An Assessment of the Diesel Fuel Market:
Demand, Supply, Trade, and Key Drivers

PIRA Energy Group
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Introduction

The Fuels Institute engaged PIRA Energy Group to conduct an extensive analysis of rising diesel fuel demand within the light vehicle fleet in the United States and the ramifications of this trend for the broader energy sector and overall economy. Sales of diesel light vehicles are rising, and automakers are adding additional diesel models to their product lineups, with these trends likely to continue. However, diesels must increasingly compete with other fuel sources and technologies such as natural gas and electrification. Given the many other uses of diesel within the U.S. and international economy, PIRA explored the impact of, and interaction between, various trends in diesel demand and supply to provide input to industry stakeholders and policymakers to help them plan better for the future.

Many factors are driving shifts in fuel usage over time in the U.S. and abroad, both within transportation and in other sectors. Vehicle demand for fuels is influenced by driver behavior, government policy, relative economics between different drivetrain technologies, vehicle purchase and retirement patterns, and demographics. Other transportation types, such as trucking, rail, and shipping, all have their own evolving demand patterns over time. And non-transportation fuel demand is influenced by relative fuel costs, including for substitutes like natural gas, composition of the economy, efficiency improvements, and fuel delivery infrastructure. Many of these factors influence one another as well, requiring an integrated, internally consistent analytical approach to forecasting.

Amidst this considerable complexity it is important to establish a consistent baseline forecast for decision makers to serve as a reference for evaluating different possible scenarios. PIRA has developed a comprehensive forecast based upon reasonable assumptions around the main drivers of diesel demand and supply, the inputs and results of which are described in this report. PIRA’s forecasting approaches have been developed over nearly 40 years of energy market analysis and incorporate detailed examination of the many factors influencing energy demand, supply, trade, and price.

While PIRA focused on diesel in this report, the forecasts are based upon a comprehensive, integrated long-term global energy outlook incorporating all energy sources and demand components. Within this outlook, diesel competes for demand with other fuels such as gasoline (in light vehicles) and natural gas (primarily in heavy and fleet vehicles, rail, and certain marine applications). On the supply side, PIRA’s U.S. and global production outlooks incorporate anticipated changes in refinery capacity, utilization, and configuration, as well as biofuels supply and gas-to-liquids (GTL) production. Supply and demand are matched with a global price outlook to ensure consistency among all factors. While there are considerable uncertainties around many components of the outlook—especially in the later years—PIRA’s forecast represents a reasonable “Reference Case” that incorporates the information known at present along with reasonable assumptions about the future.

Overall, PIRA’s analysis suggests that the U.S. should be more than able to supply its domestic diesel demand with enough surplus to provide large and growing net exports to the rest of the world. U.S. diesel demand will begin to decline after 2016 as rising efficiency and substitution by natural gas will more than offset the rise in light duty vehicle diesel demand to the end of PIRA’s outlook. The U.S. refining sector is well equipped to meet the required need for diesel for demand and exports, with rising refinery runs of crude supported by advantaged U.S. refining economics from cheap shale oil and gas.

At the global level, diesel demand will rise rapidly, driven by industrialization of emerging markets as well as growing use of diesel in shipping from tightening pollution standards. Once the anticipated growth in biofuels production and GTL is taken into account, the global refining sector should be able to supply this demand over time while keeping overall diesel yields approximately constant with today since refinery runs will be increasing.
Demand Forecasting Methodology

PIRA used its detailed U.S. long-term road fuels model to forecast diesel, gasoline, natural gas, and electricity demand by light and heavy U.S. vehicles. As described below, the model uses annual assumptions about vehicle purchase patterns, efficiency improvements, driver behavior, vehicle retirements, and the growth of alternative fuel vehicles to provide an outlook for U.S. vehicle fuel demand.

PIRA’s long-term non-U.S. global energy demand outlook was constructed using PIRA’s World Energy Demand Forecast Portal, an econometric model that computes energy demand by sector and fuel for more than 140 countries. Input assumptions include GDP growth, population growth, energy elasticities of demand by sector, efficiency improvements, feedback price effects, and economic competition between fuels. In addition, this approach was used to forecast non-road U.S. diesel demand. This approach ensures consistency within all the subcomponents of demand, and it accounts for transitions over time in economic activity and fuel preference.

