100% BEVs/FCEVs (IEA-NZE scenario)**	• Based on the IEA's backcasting "Net Zero Emissions by 2050"[4] scenario for achieving the 1.5°C climate goal • BEVs/FCEVs account for 100% of global new vehicle sales. • Limited use of CNF (biofuels only, share in liquid fuel mix: 4%[3])

*IEEJ: Institute of Energy Economics, Japan (referenced as IEEJ throughout this analysis)
[1]Powertrain configurations and CNF use rates in each scenario are assumptions made for study purposes; they do not represent auto industry commitments. The real-world feasibility of each scenario depends greatly on the energy policy, industrial policy, and consumer choices in individual countries. [2]CNF here means biofuels and synthetic fuels that will become carbon-neutral by 2050. [3]Percentage figure represents the ratio to total automotive fuel consumption in 2023. [4]"Net Zero Emissions by 2050" was originally released by the International Energy Agency (IEA) in May 2021 and an updated version was published in September 2023 (see page 11). This scenario is not a forecast-based analysis as it does not sufficiently take into account costs involved and investments required.

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2.2 Scenario Parameters: Sources Used

Scenario		Vehicle Parameters		CNF Parameters		Energy Mix
		Fuel/energy efficiency	Powertrain mix	Biofuel (2050 blending rate)	Synthetic fuel (2050 blending rate)	
BAU		JAMA calculations	IEEJ_REF[1]	IEEJ_REF[1]	IEEJ_REF[1]	IEEJ_REF[1]
Hypothetical Scenario	**CNF**	↑	JAMA calculations	IEEJ_ATS+α[1]	IEEJ_ATS+α[1]	IEEJ_ATS[1]
	CNF+	↑	↑	↑	↑	IEEJ_ATS[1]
	BEV75	↑	↑	↑	↑	IEEJ_ATS[1]
	NZE	↑	↑	IEA_NZE[2]	IEEJ_REF[1]	IEEJ_ATS[1]

[1] Source for the three IEEJ scenarios referred to here: *IEEJ Outlook 2026*, published in 2025 by the Institute of Energy Economics, Japan.
-IEEJ_REF (Reference Scenario): Takes into account real-world trends in technological advances and current energy policies, excluding any significant low-carbon measures.
-IEEJ_ATS (Advanced Technologies Scenario): Assumes the introduction of ambitious policies to address energy security and climate change issues with maximum penetration of low-carbon technologies.
-IEEJ_ATS+α is a scenario in which the supply of biofuels and synthetic fuels has been further expanded beyond the IEEJ_ATS scenario.

[2] An updated "Net Zero Emissions by 2050" was published by the International Energy Agency (IEA) in September 2023 under the title "Net Zero by 2050: A Global Pathway to Keep the 1.5°C Goal in Reach."

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2.3 Computational Models

Key Assumptions

GDP / Crude oil prices / Exchange rates / Population / Power generation plans / Global trade / Etc.

Macroeconomic Model

Estimated GDP-related indicators / Prices / Activity indicators such as raw material production / Transportation-related indicators / Etc.

Automotive Model

Vehicle fuel/energy efficiency based on stock and substitution projections

Energy Mix Model

Future cost-optimal energy mix determined based on power generation capacity and electricity demand, using linear programming

Energy Supply and Demand Model

An econometric forecasting model that projects future energy supply and demand based on an energy balance table.

Analysis not only of final energy consumption, but also energy transformation and primary energy consumption.

Estimates of CO_2 emissions, energy self-sufficiency, and other key indicators.

Expert insights from specialists in each field

Key Elements in the Macroeconomic Model

1. World economic growth rate (2.5% per year)

Assumptions based on economic development plans of various governments and forecasts from think tanks and other sources. Although the global economy is expected to slow, growth is projected for many countries, particularly emerging and developing nations in Asia and Africa.

2. Population: 9.5 billion by 2050

As global birth rates decline and populations age, population growth is expected to continue but at a gradually slowing pace, with an average annual growth rate of 0.7%.

