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Global Transportation Energy Consumption: Examination of Scenarios to 2040 using ITEDD

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List of Abbreviations

Btu	British thermal units
CNG	compressed natural gas
CO ₂	carbon dioxide
EV	electric vehicle
GDP	gross domestic product
IEO	International Energy Outlook
ITEDD	International Transportation Energy Demand Determinates
LDV	light-duty vehicle
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MMA	make and model availability
NG	natural gas
OECD	Organization for Economic Cooperation and Development
PHEV	plug-in hybrid electric vehicle
WEPS+	World Energy Projection System Plus

Executive Summary

Energy consumption in the transportation sector is evolving. Over the next 25 years, the U.S. Energy Information Administration's (EIA) *International Energy Outlook (IEO) 2016* Reference case projects that Organization for Economic Cooperation and Development (OECD) countries' transportation energy consumption will remain relatively flat. In contrast, non-OECD countries will grow to levels higher than in OECD countries by the early 2020s. This rapid non-OECD growth results in continued transportation energy consumption growth through at least 2040.

Some significant uncertainties exist in future transportation energy consumption. This study examines the potential energy impacts associated with some of those uncertainties using EIA's new international transportation model – the International Transportation Energy Demand Determinants (ITEDDD) model. The model outputs presented here are produced in a standalone run, rather than in an overall integrated global dynamic framework, and as such, are intended to be more illustrative than conclusive. However, the fundamental issues, and the use of more detailed modeling for capital stock and transportation demand, both set the stage for fully integrated analysis in future EIA work and provide new insights and reference points for related work.

One area of uncertainty in modeling the transportation sector is consumer preference and rates of vehicle ownership. Will consumers desire more fuel-efficient vehicles and will they prefer public transportation to individual vehicle ownership? Or will the reverse happen where consumers place a high value on vehicle attributes other than fuel economy improvement and desire the personal mobility and flexibility of owning and using a vehicle?

Another area of uncertainty in modeling the transportation sector is government policy. For example, several countries (Canada, China, European Union, Japan, Mexico, and the United States) have enacted light-duty vehicle fuel economy standards. A few countries (Canada, China, Japan, and the United States) also have enacted fuel economy standards for heavy-duty vehicles. Although vehicles are designed for a global market, some uncertainty remains regarding the growth in vehicle demand in non-regulated markets, whether those countries will adopt fuel economy standards, and how efficient vehicles will need to be to meet consumer preference or newly enacted fuel economy standards. Some policies encourage the adoption of alternative-fueled vehicles by consumers or require the production of alternative-fueled vehicles by automobile manufacturers. These policies exist for on-road vehicles but in the future could affect trains and marine vessels. Depending on what fuels are being replaced and what other policies exist or might be put in place, the effect on total transportation energy consumption could range from large to none.

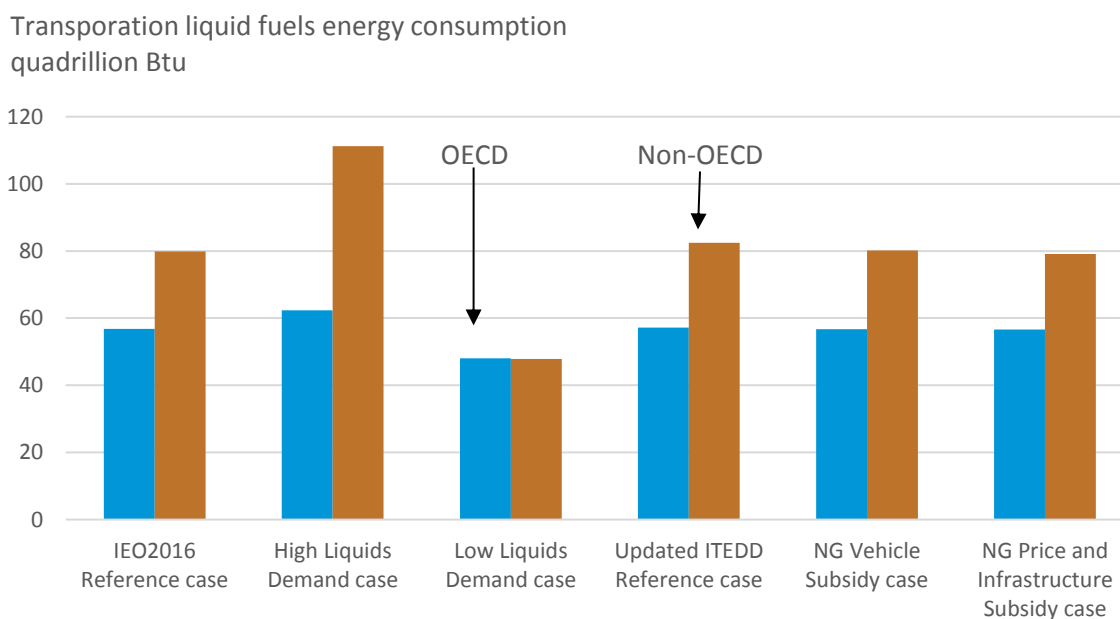
This study considered six worldwide scenarios and two region-specific scenarios to examine future transportation energy consumption. The six global scenarios presented are the following:

- International Energy Outlook (IEO) 2016 Reference case
- High Liquids Demand case
- Low Liquids Demand case
- Updated ITEDDD Reference case
- Natural Gas Vehicle Subsidy case
- Natural Gas Price and Infrastructure Subsidy case

The first scenario is the EIA's *International Energy Outlook 2016* (IEO2016) Reference case projections. The second and third scenarios (High and Low Liquids Demand) were developed by adjusting consumer preferences and policies. The third scenario (Updated ITEDD Reference case) reflects the IEO2016 Reference case with ITEDD updates to the on-road module to allow for more refined policy implementation. The last two worldwide scenarios focus on different light- and/or heavy-duty vehicle alternative fuel policies.

Across the worldwide scenarios the projections show that non-OECD countries experience greater differences in transportation liquids consumption than OECD countries (Figure 1). Non-OECD countries experience more growth in their transportation sectors than OECD countries in the reference cases, through 2040. Because many people in non-OECD countries are purchasing vehicles for the first time during the projection period, changes in vehicle fuel economy or fuel choice can have an effect more quickly than in countries with existing large vehicle stocks. Through consumer preference and policy it is easier for developing countries to have more moderate growth in personal vehicle ownership and personal vehicle-miles traveled than in developed countries that already have high vehicle-per capita ratios. However, developing countries could reach OECD-level vehicle per capita ratios more quickly than currently projected.

Figure 1. Transportation liquid fuels consumption in worldwide scenarios for OECD and non-OECD countries in 2040



Source: U.S. Energy Information Administration



Two region-specific scenarios were also considered. The first scenario adjusts consumer preference and policies in OECD Europe to reduce light-duty vehicle diesel sales. This scenario made no assumption about which powertrain would take the place of diesel vehicles. Based on make and model availability and price, motor gasoline vehicles sales more than offset the reduction in diesel sales. The second region-specific scenario considered the effects on the transportation sector of slower GDP growth in China than the current forecast. The slowdown in China's GDP growth results in reduced passenger travel and freight travel.

Preface

The movement of people and products is an important factor in determining the potential growth in international energy demand. As part of our overall effort to expand modeling and analytical capability to understand global energy demand, the U.S. Energy Information Administration (EIA) has developed a new global transportation energy model, the International Transportation Energy Demand Determinants (ITEDD) model, within the World Energy Projection System Plus (WEPS+) model. ITEDD examines in greater detail issues related to demand for transportation services and associated uncertainties and demand for energy.

Analyses presented in this report are based on model results for a number of international transportation energy consumption scenarios using ITEDD. This analysis demonstrates new EIA modeling and analysis capabilities, presents examples of key energy-demand determinants, and shows how a quantitative framework can aid in understanding them. The model outputs presented here are not produced in an overall integrated global dynamic framework (discussed below) and, as such, are intended to be more illustrative than conclusive. However, the fundamental issues, and the use of the new, more detailed capital stock and transportation demand modeling, both set the stage for fully integrated analysis in EIA publications and provide interested parties with new insights and reference points for related work. The new model's [documentation](#) and framework ([Component Design Report](#)), together with the results in this report, contribute to a stronger base for research, analysis, and discussion of global energy demand topics.

The IEO2016 Reference case, including corresponding input assumptions and modules, was used in this analysis, but some scenarios also reflect updates incorporated in other WEPS+ modules to test the ITEDD response. As such, multiple Reference cases were developed and are described in this report along with the scenarios associated with those Reference cases.

This report begins with a brief description of the global transportation modeling system and then describes, by section, the Reference case, corresponding sensitivity cases, and results for each of the topic areas examined. It concludes with a summary of the energy impacts examined in the analyses.

1. EIA's Global Modeling Systems

WEPS+ is used to project global energy supply, demand, and prices. We present the results of the WEPS+ model EIA uses in the *International Energy Outlook* (IEO). The model consists of four demand modules (residential, commercial, industrial, and transportation); two transformation models (electricity generation and district heating); five supply models (petroleum, natural gas, coal, and two refinery models); and two additional submodules (macroeconomic and greenhouse gas emission models). The ITEDD model is the transportation submodule in WEPS+. We first used the ITEDD model in the IEO2016 analysis.¹

Energy consumption by passenger and freight travel is determined in the ITEDD submodule by mode and fuel. The four transportation modes are on-road, rail, water, and air. Each of these modes is divided into sub-modes for passenger and freight travel. The six on-road sub-modes are light-duty vehicles (private and commercial), 2- and 3-wheel vehicles, buses, light-duty trucks, medium-duty trucks, and heavy-duty trucks. The first three on-road sub-modes are passenger services measured in passenger-miles. The latter three are freight services measured in ton-miles. WEPS+ considered 13 fuel types, but this report focuses on seven fuels of interest to transportation services— motor gasoline, diesel, jet fuel, residual fuel, liquefied petroleum gas (LPG), natural gas, and electricity.

The ITEDD model solves for energy consumption in the transportation sector for the 16 WEPS+ regions. Seven of the regions are part of the Organization for Economic Cooperation and Development (OECD) – United States, Canada, Mexico/Chile, OECD Europe, Japan, Australia/New Zealand, and South Korea. The remaining nine regions consist of non-OECD countries – Russia, Other Non-OECD Europe and Eurasia, China, India, Other Non-OECD Asia, Middle East, Africa, Brazil, and Other Central and South America.

After first using the ITEDD model in IEO2016, we ran additional side cases. Two of these side cases – the High Liquids Demand case and Low Liquids Demand case – tested the flexibility of the model. These cases help to inform the development of new modeling capabilities in the ITEDD model that are highlighted in two other cases – the Natural Gas Vehicle Subsidy case and the Natural Gas Price and Infrastructure Subsidies case. These cases showed the potential effect of policies on accelerating the adoption of alternative fuels as on-road transportation fuels. The remaining cases focus on potential region-focused events – the Diesel Reduction in Europe case and the Low Growth in China case.

These cases are from different stages of ITEDD model refinement and consequently are based on different reference cases (baselines) (Table 1). The first set of cases uses the IEO2016 Reference case as a base for the analysis – High Liquids Demand case, Low Liquids Demand case, and Diesel Reduction in Europe case. An overview of the first set of cases is provided in Section 0. The second Reference case includes the same ITEDD model, but the macroeconomic variables were updated (Section 0). Only the Low Growth in China case uses the second Reference case. The last Reference case (Section 0) uses an updated version of the ITEDD model. Two cases use the third Reference case - Natural Gas Vehicle Subsidy case and Natural Gas Price and Infrastructure Subsidies case.

¹ The previous transportation model was the International Transportation Model (ITran).

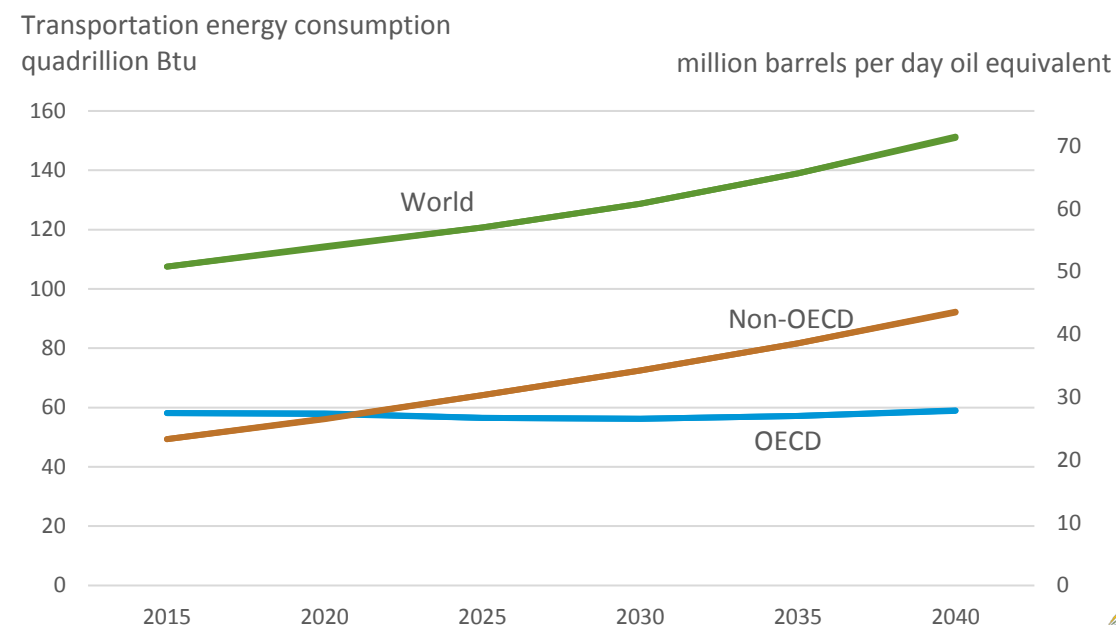
Table 1. Reference case and side case alignment

	IEO2016 Reference case	Updated Macro Reference case	Updated ITEDD model Reference case
Low Liquids Demand case	X		
High Liquids Demand case	X		
Diesel Reduction in Europe case	X		
Low Growth in China case		X	
Natural Gas Vehicle Subsidy case			X
Natural Gas Price and Infrastructure Subsidies case			X

2. IEO2016 Reference case

The Low Liquids Demand case, the High Liquids Demand case, and the Diesel Reduction in Europe case are all based on the IEO2016 Reference case. Worldwide transportation energy consumption is projected to reach 151 quadrillion British thermal units (Btu) in 2040, an increase of 44 quadrillion Btu from 2015 in the IEO2016 Reference case (Figure 2). Through 2020, OECD countries are projected to consume more energy for transportation than non-OECD countries. Transportation energy consumption in OECD countries remains relatively flat through the projection period because fuel efficiency improvements keep pace with increases in energy demand. However, transportation energy consumption in non-OECD countries increases throughout the entire projection period. This growth occurs because demand for transportation services in non-OECD countries, due to population and GDP growth, outpaces fuel efficiency improvements realized in the transportation modes delivering those services.

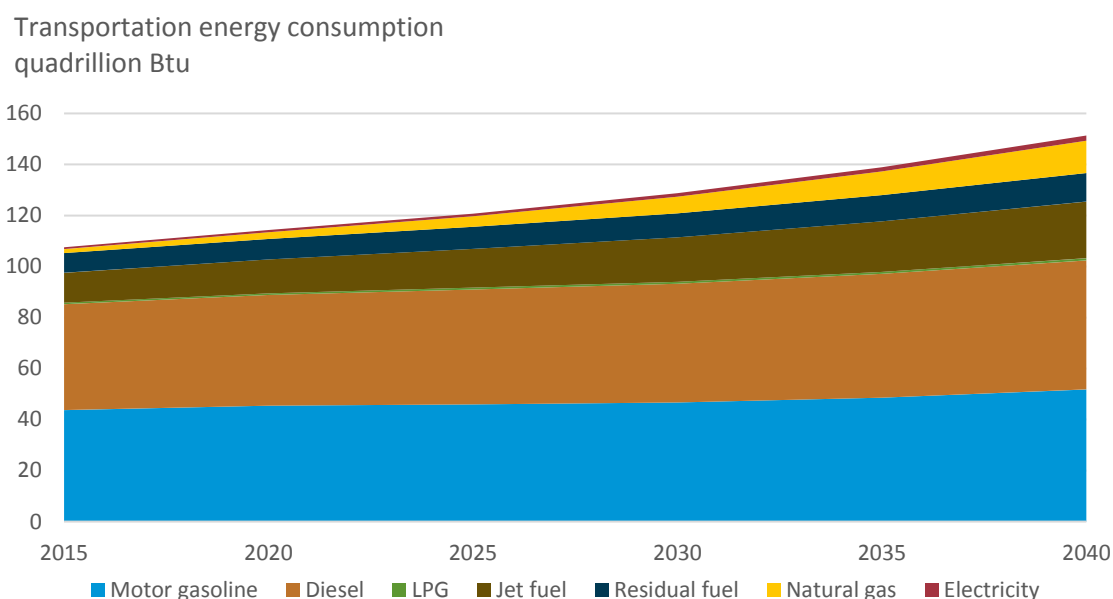
Figure 2. IEO2016 Reference case transportation energy consumption



Source: U.S. Energy Information Administration



Petroleum-based liquid fuels currently account for most of global transportation energy consumption and will continue to do so through 2040 in the IEO2016 Reference case (Figure 3). However, demand for natural gas as a transportation fuel grows more than any other transportation fuel, increasing from 1.6 quadrillion Btu in 2015 to 12.7 quadrillion Btu in 2040. As with overall transportation energy consumption growth, most of this growth in natural gas use occurs in non-OECD countries because countries in several regions have policies in place to support the growth of natural gas in vehicles, including the Middle East and Other non-OECD Asia.

