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

Japan Automobile Manufacturers Association

September 2022

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1.0 Overview

1.1 Overview of Study

1. Purpose of using scenarios

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

2. Data applied

New-vehicle sales data, in-use vehicle fleet data, energy/fuel mix data, vehicle fuel efficiency data, vehicle kilometers travelled annually, etc.

3. Scenario parameters and study findings (partial)

2050 Scenario Designation & Definition	BEV/FCEV Share of New Passenger Vehicle Sales			2050 Projected CNF Share in Automotive Fuel Mix [2020 FC*-Based]
	Worldwide	Advanced economies	Emerging economies	
Scenario 0 BAU[1]	BAU	←	←	←
Scenario 1 CNF: Wide use of CNF	40%	50%	25%	**30% approx.**
Scenario 2 BEV75: Wide electrified vehicle adoption	75%	100%	50%	**20% approx.**
Scenario 3 NZE: 100% BEVs/FCEVs (IEA NZE[2] scenario)	100%	100%	100%	7% (biofuel only)

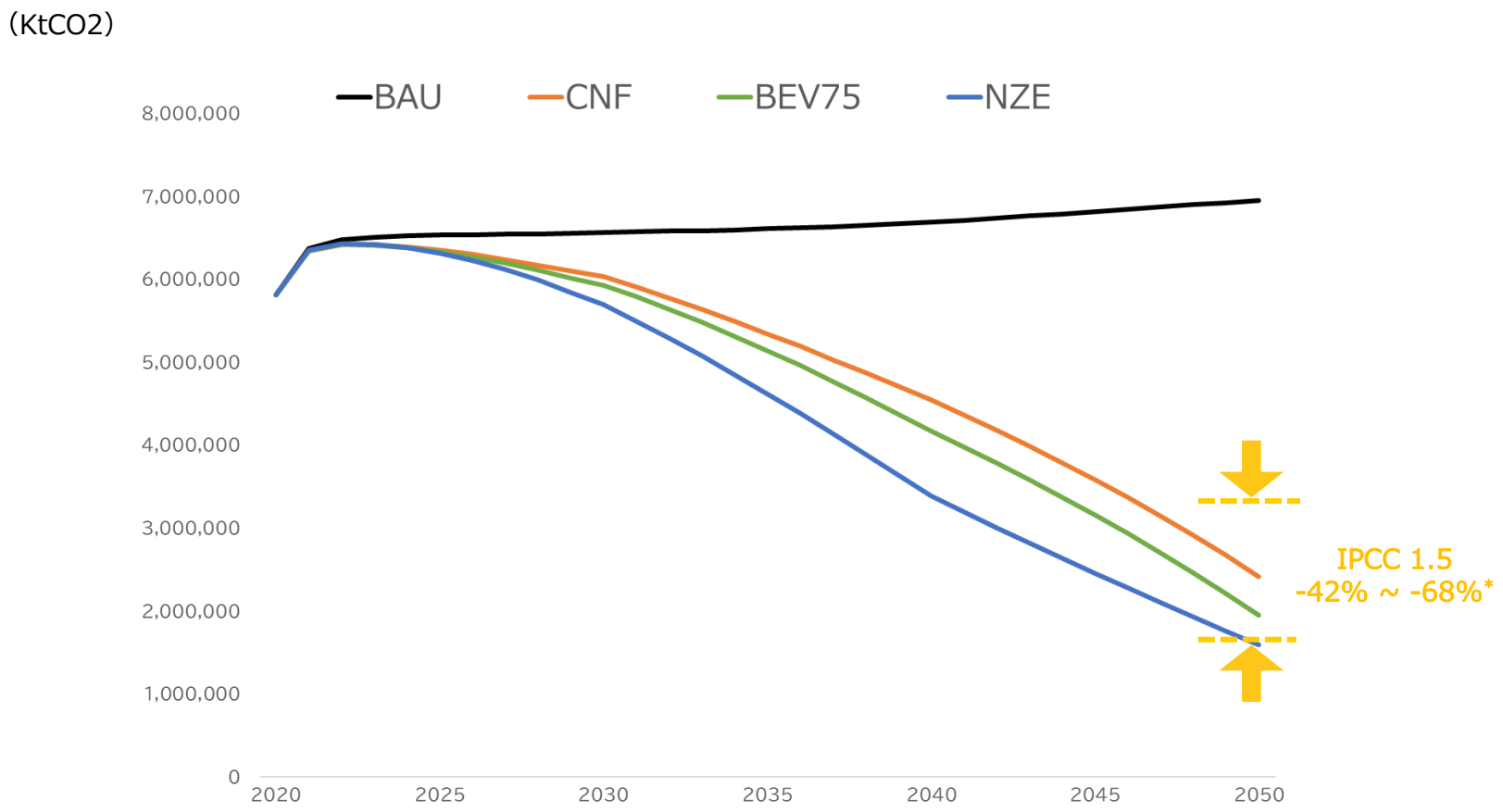
*FC: Fuel consumption [1] BAU: "Business as usual" [2] IEA: International Energy Agency; NZE: "Net Zero Emissions by 2050"
Advanced economies: Japan; North America; Europe; etc.; Emerging economies: India; ASEAN; Africa; etc.

1.2 Summary of Study Findings

Context	CO_2 Emission Levels in 2050
Worldwide	• **Findings show that the study's three 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 2050 1.5°C climate scenarios**. IPCC: Intergovernmental Panel on Climate Change • 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 study's three scenarios 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 amount of CNF in the automotive fuel mix in 2050 can be increased to a level equivalent to 40% (approx.) of global automotive fuel consumption in 2020, it will be **possible for CO_2 emissions** in emerging economies **to be in line with the IPCC's 1.5<2°C climate scenarios for 2050.**

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.

CO_2 Emissions Worldwide 2020-2050, by Scenario

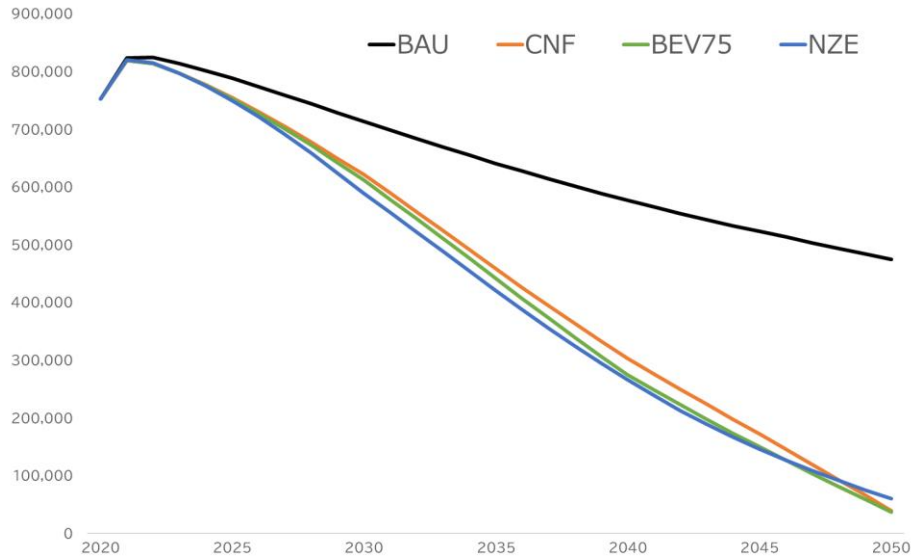


In all three scenarios, CO_2 emissions worldwide are in line with the IPCC's 2050 1.5℃ climate scenarios.

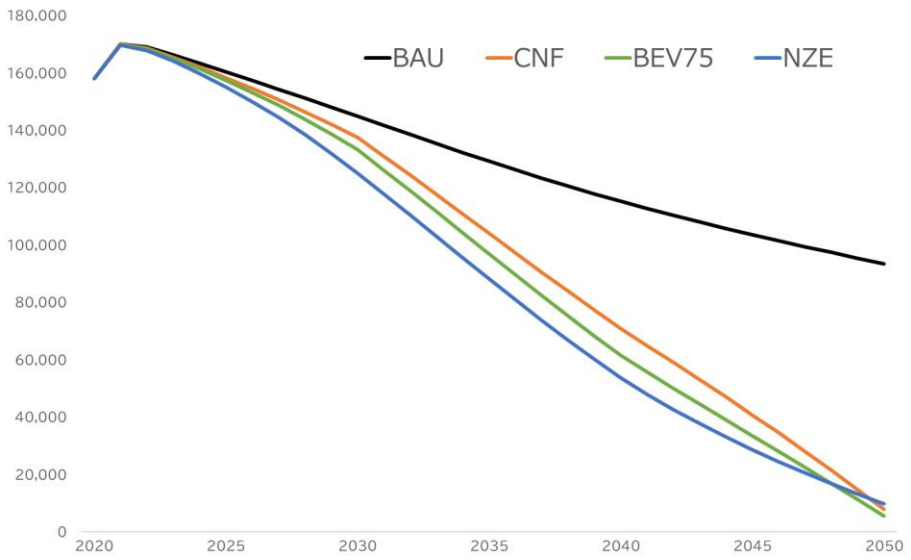
CO_2 Emissions in Advanced Economies 2020-2050, by Scenario

(KtCO2)

Advanced economies Europe



Japan



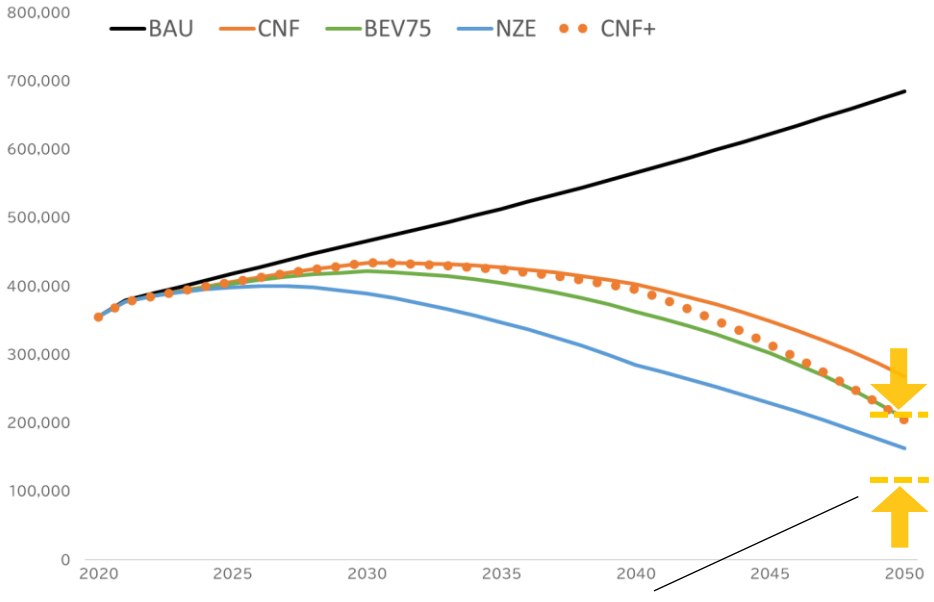
All scenarios (excluding the BAU scenario) demonstrate the potential in advanced economies for carbon neutrality in automotive transport by 2050.

CO_2 Emissions in Emerging Economies 2020-2050, by Scenario

In many emerging economies, vehicle sales volumes and BAU emissions are expected to rise significantly.

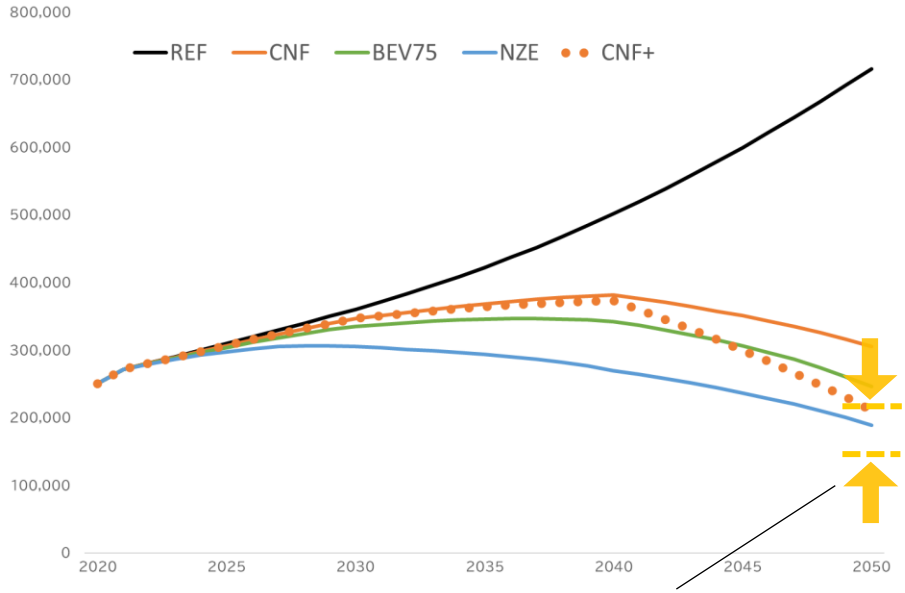
(KtCO2)

ASEAN



IPCC1.5 :
-42%～-68%

India



IPCC2.0 :
-14%～-44%

Note: The CNF+ scenario assumes that CNF supply is 1.25 times greater than in the CNF scenario, has a 40% (approx.) instead of 30% share (approx.) in the fuel mix and that most of the increase will be supplied to Africa, the Middle East, India, and ASEAN where the supply of decarbonized energy is a major challenge.

A 1.25 increase in carbon-neutral fuel supply compared to the CNF scenario will make it possible for CO_2 emissions in emerging economies to be in line with the IPCC's $1.5<2^0C$ scenarios for 2050.