U.S. On-Road Vehicles

PIRA utilizes a fully vintaging light vehicle model to establish the basis for its U.S. road fuel forecasts, for both gasoline and diesel fuel. Individual vehicle types are modeled with regard to new sales, retirements, miles driven, and efficiencies. PIRA has included the penetration of several electric based technologies: regular hybrids, plug-in hybrids (PHEVs), and pure electric vehicles (EVs). Natural gas vehicles primarily are in the commercial fleet, rather than in light vehicles, since the economics and use cases are more attractive with larger commercial vehicles that drive far more miles per year than typical light vehicles.

PIRA’s framework for developing the fuel consumption profile is driven first by demographics and then by a rolled-up assessment of the type of vehicles that are sold and how they penetrate the existing vehicle stock. The current U.S. vehicle stock comprises about 267 million vehicles, of which about 257 million are classified as cars or light trucks. The balance consists of heavy duty trucks, which are almost entirely diesel fueled. The larger sizes and higher annual mileage of heavy duty trucks result in them accounting for a greater share of the fuel consumed.

On-Road Vehicles Outside the U.S.

Outside of the U.S., PIRA used its World Energy Demand model to estimate road vehicle fuels demand by fuel. PIRA’s model links vehicle miles traveled (VMT) growth to economic activity and the elasticity of travel.
demand. The VMT are partitioned according to assumed changes in fuel split (gasoline, diesel, LPG, natural gas, electric, etc.) based on government policies, including fuel efficiency targets, consumer preference, and economics. This component of diesel demand is particularly important on a global basis since the fast-growing emerging markets typically use relatively high shares of diesel fuel in transportation. With future oil demand growth expected to come overwhelmingly from the developing world on a net basis, these emerging market trends are critical to the global diesel balances.

Other Transportation

Outside of vehicle usage, diesel also plays a large role as a fuel in shipping and rail transportation. While large, long-haul vessels such as dry bulk carriers, oil tankers, and container ships typically use heavy fuel oil for most of their journeys, diesel of some form or another is the primary fuel for smaller vessels, totaling on the order of 1.3 MMB/D (million barrels per day) of demand around the world, or roughly 5% of global diesel demand. Diesel is also the preferred fuel for trains, totaling 200-250 MB/D (thousand barrels per day) of demand in the U.S. alone, or roughly 6% of total U.S. diesel demand. As global trade grows and countries expand their rail networks, these sources of demand are expected to increase.

One additional driver of increased diesel demand is the tightening of specifications on shipping fuels (bunker fuels), which will force a greater number of ships to convert from heavy fuel oil to diesel as sulfur emissions regulations become more restrictive. Initial regulations limiting bunker fuel sulfur levels within 200 miles of the U.S., Canada, and Northern Europe will come into force at the beginning of 2015, with global standards having a much larger volumetric impact beginning in either 2020 or 2025 depending on the state of readiness of the shipping industry. These regulations will be discussed at length below in the Policy section.

The World Energy Demand model grows small-vessel shipping and rail sources of diesel demand based on country-level economic and population outlooks as well as on efficiency improvements and fuel switching. Large-vessel fuel demand growth is linked to forecast growth in world trade, as well as vessel emissions regulations and the availability of alternative options such as sulfur scrubbing technology and LNG-fueled vessels.

Non-Transportation Demand

Outside of transportation, diesel-type fuels (broadly termed distillate fuel oils or gasoils) are used in a multitude of applications throughout the global economy, including residential and commercial heating, power generation, farming, industrial applications, and natural resource extraction. PIRA forecasts this demand over time using the bottom-up methodology of the World Energy Demand model, in which individual sectors have individual demand elasticities, fuel switching trends, and efficiency improvement parameters.