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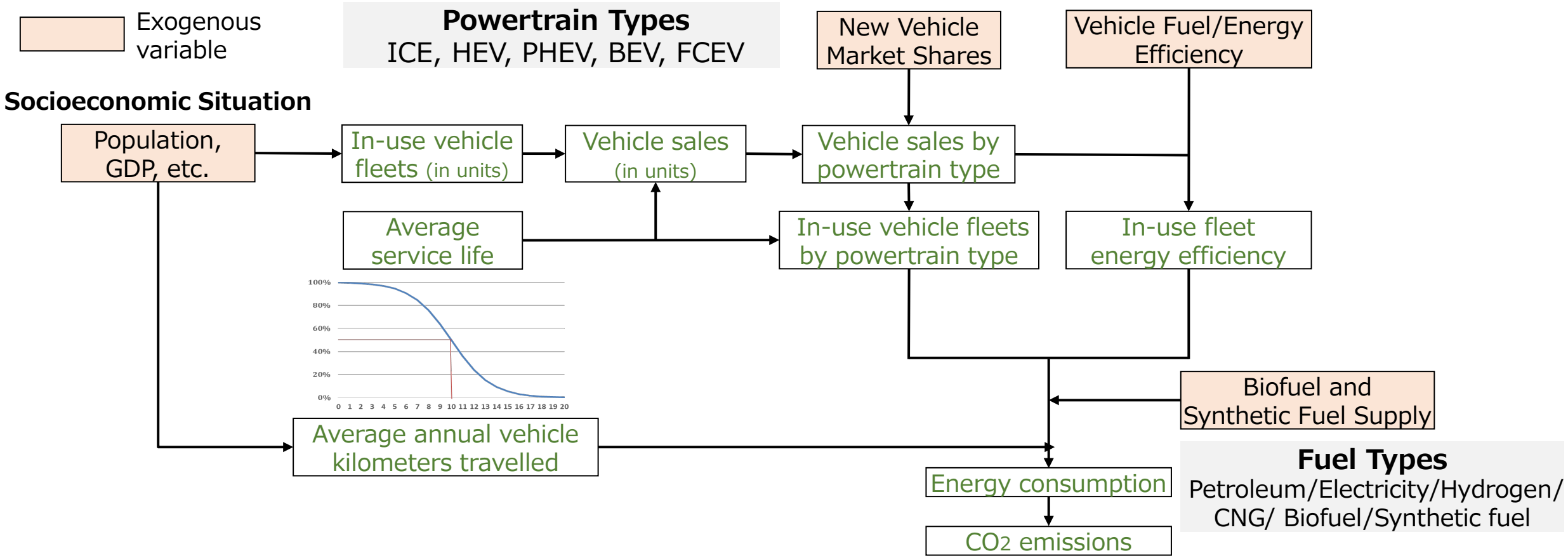
2.3 Computational Models



Based on the macroeconomic model and energy demand model established by the IEEJ, future final fuel consumption (direct CO_2 emissions) was calculated based on JAMA's vehicle sales mix estimates for each scenario.