2.0 Details of Study

2.1 Details of Study (Summary)

Scenario designation & definition[1]	Abbreviation used in study	Basic assumptions (2050)
0-"Business as usual"	BAU	Source: *IEEJ Outlook 2021**
1-Wide use of carbon-neutral fuel (CNF)[2]	CNF	• The share of BEVs/FCEVs in new passenger car sales reaches 50% in advanced economies and about 30% in emerging economies. • CNF is in wide use (share in fuel mix: 30% approx.).
2-Wide adoption of electrified vehicles	BEV75	• The share of BEVs/FCEVs in new passenger car sales reaches 100% in advanced economies and 50% in emerging economies (75% worldwide). • Growing use of CNF (share in fuel mix: 20% approx.)
3-100% BEVs/FCEVs	NZE	• Based on IEA's backcasting "Net Zero Emissions by 2050"[3] scenario for achieving the 1.5^{0}C climate goal • The share of BEVs/FCEVs in global new vehicle sales reaches 100%. • Limited use of CNF (biofuels only, share in fuel mix: 7%)

* IEEJ: Institute of Energy Economics, Japan

[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. CNF shares "in fuel mix" were calculated on the basis of total automotive fuel consumption in 2020.

[3] "Net Zero Emissions by 2050" was published by the International Energy Agency (IEA) in May 2021. This scenario is not a forecast-based analysis as it does not sufficiently take into account costs involved and investments required.

2.2 Scenario Parameters: Sources Used

Scenario	Vehicle Parameters		CNF Parameters		Energy Mix
	Fuel efficiency	Powertrain mix	Biofuel	Synthetic fuel	
BAU	JAMA calculations	IEEJ_REF[1]	IEEJ_REF[1]	IEEJ_REF[1]	IEEJ_REF[1]
CNF	↑	JAMA calculations	IEEJ_CCE[1]	IEEJ_CCE[1]＋α	IEEJ_ATS[1]
BEV75	↑	↑	↑	↑	IEEJ_ATS[1]
NZE	↑	↑	IEA_NZE[2]	–	IEEJ_ATS[1]

[1] Source for the three IEEJ scenarios referred to here: *IEEJ Outlook 2021*, published in 2020 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 introduction of ambitious policies to address energy security and climate change issues with maximum penetration of low-carbon technologies.

-IEEJ_CCE（Circular Carbon Economy Scenario): In addition to the assumptions introduced in the ATS scenario, the CCE scenario assumes optimized adoption of 4R (“reduce, reuse, recycle, remove”) technologies to decarbonize fossil fuel use.

[2] “Net Zero Emissions by 2050” was published by the International Energy Agency (IEA) in May 2021.

2.3 Computational Models

Macroeconomic model ⟷ Interactions ⟷ Energy demand model ⟷ Interactions ⟷ Automotive model

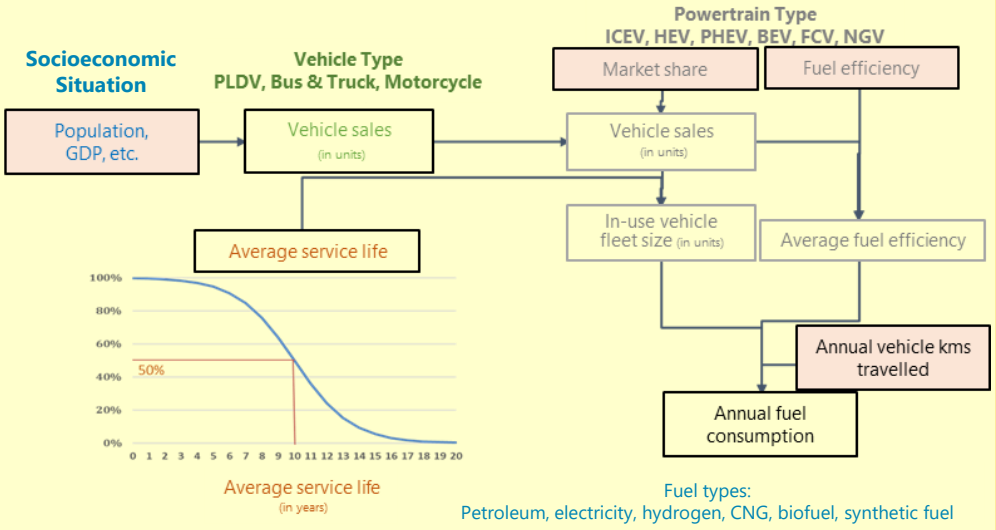
Key elements in the macroeconomic model:

1. World economic growth rate (2.5% per year)
Economic growth rates of individual countries, especially in emerging economies in Asia and Africa, were assumed by IEEJ based on the economic development plans of national governments and the forecasts of think tanks and other organizations, with the expectation that the economic downturn resulting from the COVID-19 pandemic will cease at an early stage.

2. Population projection (9.7 billion people by 2050)
IEEJ refers to the United Nations' "World Population Prospects" and other sources, and assumes that population growth will continue owing to developments in medical technology and improvements in food and sanitary conditions, while taking into account the increasing downward pressure on the population caused by COVID-19 and the resulting economic stagnation.

Calculation Methodology for Automotive Model

Energy consumption =
In-use vehicle fleet size × Average annual vehicle kilometers travelled × Average fuel efficiency



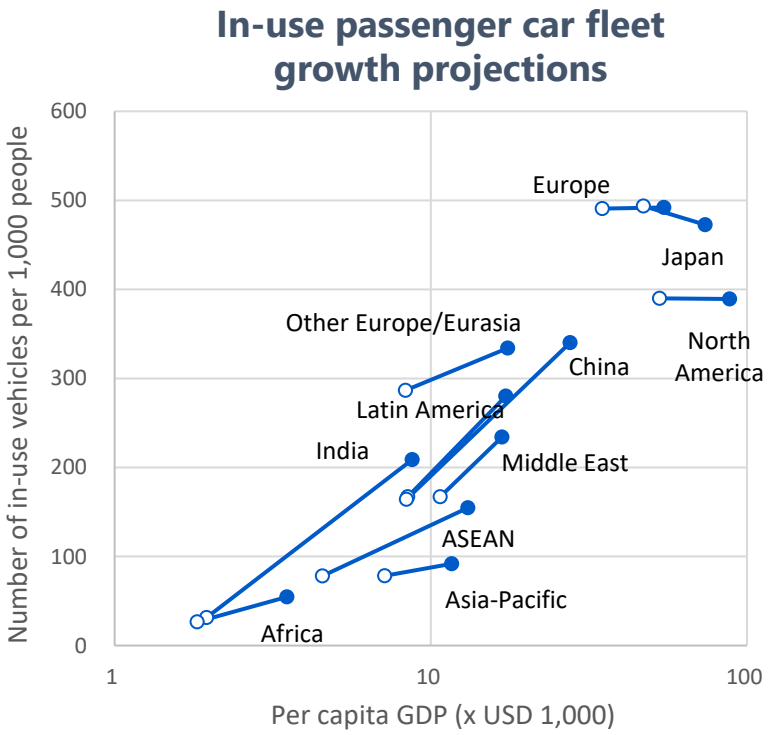
Figures for future fuel consumption (CO_2 emissions) were calculated using IEEJ's macroeconomic model and energy demand model reflecting JAMA's powertrain mix estimates.

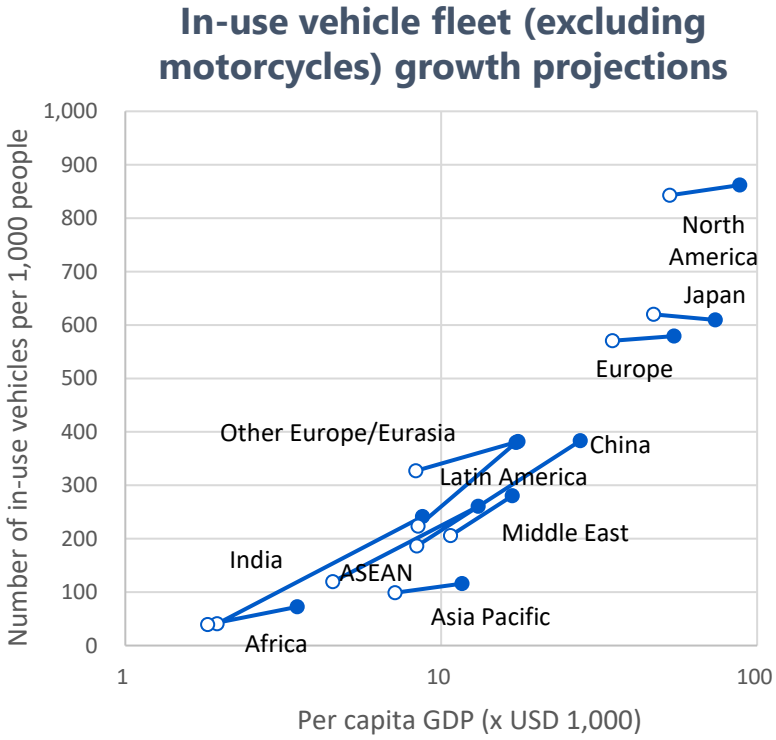
2.4 New-Vehicle Market Shares: Assumptions

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.
Commercial Vehicles	• 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.
Motorcycles	• Powertrain mix figures are per IEEJ's Advanced Technologies Scenario.

Powertrain mix figures for passenger cars and commercial vehicles are JAMA estimates.
Powertrain mix figures for motorcycles are per an IEEJ scenario.

2.5 In-Use Vehicle Fleets: Growth Projections





○2020 ➡ ●2050

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 1.7-fold,
from 1.5 billion vehicles in 2020 to 2.7 billion vehicles in 2050, or
from 199 units per 1,000 people in 2020 to 277 units per 1,000 people in 2050.

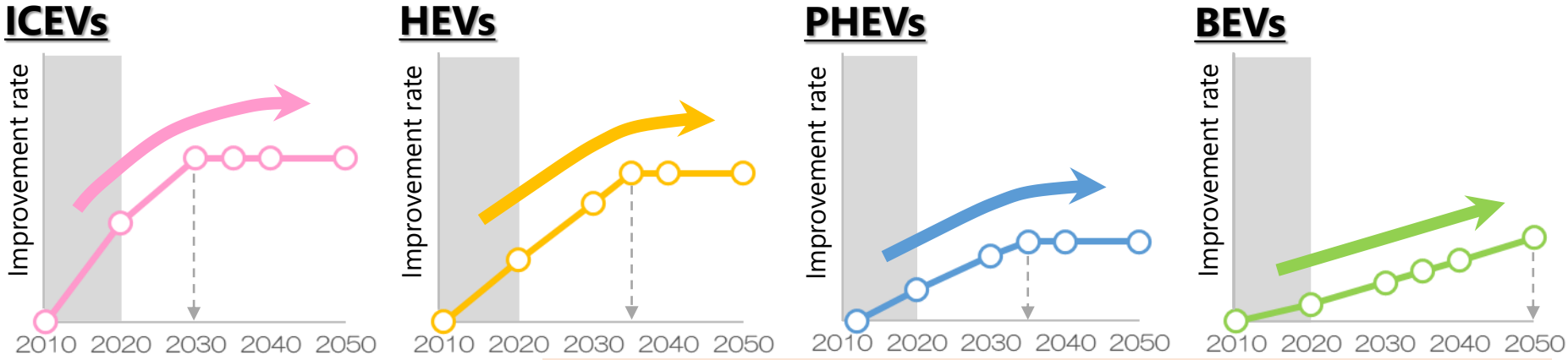
2.6 Vehicle Fuel Efficiency Data: Assumptions

Vehicle Type	Assumptions
Passenger Cars	• See next slide.
Commercial Vehicles	• Vehicle fuel efficiency improvement rates per country/region are as cited in *IEEJ Outlook 2021*.
Motorcycles	• ICEV (internal combustion engine vehicle) and BEV (battery electric vehicle) figures are as cited in *IEEJ Outlook 2021*.

Figures for passenger car fuel efficiency are JAMA estimates.
Commercial vehicle and motorcycle figures are as cited in *IEEJ Outlook 2021*.

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

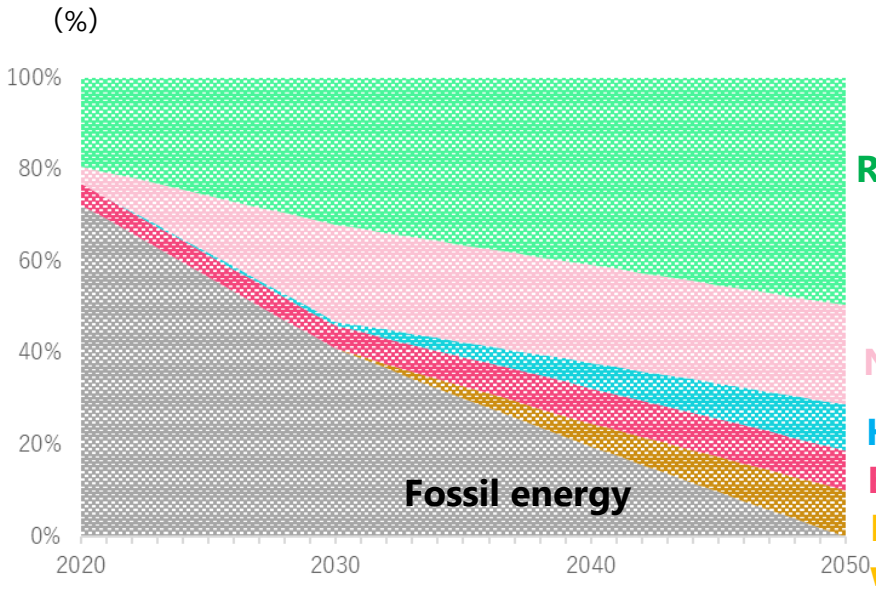
Top runner: A model with the leading fuel efficiency performance in its weight category.