In general, the demand from this grouping will shrink over time as efficiency improvements and shifts to cheaper sources of energy (e.g. natural gas) gradually reduce demand for non-transportation usage of diesel fuel in both the U.S. and the rest of the world. Growing natural gas availability in the U.S., in part enabled by the so-called shale revolution, will help displace remaining sources of non-transportation diesel demand. In the rest of the
world, growing LNG availability, technological improvements, and a stronger price incentive to move away from oil-based fuels all will serve to moderately reduce diesel demand in the non-transportation sector. Also, as many developing countries improve their existing energy infrastructure, they can reduce demand for diesel fuels, which often serves as a stopgap measure due to portability and the ease of setting up diesel generators in remote areas.
Outlook for U.S. Diesel Demand

Based on the models already described and the assumptions explained in the following pages, PIRA expects overall U.S. diesel demand to increase through 2015, but then to begin to decline gradually post-2016, and more rapidly post-2025. Improvements in efficiency, substitution away from diesel in the non-transportation sector, and growing use of natural gas in the heavy duty vehicle (HDV), railroad, and marine segments are expected to reduce diesel demand in the later years. These declines will outpace the expected increase in light duty vehicle (LDV) diesel demand, leaving the U.S. with ample diesel availability both to satisfy its own demand and to play a role as a growing diesel exporter to other countries.

Total diesel demand (including biodiesel and GTL diesel) will decline from a near-term peak of roughly 4 MMB/D in 2015-2016 to 3.5 MMB/D in 2030. Of this, LDV diesel demand will increase from less than 0.3 MMB/D at present to over 1 MMB/D in 2030 due to greater model availability, while HDV demand will decline from nearly 2.6 MMB/D at present to around 1.8 MMB/D by 2030 as natural gas substitution grows.

PIRA expects natural gas in all U.S. transportation to grow from negligible amounts at present to nearly 1.3 MMB/D of oil equivalent demand by 2030. For heavy transportation uses, the economic advantages of natural gas are considerable, and the shale revolution has unlocked a vast supply of low-priced gas, which should support this economic advantage versus oil-based fuels for a long time to come. Of course, this is dependent on a buildout of refueling infrastructure, which is currently at a very early stage. PIRA also evaluated a U.S. diesel scenario with lower natural gas substitution of 0.6 MMB/D oil equivalent by 2030, reflecting negligible natural gas uptake in long-haul trucking and substantially lower uptake in fleet vehicles and other uses than the Reference Case.

The on-road transportation sector is the largest user of petroleum in the U.S., making up around 73% of diesel demand, increasing to 81% in 2030 (including biodiesel and GTL diesel). As diesel is gradually removed from non-transportation uses due to greater fuel switching and efficiency improvements, transportation usage—which is more difficult to substitute away from than stationary sources—will grow as a share of diesel demand.

Light Duty Vehicles (LDVs)

In terms of forecasting overall fuel demand for cars and light trucks (LDVs), the key drivers are the growth in vehicle miles traveled (VMT) and the rate of fuel efficiency improvement, which will reflect both price incentives and government regulations. In recent years, VMT has stagnated, handicapped by the large oil price increase over the last several years and weak employment growth since the Great Recession of 2009. With more stable oil prices and a gradual recovery in employment, PIRA assumes in the Reference Case that VMT grow in the U.S. at an average 1.3%/yr. through 2030, which is below typical historical VMT growth.

The Reference Case also assumes that the U.S. fuel efficiency targets remain in place, bringing new car real-world efficiency across all fuels from roughly 34 MPG in 2013 to nearly 39 MPG in 2020. While longer-term
targets of over 50 MPG remain uncertain, the trend of increased efficiency through 2020 looks very likely. This increase in MPG will occur via a combination of greater efficiency in conventionally powered vehicles and continued penetration of hybrids and pure electric vehicles. By 2030 PIRA’s Reference Case projects that electricity will provide the energy for around 3.1% of light vehicle miles travelled in the U.S. No meaningful volume of natural gas light vehicles is expected (natural gas usage is expected mainly in HDVs, rail, and certain shipping applications). Overall, with slow income growth offset by efficiency improvement as the fleet evolves, gasoline consumption (including ethanol) will recover slightly and then go into structural decline in North America post-2015.

In recent years the share of LDVs powered by diesel fuel has risen considerably, driven by improved diesel model availability as automakers bring a better diesel vehicle selection to market. Diesel sales of LDVs rose from around 2% of new sales in 2000 to around 4% in 2010, and they are expected to increase to about 10% in 2020, and 14% in 2030. Higher overall oil prices increase the economic benefits of diesel engines, which are more efficient than gasoline engines, and greater availability of smaller-format diesel engines improves the options that consumers face. Of course, those options also include other technologies like hybrids and electric vehicles.