Figure 3. IEO2016 Reference case world transportation energy consumption by fuel

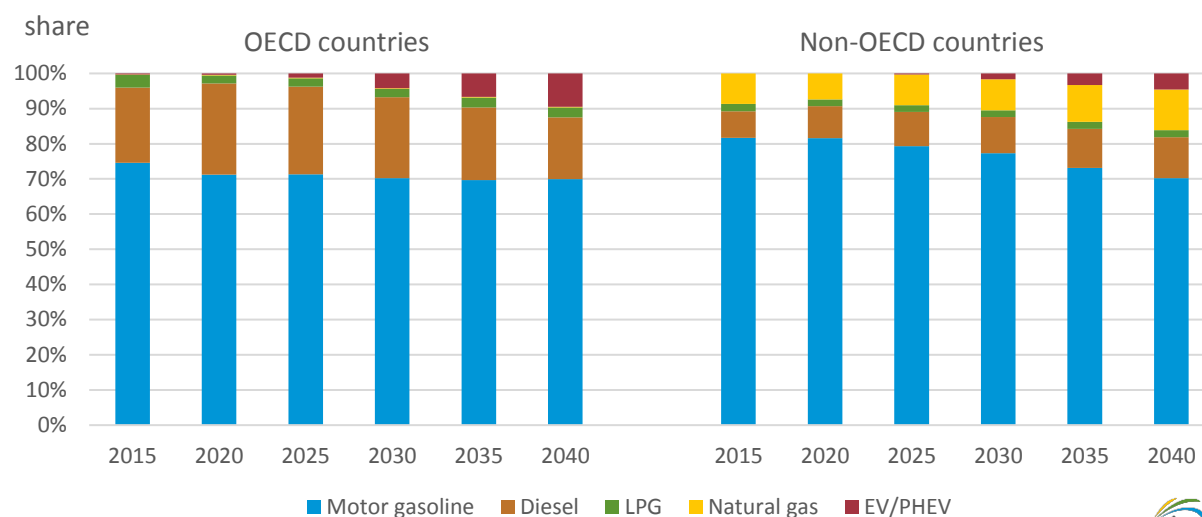
Source: U.S. Energy Information Administration



In the IEO2016 Reference case, three main attributes were considered when determining light-duty vehicle (LDV) sales: vehicle price, the cost of driving, and make and model availability (MMA). MMA represents the availability of each type of vehicle in the market. When a new vehicle type is introduced, such as a plug-in hybrid electric or natural gas vehicle, generally only a few manufacturers sell it in a few models. A low MMA tends to reduce market share because the model varieties some consumers wish to buy are not available. As a vehicle type becomes more popular, more models are offered, which in turn makes that vehicle type attractive to more customers.

Vehicles fueled by motor gasoline are the primary new LDV sold throughout the projection period, although alternative-fueled vehicles do gain market share (Figure 4). In OECD countries, the primary alternative-fueled vehicles at the end of the projection period are electric and plug-in hybrid electric vehicles. The combined share of electric and plug-in hybrid electric vehicles in OECD countries increases from less than 1% in 2015 to 10% in 2040. In non-OECD countries, diesel, natural gas, and electric and plug-in hybrid electric vehicles experience a three-to-five percentage point increase in the total share of LDVs sold in non-OECD countries. In 2040, diesel and natural gas vehicles each represent approximately 11.5% of the total LDV new sales market in non-OECD countries, and electric and plug-in hybrid electric vehicles combined represent 4.5%.

Figure 4. IEO2016 Reference case new LDV sales shares in 2015-2040 for OECD and non-OECD countries



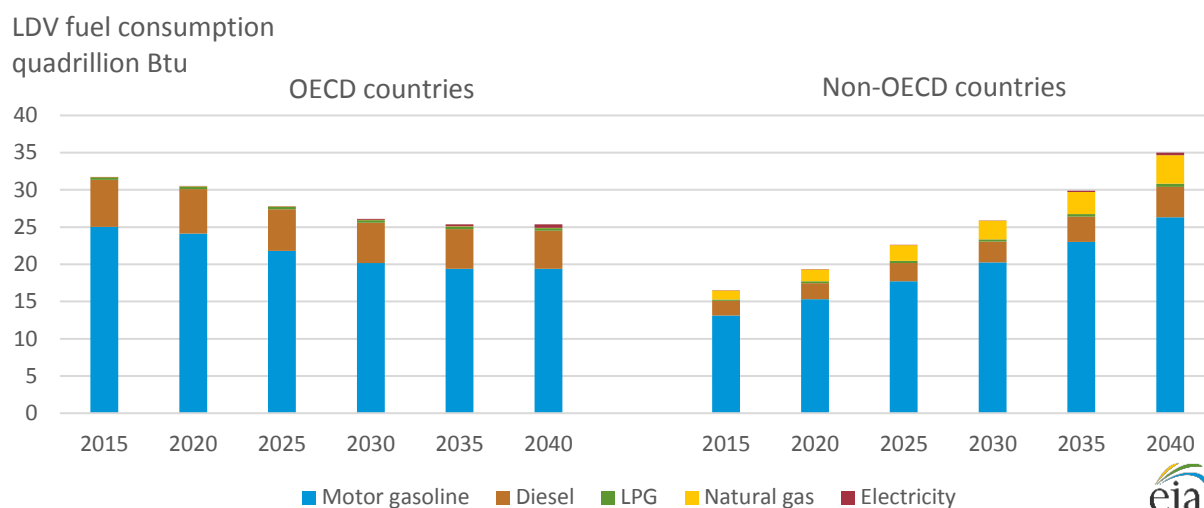
Source: U.S. Energy Information Administration



Despite increases in the share of alternative-fueled LDVs in OECD countries, motor gasoline remains the primary transportation fuel. Overall OECD LDV fuel consumption decreases from 32 quadrillion Btu in 2015 to 25 quadrillion Btu in 2040 (Figure 5). Motor gasoline and diesel consumption both decrease by approximately 20% during the projection period. These results are largely influenced by improvements in fuel economy as a result of fuel economy standards in most OECD countries. The share of motor gasoline decreases from 79% of the LDV transportation energy consumption in 2015 to 76% in 2040. The natural lag due to vehicle stock turnover means the fuel consumption of alternative-fueled vehicles is still relatively low by 2040.

In non-OECD countries, where more people will purchase a vehicle for the first time during the projection period than in OECD countries, LDV fuel consumption more than doubles between 2015 and 2040, increasing from 16 quadrillion Btu to 35 quadrillion Btu (Figure 5). Motor gasoline increases from 13 quadrillion Btu in 2015 to 26 quadrillion Btu in 2040 but, as a percent of LDV fuel consumption, decreases from 80% to 75% between 2015 and 2040. Natural gas energy consumption as a percent of total LDV energy consumption increases by almost four percentage points over the projection period.

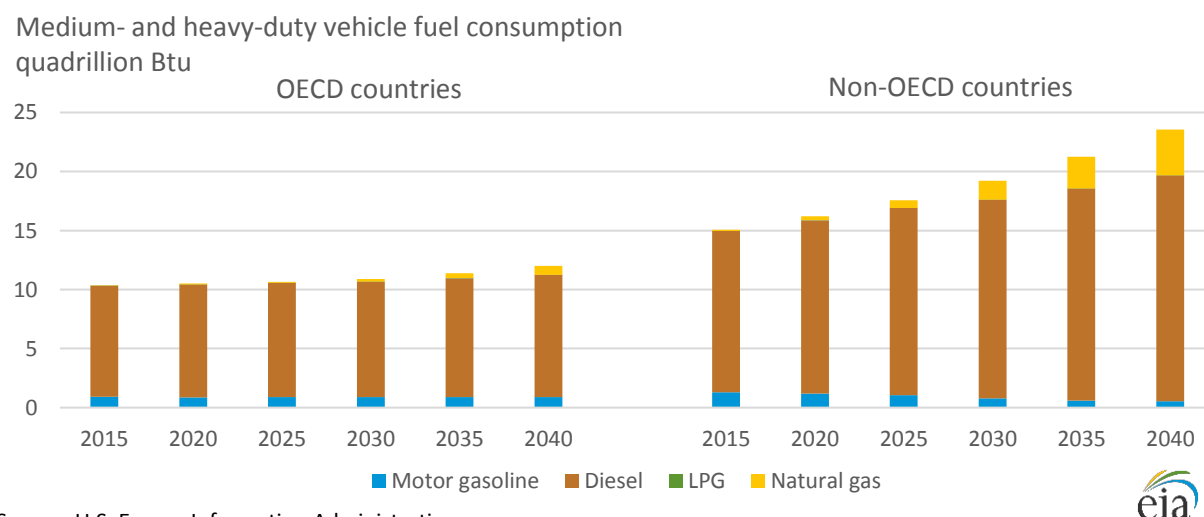
Figure 5. IEO2016 Reference case LDV fuel consumption in OECD and non-OECD countries



Source: U.S. Energy Information Administration

Growth in fuel consumption in the medium- and heavy-duty vehicle sector comes mainly from non-OECD countries (Figure 6). Total medium- and heavy-duty fuel consumption increases from 15.1 quadrillion Btu in 2015 to 23.6 quadrillion Btu in 2040 in non-OECD countries. In OECD countries, medium- and heavy-duty vehicle fuel consumption increases from 10.4 quadrillion Btu in 2015 to 12.0 quadrillion Btu in 2040. Diesel remains the primary fuel consumed in both OECD and non-OECD countries during the projection period. However, as a result of relative fuel costs of natural gas and diesel, natural gas fuel use increases from less than 1% of all fuel consumed to 6% and 17% of medium- and heavy-vehicles for OECD and non-OECD countries, respectively.

Figure 6. IEO2016 Reference case medium- and heavy-duty vehicle fuel consumption in OECD and non-OECD countries



Source: U.S. Energy Information Administration

2.1 Low Liquids Demand case

The Low Liquids Demand case tests the flexibility of the newly developed ITEDD model. In this case, policies and consumer preferences were changed to reflect possible events that could lead to lower liquids and energy consumption in the transportation sector. The changes were assumed to begin in 2021. Most of the changes were in the LDV sector:

- LDV ownership growth rates were lowered
- Region-specific consumer preference coefficients for LDV purchase by fuel and technology type and rate of change were allowed to increase the preference for alternative-fuel vehicles
- Prices of new alternative-fuel LDVs were changed to reflect either technology cost reduction or subsidy increase

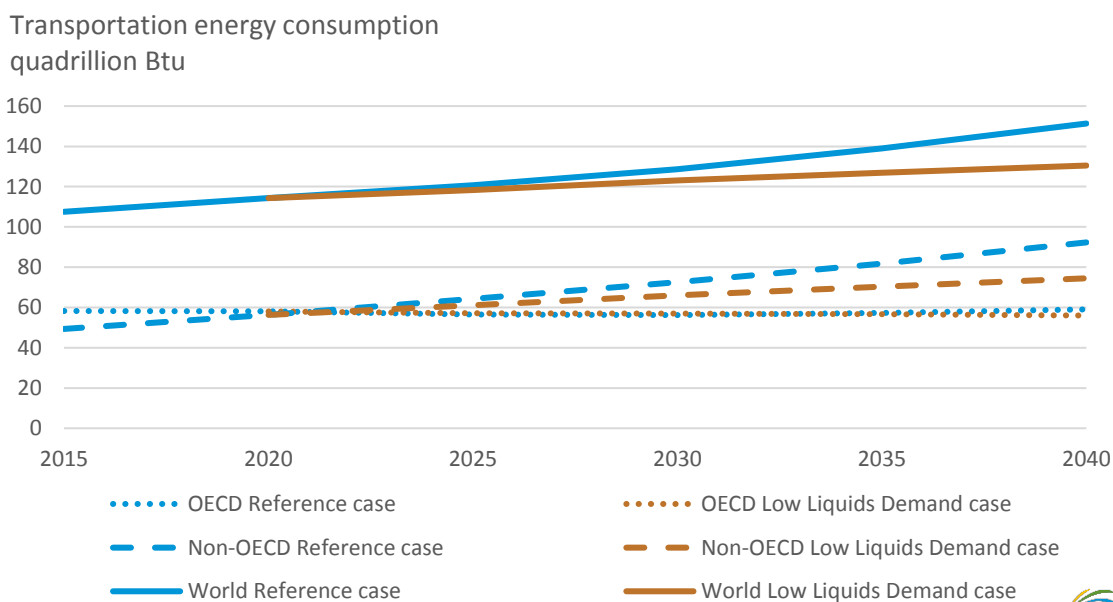
Fuel economy standards for LDVs were not changed from the IEO2016 Reference case for this scenario.

Additional changes were made in the freight sector:

- Increased the rates of fuel efficiency improvement for rail and marine
- Increased load factors for medium- and heavy-duty vehicles
- Increased the willingness to fuel switch for all freight modes

Worldwide transportation energy consumption was 21 quadrillion Btu lower in the Low Liquids Demand case than in the IEO2016 Reference case in 2040 (Figure 7). Most of the difference between the IEO2016 Reference case and the Low Liquids Demand case occurs in non-OECD countries.

Figure 7. IEO2016 Reference case and Low Liquids Demand case transportation energy consumption

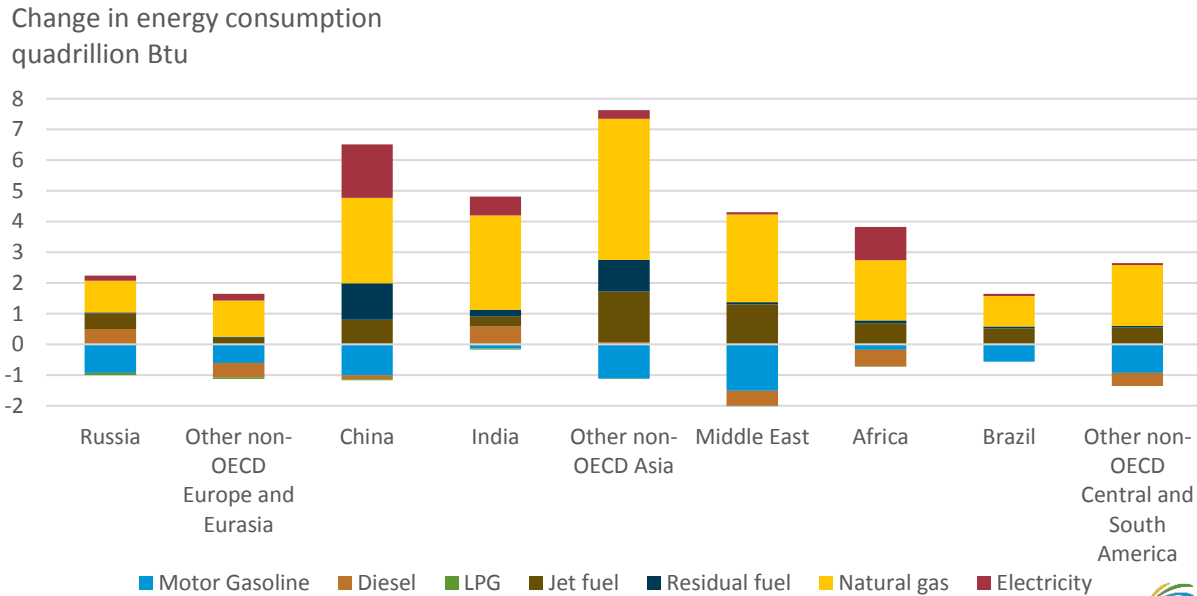


Source: U.S. Energy Information Administration



In the Low Liquids Demand case, natural gas increases by 20 quadrillion Btu across all non-OECD regions between 2015 and 2040 (Figure 8). Natural gas replaces motor gasoline and diesel in LDV and medium- and heavy-duty vehicle sectors. Electricity energy consumption increases by 4 quadrillion Btu over the projection period. China accounts for 40% of the growth in electricity as a result of their existing pro-electric vehicle policies. Motor gasoline consumption decreases by 7 quadrillion Btu across all non-OECD regions.