About JAMA's projections

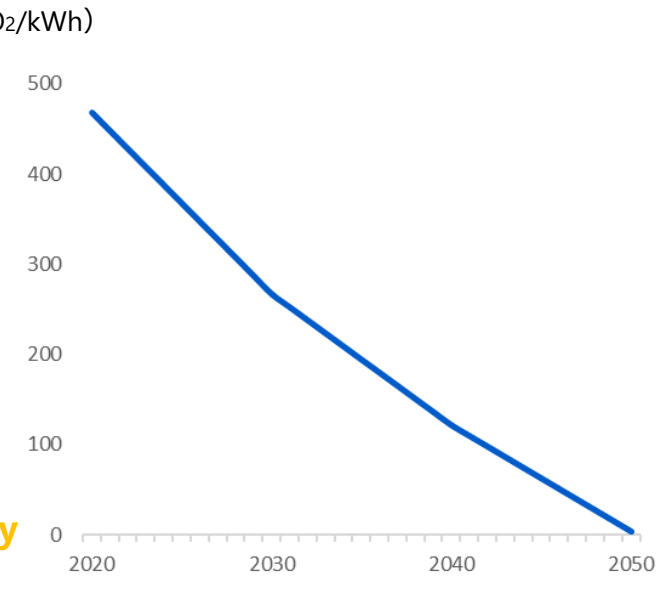
- ✓ Fuel/energy efficiency improvement rates were calculated based on the anticipated introduction of technological advances by the OEMs, as indicated by them in their responses to a questionnaire submitted during a study on passenger car fuel efficiency standards for fiscal 2030.
- ✓ ICEVs: Projections could be established only up to 2030; HEVs/PHEVs: Only up to 2035.
- ✓ BEVs: Projections could be established up to 2050.
- ✓ FCEVs are projected to maintain their current FE performance level (152km/kg) up to 2050.

2.8 Energy Mix Projections (Global)

Energy mix, 2020-2050



CO_2 emissions intensity



*CCS: Carbon capture and storage
IEEJ_ATS (Advanced Technologies Scenario): Assumes introduction of ambitious policies to address energy security and climate change issues with maximum penetration of low-carbon technologies.
[CO_2 emissions intensity for Japan in 2050 was amended to less than 100 gCO_2/kWh in line with government policy.]

Energy mix projections in the study scenarios were 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.)

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 to be approximately 30 to 40% of total automotive fuel consumption in 2020.

Synthetic fuel supply

- Taking into consideration various perspectives, JAMA also made estimates and confirmed that potential supply volumes will be almost the same as in the IEEJ study data.
  - The International Air Transport Association (IATA) has issued a "2050 net zero" declaration and estimated that 449 billion liters of sustainable aviation fuel (SAF) will be necessary by 2050.*
  - JAMA estimated synthetic fuel supply volumes by assuming 1/3 to 1/2 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 (Shulz-Flory distribution).
- Since synthetic fuels are a byproduct of sustainable aviation fuel (to be "net zero" by 2050), JAMA confirmed that synthetic fuel carbon intensity becoming "zero" by 2050 is possible.

Biofuel supply

- JAMA 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 confirmed that biofuel carbon intensity becoming "zero" by 2050 is possible.

*SAF estimates: https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet---alternative-fuels/
CNF supply volume in the CNF scenario is based on the assumption that 1/3 of the 449 billion liters of SAF will be produced by the FT process.
CNF supply volume in the CNF+ scenario is based on the assumption that 1/2 of SAF will be produced by the FT process (for a 50% increase in synthetic fuel supply volumes and a 25% increase in total CNF supply volumes compared to the CNF scenario), consistent with IATA's estimates. The additional supply of CNF in the CNF+ scenario is allocated to Africa, the Middle East, India, and the ASEAN region where decarbonized energy supply poses a major challenge.

3.0 Details of Study Findings, By Country/Region

3.1 Japan

Trends in Japan @2050

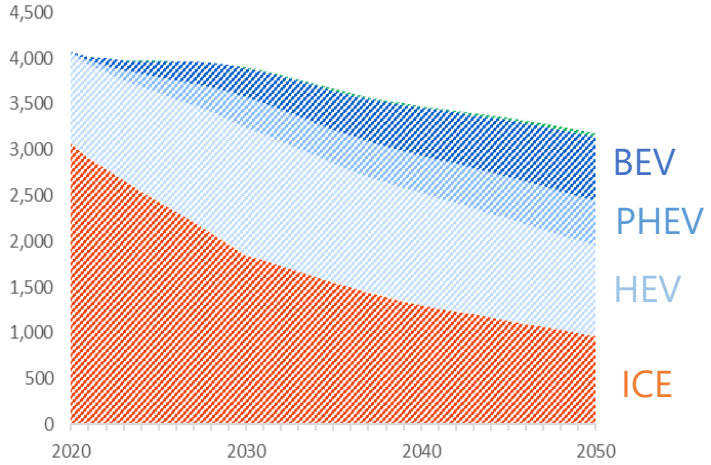
Scenario	Trends in Japan		2050/2020 CO_2 emissions
All	Market	• For all vehicle types: Gradual declines in both new vehicle sales and in-use fleets.	
	Energy mix	• Increased supply of diversified clean energy + CCS leads to mostly decarbonization.	
CNF	Electrified vehicles	• Share of electrified vehicles in new vehicle sales for all vehicle types (passenger cars, trucks, buses) is almost 100%, with about 50% of new passenger cars being PHEVs. • Share of BEVs/FCEVs in the in-use passenger car and commercial vehicle fleets is approximately 40%.	-95% approx.
	Fuel mix	• More than 80% is CNF (synthetic fuels, biofuels) + electricity + hydrogen. • CNF share represents approx. 20% of total fuel consumption in 2050.	
BEV75	Electrified vehicles	• Share of BEVs/FCEVs in new vehicle sales for all vehicle types is 100%. • Share of BEVs/FCEVs in the in-use passenger car and commercial vehicle fleets is approximately 70%.	-96% approx.
	Fuel mix	• More than 90% is CNF (synthetic fuels, biofuels) + electricity + hydrogen. • CNF share represents approx. 15% of total fuel consumption in 2050.	
NZE	Electrified vehicles	• Share of BEVs/FCEVs in new vehicle sales for all vehicle types is 100%. • Share of BEVs/FCEVs in the in-use passenger car and commercial vehicle fleets is approximately 90%.	-94% approx.
	Fuel mix	• About 80% is biofuels + electricity + hydrogen. (Assumption: Synthetic fuels = 0%.) • Biofuel share = approx. 3% of total fuel consumption in 2050.	

In all non-BAU scenarios, CO_2 emission levels are close to carbon neutrality.

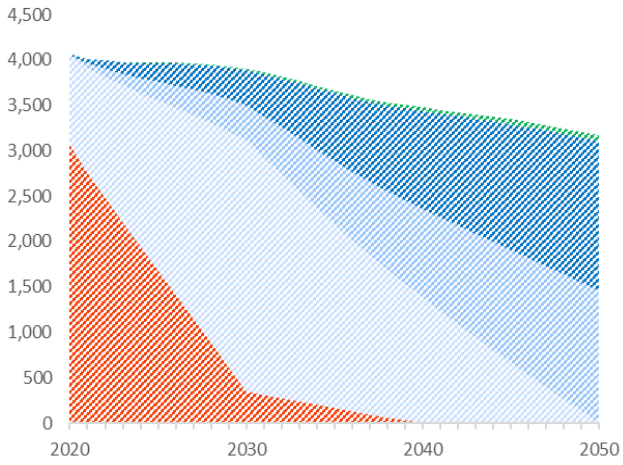
New Passenger Car Sales (Japan)

(x 1,000 units)

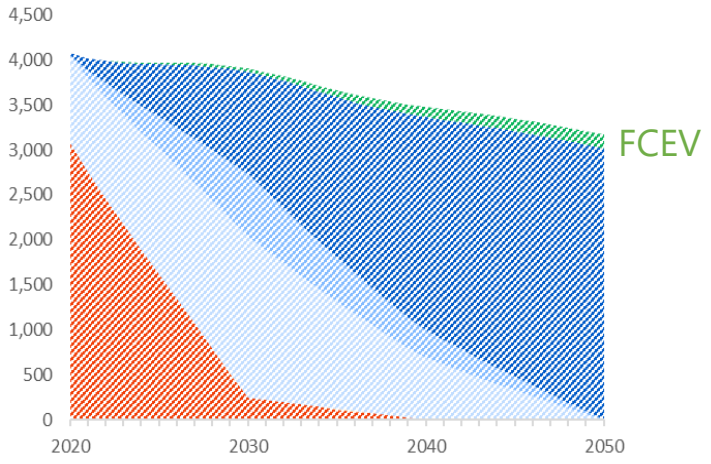
BAU



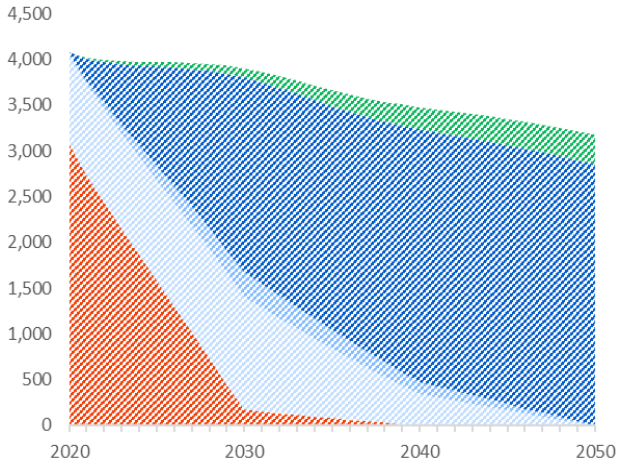
CNF



BEV75



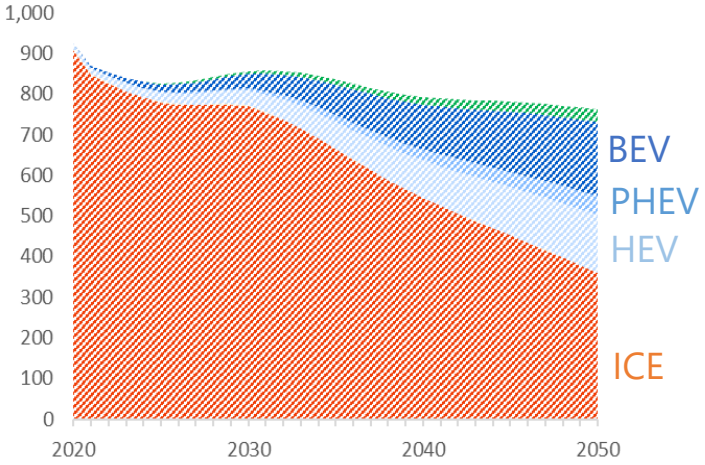
NZE



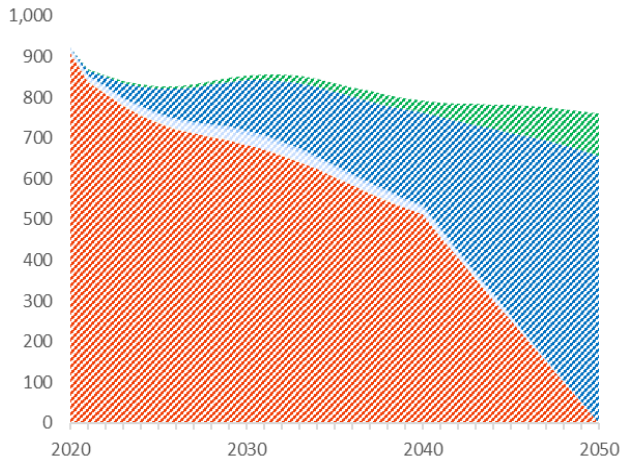
New Commercial Vehicle Sales (Japan)

(x 1,000 units)

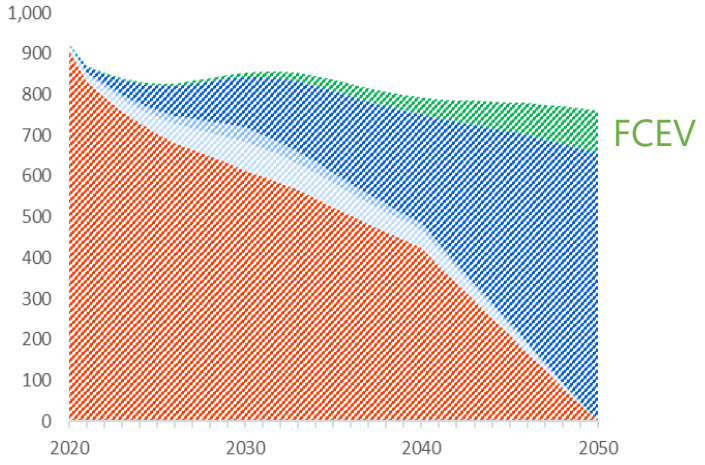
BAU



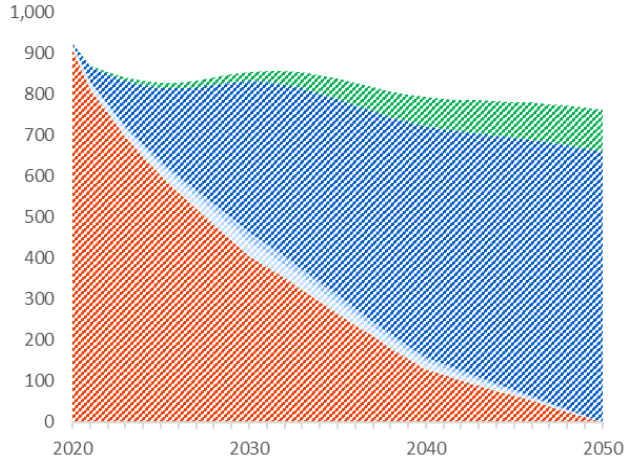
CNF



BEV75



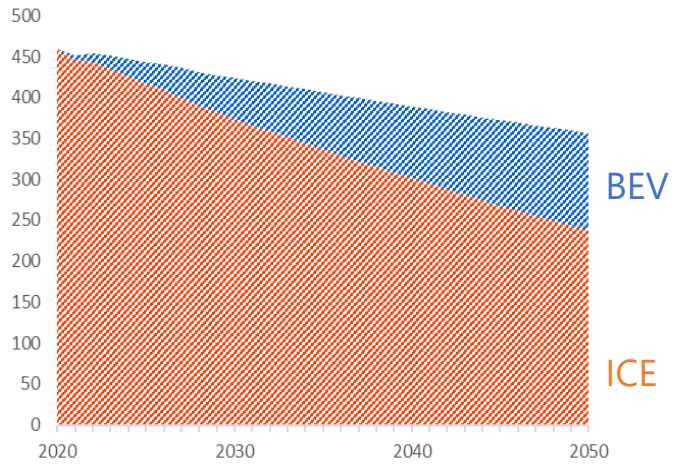
NZE



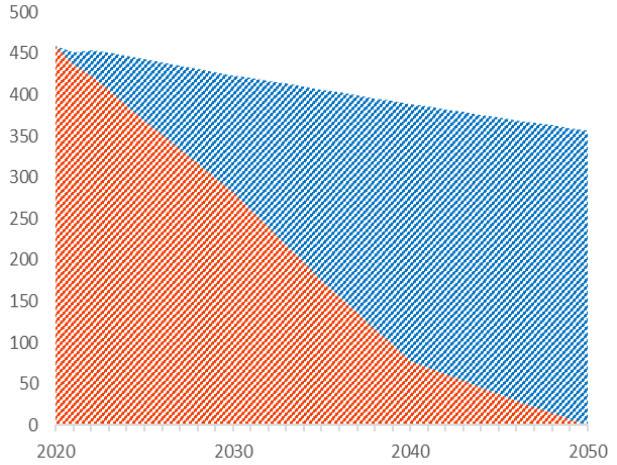
New Motorcycle Sales (Japan)