While sales of diesel LDVs and other powertrains are increasing rapidly, conventional gasoline vehicles are still expected to compose a large majority of vehicle sales through the end of PIRA’s outlook. Moreover, since the vehicle fleet takes time to turn over, the share of the vehicle fleet composed of non-gasoline vehicles will lag their share of new sales, leading to a slower transition in terms of fuel demand than in terms of new vehicle sales.

**Heavy Duty Vehicles (HDVs)**

In the case of trucks and other heavy duty vehicles, growth in industrial production and freight movements should lead to a steady increase in freight ton-miles. This will be more than offset by continued increases in truck efficiency. PIRA therefore expects diesel demand for U.S. HDVs to decline at an annual rate of around 0.5% per year through 2020. There is a push for use of natural gas (both CNG and LNG) for fleet vehicles and long-haul trucking. While government incentives have been slow in coming, private initiatives are moving forward to provide both the refueling infrastructure (Clean Energy etc.) and the LNG-fueled trucks themselves (Westport). Volumetric penetration of natural gas is likely small by 2015 but increased penetration of natural gas post-2020 leads to a decline in HDV diesel demand, averaging -3% per year from 2020 to 2030. The extent of the penetration of natural gas displacing diesel fuel in heavy trucks is a major uncertainty. PIRA assumes approximately 1.3 MMB/D of transportation diesel demand (vehicles, rail, marine) is replaced by natural gas by 2030 in the U.S., but under optimal conditions the number could be substantially higher. Alternatively, if crude and diesel prices remain below current levels, the incentive may never be great enough to drive natural gas penetration. The economic and operational details of natural gas substitution are discussed further below.
Other Uses

Diesel is used extensively in non-road applications within the U.S., with demand historically totaling 1.4-1.6 MMB/D. This includes a variety of transportation uses (off-road vehicles, railroads, and vessel bunkering), as well as a variety of stationary uses (residential/commercial heating, farm/industrial machinery). Over time, PIRA expects demand for these uses to decline in aggregate due to efficiency improvements and fuel substitution.

Historically this non-road diesel demand has trended closely with economic growth, notably showing declines in 2001-2002 and 2007-2009. However, there is also a decline from 2011-2012 (the most recent year where detailed data are available) that indicates the potential effect of efficiency improvements and other demand-reducing factors even during a period of economic expansion.
Outlook for Global Diesel Demand

PIRA’s World Energy Demand model has diesel fuel demand on a global basis growing rapidly to 2030, supported by steady increases in emerging markets as they industrialize. With the industrialized economies (the U.S., Canada, Europe, Japan, and Australia/New Zealand) expected to show a net decline in oil demand going forward, emerging markets will make up more than the net total global oil demand growth to the end of PIRA’s outlook. As countries undergo oil-intensive economic expansion, it is generally diesel that shows the strongest demand growth due to its broad uses throughout industry and in industry-linked transportation.

Diesel/distillate’s share of the barrel will display two distinct patterns to 2030 due to the impact of fuel switching. While a variety of industrial and freight uses will support distillate demand in developing countries, improved efficiency and natural gas substitution in some sectors in industrialized countries will lead to a slight decline in distillate’s share of the barrel from 2015 to 2020. From 2020 to 2025, sulfur regulations in ship bunkers will force ship owners to switch some fuel oil demand to distillate, increasing distillate’s share of the barrel. Post-2025, slowing demand growth in developing countries coupled with greater transportation use of natural gas in North America will again reduce distillate’s share of the barrel. Post-2025, the growth of distillate will be only marginally stronger than gasoline. Overall, the diesel share remains within a narrow band throughout the forecast.

Transportation

More than 70% of global diesel demand is used in transportation, with this expected to rise above 80% of total diesel demand by 2030 as transportation uses grow rapidly and non-transportation demand declines somewhat due to greater efficiency and fuel substitution. Transportation diesel demand is expected to grow around 7.5 MMB/D from 2013 to 2030, supported by the industrializing trends of the emerging markets.