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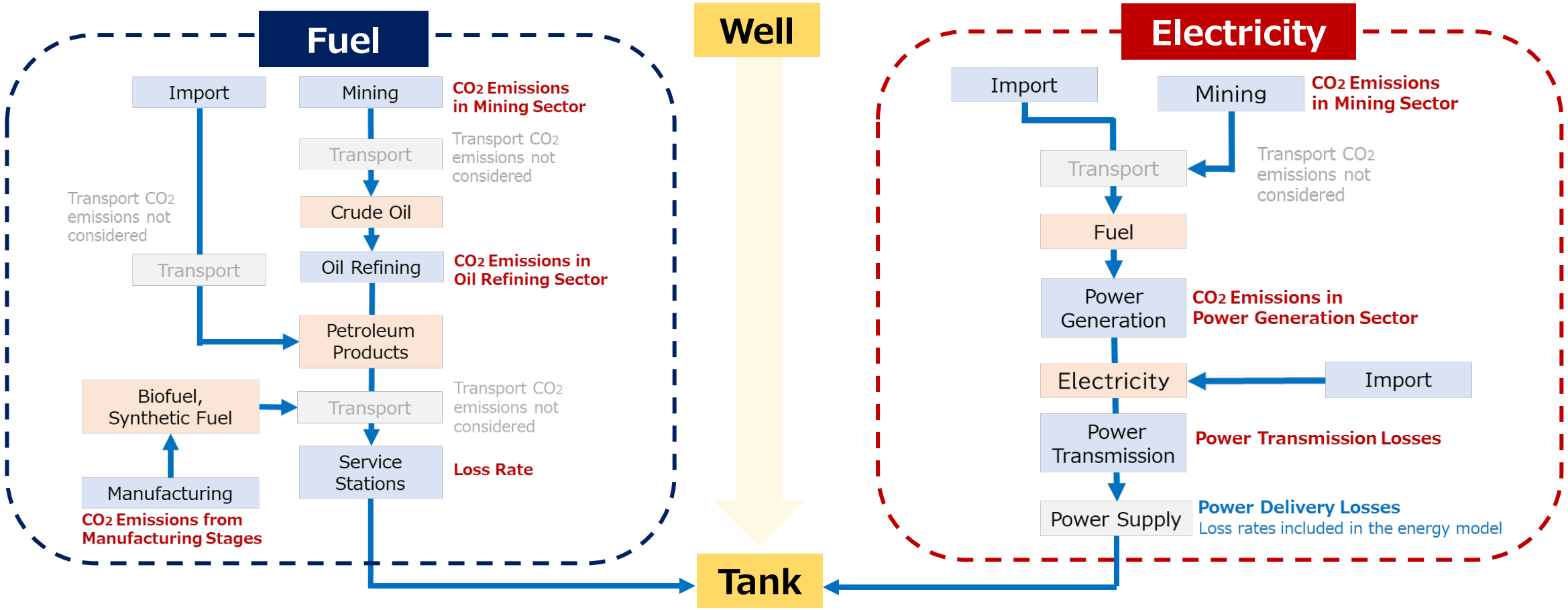
2.3 Computational Models

This schematic breaks down the well-to-tank component in the CO_2 emissions entry shown on page 13.



Indirect emissions were estimated by aggregating the emissions from each energy source.
However, emissions from the transport of fuel were not considered.

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2.4 New Vehicle Market Shares: Assumptions

Vehicle Type	Assumptions
Passenger Cars	• Each scenario makes assumptions concerning the powertrain mix in advanced economies and emerging economies. • The NZE scenario assumes that BEVs/FCEVs will be introduced in emerging economies at the same pace as in advanced economies. The other scenarios, however, assume that BEVs/FCEVs will be introduced in emerging economies at almost half the pace compared to advanced economies.
Trucks & Buses	• Includes mini commercial vehicles. • The powertrain mix for both advanced economies and emerging economies is based on actual shipment volume ratios in Japan. • The timing of BEV/FCEV introduction in this segment is assumed to be 5-10 years later than in the passenger car segment. -The actual mix will vary significantly depending on vehicle class, application, mileage, payload, and operating hours, and on electricity, hydrogen, and fuel infrastructure. -For commercial vehicles, a variety of transition pathways can be envisaged that combine BEVs, FCEVs, HEVs, PHEVs, internal combustion engines, and carbon-neutral fuels. Liquid carbon-neutral fuels can contribute not only to applications where electrification is difficult but also to an early reduction of CO_2 emissions.
Motorcycles	• The powertrain mix for both advanced economies and emerging economies is based on actual shipment volume ratios in Japan. • All scenarios assume that BEVs will be introduced in emerging economies at the same pace as in advanced economies.

Powertrain mix figures are JAMA estimates. (Figures are not shown here.)