(x 1,000 units)

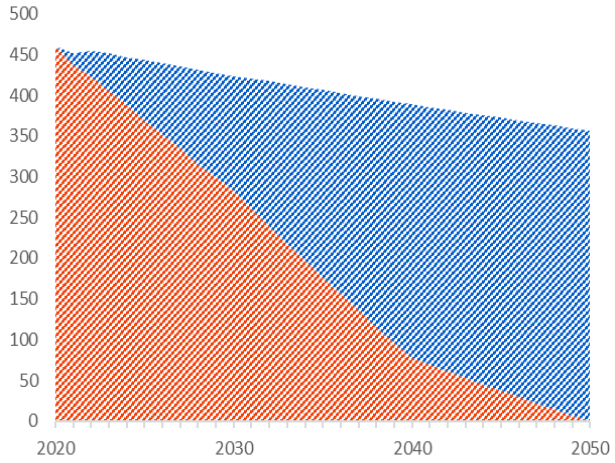
BAU



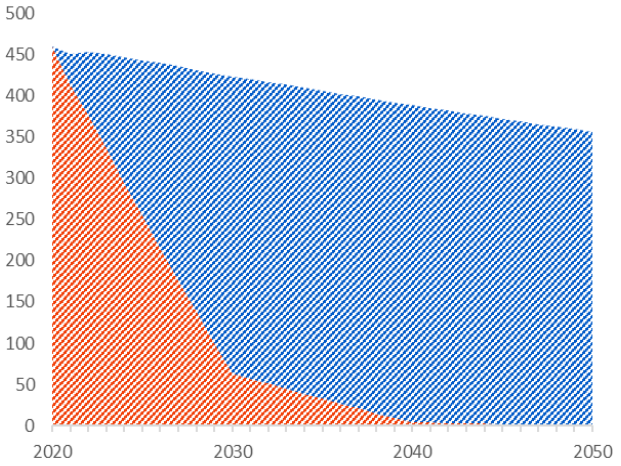
CNF



BEV75



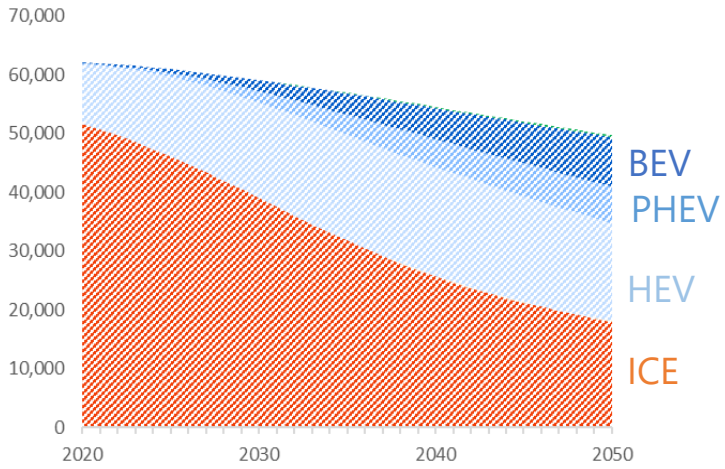
NZE



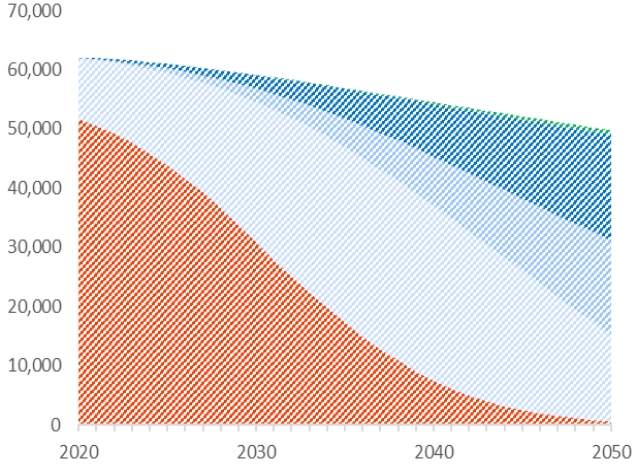
In-Use Passenger Car Fleet (Japan)

(x 1,000 units)

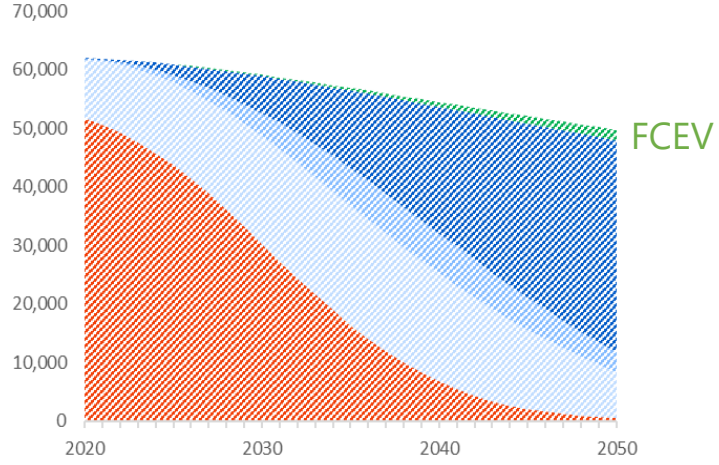
BAU



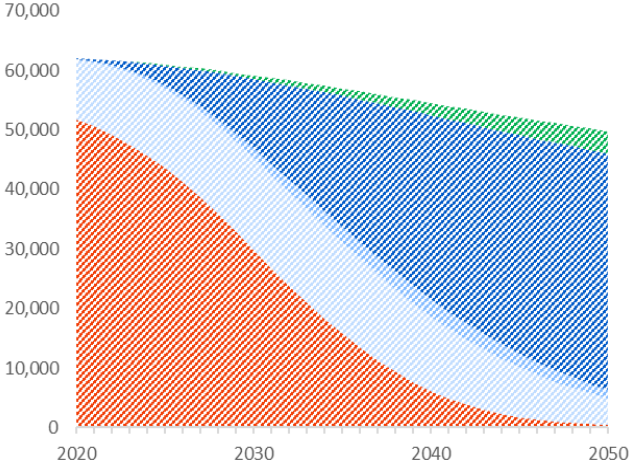
CNF



BEV75



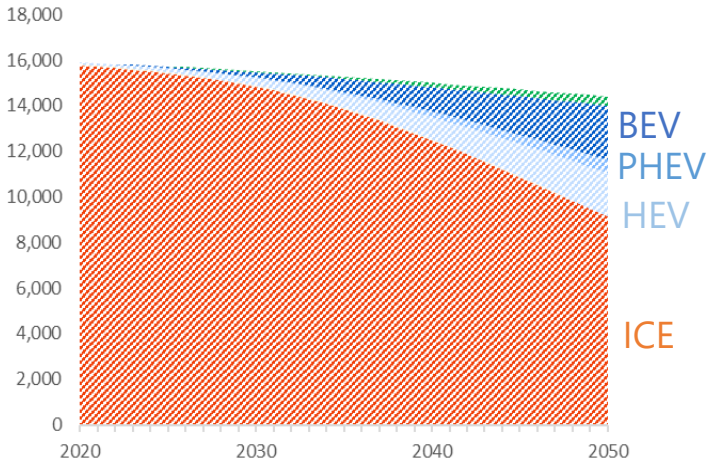
NZE



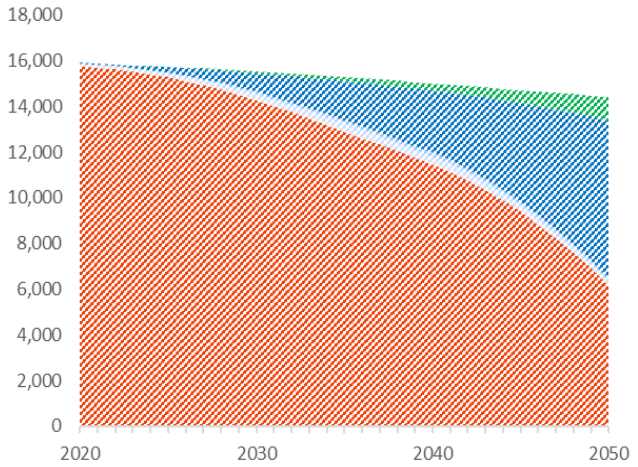
In-Use Commercial Vehicle Fleet (Japan)

(x 1,000 units)

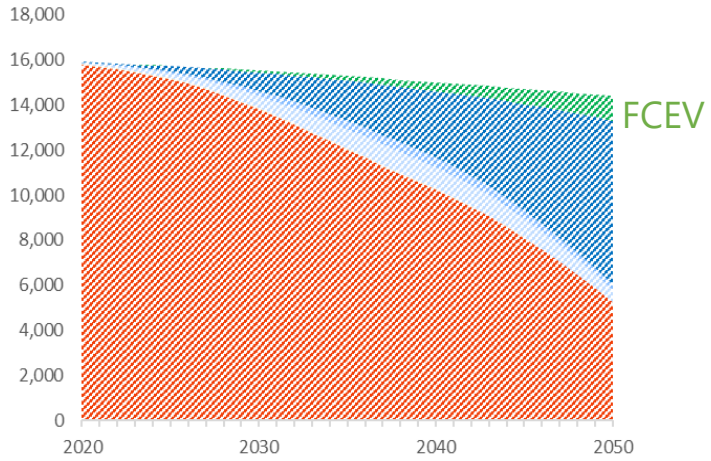
BAU



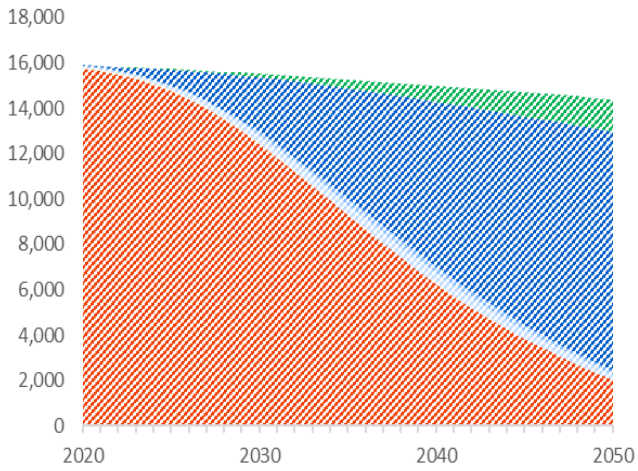
CNF



BEV75



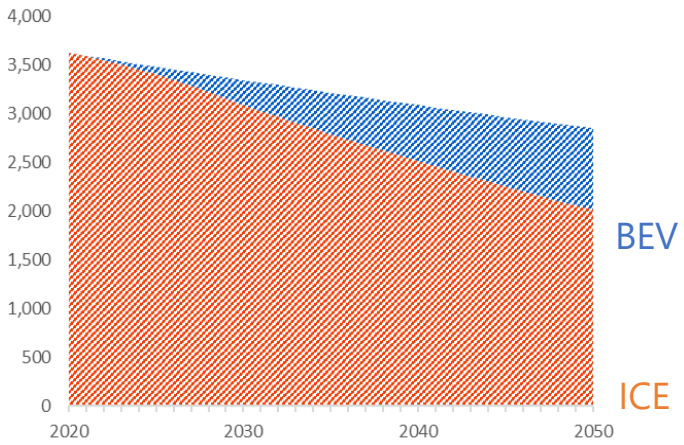
NZE



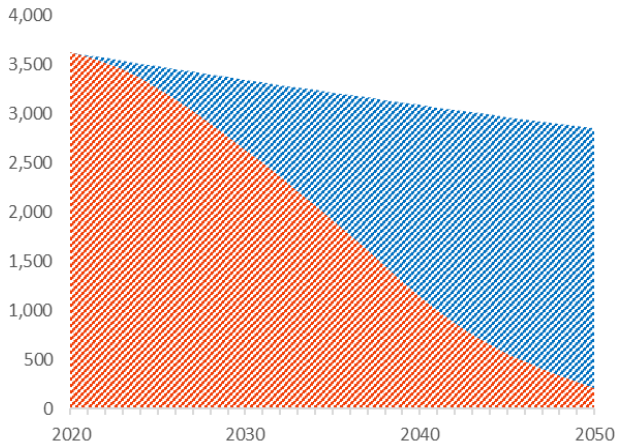
In-Use Motorcycle Fleet (Japan)

(x 1,000 units)