Figure 8. Change in non-OECD energy consumption between 2015 and 2040 in the Low Liquids Demand case

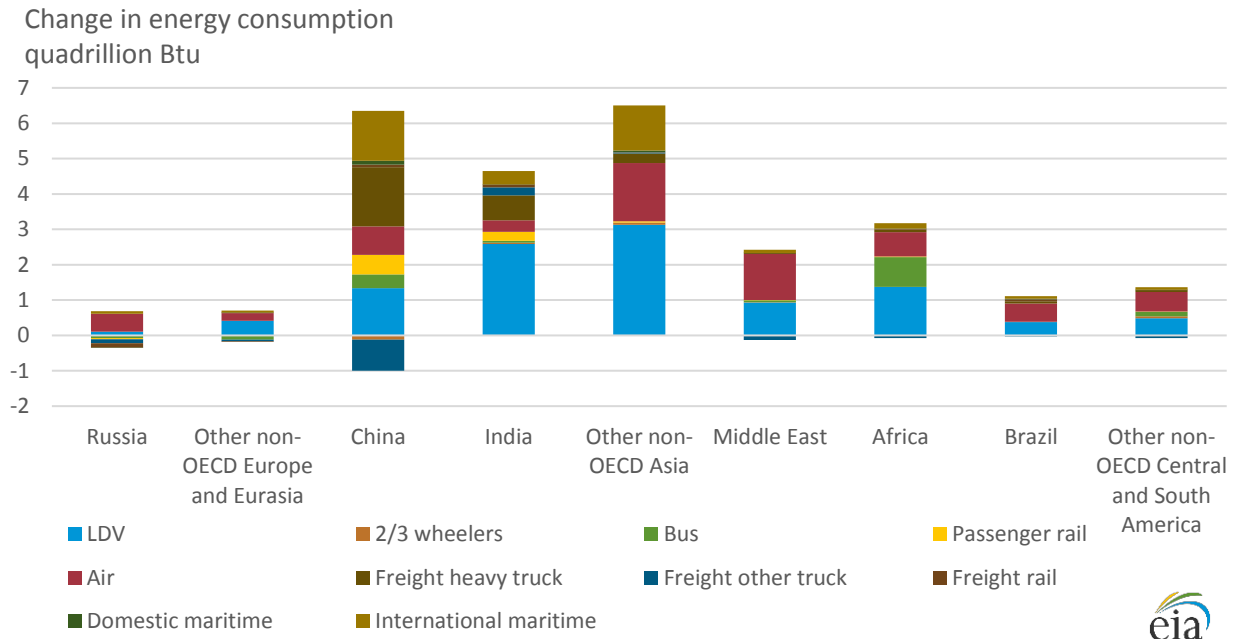


Source: U.S. Energy Information Administration



LDVs grow more than any other mode in the Low Liquids Demand case (Figure 9). Across all non-OECD regions, LDV fuel consumption grows by 10.8 quadrillion Btu between 2015 and 2040. International maritime fuel use increases more than any other freight mode – 3.6 quadrillion Btu between 2015 and 2040.

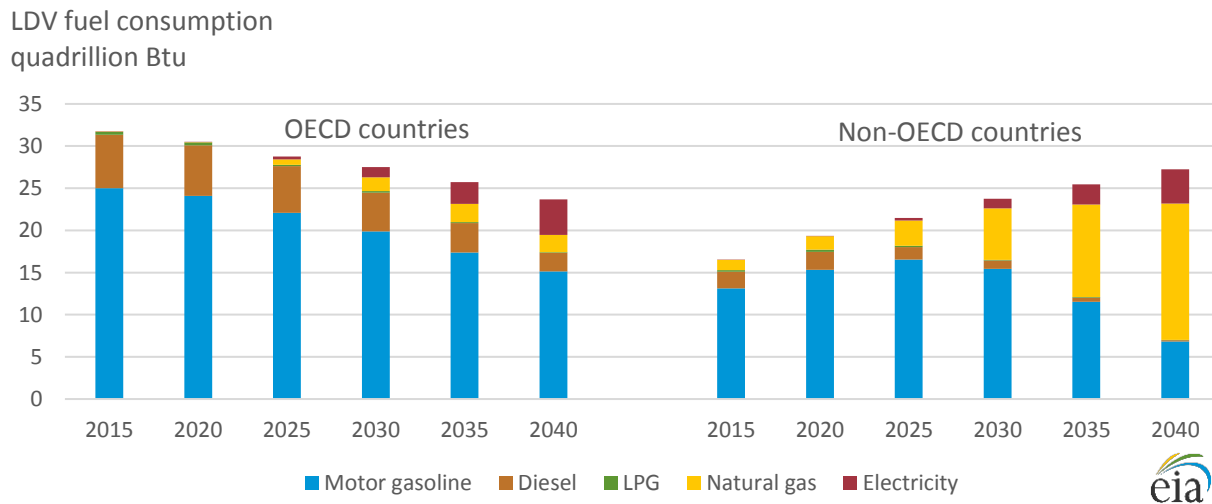
Figure 9. Change in non-OECD energy consumption by mode between 2015 and 2040 in the Low Liquids Demand case



Source: U.S. Energy Information Administration

In the LDV sector, natural gas is the primary replacement for motor gasoline and diesel fuel consumption in non-OECD countries (Figure 10). Non-OECD natural gas consumption increases by 15 quadrillion Btu between 2015 and 2040. Electricity is the primary replacement for motor gasoline and diesel fuel in OECD countries, increasing by 4 quadrillion Btu over the projection period. Electricity consumption also increases by 4 quadrillion Btu in non-OECD countries.

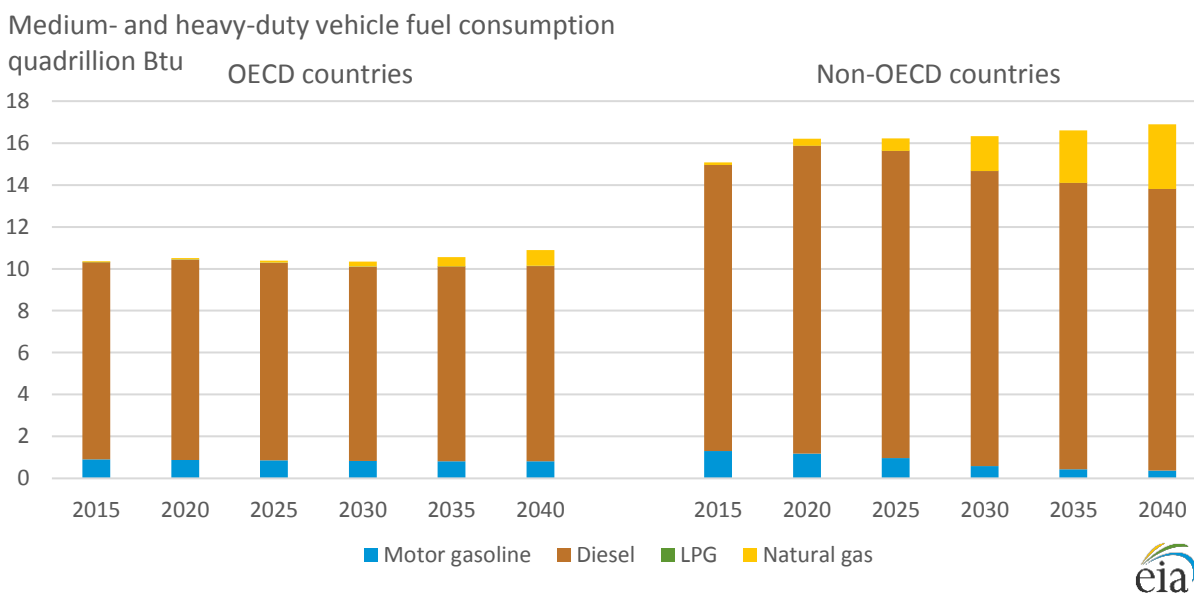
Figure 10. Low Liquids Demand case LDV fuel consumption in OECD and non-OECD countries



Source: U.S. Energy Information Administration

Fuel consumption by medium- and heavy-duty vehicles remains relatively constant across the projection period (Figure 11). Fuel consumption in OECD countries increases from 10 quadrillion Btu in 2015 to 11 quadrillion Btu in 2040. In non-OECD countries, fuel consumption increases from 15 quadrillion Btu in 2015 to 17 quadrillion Btu in 2040.

Figure 11. Low Liquids Demand case medium- and heavy-duty vehicle fuel consumption in OECD and non-OECD countries



2.2 High Liquids Demand case

The High Liquids Demand case tested the flexibility of the newly developed ITEDD model. In this case, policies and consumer preferences were changed to reflect possible events that could lead to higher levels of liquids and energy consumption in the transportation sector. These changes were assumed to begin in 2021. Most of the changes were in the LDV sector:

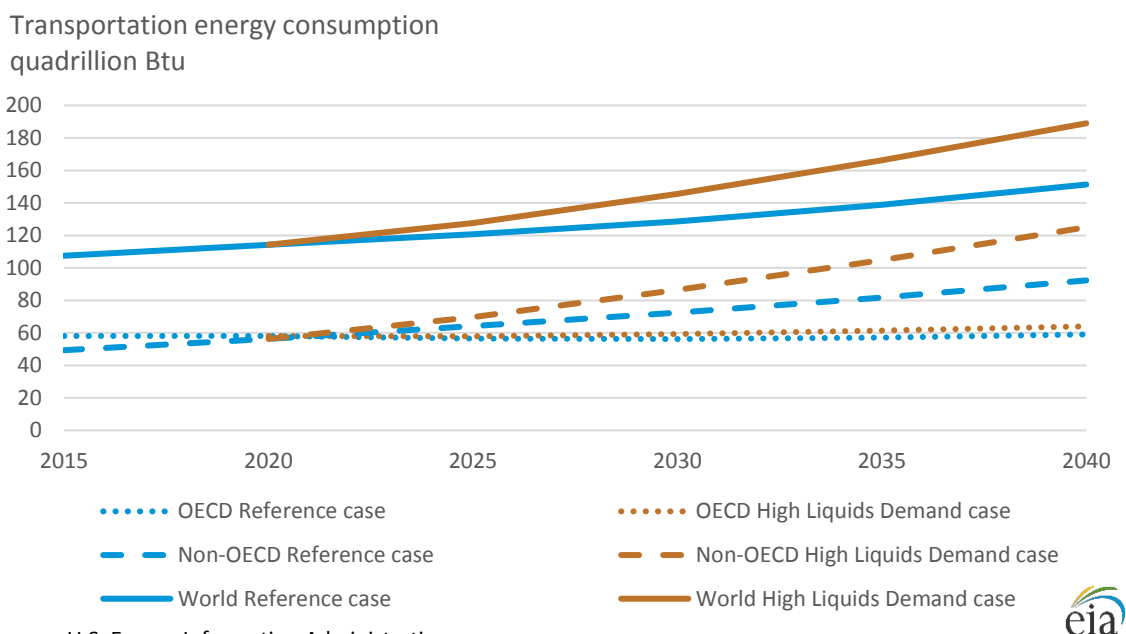
- Increased LDV ownership growth rates
- Adjusted region-specific consumer preference coefficients for LDV purchase by fuel and technology type and rate of change allowed to increase preference for petroleum-fueled vehicles
- Assumed changes in new alternative-fuel LDV prices to reflect subsidy adjustment or removal
- Removed commercial LDV subsidies for alternative-fuel vehicles
- Fuel economy standards held constant at 2020 levels

Additional changes were made in the freight sector:

- Reduced rates of fuel efficiency improvement for rail and marine
- Reduced load factors for medium- and heavy-duty vehicles
- Increased willingness to fuel switch for all freight modes

World transportation energy consumption in 2040 is 189 quadrillion Btu in the High Liquids Demand case, compared with 151 quadrillion Btu in 2040 in the IEO2016 Reference case (Figure 12). Most of the difference, 33 quadrillion Btu, is in non-OECD countries.

Figure 12. IEO2016 Reference case and High Liquids Demand case transportation energy consumption



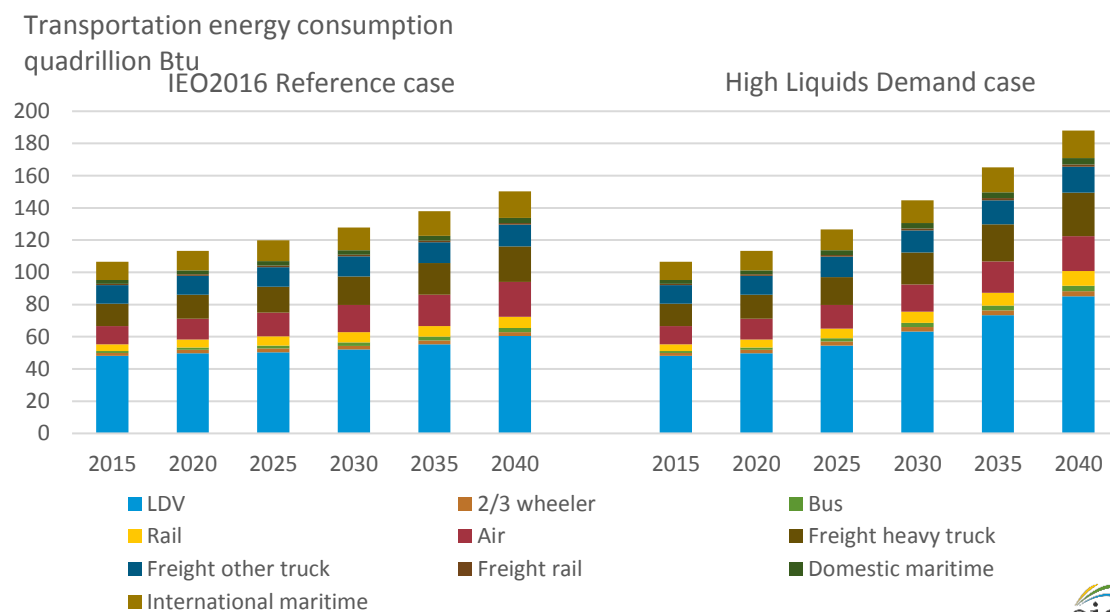
Source: U.S. Energy Information Administration

The difference between LDV energy consumption in the IEO2016 Reference case and in the High Liquids Demand case is larger than any other mode of transportation. In 2040, LDV energy consumption is 60 quadrillion Btu in the IEO2016 Reference case compared with 85 quadrillion Btu in the High Liquids Demand case (Figure 13). This difference results in almost 41% more fuel consumed by LDVs in the High Liquids Demand case than in the IEO2016 Reference case, in 2040.

Similar to the overall increase in transportation energy consumption, most of the growth in LDV energy consumption comes from non-OECD countries because non-OECD countries have more opportunities for growth than the OECD countries. For example, current vehicle stock per capita rates are lower in non-OECD countries than in OECD countries. Most OECD countries have vehicle stocks per capita in excess of 50% (meaning the countries have more than 500,000 vehicles per every million people), whereas most non-OECD countries have vehicle stock per capita of less than 20%. This difference implies that non-OECD countries have greater potential for people to purchase vehicles for the first time than in OECD countries.

In addition, fuel economy standards are more stringent heading into 2020 for most OECD countries than non-OECD countries. In this analysis, because fuel economy standards were held constant at the 2020 level as consumers in non-OECD countries purchase vehicles for the first time, these vehicles will be less efficient than those purchased in OECD countries.