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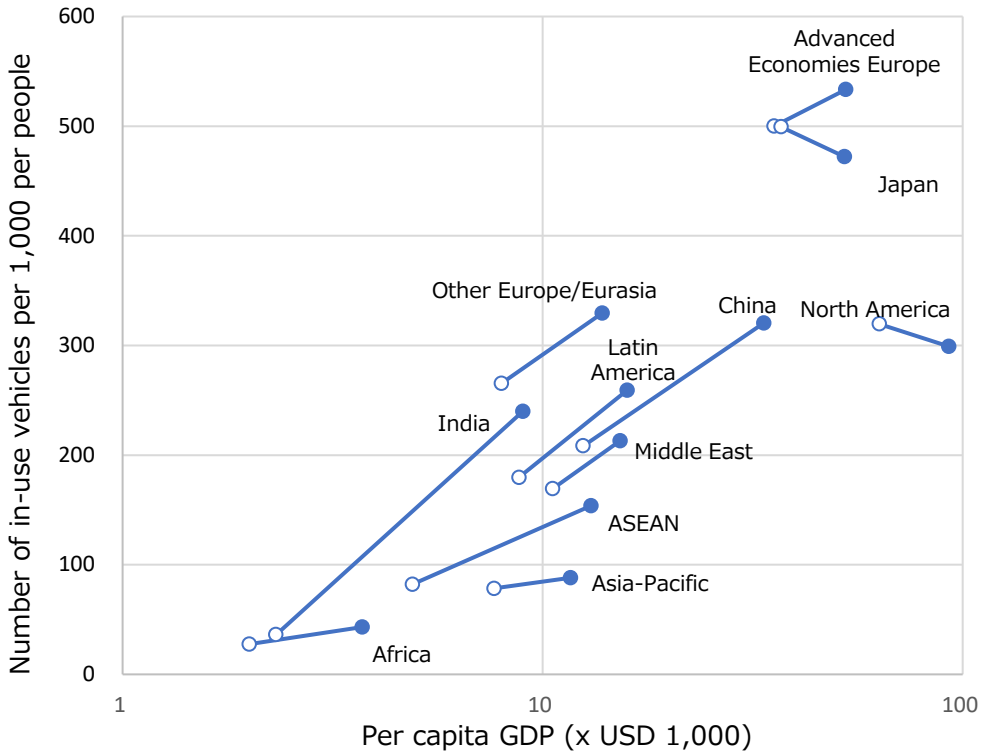
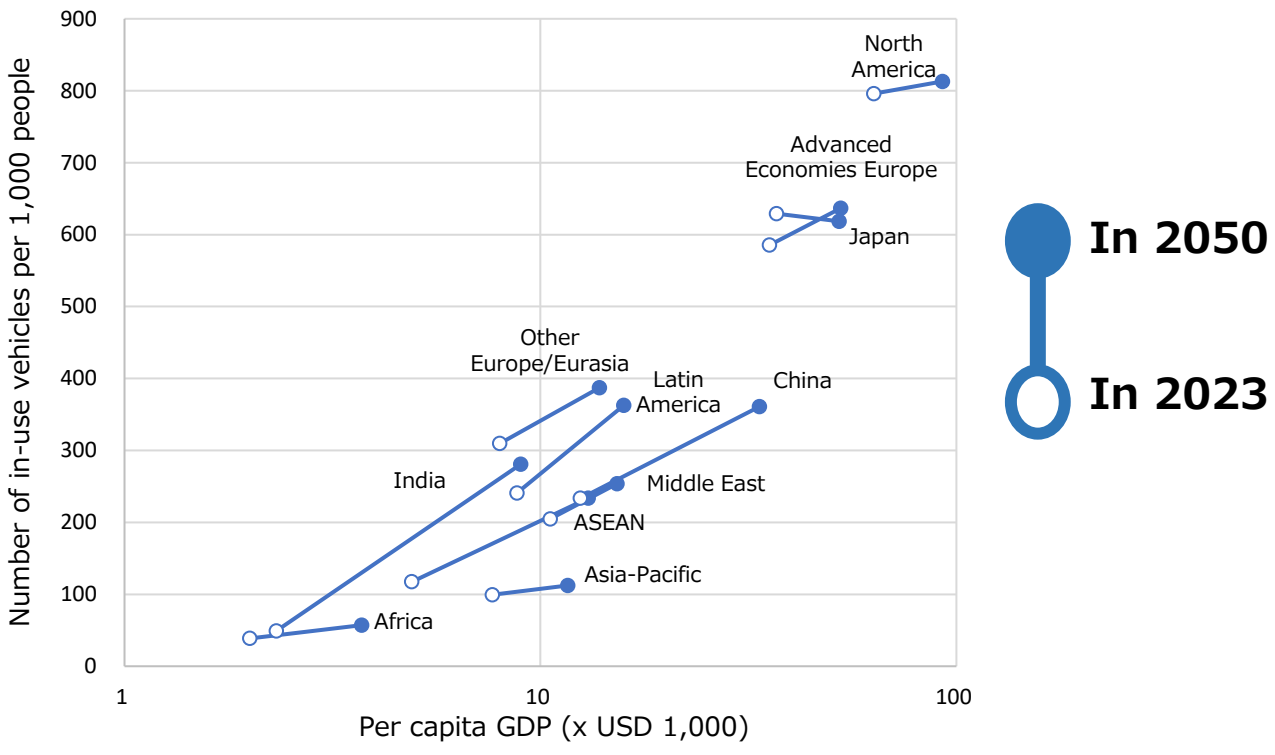
2.5 In-Use Vehicle Fleets: Growth Projections