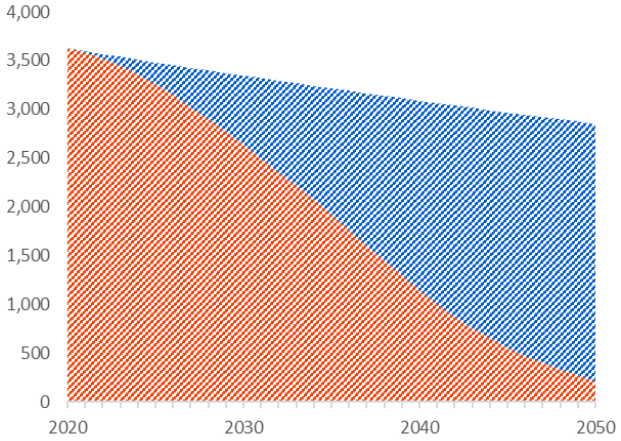
BAU



CNF



BEV75



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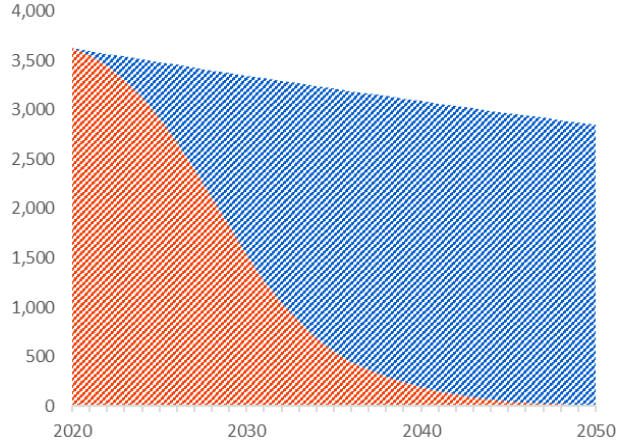
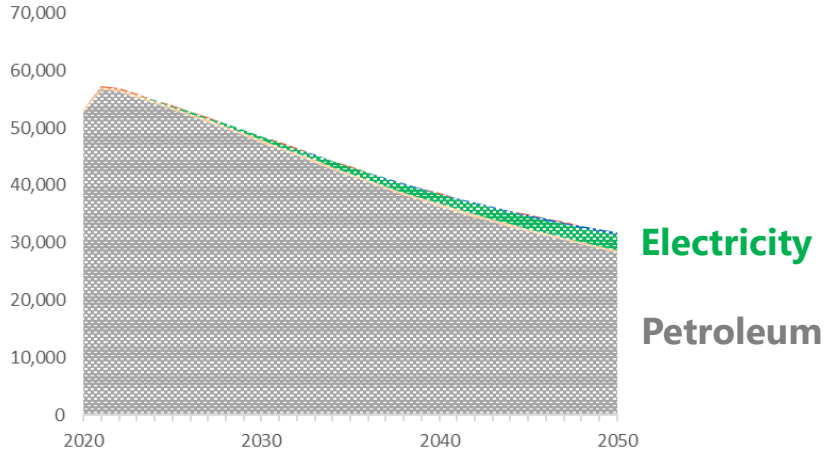


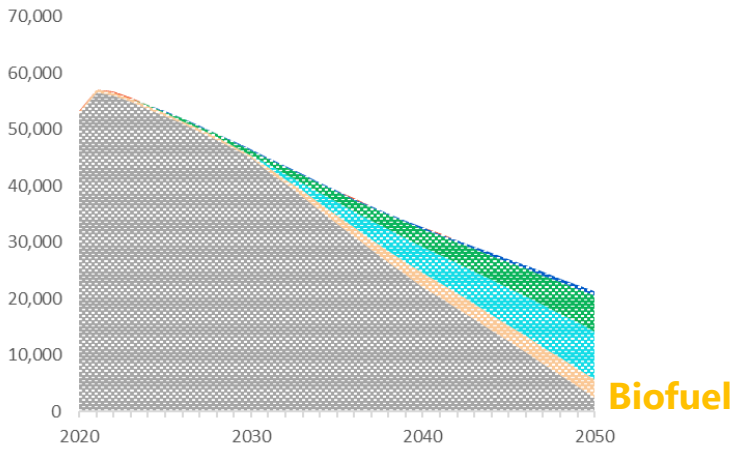
Automotive Fuel Mix (Japan)

(In ktoe)

BAU



CNF



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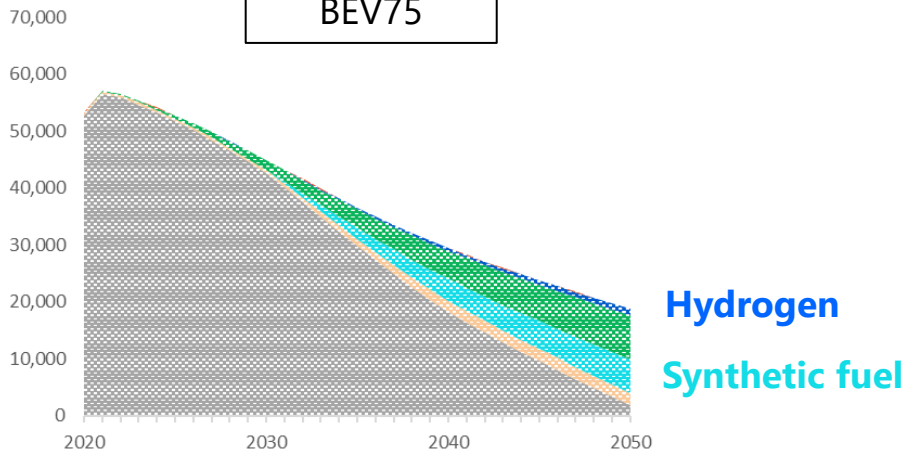

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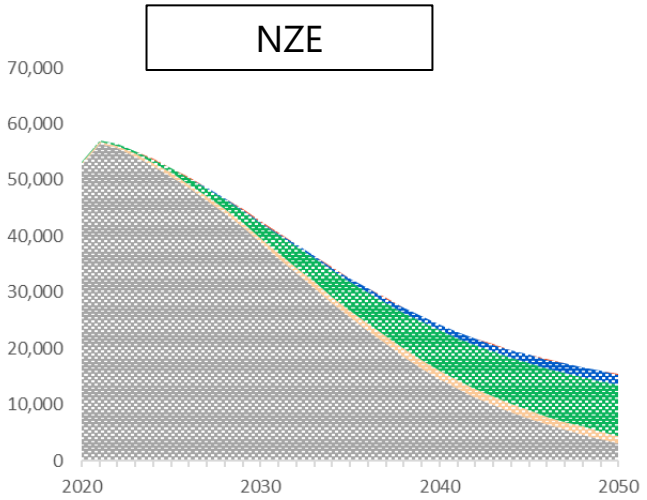
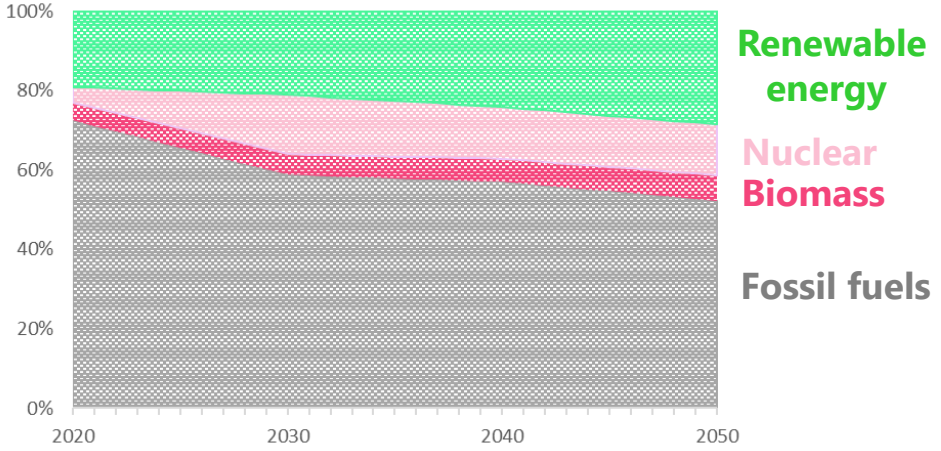


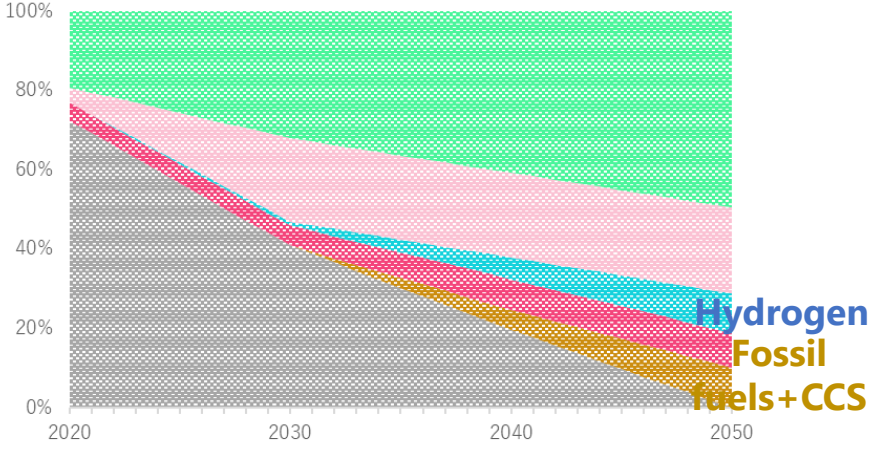
Energy Mix (Japan)

(In %)

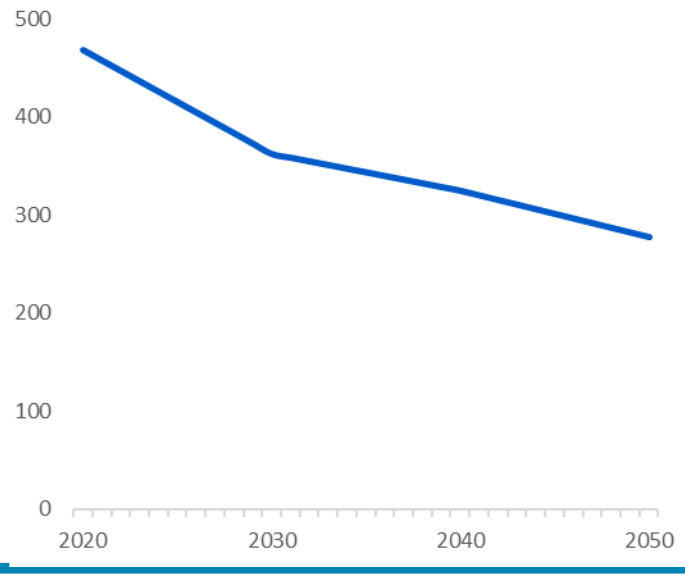
BAU

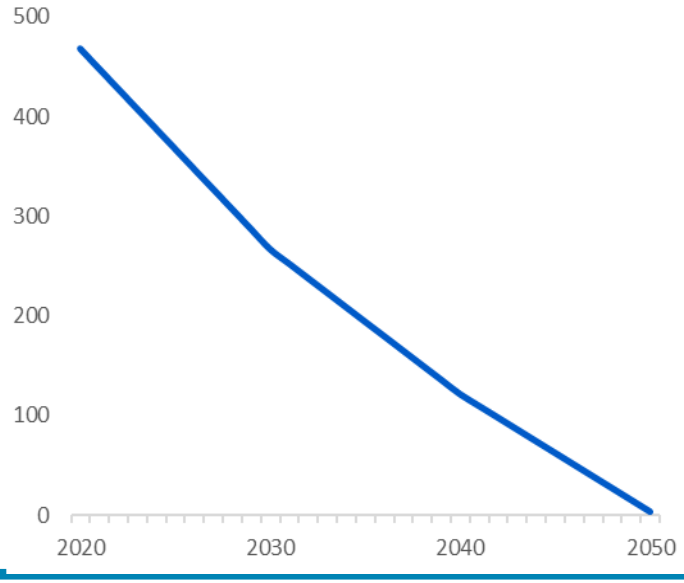


Other than BAU



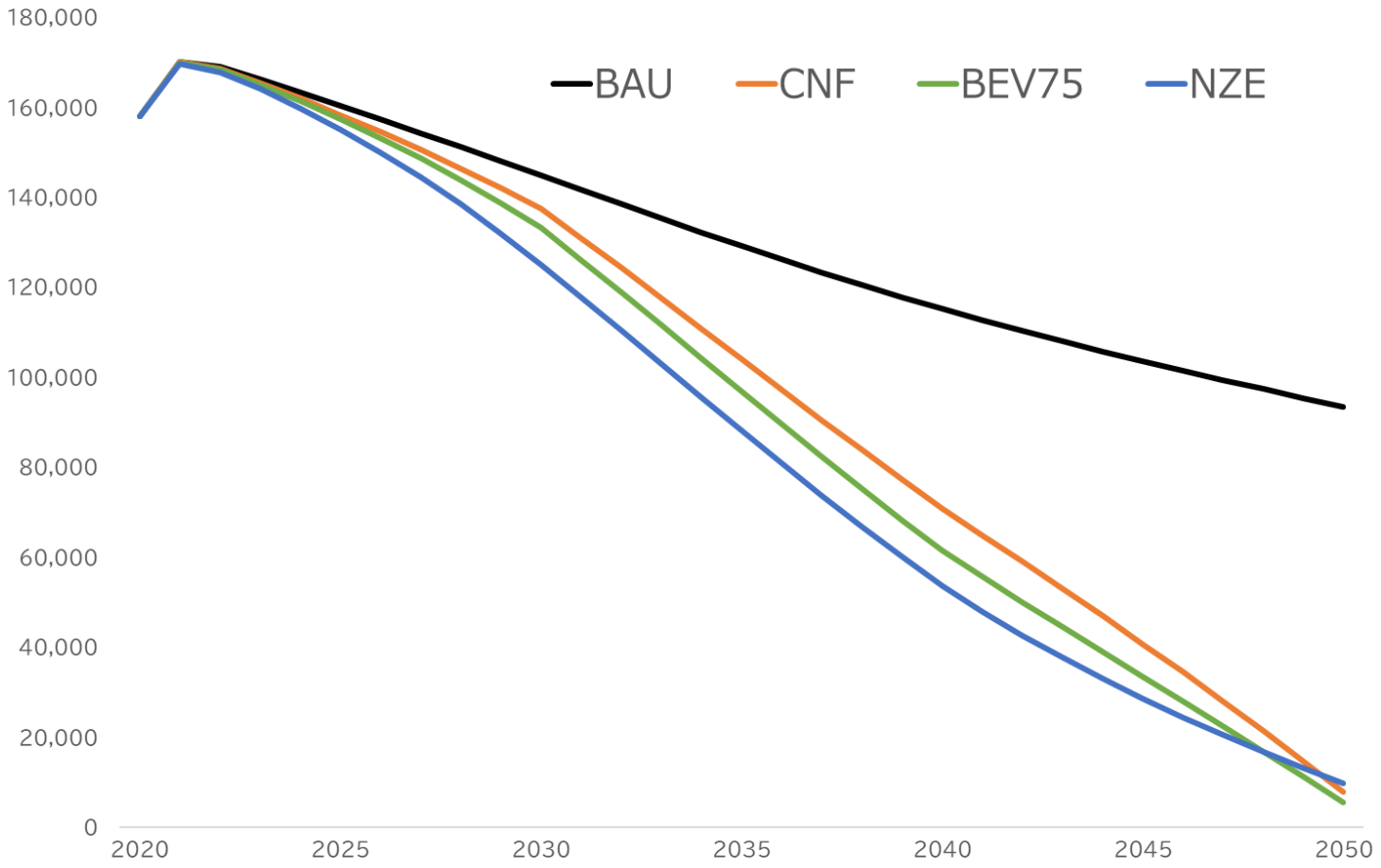
(gCO_2/kWh)





CO_2 Emissions (Japan)

(In $ktCO_2$)



In all the scenarios, CO_2 emission levels are close to carbon neutrality.