Figure 13. Worldwide transportation energy consumption by mode in the IEO2016 Reference case and High Liquids Demand case

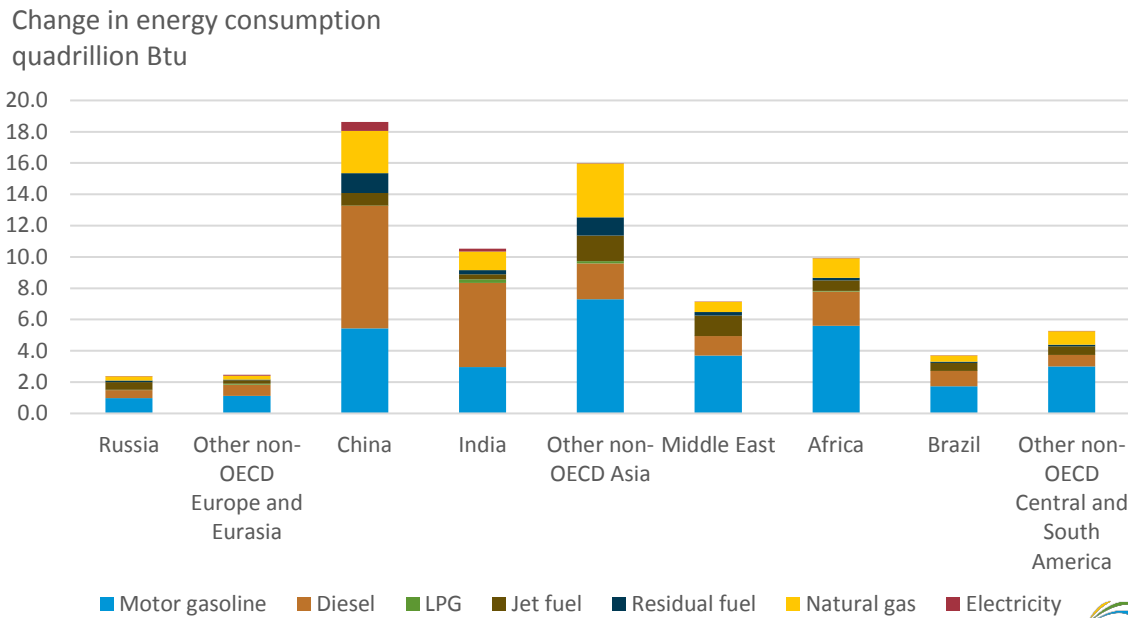


Source: U.S. Energy Information Administration



In non-OECD countries, motor gasoline grows more than any other transportation fuel, 32 quadrillion Btu, in the High Liquids Demand case between 2015 and 2040 (Figure 14). The growth in motor gasoline consumption is mainly from new LDV sales. Diesel is the second-fastest growing fuel at 22 quadrillion Btu. In all regions except India, the diesel growth is mostly attributed to growth in freight movement by medium- and heavy-duty vehicles. India, like Europe, has a high percentage of diesel LDV ownership compared with the rest of the world. Non-OECD natural gas consumption increases by 11 quadrillion Btu between 2015 and 2040. Unlike with the increases in motor gasoline and diesel consumption, natural gas consumption is growing in both LDVs and medium- and heavy-duty vehicles in most regions.

Figure 14. Change in energy consumption between 2015 and 2040 in the High Liquids Demand case

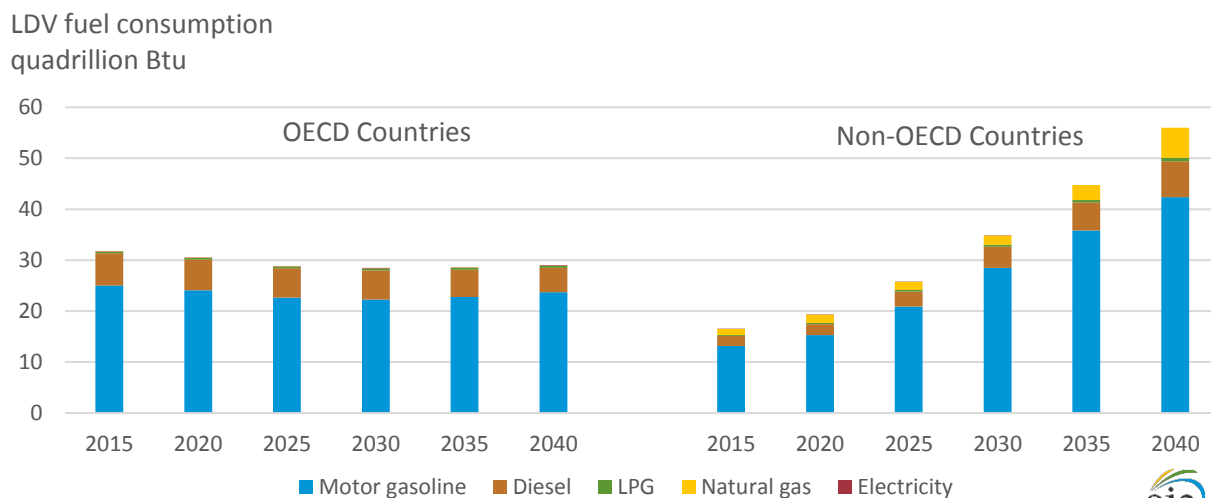


Source: U.S. Energy Information Administration



Motor gasoline remains the primary LDV transportation fuel through 2040 (Figure 15) in the High Liquids Demand case. Between 2015 and 2040 in OECD countries, LDV motor gasoline consumption decreases by 1.3 quadrillion Btu while natural gas and electricity increase by 0.03 and 0.12 quadrillion Btu, respectively. In the non-OECD countries, motor gasoline increases by 29 quadrillion Btu. Both diesel and natural gas increase by approximately 5 quadrillion Btu.

Figure 15. High Liquids Demand case fuel consumption in OECD and non-OECD countries



Source: U.S. Energy Information Administration

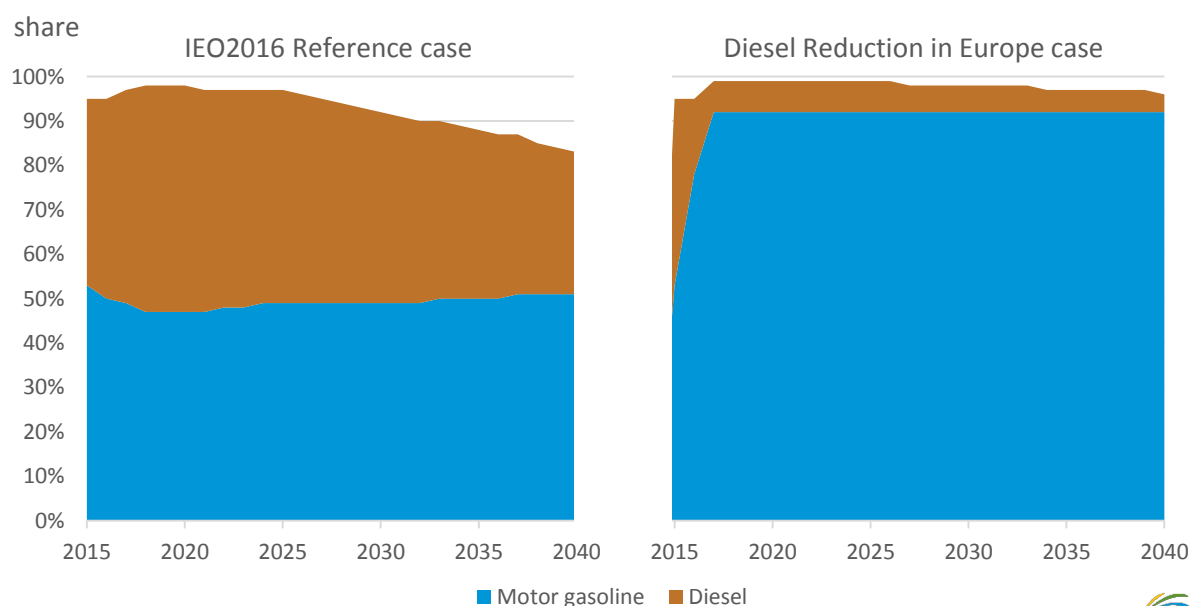


2.3 Diesel Reduction in Europe case

Unlike in the rest of the world, diesel's LDV market share is above 40% in Europe. Several factors have contributed to diesel's high European market share – pro-diesel policies, including a lower at-pump fuel tax, high diesel vehicle make and model availability (on par with motor gasoline vehicles), and a high number of fueling stations (on par with motor gasoline stations). However, given current concerns regarding criteria² emission compliance and growing research on the health implications of using diesel, the dynamics of the light-duty vehicle market could change. This case removes the preferential treatment diesel received based on policy beginning in 2016 but gives no preferential treatment to any other powertrain.

Motor gasoline becomes the main fuel source in Europe when the preferential diesel policies are removed (Figure 16). In the IEO2016 Reference case, diesel and motor gasoline vehicles have similar shares in the light-duty vehicle new sales market in 2020, at 47% and 52%, respectively. In 2040, motor gasoline increases to account for 51% of the new vehicle market, while diesel decreases to 32% of new sales as new alternative-fueled vehicles enter the market in the IEO2016 Reference case. In the Diesel Reduction in Europe case, motor gasoline vehicles make up 92% of new sales by 2018 and maintain that market share throughout the projection period.

Figure 16. Motor gasoline and diesel LDV sales shares in Europe



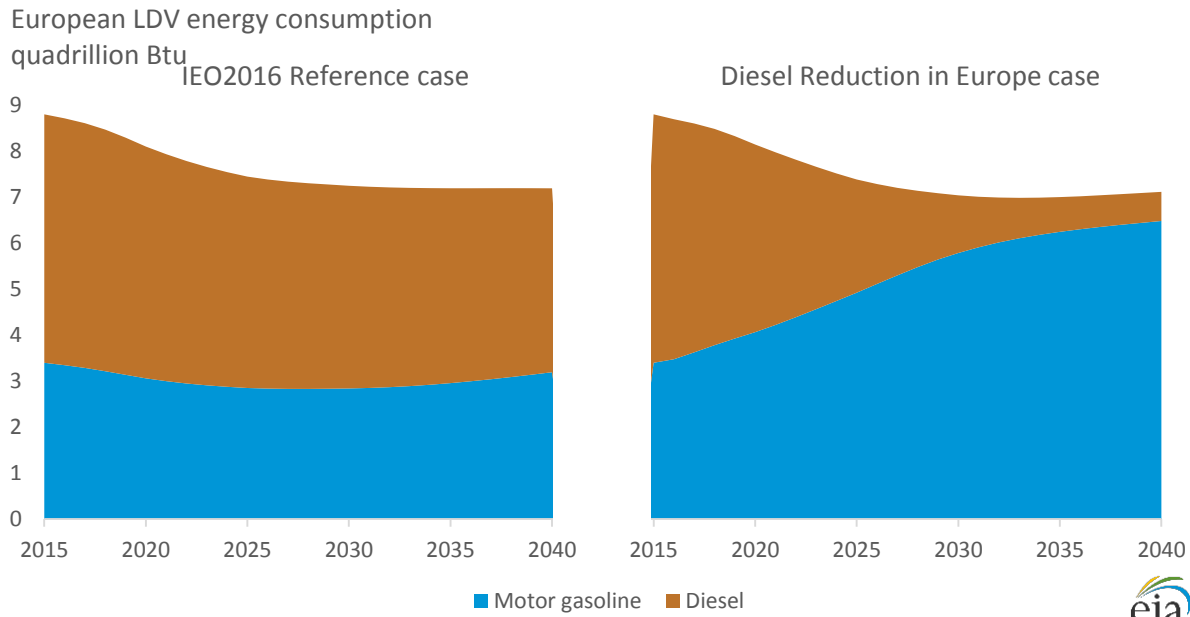
Source: U.S. Energy Information Administration



² Criteria emissions include carbon monoxide, nitrogen dioxide, ozone, particulate matter, sulfur dioxide, and lead.

Total combined motor gasoline and diesel energy consumption is lower in the Diesel Reduction in Europe case in 2040 compared to the IEO2016 Reference case, 7.1 quadrillion Btu compared to 7.2 quadrillion Btu, respectively (Figure 17).

Figure 17. European motor gasoline and diesel LDV energy consumption



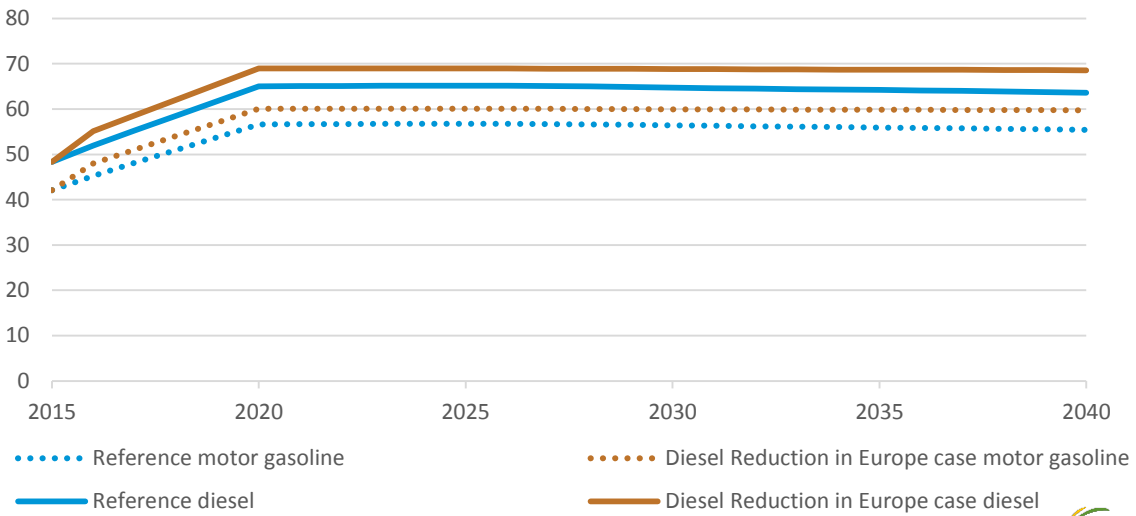
The lower level of combined motor gasoline and diesel energy usage in LDVs in 2040 is due to higher fuel economy in both motor gasoline and diesel vehicles (Figure 18). This result illustrates the model's responsiveness to regulatory policy in the European markets. Without the fuel efficiency standards, the increasing share of gasoline-powered LDVs might be expected to increase the overall fuel consumption level. But, in the presence of the regulatory standards, if consumers choose not to purchase diesel vehicles, both motor gasoline and diesel LDVs become more efficient to meet CO₂ standards.

Currently, diesel vehicles are inherently more efficient than motor gasoline vehicles, which allows both types of vehicles to be less efficient and meet the same standard. However, because fewer diesel vehicles are sold in the Diesel Reduction in Europe case, all types of vehicles have to become more efficient to meet the standard.

The higher fuel efficiency of motor gasoline and diesel vehicles is also why the Diesel Reduction in Europe case has fewer alternative-fuel vehicles than in the IEO2016 Reference case; as traditional vehicles become more efficient, the cost savings from alternative-fueled vehicles are reduced. Because no policies to reduce the costs of alternative-fueled vehicles were included in this case, the costs outweigh the benefits for most consumers.

Figure 18. New motor gasoline and diesel LDV fuel efficiency

New vehicle fuel efficiency
miles per gallon gasoline equivalent



Source: U.S. Energy Information Administration



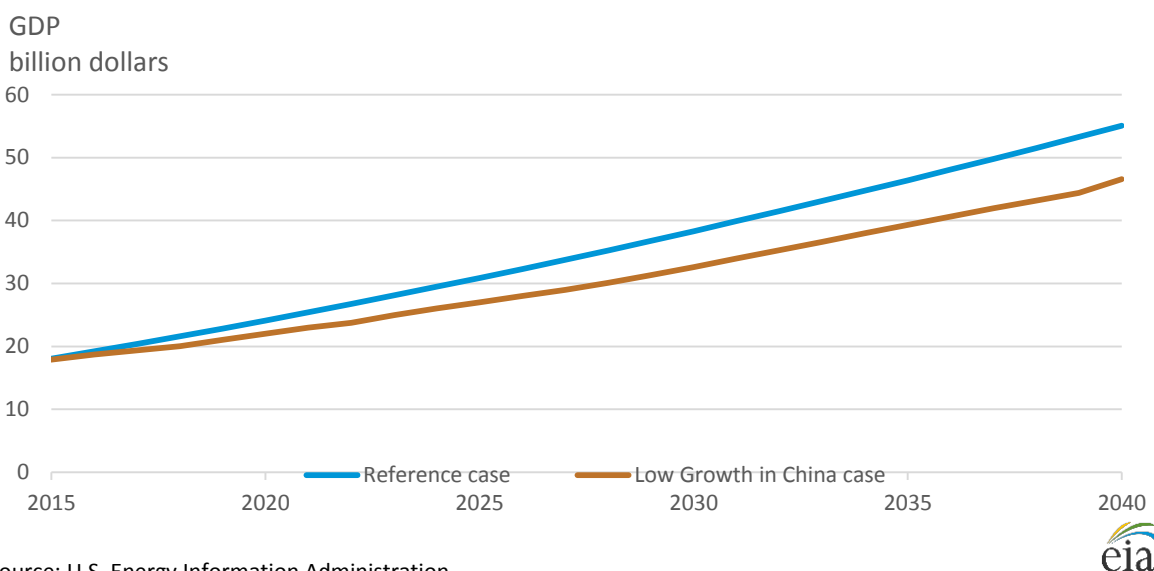
3. Updated Macroeconomic Reference case

The Updated Macroeconomic Reference case consists of new macroeconomic parameters for all regions. However, the focus of this analysis is on China as a key region for global transportation and liquid fuel demand. This case did not include any updates to ITEDD, but did include changes to macroeconomic assumptions to produce a sensitivity case for analysis. Throughout Section 0, the Updated Macroeconomic Reference case will be referred to as the Updated Macro Reference case.