This global increase will actually be a combination of higher demand in emerging markets offset by decreases in the U.S. and Canada from natural gas substitution, as well as declines in Europe from greater efficiency, weak demand for vehicle travel, and some electrification of the vehicle fleet. In Europe, diesels make up more than half the light vehicle fleets in some countries, so diesel demand is much more closely linked with personal
transportation than in the U.S., where it is primarily a commercial transportation fuel. Thus, trends reducing personal vehicle fuel demand in Europe, such as more stringent fuel efficiency standards and changing demographics, will have a large impact on diesel.

One area of demand increase across all regions is vessel bunkers, which will grow with domestic and international trade. The composition will change from high sulfur fuel oil more towards low sulfur fuel oil and gasoil/diesel in line with tightening sulfur regulations, first with the implementation of Emission Control Areas (ECAs) within 200 miles of the U.S., Canadian, and Northern European coasts and, after 2020, with a global limit of 0.5% sulfur in bunker fuels. Low natural gas prices in the U.S. and Canada will give an extra incentive, on top of sulfur regulations, to substitute LNG for oil in bunker use (mostly for LNG tankers and for vessels that travel mostly within ECAs). But overall the impact will be to increase diesel demand within shipping.

Other Uses

Outside of transportation, global diesel usage is expected to decline around 1.2 MMB/D from 2013 to 2030, driven by attractive economics for alternative sources of energy like natural gas, as well as improvements in efficiency. The bulk of these declines will be in industrial demand and residential/commercial heating, as well as a smaller contribution from lower electricity generation demand. Higher oil prices relative to a decade ago are encouraging many stationary-source energy consumers to make investments away from oil price-linked fuels like diesel.
Diesel Supply and Trade

The U.S. is currently a large net exporter of diesel fuel to other markets, mostly Latin America and Europe. With refinery runs (the amount of crude fed into refineries) expected to grow moderately over time and overall diesel demand expected to decline somewhat over the outlook, the U.S. is expected to grow from around 0.9 MMB/D net exports in 2013 to 1.8 MMB/D in 2030. Thus, even given the expected rise in light duty vehicle diesel demand, the U.S. should have more than adequate diesel supply to satisfy its own demand with plenty of spare product for export. And even if diesel demand is much higher (perhaps under a scenario where natural gas substitution is much lower than the expected 1.3 MMB/D equivalent in 2030), the U.S. would still have adequate supply to meet its own demand along with some exports.

Supply

U.S. refining is benefiting from the shale oil and shale gas booms due to lower natural gas costs (for refinery fuel and hydrogen, which is used in many refinery processes) and advantaged crude pricing as the growing U.S. shale oil supply has driven down domestic crude oil prices relative to international crude and product prices. With these lower costs, the large, complex refineries on the U.S. Gulf Coast have been able to out-compete other regional suppliers in the export market. As refineries on the East and West coasts increasingly access domestic crude, they too are seeing improved economics.

These advantaged economics have led U.S. refiners to run their facilities at higher rates, turning the U.S. into a growing net exporter. The utilization rate increases have largely followed the economics, with Midcontinent refiners and refiners on the U.S. Gulf Coast initially increasing utilization rates, and East Coast refineries doing so more recently as they increasingly use economically advantaged domestic crude oil shipped by rail.

In addition, the advantaged economics and growing domestic supply of light, low-sulfur (sweet) shale crude have motivated some refiners to begin to expand capacity in various ways, such as debottlenecking existing facilities and building small condensate splitters. While PIRA does not assume any newbuild full-scale refineries in the U.S. in its outlook, these incremental changes do add up. When coupled with continued high utilizations, U.S. refinery runs will grow moderately over time (roughly 1.5 MMB/D from 2013 to 2030).

The other key factor in refinery diesel production is the diesel yield, which is simply the number of barrels of diesel produced by refineries per barrel.
of crude oil refined. Diesel and jet fuel, the so called “middle distillates,” have been the most profitable products for refiners over recent history, so refiners have been working to increase their yields, generally by reducing yields of gasoline and fuel oil. In the U.S., for example, diesel yields have risen from 26.4% in 2005 to 28.4% in 2010 and to 30.6% in 2013. PIRA’s long-term outlook assumes diesel yields of between 30% and 31% out to 2030, which should not be problematic for the industry to achieve.