In-use passenger car fleet growth projections



In-use vehicle fleet (excluding motorcycles) growth projections



In-use passenger car fleets are projected to grow in line with income growth.
The global in-use vehicle fleet (excluding motorcycles) is projected to grow 1.6-fold,
from 1.6 billion vehicles in 2023 to 2.6 billion vehicles in 2050, or
from 205 units per 1,000 people in 2020 to 272 units per 1,000 people in 2050.

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2.6 Vehicle Fuel/Energy Efficiency Data: Assumptions

Vehicle Type	Assumptions
Passenger Cars	See page 18.
Trucks & Buses	Same improvement rates (efficiency gains) as for passenger cars
Motorcycles	ICEV (internal combustion engine vehicle) and BEV (battery electric vehicle) figures are as cited in *IEEJ Outlook 2026*

Figures for passenger car and commercial vehicle (trucks and buses) fuel efficiency are JAMA estimates. Motorcycle figures are as cited in *IEEJ Outlook 2026.* (Figures are not shown here.)

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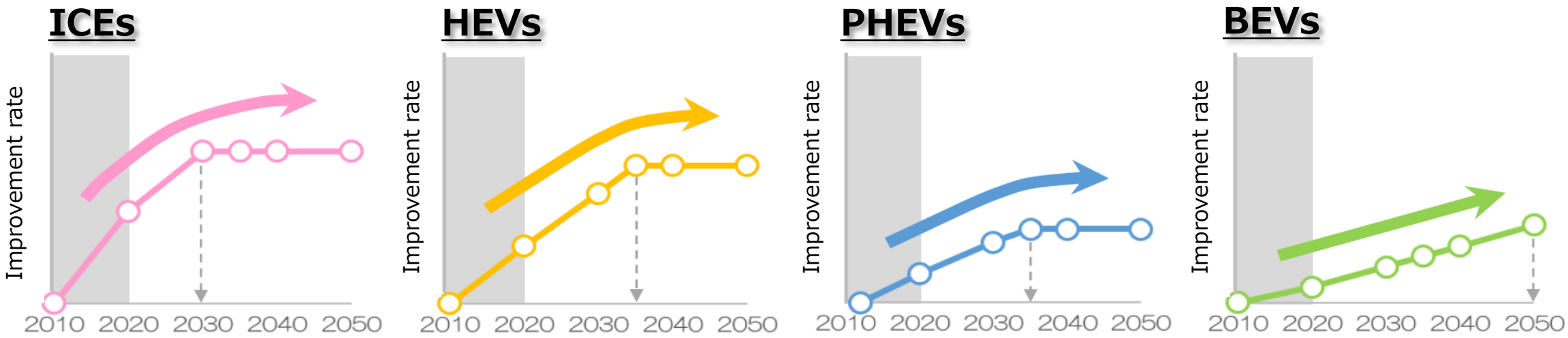
2.7 Projected Increases in Passenger Car Fuel/Energy Efficiency by 2050

Projected average fuel/energy efficiency improvement rates in conventional and electrified vehicles



Basis of JAMA calculations for the 2010-2020 timeframe

・ICEVs/HEVs: Average fuel efficiency of 5 "top runner" models (curb weight: 1300kg±100kg).
・PHEVs: Average fuel efficiency of a few top-runner models.
・BEVs: Difference in energy efficiency of top-runner model before/after full model change.
Top runner: A model with the leading fuel efficiency performance in its weight category.