3.1 Low Growth in China case

Though the IEO includes a high and low macroeconomic case, this case specifically looks at changes in the transportation sector if the growth in China were slower than the current forecast. The assumption of this scenario is that by 2040, China's GDP in the Low Growth in China case is 15% lower than in the Updated Macro Reference case (Figure 19). The GDP slowdown was assumed to begin in 2016 and increase to the 15% by 2040.

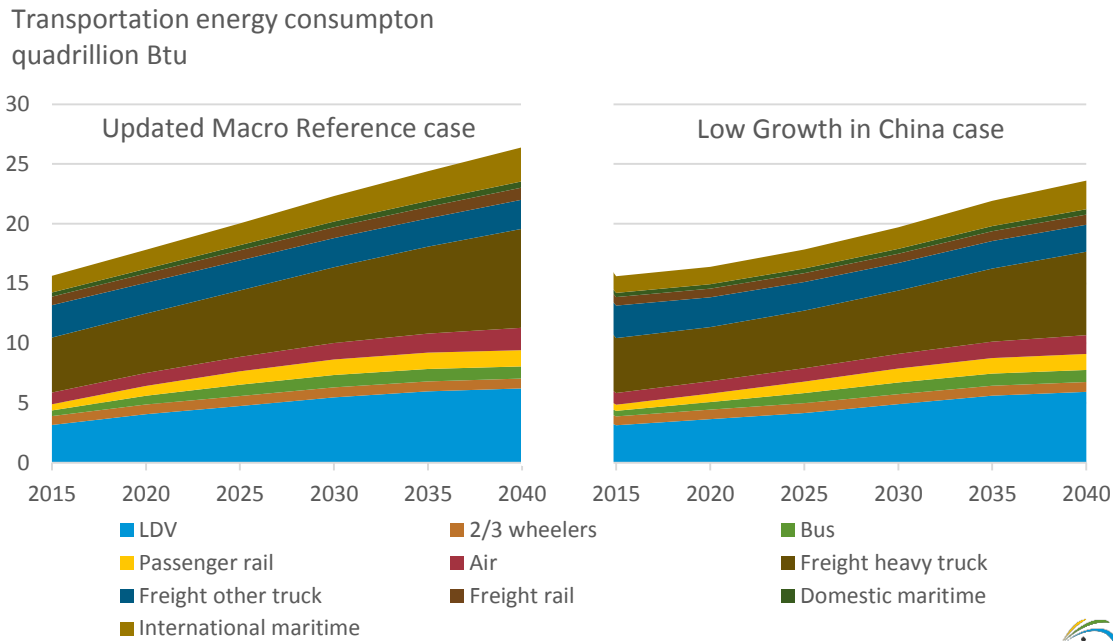
Figure 19. Chinese GDP growth: Updated Macro Reference case and Low Growth in China case



The slowdown in China's GDP affects both passenger and freight fuel consumption. A lower GDP, with no change in population, implies that per capita income is lower, and fewer consumers will be able to afford to purchase a vehicle or to fly. Because GDP and industrial output are strongly correlated in China, lower GDP also implies that fewer goods are being produced and shipped, which reduces freight transportation (Figure 20).

Consumption levels for all fuels are lower in the Low Growth in China case compared with the Updated Macro Reference case in 2040 (Figure 21). Jet fuel and residual fuel oil consumption are both 16% lower in 2040 in the Low Growth in China case than in the Updated Macro Reference case, resulting in the largest difference for any fuel. The reduction occurs because air travel and international maritime are the modes that are most effected by the slowdown (Figure 20). Overall, the reduction in industrial output had a larger affect on fuel consumption in freight modes than the reduction of GDP growth had on the fuel consumption in passenger modes.

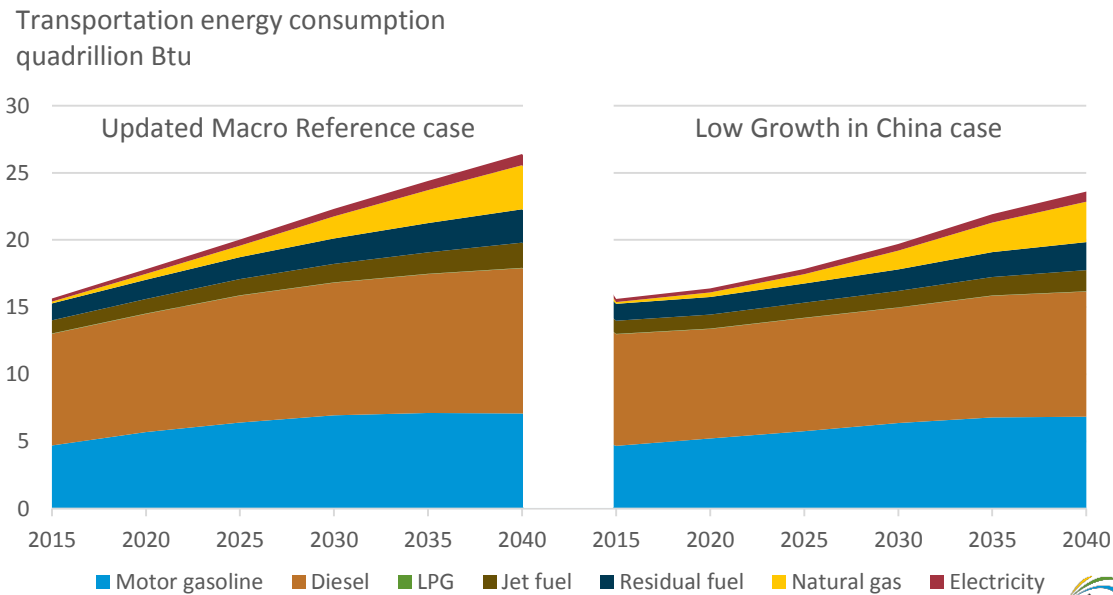
Figure 20. Transportation fuel consumption in China by mode in the Updated Macro Reference case and Low Growth in China case



Source: U.S. Energy Information Administration



Figure 21. Transportation fuel consumption in China in the Updated Macro Reference case and Low Growth in China case



Source: U.S. Energy Information Administration



4. Updated ITEDD Model Reference case

EIA used an updated version of ITEDD in the third set of cases. Throughout Section 0, the Updated ITEDD Model Reference case will be referred to as the Updated ITEDD Reference case. The updated model includes expanded modeling capabilities, particularly in the representation of alternative-fueled vehicles. Fuel availability has been added as an explicit consideration in the LDV market share determination. In addition, the model has been expanded to incorporate vehicle price and fuel price subsidies. For fuels such as natural gas or electricity, a lack of fueling stations at the outset dampens interest by consumers who may perceive that it will be inconvenient and/or time consuming to find fueling stations. As more alternative-fueled vehicles are sold, more fueling stations are likely to offer the fuel, and refueling would gradually cease to be a concern.

ITEDD does not explicitly represent the investment decision of building new fueling stations. In many regions government policy will likely influence the expansion of alternative fueling stations. Alternative fueling stations are assumed to increase as more alternative-fuel vehicles are sold at a rate that is based on an EIA-specified policy variable. Some countries already have in place subsidies for or direct investments in alternative fueling stations. The policy parameter relates the expansion of stations to vehicles sold.

Bus and medium- and heavy-duty vehicle stocks in ITEDD are not projected based on annual sales and sales shares as are vehicle sales for LDVs. Instead, fuel shares are applied directly to the total vehicle-kilometers traveled for buses and ton-miles traveled for medium- and heavy-duty vehicles. The projection methodology for natural gas shares in these modes has been updated. A key assumption is that the adoption rate of alternative-fueled vehicles will be driven in large part by government policy.

The relative prices of diesel and natural gas are also assumed to be important, and, together with a user-defined assumption representing government policy, determine the maximum natural gas share achieved. For medium-duty vehicles that will likely use the same refueling stations as LDVs, the maximum share is also influenced by the fuel availability projected for LDVs. In turn, the expansion of natural gas use in these vehicles increases the station build-out.

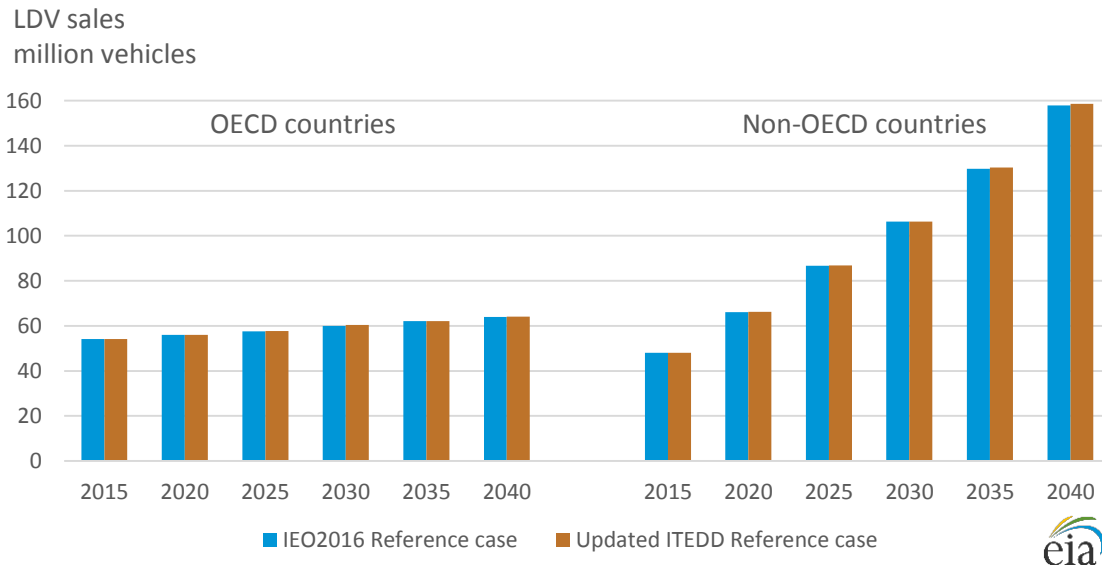
The speed of alternative fuel adoption for buses and medium- and heavy-duty vehicles is assumed to be linked to the same policy assumption of medium- and heavy-duty vehicles and growth in GDP per capita. For buses, the share of natural gas is subtracted from the diesel shares. For medium- and heavy-duty vehicles the natural gas share is subtracted from the motor gasoline share first. If the share of motor gasoline in medium- and heavy-duty vehicles reaches zero, then the remaining natural gas share is subtracted from the diesel share.

In the Updated ITEDD Reference case, the policy parameter in each region is generally set so that fuel availability expands modestly as the number of alternative-fuel vehicles increases. Exceptions are made for some regions that currently have policies encouraging the expansion of alternative fueling stations. For example, several regions have policies promoting compressed natural gas (CNG) vehicles, so these regions (Middle East, Central and South America, and Other non-OECD Asia) are assumed to build out CNG refueling stations more quickly.

As noted in the Preface, these scenarios use the ITEDD transportation module of EIA's global WEPS+ system in standalone mode, so the implications of varying levels of natural gas demand for supply, delivery, and pricing in regional markets are not dynamically represented in these cases.

Total LDV ownership stays relatively consistent between the IEO2016 and Updated ITEDD Reference cases (Figure 22). However the composition of the vehicles does change (Figure 23). There are more motor gasoline vehicles in both OECD and non-OECD countries in the Updated ITEDD Reference case than in the IEO2016 Reference case in 2040. In addition, OECD countries have more natural gas vehicles in the Updated ITEDD Reference case. In both OECD and non-OECD countries, battery electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) decrease by more than any other power train type between the IEO2016 Reference case and Updated ITEDD Reference case.

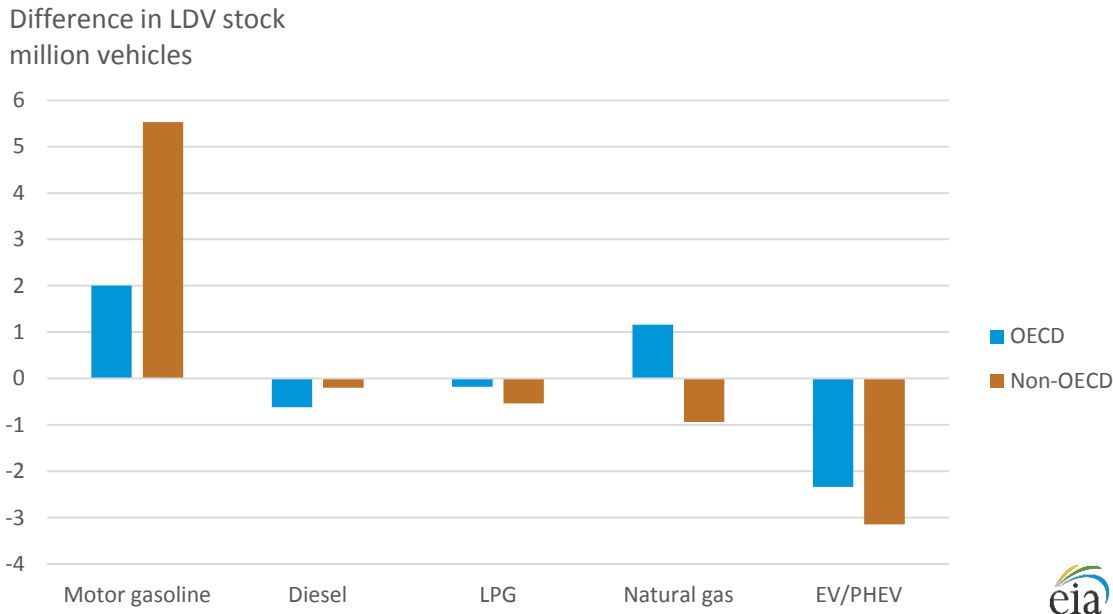
Figure 22. Total LDV sales in the IEO2016 and Updated ITEDD Reference cases



Source: U.S. Energy Information Administration



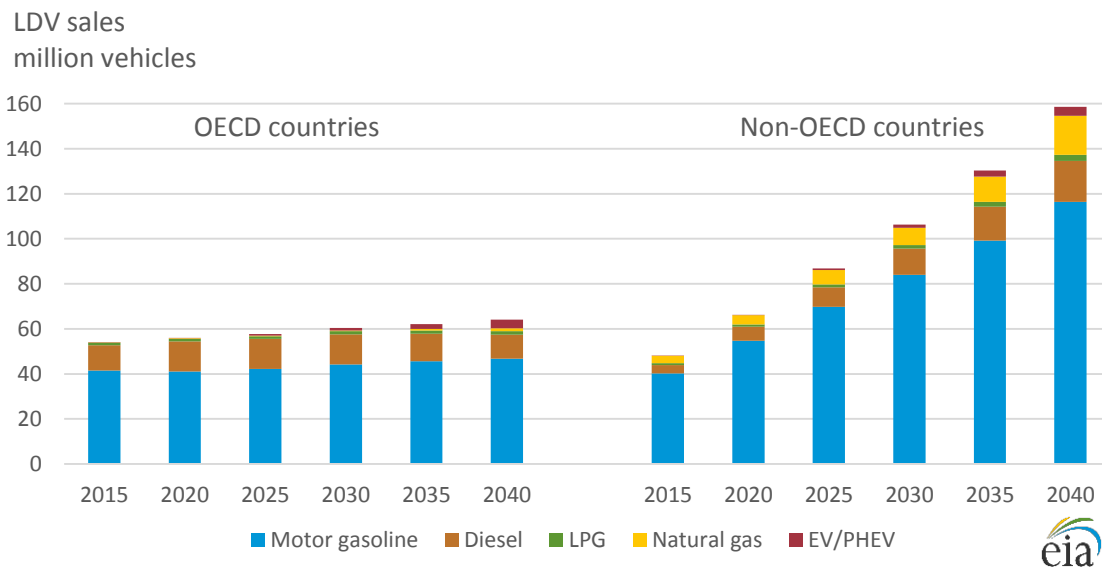
Figure 23. Difference between LDV stock by vehicle power train in the IEO2016 Reference case and Updated ITEDD Reference case in 2040