3.2 The ASEAN Region

Trends in ASEAN @2050

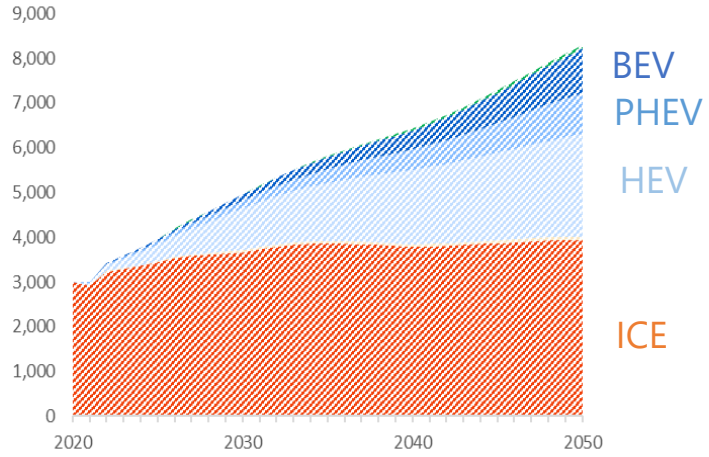
Scenario		Trends in ASEAN	2050/2020 CO_2 emissions
All	Market	• Passenger cars and commercial vehicles: Significant increases in both new vehicle sales and in-use fleets; for motorcycles, gradual increases in new vehicle sales and in-use fleet.	
	Energy mix	• Share of clean energy is approximately 60%.	
CNF	Electrified vehicles	• Share of electrified vehicles in new passenger car sales is about 90%, with about 30% of new passenger cars being BEVs/FCEVs. • Share of BEVs/FCEVs in the in-use passenger car and commercial vehicle fleets is approximately 20%.	-24% approx. (In CNF+, -42% approx.)
	Fuel mix	• About 80% is biofuels + electricity + hydrogen. • CNF share represents approx. 40% of total fuel consumption in 2050. (In CNF+ scenario, CNF share increases to approx. 52%.)	
BEV75	Electrified vehicles	• Share of electrified vehicles in new passenger car sales is 100%, with about 60% of new passenger cars being BEVs/FCEVs. • Share of BEVs/FCEVs in the in-use passenger car and commercial vehicle fleets is approximately 40%.	-42% approx.
	Fuel mix	• About 70% is biofuels + electricity + hydrogen. • CNF share represents approx. 30% of total fuel consumption in 2050.	
NZE	Electrified vehicles	• Share of BEVs/FCEVs in new vehicle sales for all vehicle types is 100%. • Share of BEVs/FCEVs in the in-use passenger car and commercial vehicle fleets is approximately 80%.	-54% approx.
	Fuel mix	• About 80% is biofuels + electricity + hydrogen. (Assumption: Synthetic fuels = 0%.) • Biofuel share = 11% of total fuel consumption in 2020.	

CO_2 emissions fall by about 24% to about 54% compared to 2020.
(CO_2 emissions in non-BAU scenarios just meet or are within the IPCC 2050 1.5℃ climate scenarios' -42% to -68% range.)

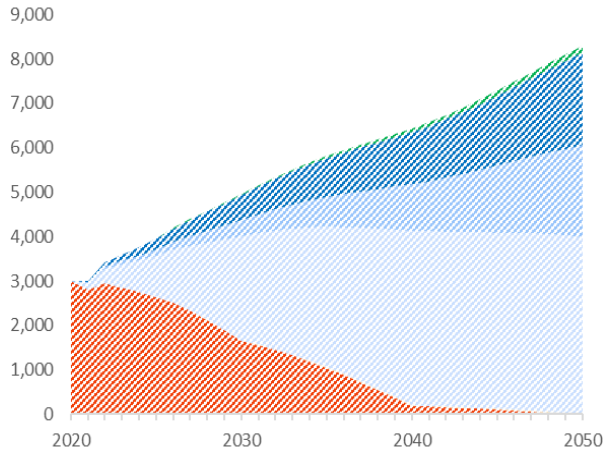
New Passenger Car Sales (ASEAN)

(x 1,000 units)

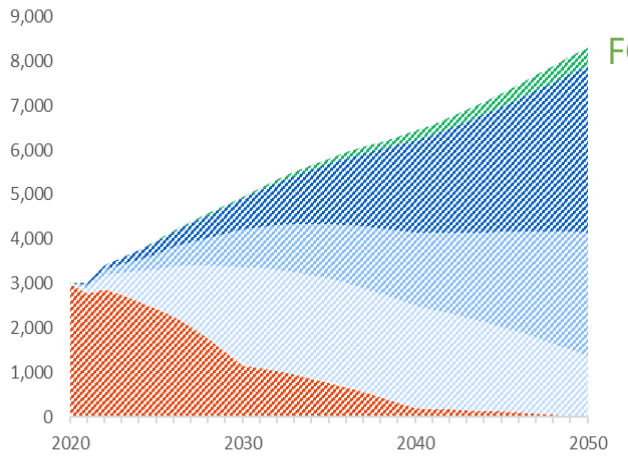
BAU



CNF



BEV75



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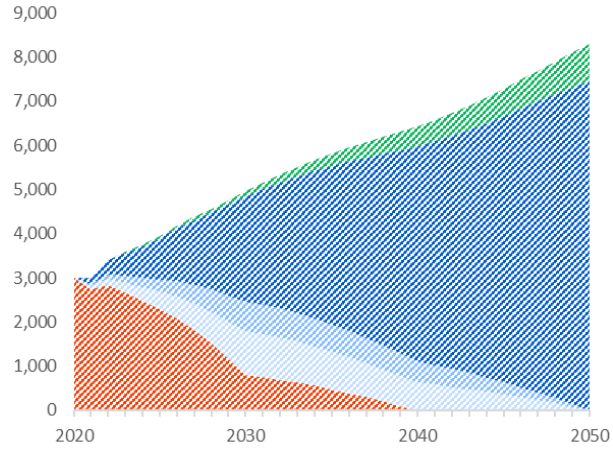
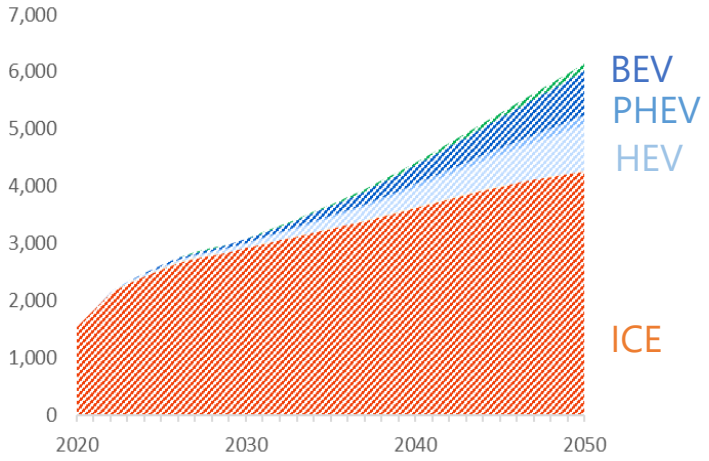


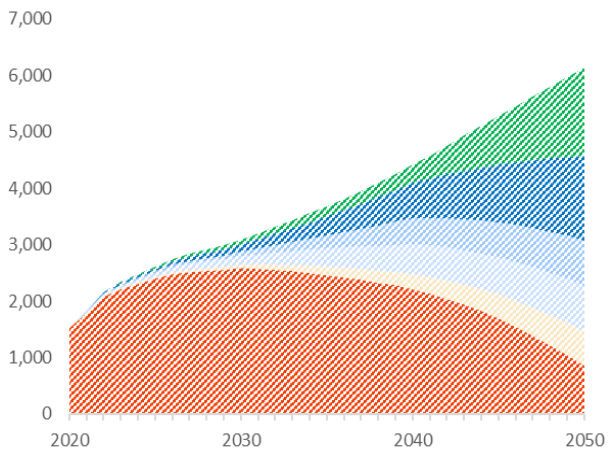
New Commercial Vehicle Sales (ASEAN)

(x 1,000 units)

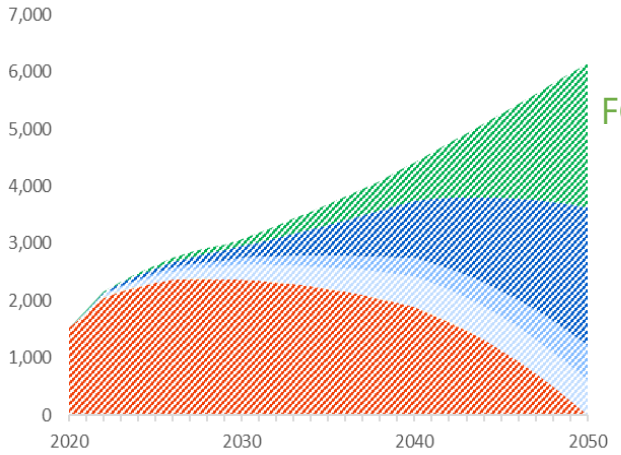
BAU



CNF



BEV75



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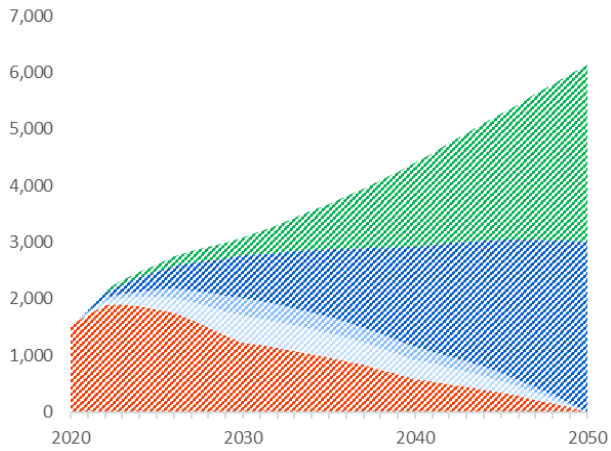
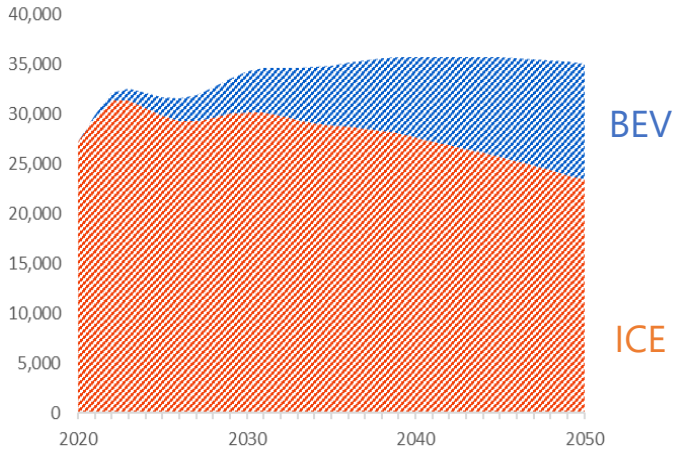


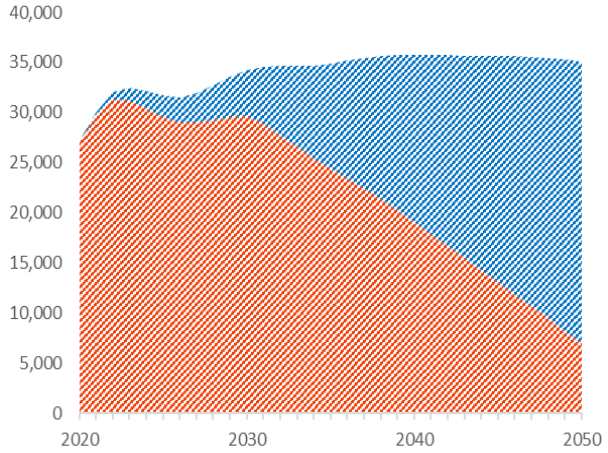
New Motorcycle Sales (ASEAN)

(x 1,000 units)