About JAMA's projections

- ✓ Fuel/energy efficiency improvement rates were calculated based on the anticipated introduction of technological advances by the OEMs, as indicated by them in their responses to a questionnaire submitted during a study on passenger car fuel efficiency standards for fiscal 2030.
- ✓ ICEVs: Projections could be established only up to 2030; HEVs/PHEVs: Only up to 2035.
- ✓ BEVs: Projections could be established up to 2050.
- ✓ The improvement rate for FCEVs is assumed to be the same as for BEVs.

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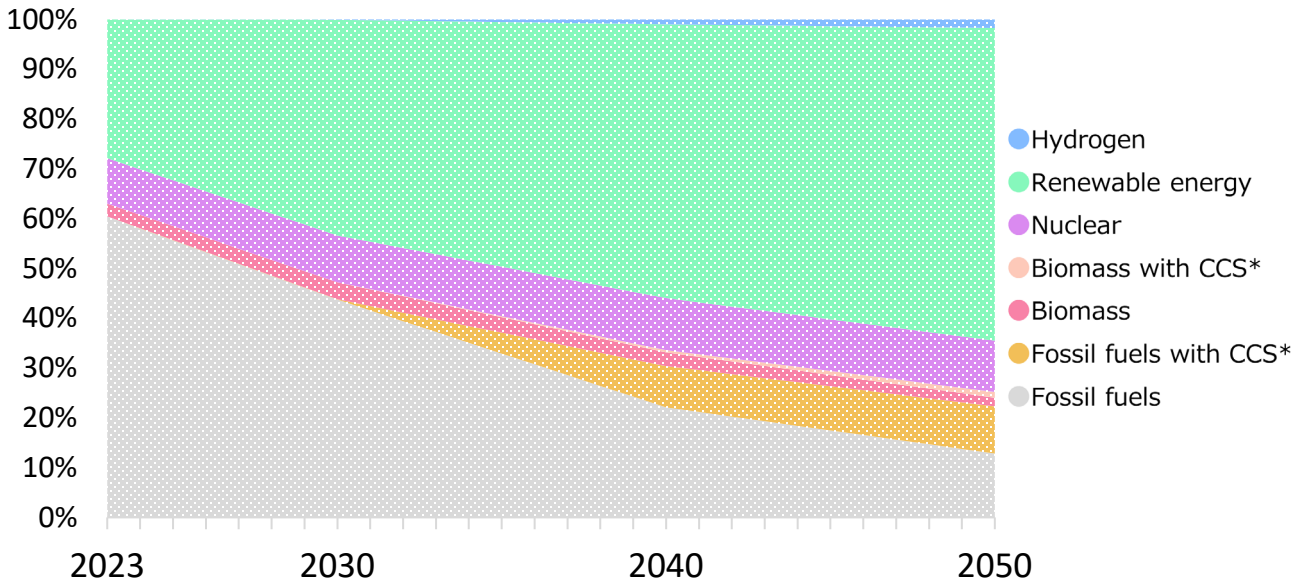
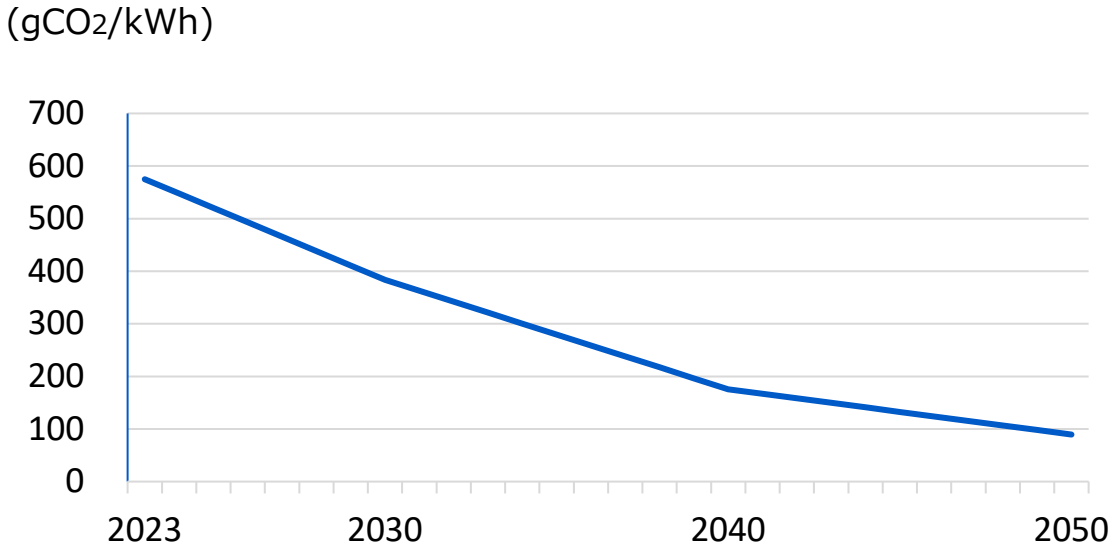
2.8 Energy Mix Projections (Global)