Source: U.S. Energy Information Administration

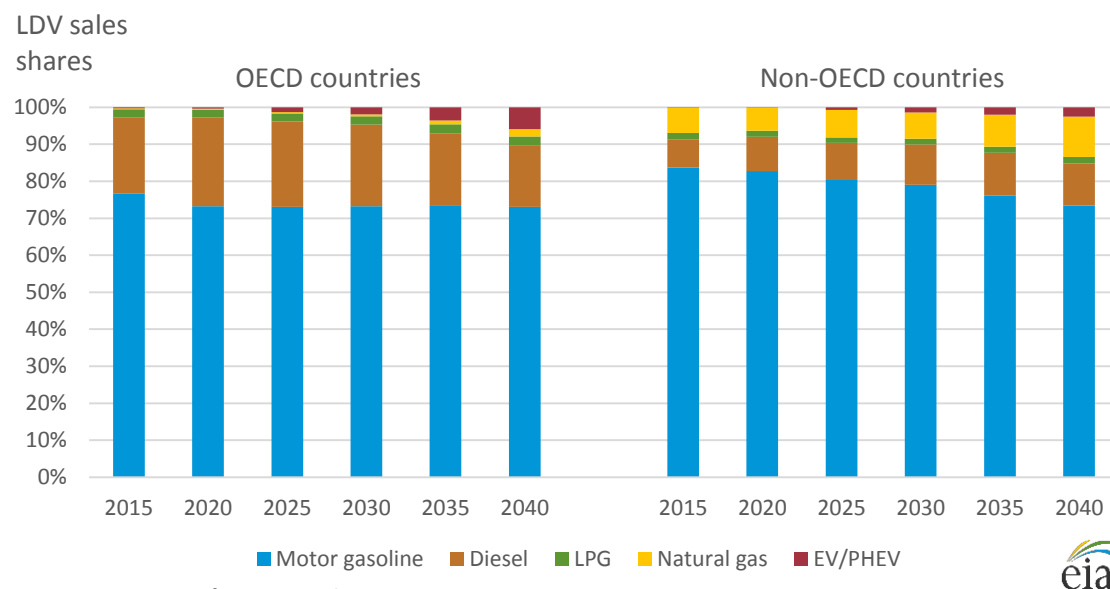
Most of the growth in LDV sales occurs in non-OECD countries (Figure 24). The non-OECD countries also have a larger share of natural gas fueled vehicles (Figure 25). EV and PHEV shares are projected to increase to 6% in OECD countries in 2040 and to 3% in non-OECD countries. Shares of natural gas vehicles increase in the non-OECD countries from 7% in 2015 to 11% by 2040.

Figure 24. Updated ITEDD Reference case LDV sales in OECD and non-OECD countries



Source: U.S. Energy Information Administration

Figure 25. Updated ITEDD Reference case LDV technology sales shares in OECD and non-OECD countries



Although sales of LDVs in the OECD are projected to remain relatively steady over the forecast period, energy consumption is projected to decline because of improved vehicle fuel economy. The increasing sales shares of EVs and PHEVs have a small effect on electricity consumption for several reasons. The natural lag in vehicle stock turnover means the stocks of EVs and PHEVs is still relatively low by 2040. Also, roughly a quarter of the EV and PHEV combined sales share of 6% in 2040 is PHEVs that use electricity for only a portion of their travel. Finally, electric motors are more efficient than internal combustion engines on a delivered-energy basis, meaning that liquid fuel use is reduced more than proportionately to the end use energy share for electric vehicles.

In 2040, motor gasoline fueled LDVs consume more energy in the Updated ITEDD Reference case than in the IEO2016 Reference case in both OECD and non-OECD countries (Figure 26). The difference is caused by an increase in motor gasoline fueled vehicles. Overall growth of vehicle ownership in non-OECD countries leads to rising energy consumption despite rising fuel economy (Figure 27). Non-OECD energy use for LDVs is projected to increase at 3% per year, or to more than double between 2015 and 2040. The fuel shares are projected to remain relatively constant.

Figure 26. Difference in LDV energy consumption by fuel type between the IEO2016 Reference case and the Updated ITEDD Reference case in 2040

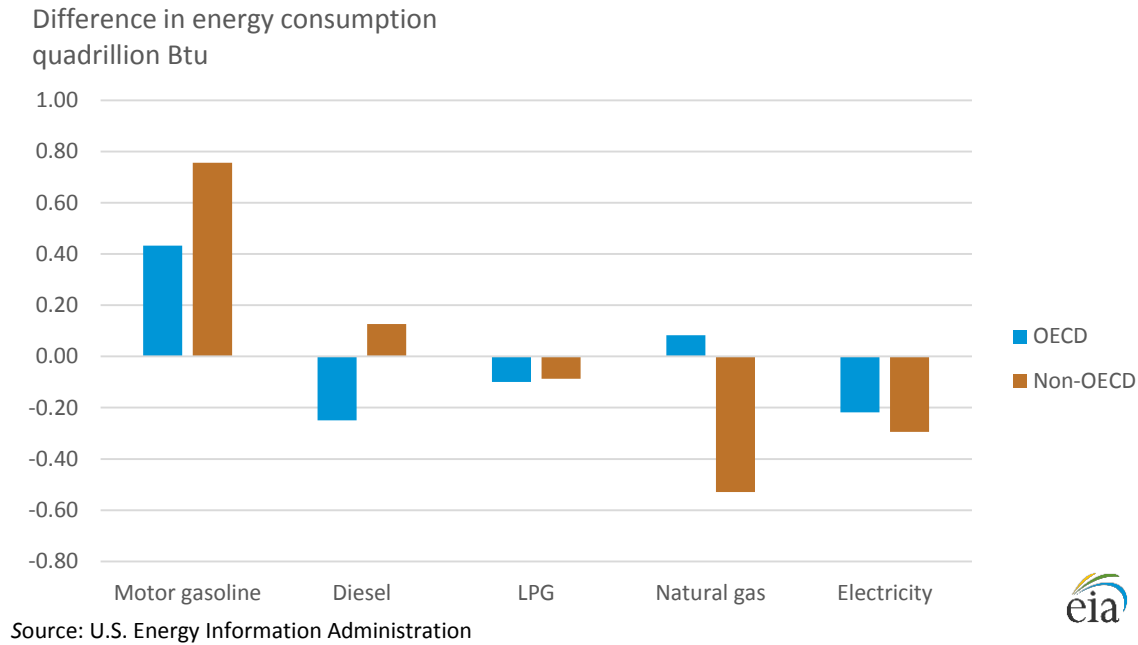
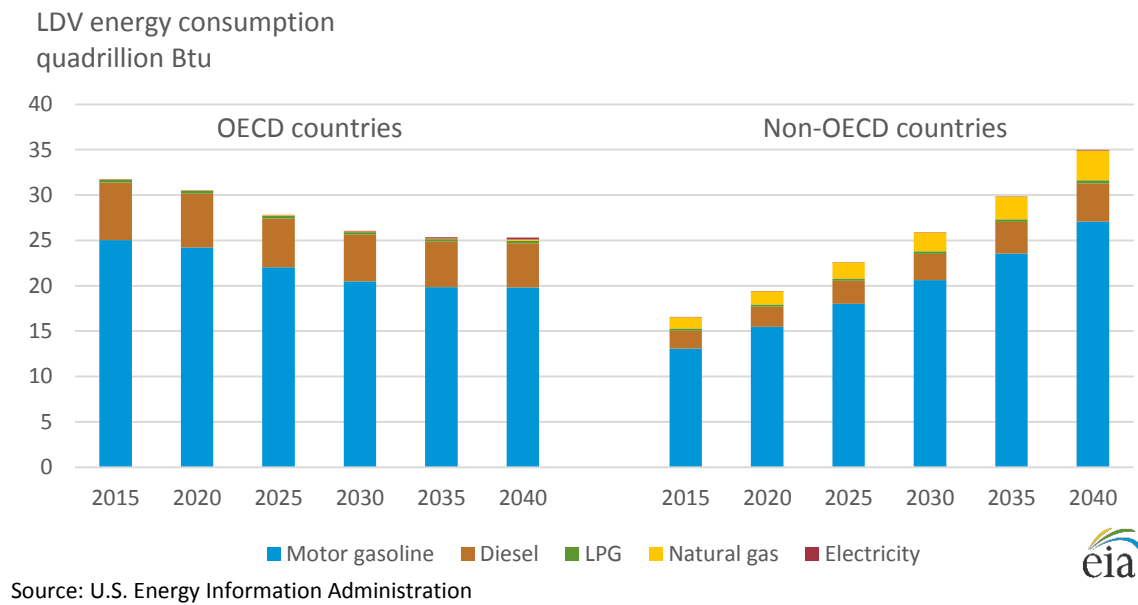
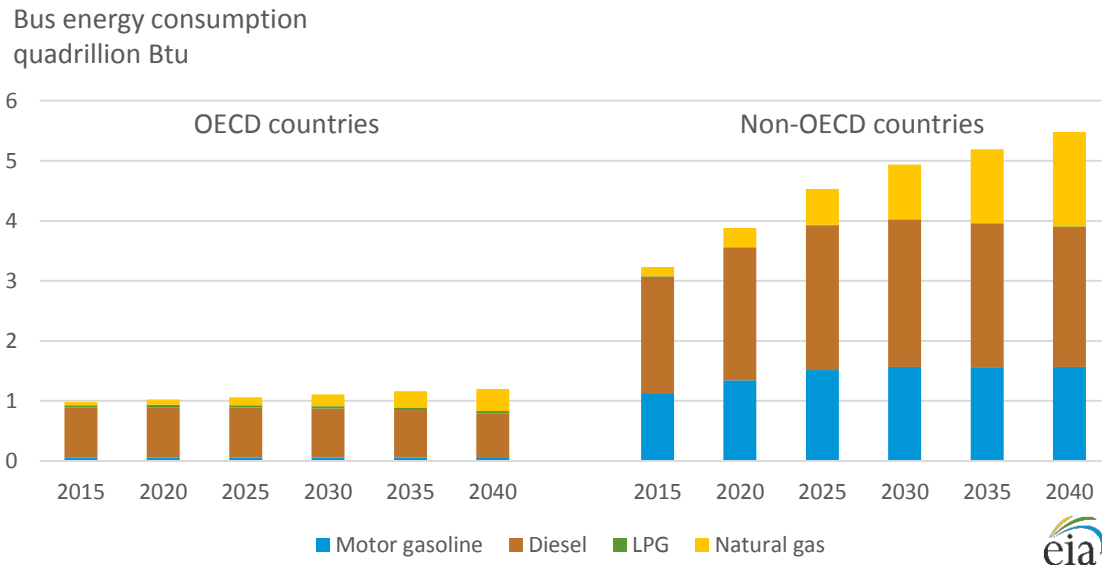


Figure 27. Updated ITEDD Reference case LDV energy consumption in OECD and non-OECD countries



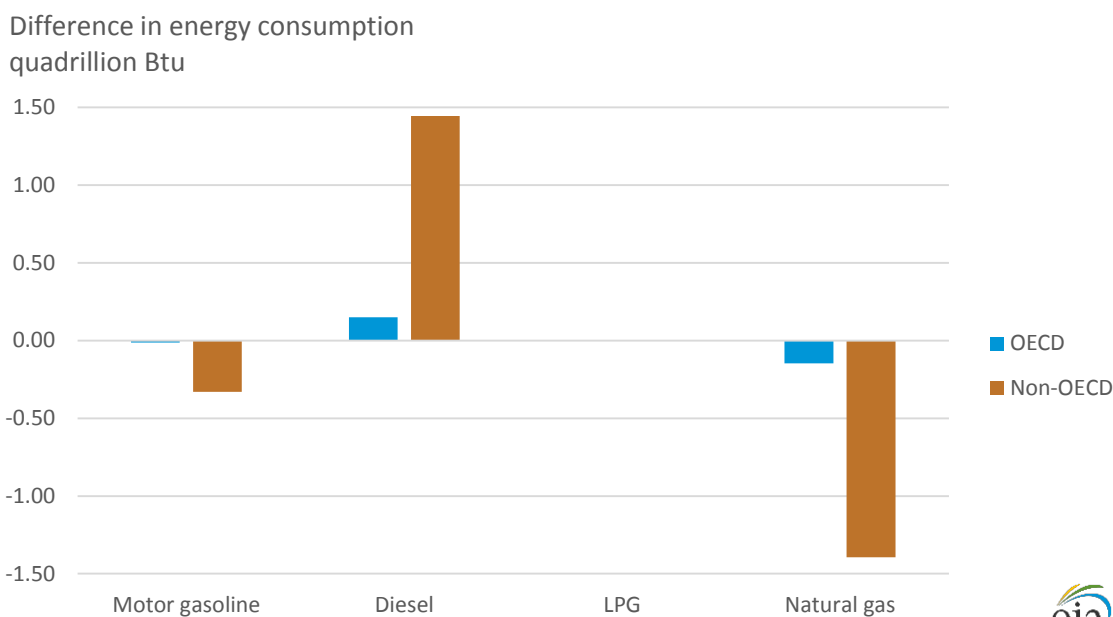
Energy consumption by buses is higher in non-OECD countries than in the OECD countries because more people in those areas travel by bus (Figure 28). Bus energy consumption is projected to rise more rapidly in the non-OECD countries (2.1% a year) than in OECD countries (less than 1% per year). In 2040, less natural gas is consumed in the Updated ITEDD Reference case than in the IEO2016 Reference case (Figure 29). The lower level of natural gas consumption is almost completely offset by higher diesel consumption in both OECD and non-OECD countries. There is no change in LPG consumption. Overall, total bus energy consumption is lower in the Updated ITEDD Reference case.

Figure 28. Updated ITEDD Reference case bus energy consumption in OECD and non-OECD countries



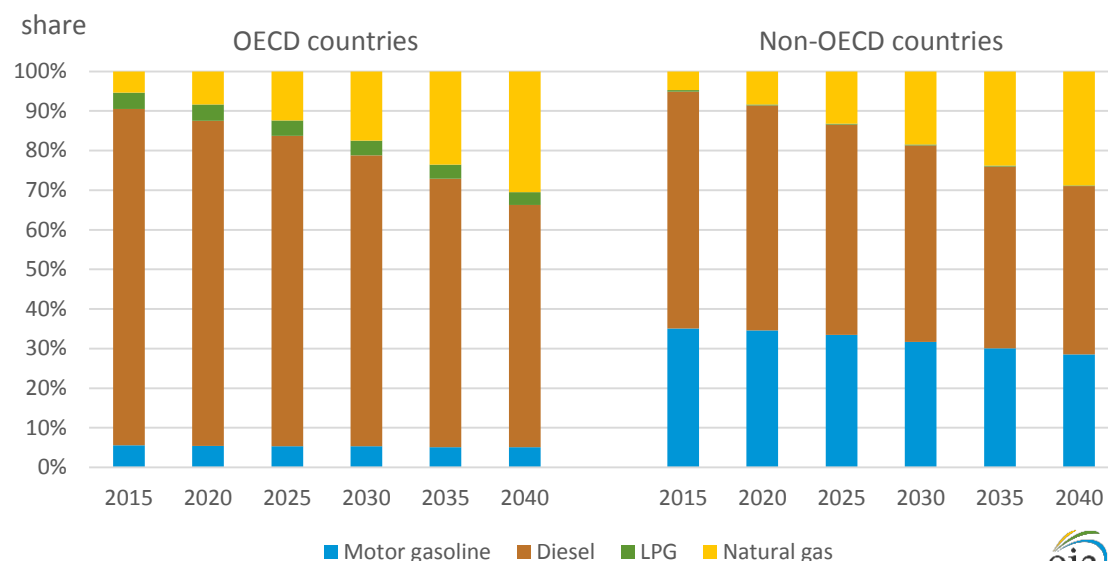
Source: U.S. Energy Information Administration

Figure 29. Difference in bus energy consumption by fuel between the IEO2016 Reference case and the Updated ITEDD Reference case in 2040



In aggregate, both the OECD and non-OECD countries are projected to see rising shares of natural gas consumption relative to motor gasoline and diesel in the transportation sector (Figure 30). The initial natural gas bus fuel shares in both OECD and non-OECD countries are 5% in 2015 and rise to around 30% by 2040. The growth is not uniform across all countries within each group. For example, natural gas bus shares are low and projected to remain low in Canada, Australia/New Zealand, and Africa, and they are high in China, India, and Other non-OECD Europe and Eurasia.