BAU



CNF



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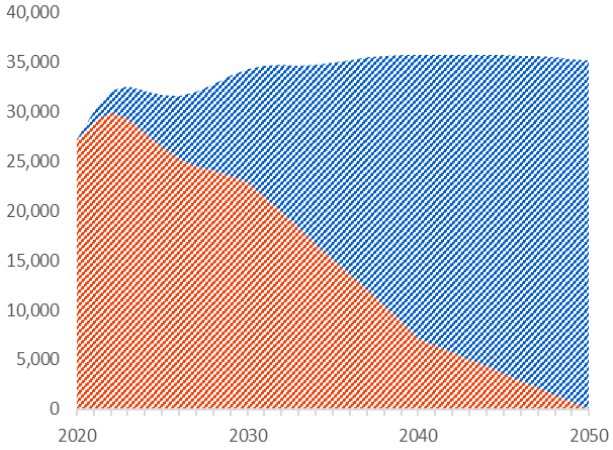

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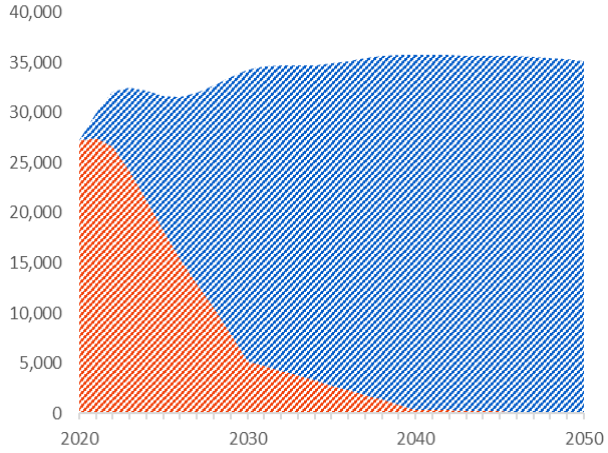
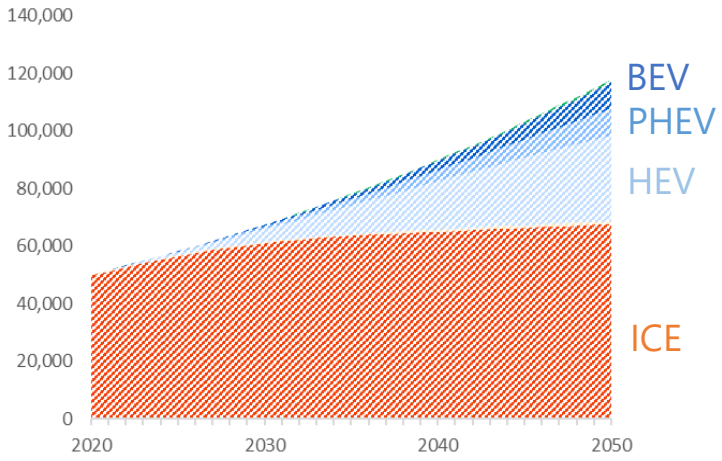


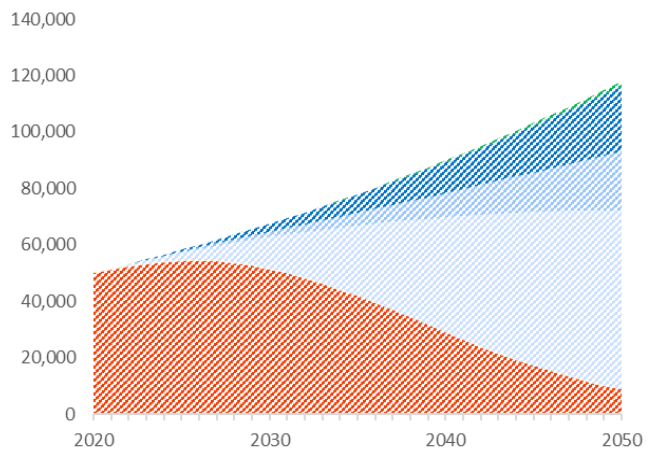
In-Use Passenger Car Fleet (ASEAN)

(x 1,000 units)

BAU



CNF



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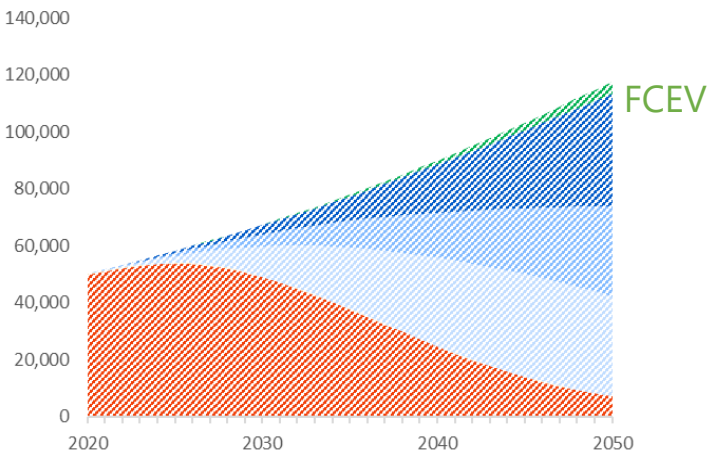

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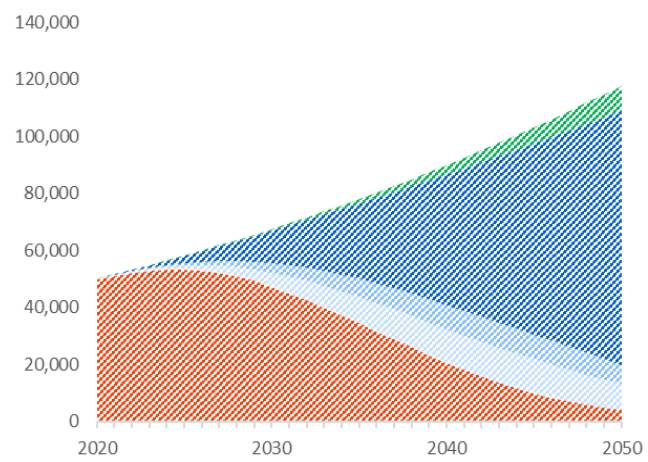
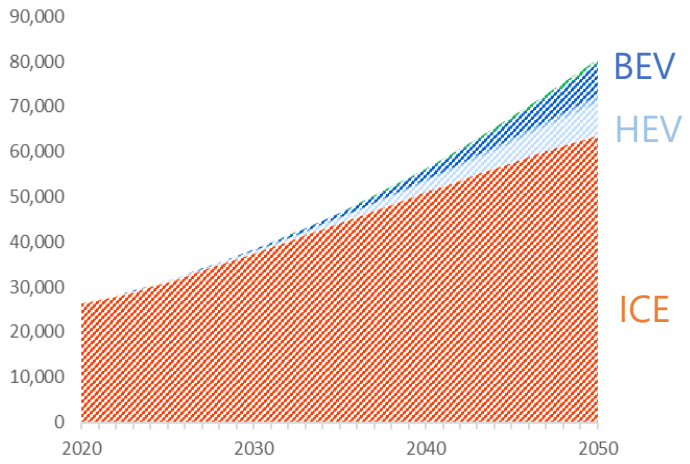


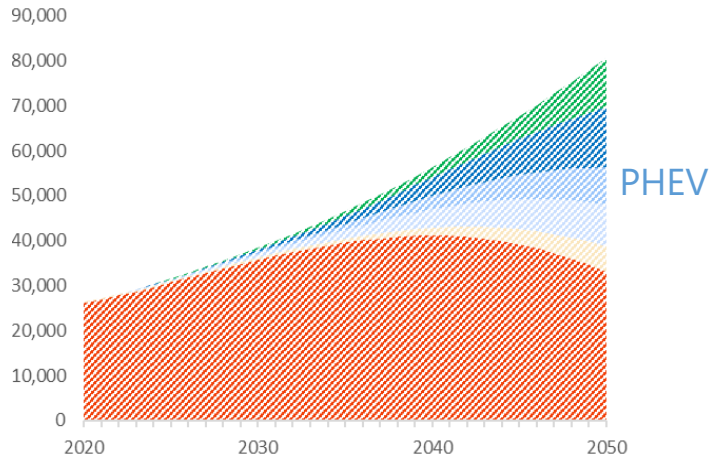
In-Use Commercial Vehicle Fleet (ASEAN)

(x 1,000 units)

BAU



CNF



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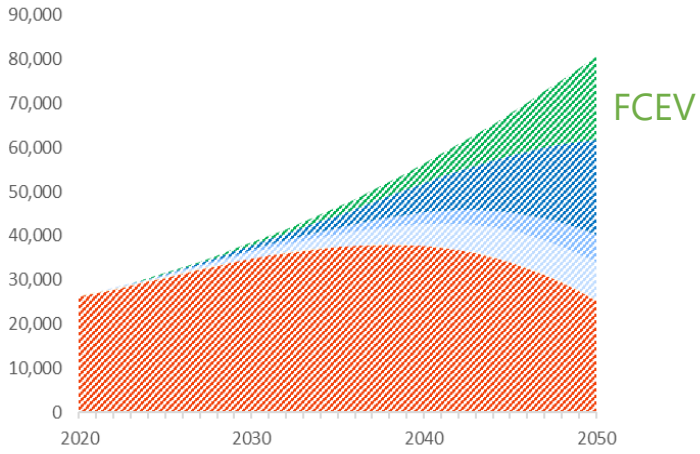

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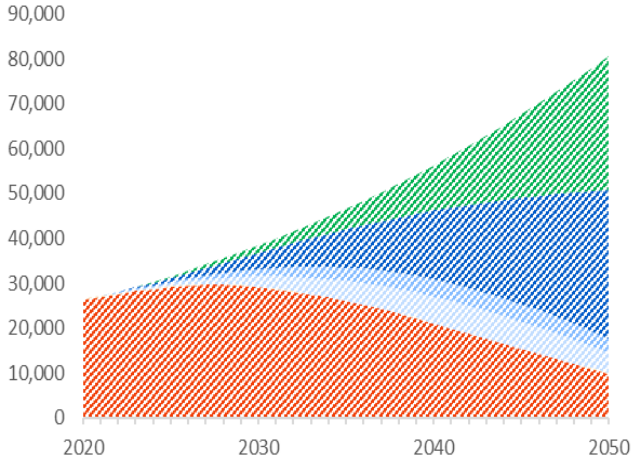
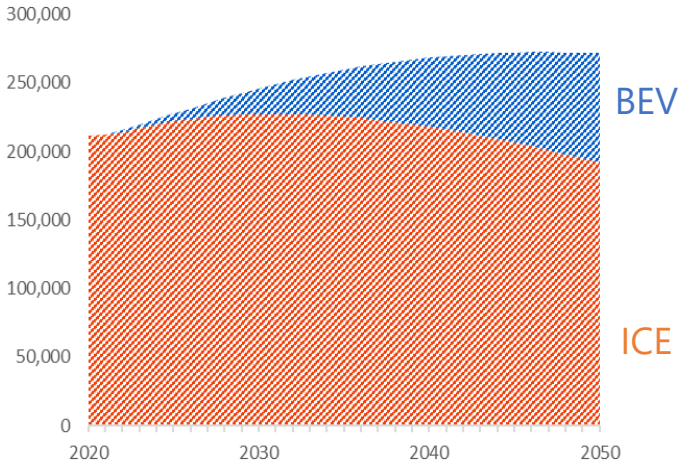


In-Use Motorcycle Fleet (ASEAN)

(x 1,000 units)

BAU



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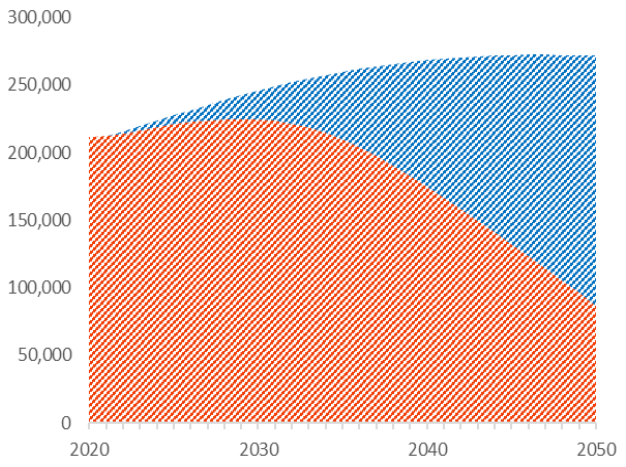

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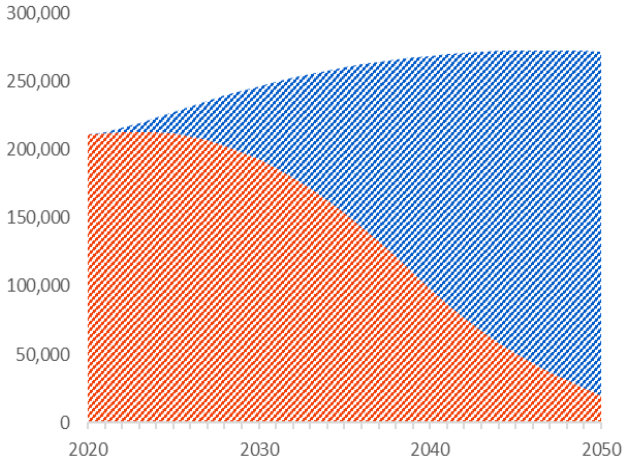