Energy Mix, 2020-2050



CO_2 Emissions Intensity



*CCS: Carbon capture and storage is a technology used to reduce atmospheric CO_2 emissions by capturing CO_2 emitted from power plants, factories, and other sources and storing it underground or in other locations.

Note: The IEEJ Advanced Technologies Scenario (IEEJ_ATS, see below) assumes energy and environmental technologies are deployed to the fullest extent to ensure a stable energy supply and strengthen climate change countermeasures. In accordance with government policy, CO_2 emissions intensity in Japan is to be reduced to just under 55 gCO_2/kWh by 2050.

Energy mix projections in the study scenarios are based on energy mix data in IEEJ_ATS, taking into account the energy supply situation worldwide.
(IEA_NZE does not include energy mix data by country/region.)

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2.9 Fuel Mix and CNF Supply: Assumptions

Based on IEEJ study data, the potential CNF share in the automotive fuel mix in 2050 is estimated at between 30 and 35% (approximately) of total automotive fuel consumption in 2023.

1. Synthetic Fuel Supply

- Taking into consideration various perspectives, JAMA has also made estimates and confirmed that potential supply volumes will be almost the same as in the IEEJ study data.
  - In its "2050 net zero" declaration, the International Air Transport Association (IATA) has estimated that 449 billion liters of sustainable aviation fuel (SAF) will be necessary by 2050.
  - JAMA has estimated synthetic fuel supply volumes by assuming that one-third to one-half of the amount of SAF will be produced by the Fischer-Tropsch (FT) process, which yields high rates of SAF while producing gasoline and diesel as byproducts (Schulz-Flory distribution).
- Since synthetic fuels are a byproduct of sustainable aviation fuel (to be "net zero" by 2050), JAMA has confirmed that synthetic fuel carbon intensity becoming "zero" by 2050 is possible.

2. Biofuel Supply

- JAMA has confirmed potential supply volumes based on data in the IEA's "Energy Technology Perspectives."
- With the U.S. corn ethanol industry association having confirmed that corn ethanol can be carbon-neutral by 2050, JAMA has confirmed that biofuel carbon intensity becoming "zero" by 2050 is possible.

Notes: 1. IATA estimates that 449 billion liters of SAF will be required by 2050 (Sustainable Aviation Fuels (SAF) Fact Sheet). 2. CNF supply volume in the CNF scenario is consistent with the scenario in which approximately one-third of the 449 billion liters of SAF is produced via FT synthesis. 3. CNF supply volume in the CNF+ scenario assumes that approximately one-half of the 449 billion liters of SAF is produced via FT synthesis; synthetic fuel supply volume is approximately 1.5 times greater than in the CNF scenario, and CNF supply volume is approximately 1.2 times greater than in the CNF scenario—an increase with a preferential allocation to Africa, the Middle East, India, and ASEAN, regions in which decarbonization of the power sector is relatively difficult. 4. Schulz-Flory distribution: the proportion of hydrocarbon products by carbon number in FT synthesis. 5. Carbon intensity (CI): the unit of greenhouse gas emissions per unit of fuel throughout its life cycle.

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