Figure 30. Updated ITEDD Reference case bus energy consumption shares in OECD and non-OECD countries

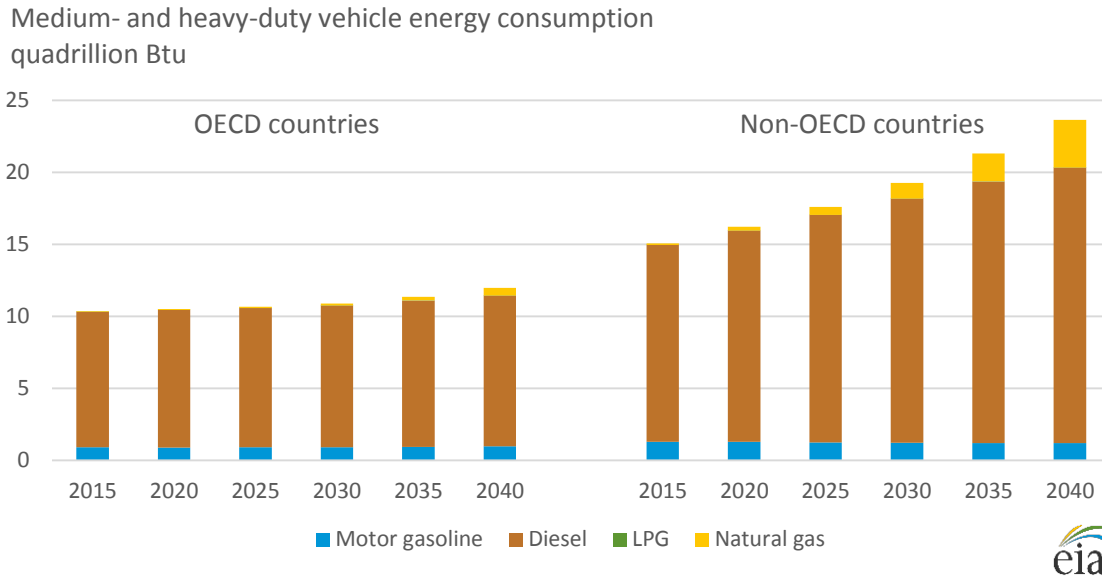


Source: U.S. Energy Information Administration

As with the other transportation modes, energy consumption by medium- and heavy-duty vehicles is projected to increase more in the non-OECD countries than in OECD countries because of differences in expected economic growth rates between the two groups of countries. In the non-OECD regions, medium- and heavy-duty vehicle energy consumption increases at 1.8% per year, which is slower than consumption growth by LDVs.

Medium- and heavy-duty vehicles energy use is mostly from diesel fuel with some motor gasoline used in medium-duty vehicles (Figure 31). In response to rising oil prices and relatively low natural gas prices in many countries, the natural gas share of medium- and heavy-duty vehicles is projected to increase to 4% in the OECD countries and to 14% in the non-OECD countries by 2040.

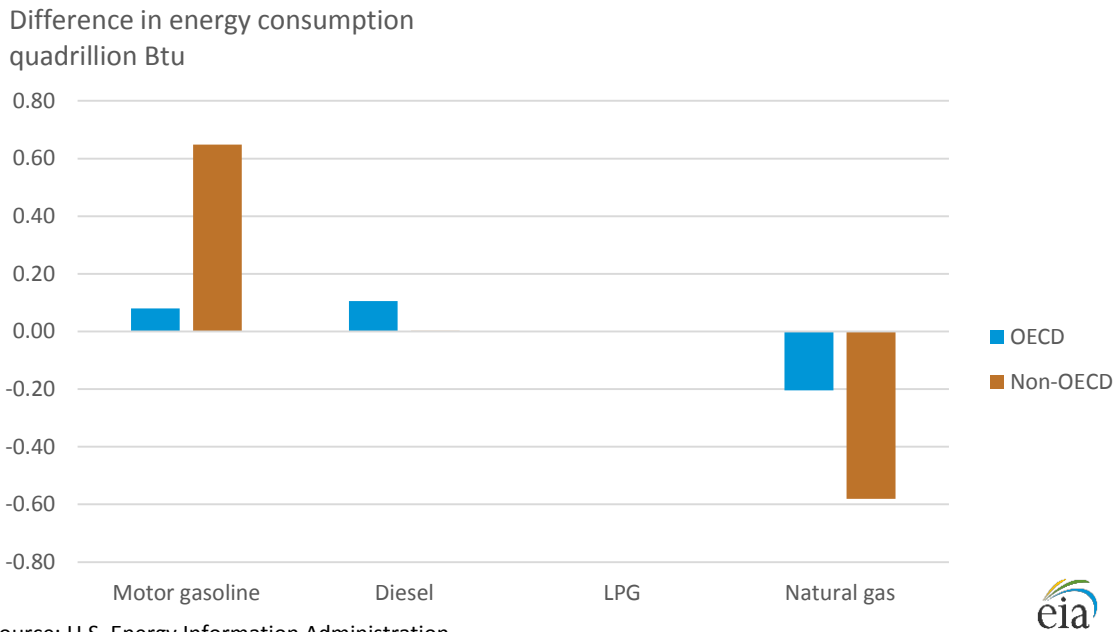
Figure 31. Updated ITEDD Reference case medium- and heavy-duty vehicle energy consumption in OECD and non-OECD countries



Source: U.S. Energy Information Administration

Similar to buses, natural gas energy consumption in medium- and heavy-duty vehicles is lower in the Updated ITEDD Reference case than in the IEO2016 Reference case (Figure 32). The decrease in natural gas fuel use in OECD countries is offset by an almost equal increase in motor gasoline and diesel fuel use. However, the decrease in natural gas fuel use in non-OECD countries is more than offset by an increase in motor gasoline fuel use and relatively no change in diesel use.

Figure 32. Difference in medium- and heavy-duty vehicle energy consumption by fuel between the IEO2016 Reference case and the Updated ITEDD Reference case in 2040



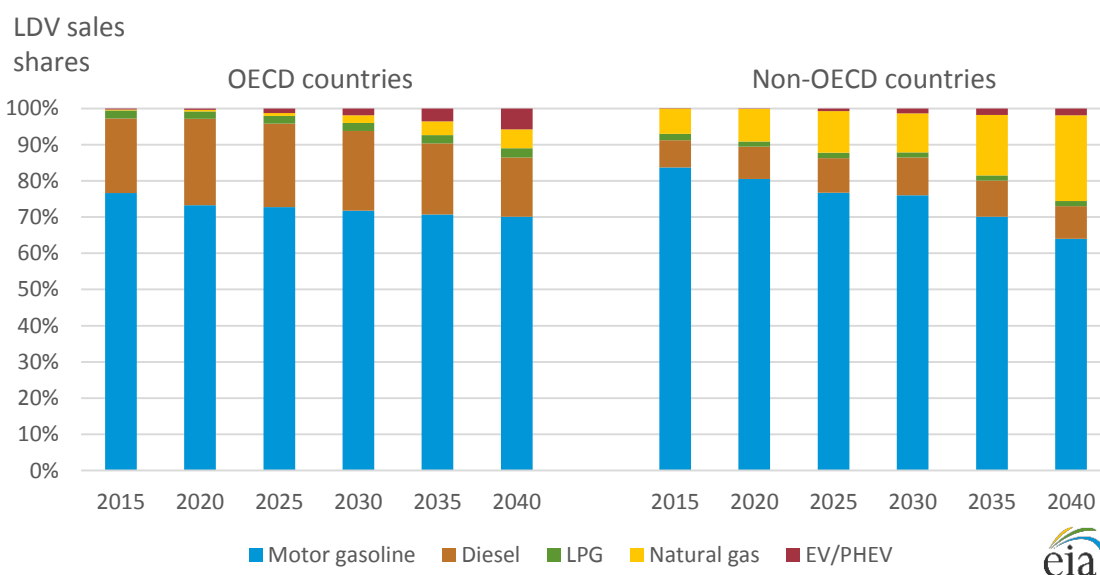
Source: U.S. Energy Information Administration

4.1 Natural Gas Vehicle Subsidy case

In the Natural Gas Vehicle Subsidy case, a subsidy of \$3,000 per vehicle for private and commercial LDVs is provided starting in 2018 in all regions that have natural gas resources and some current share of natural gas vehicles. Five regions were excluded: Europe, Japan, Australia/New Zealand, South Korea, and Africa. The subsidy defrays some, but not all, of the roughly \$5,200 incremental cost of CNG vehicles relative to motor gasoline vehicles. Because governments are not likely to continue to subsidize vehicles once they gain significant market share, the subsidy is phased out as cumulative sales of CNG vehicles increase. Once the shares reach a cumulative 2% of total LDV sales, the subsidy declines to \$1,500. In a few regions that already have a significant share of natural gas vehicles, the subsidy starts at \$1,500. Once the shares reach 30% of cumulative LDV sales, the subsidy is eliminated.

The share of natural gas LDVs sold increases in both OECD and non-OECD regions (Figure 33) although motor gasoline and diesel vehicles remain dominant (compared with the Updated ITEDD Reference case shown in Figure 25). By 2040, the OECD natural gas vehicle share increases to 5% compared with 2% in the Updated ITEDD Reference case. The subsidy drops to \$1,500 in the participating OECD regions between 2025 and 2028. The non-OECD natural gas vehicle share in 2040 is 10% in the Updated ITEDD Reference case but 24% in the Natural Gas Vehicle Subsidy case. Shares are higher in the non-OECD, regions in part because several regions already have some natural gas fueling station infrastructure. The subsidy phase-out is more varied among non-OECD regions with some regions starting at \$1,500 and others not transitioning to \$1,500 until as late as 2035, but in all regions the subsidy is at the lower level or eliminated by 2040.

Figure 33. Natural Gas Vehicle Subsidy case LDV technology sales shares in OECD and non-OECD countries



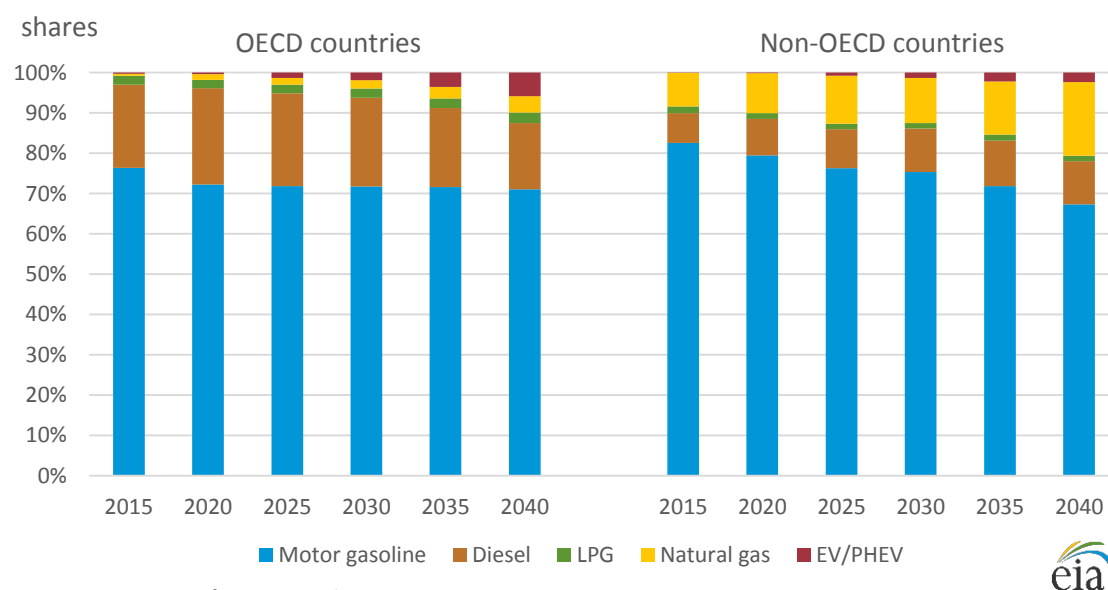
Source: U.S. Energy Information Administration

4.2 Natural Gas Price and Infrastructure Subsidies case

An alternative policy to encourage natural gas vehicles would be to reduce the price of natural gas at fueling stations. Subsidies or other policies could also be enacted that encourage the addition of more stations offering natural gas, which would increase the attractiveness of natural gas vehicles to consumers. In this case, a \$4/MMBtu fuel subsidy, which is roughly 50 cents/gallon equivalent, is provided starting in 2018 in the regions where the vehicle subsidies are offered in the prior Natural Gas Vehicle subsidy case. In addition, the expansion of fueling stations for CNG is assumed to occur more rapidly. Finally, CNG and liquefied natural gas (LNG) use in buses and medium- and heavy-duty vehicles is assumed to receive some type of support that raises the maximum potential natural gas share and accelerates the adoption rate of natural gas in medium- and heavy-duty vehicles and buses in many regions.

Although the natural gas share of LDV fuel consumption increases in this case (Figure 34), the increases are smaller than in the Natural Gas Vehicle Subsidy case (Figure 33). The 2040 natural gas shares are 4% and 18% for the OECD region and non-OECD region respectively, compared with 5% and 24% in the Natural Gas Vehicle Subsidy case.

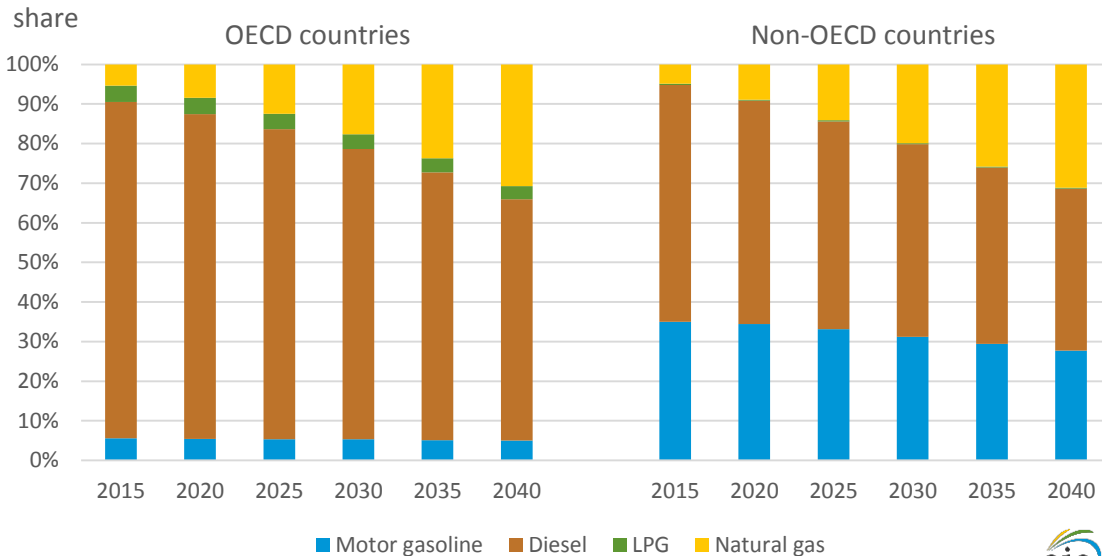
Figure 34. Natural Gas Price and Infrastructure Subsidies case LDV technology sale shares in OECD and non-OECD countries



Source: U.S. Energy Information Administration

The natural gas share for buses also is higher in non-OECD countries in this case. By 2040, the natural gas share in the non-OECD region is 31% (Figure 35). China and India, which together comprise almost a quarter of bus consumption in the non-OECD countries in 2040, are projected to have relatively high natural gas shares in the Updated ITEDD Reference case, so an increase in the rate of adoption has little effect on the 2040 shares. Africa, which accounts for more than 30% of bus travel in the Updated ITEDD Reference case and the Natural Gas Price and Infrastructure Subsidies case has low natural gas shares even in the Natural Gas Price and Infrastructure Subsidy case.