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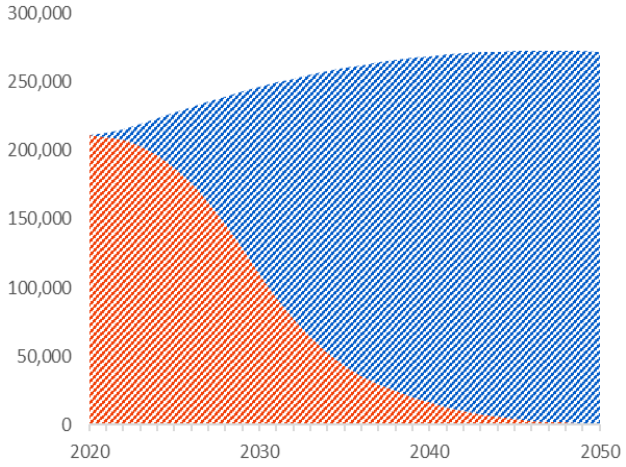
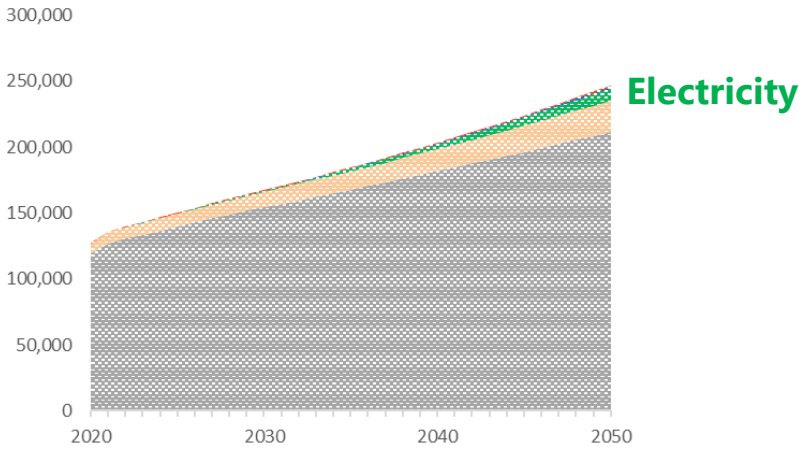


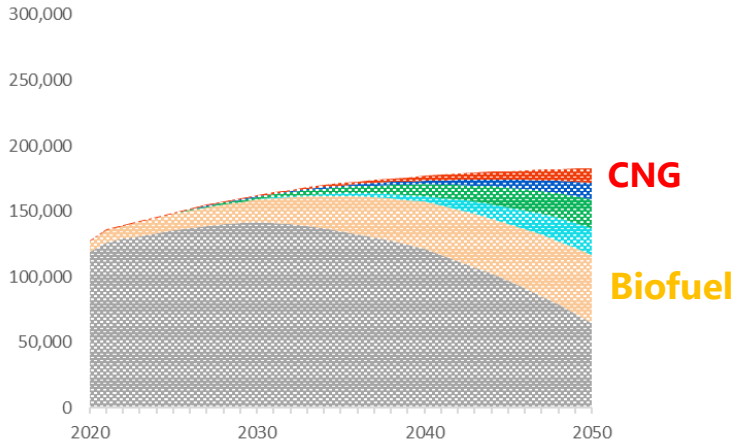
Automotive Fuel Mix (ASEAN)

(In ktoe)

BAU



CNF



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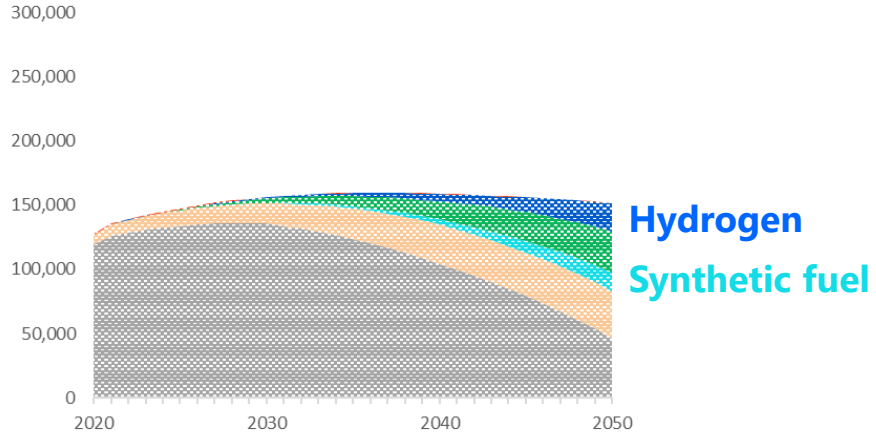

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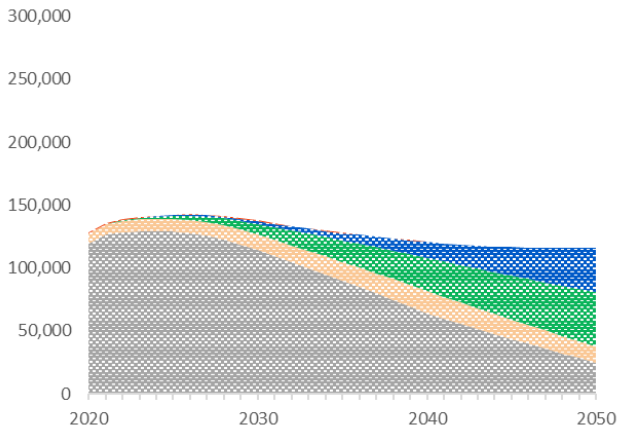
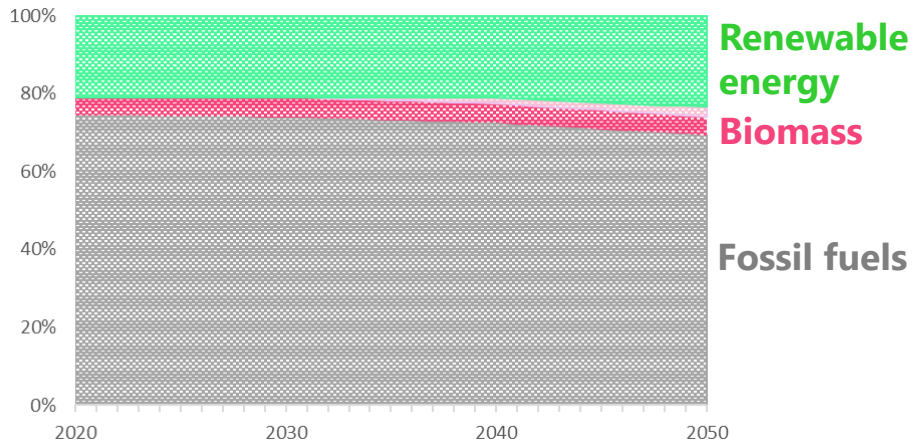


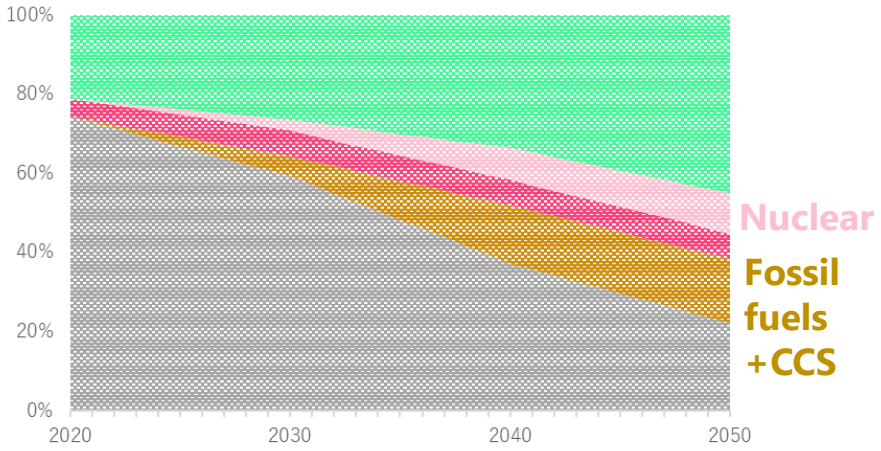
Energy Mix (ASEAN)

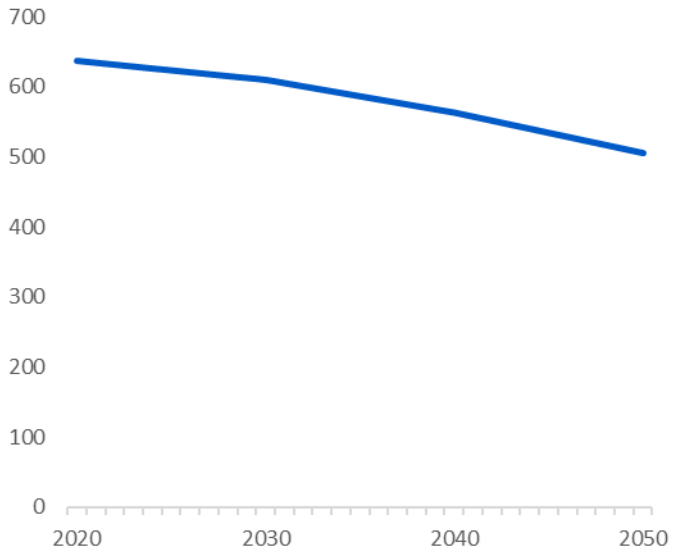
(In %)

BAU

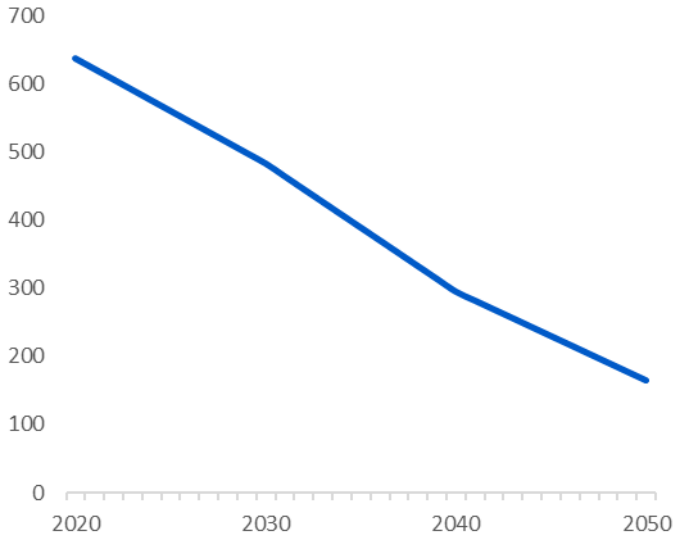


Other than BAU



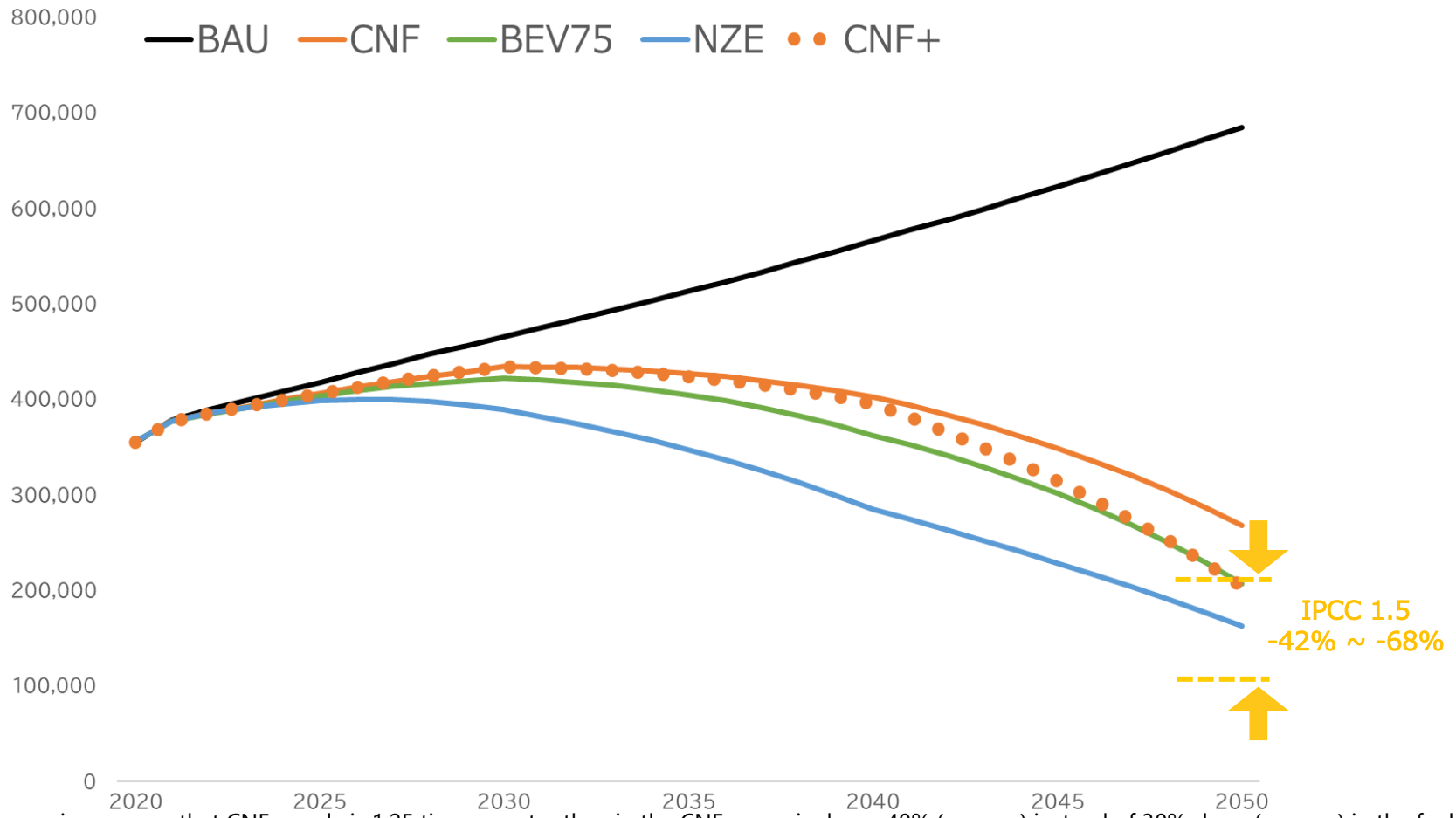


(gCO2/kWh)



CO_2 Emissions (ASEAN)

(In $ktCO_2$)



Note: The CNF+ scenario assumes that CNF supply is 1.25 times greater than in the CNF scenario, has a 40% (approx.) instead of 30% share (approx.) in the fuel mix and that most of the increase will be supplied to Africa, the Middle East, India, and ASEAN where the supply of decarbonized energy is a major challenge.

CO_2 emissions fall by about 24% to about 54% compared to 2020.
(CO_2 emissions in non-BAU scenarios just meet or are within the IPCC 2050 1.5℃ climate scenarios' -42% to -68% range.)