Figure 35. Natural Gas Price and Infrastructure Subsidies case bus consumption shares in OECD and non-OECD countries



Source: U.S. Energy Information Administration

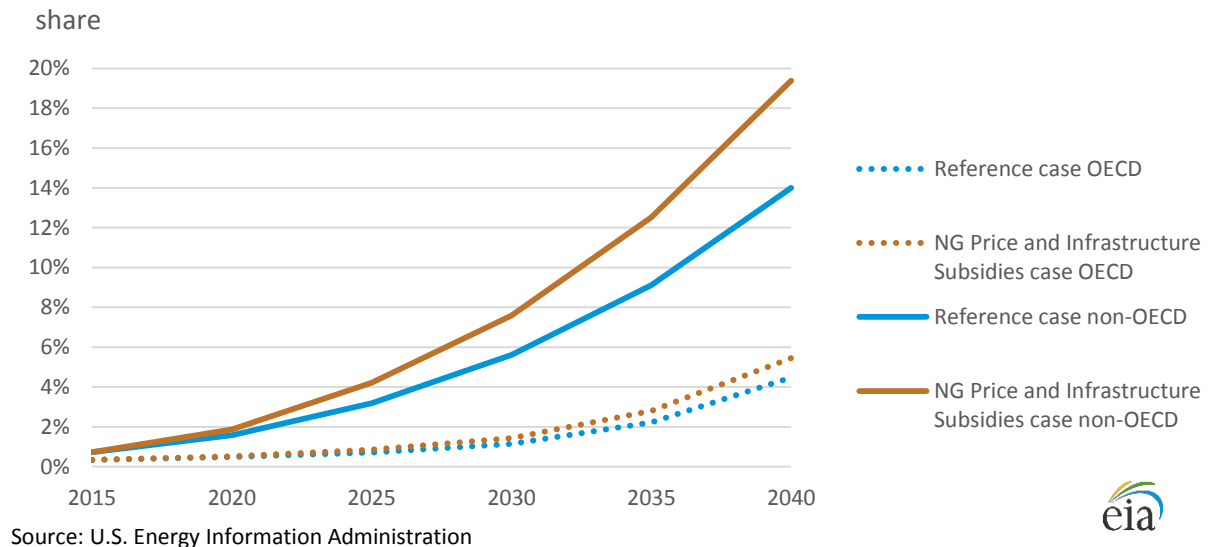


Natural gas use in medium- and heavy-duty vehicles increases in the Natural Gas Price and Infrastructure Subsidies case. The increase results from an assumed increase in the maximum potential market share for natural gas associated with greater government support for both LNG fueling stations for heavy-duty vehicles and CNG-dispensing stations for use by LDVs and medium-duty vehicles. As with the subsidies, the higher level of government support is assumed in all regions except Europe, Japan, Australia/New Zealand, South Korea, and Africa.

Policies in China and the Middle East are assumed to enhance use of natural gas in medium- and heavy-duty vehicles in the Updated ITEDD Reference case, so these regions are not affected in the Natural Gas Price and Infrastructure Subsidies case. Expanded shares of natural gas LDVs and an associated increase in fueling stations contribute to increasing natural gas shares of medium-duty vehicles and to a direct increase in the assumed maximum potential natural gas shares for these vehicles.

In OECD regions, the natural gas fuel share across all medium- and heavy-duty vehicle types in 2040 is higher reaching 5% in the Natural Gas Price and Infrastructure Subsidies case compared with 4% in the Updated ITEDD Reference case (Figure 36). The share in non-OECD regions rises from 14% to 19% between the Updated ITEDD Reference case and the Natural Gas Price and Infrastructure Subsidies case, respectively.

Figure 36. Updated ITEDD Reference case and Natural Gas Price and Infrastructure Subsidies case medium- and heavy-duty vehicle natural gas consumption shares in OECD and non-OECD regions

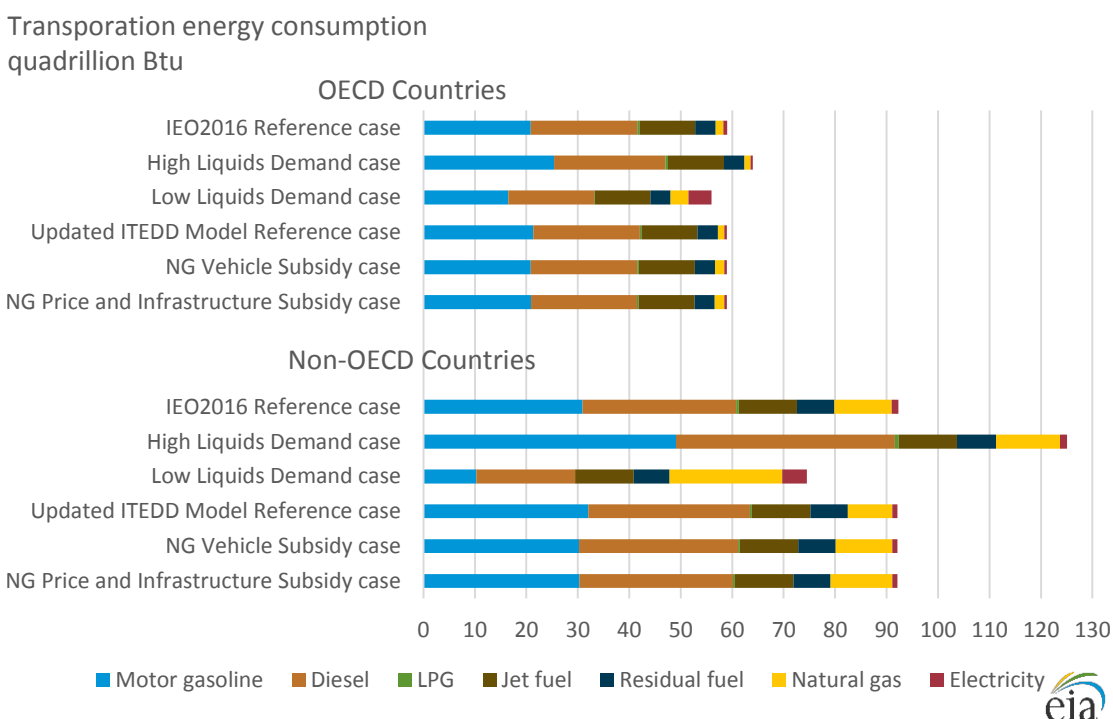


5. Conclusions

The International Transportation Energy Demand Determinants (ITEDDD) model has been fully integrated and tested as a component of the World Energy Projection System Plus (WEPS+). WEPS+ is the model the U.S. Energy Information Administration uses for projections that are presented in the *International Energy Outlook* (IEO). IEO2016 was the first year that EIA used ITEDDD for the transportation section of the projection. After the release of IEO2016, several scenarios were examined to consider uncertainty in the transportation sector and to test the flexibility and response of the ITEDDD model as well as the new model capabilities. The actual model outputs presented here were not produced in an overall integrated framework, and as such, are intended to be more illustrative than conclusive. Three reference cases were used as the basis for the side cases because of updates to macroeconomic variables or ITEDDD model updates and capabilities at the time of the side case analyses. Six side cases were analyzed.

The scenarios examined using ITEDDD gave the expected responses in both direction and dynamics. In the High and Low Liquids Demand cases, non-OECD countries were affected more than OECD countries. Non-OECD total transportation energy consumption was higher by 33 quadrillion Btu in the High Liquids Demand case and lower by 18 quadrillion Btu in the Low Liquids Demand case, respectively, compared with the IEO2016 Reference case in 2040 (Figure 37). The changes in the High and Low Liquids Demand cases follow the IEO2016 Reference case where OECD transportation energy consumption was relatively flat while non-OECD transportation was increasing throughout the projection period.

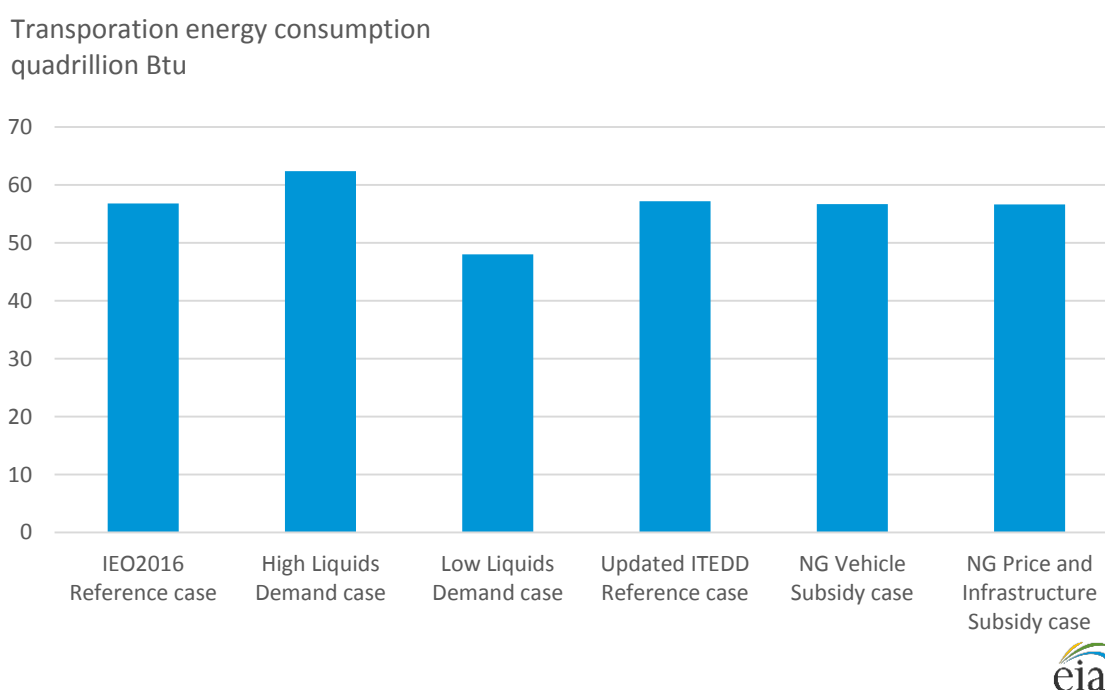
Figure 37. Transportation energy consumption for worldwide cases by OECD and non-OECD countries in 2040



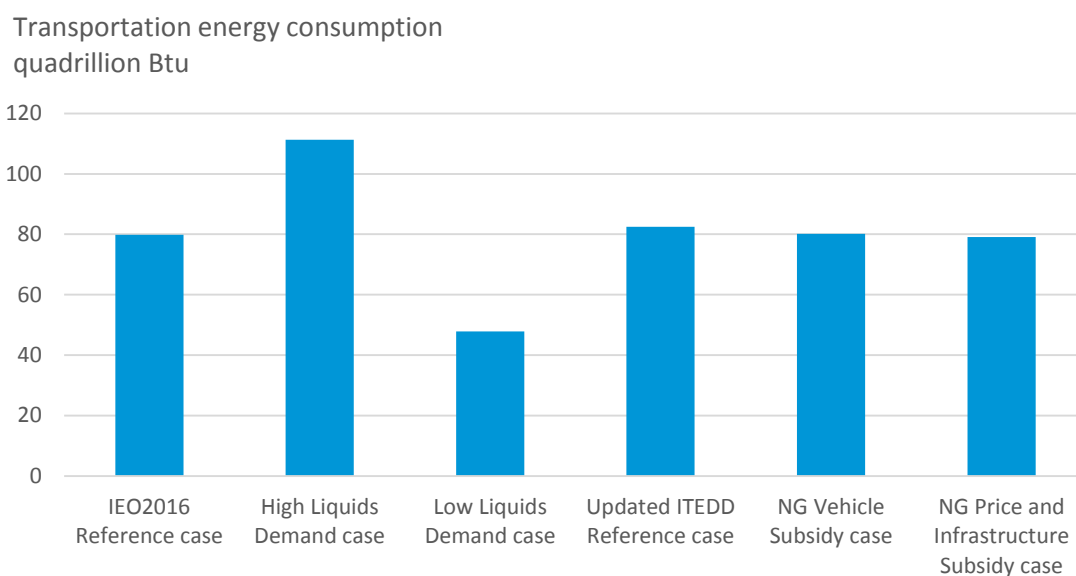
Changes in petroleum-based transportation energy consumption are larger than changes in overall transportation energy consumption in the side cases. In OECD countries, petroleum-based energy consumption was higher by 6 quadrillion Btu in the High Liquids Demand case compared with the IEO2016 Reference case in 2040 (Figure 38). In the Low Liquids Demand case, petroleum-based energy consumption was 9 quadrillion Btu lower than in the IEO2016 Reference case in 2040. In non-OECD countries, petroleum-based transportation energy consumption is 31 quadrillion Btu higher in the High Liquids Demand case and 32 quadrillion Btu lower in the Low Liquids Demand case, compared with the IEO2016 Reference case in 2040 (Figure 39).

The difference in the changes between total transportation energy consumption and petroleum-based transportation energy consumption is because of changes in the consumption of alternative fuels – natural gas and electricity. To the extent that global energy analysis considers various indicators, including total consumption, liquid fuels consumption, alternative fuels and technologies, greenhouse gas emissions, regional prices, etc., the ITEDD system as used in EIA’s global WEPS+ projection framework can provide greater detail and more rigor in the representation and dynamics of international transportation energy demand determinants.

Figure 38. Transportation petroleum-based energy consumption in OECD countries in 2040



Source: U.S. Energy Information Administration

Figure 39. Transportation petroleum-based energy consumption in non-OECD countries in 2040

Source: U.S. Energy Information Administration

The Diesel Reduction in Europe case was developed because of current concerns about criteria emission compliance and growing research on the health implications of using diesel. These issues could result in a change in the dynamics of the light-duty vehicle market. In this case, favorable treatment for diesel was removed in Europe, and no preferential treatment was given to any other powertrain. Diesel vehicles were replaced with motor gasoline vehicles. As a result of CO₂ emission standards in Europe, both types of vehicles become more fuel-efficient because diesel vehicles are inherently more efficient than motor gasoline vehicles and fewer diesel vehicles are now purchased. Overall transportation energy consumption in Europe was reduced from 19.7 quadrillion Btu in the IEO2016 Reference case to 19.4 quadrillion in the Diesel Reduction in Europe case (Table 2).

The Low Growth in China case tested how the ITEDD model reacts to slower economic growth, in China. China's GDP was reduced by 15% in 2040, compared with the Updated Macro Reference case. As expected, the reduction in GDP resulted in a reduction in passenger and freight travel, related to a corresponding decrease in industrial output. Overall transportation energy consumption in China was 11% lower in the Low Growth in China case than in the Updated Macro Reference case in 2040 (Table 2).

In each of the subsidy cases, energy consumption stays relatively constant compared with the Updated ITEDD Reference case for both OECD and non-OECD countries in 2040 (Figure 37). However, energy consumption is shifted away from motor gasoline and diesel fuel. The shifts are greater in the two natural gas cases in non-OECD countries, with a larger reduction in motor gasoline in the Natural Gas Vehicle Subsidy case that encourages the adoption of light-duty natural gas vehicles. The Natural Gas Price and Infrastructure Subsidies case leads to larger reductions in diesel as it shifts fuels consumed in buses and medium- and heavy-duty vehicles, as well as LDVs. Overall, the petroleum-based fuel consumption in 2040 is approximately 3% lower in non-OECD countries (Figure 39) relative to the Updated ITEDD Reference case in the Natural gas vehicle subsidy case. In the Natural Gas Price and Infrastructure Subsidy case, fuel consumption is 4% lower in non-OECD countries relative to the Updated ITEDD Reference case.

Table 2. Transportation energy consumption for cases in 2040
(quadrillion Btu)

	IEO2016 Reference case	High Liquids Demand case	Low Liquids Demand case	IEO2016 Reference case	Diesel Reduction in Europe case	Updated Macro Reference case	Low Growth in China case	Updated ITEDD Model Reference case	NG Vehicle Subsidy case	NG Price and Infrastructure Subsidy case
	OECD countries			Europe		OECD countries				
Motor gasoline	20.84	25.38	16.50	3.34	6.63			21.34	20.86	20.88
Diesel	20.72	21.67	16.65	9.29	5.92			20.72	20.70	20.61
LPG	0.41	0.48	0.13	0.12	0.05			0.31	0.31	0.32
Jet fuel	10.85	10.85	10.85	4.04	4.04			10.87	10.87	10.87
Residual fuel	3.95	4.00	3.91	2.01	2.01			3.95	3.95	3.95
Natural gas	1.52	1.19	3.44	0.54	0.52			1.25	1.76	1.81
Electricity	0.75	0.45	4.51	0.37	0.22			0.53	0.53	0.53
OECD Europe total				19.71	19.39					
OECD total	59.04	64.01	55.99					58.97	58.98	58.97
	Non-OECD countries			China		Non-OECD countries				
Motor gasoline	30.95	49.11	10.30			7.08	6.84	32.02	30.23	30.28
Diesel	29.85	42.51	19.18			10.82	9.32	31.43	30.93	29.89
LPG	0.45	0.71	0.03			0.03	0.02	0.36	0.32	0.33
Jet fuel	11.36	11.36	11.36			1.88	1.57	11.38	11.38	11.38
Residual fuel	7.26	7.58	6.97			2.48	2.09	7.27	7.27	7.26
Natural gas	11.16	12.47	21.89			3.29	3.01	8.66	10.98	11.95
Electricity	1.29	1.32	4.77			0.83	0.76	1.01	1.00	1.01
China total						26.40	23.60			
Non-OECD total	92.31	125.04	74.48					92.12	92.09	92.09
World total	151.35	189.05	130.47					151.09	151.07	151.06

Source: U.S. Energy Information Administration