While some commentators have worried that a lighter refinery slate will push up gasoline yields and depress diesel yields, PIRA believes that these worries are overblown. It is true that a barrel of lighter shale oil will produce more of the light products (LPG, naphtha, and gasoline) in a refinery distillation unit than a barrel of medium density crude. But once the effects of secondary conversion units are worked in, the overall yields are closer. Also, there are many operational techniques that U.S. refiners can use to maintain or increase middle distillate yields, particularly high hydrocracker runs, as well as altering product cut points to preferentially increase yields of diesel and jet fuel. In Europe, where diesel demand is a much higher proportion of oil demand, refiners have been able to boost diesel/gasoil yields into the mid-40s using a series of similar configuration/operational changes.

In addition to refinery diesel production growth, PIRA assumes around 0.2 MMB/D of growth to 2030 in the U.S. from non-refinery sources of diesel (biofuels and some GTL-type technologies). Overall, with supply growth coupled with slightly declining local diesel demand, the U.S. will grow as a net exporter of diesel.

At the global level, the middle distillates are likely to remain “premium products” and capture the highest product prices per barrel over the outlook period, driven by rising demand in industrializing economies as well as the global shift in shipping fuels away from high-sulfur fuel oil post-2020. Diesel supply should similarly have few issues in meeting anticipated demand. Refiners at a global level will need to maintain diesel yields of 34-35% to 2030, a rate they are currently achieving. This is net of an assumed 0.9 MMB/D of growth in non-refinery diesel (biofuels, GTL, etc.), but even if this growth in non-refinery sources is considerably lower, refiners should be able to adjust yields without much difficulty. That said, the shift in bunker specs will require changes in operations as already noted, and those changes will only occur if the market gives the appropriate price signal. PIRA’s long-term outlook has diesel prices increasing moderately more than other products when that transition occurs.

**Product Trade**

Over the last several years, the U.S. has increasingly become a major product exporter. Initially, this was mostly due to a decline in local product demand along with the increased use of ethanol. Exports rose even though refinery runs declined through 2009, and they have increased further as runs increased since 2010.

Looking forward, U.S. runs will increase further (but more slowly as existing capacity is already fully utilized) and local demand for major products from refining (excluding biofuels, NGLs, LPG, and byproducts) will trend lower. This implies that exports will increase.

The U.S. net middle distillate trade has already flipped from importer to exporter with the Gulf Coast being the largest source of exports. These exports will also grow substantially to 2030. The export volumes assume slower
growth in U.S. diesel demand (as natural gas makes inroads in trucking) and that refiners continue to modestly shift yields from gasoline to middle distillates. Exports will primarily go to Latin America. Europe will likely remain a smaller, relatively stable buyer from the U.S. The U.S. has substantial flexibility to increase gasoline yield (at the expense of middle distillates), and should be able to adapt if product importers’ needs shift toward gasoline.

With this flexibility, the U.S. should be well supplied in terms of vehicle fuels even given the long-term uncertainties. If domestic diesel demand is higher than expected, the U.S. can export less; while if it is lower than expected, refiners can export more or shift their yields away from diesel to other products. And if natural gas demand in transportation is higher than expected, abundant U.S. shale gas supplies should be able to meet any anticipated vehicle demand.

**Low Natural Gas Substitution Scenario**

Given the uncertainty around ultimate U.S. natural gas substitution into trucking and other uses, PIRA explored an alternative scenario for U.S. diesel balances that assumes much lower natural gas substitution than the Reference Case. In this scenario, natural gas in long-haul trucking was assumed to be negligible to 2030. In addition, PIRA substantially reduced natural gas usage in fleet vehicles and other uses. The result of this is natural gas substitution for diesel only growing to 0.6 MMB/D of oil equivalent by 2030. Under this scenario, U.S. diesel net exports are lower than in the Reference Case, but still 0.9 MMB/D or higher in all forecast years, indicating ample capacity to supply the U.S. market.

This scenario essentially reflects slow development of natural gas refueling infrastructure as well as persistently high premiums for natural gas trucks. It is also possible for natural gas penetration of the diesel market to be higher than the Reference Case. Based on expected oil and natural gas prices, the economics are quite supportive for natural gas substitution.
Vehicle Fleet Composition and Efficiency

Vehicle Sales, Retirements, and Fleet Composition

Dieselization of the U.S. auto fleet is projected to increase, but only relatively slowly among LDVs. Hybrids and electrification of the vehicle fleet will become more significant technologies moving forward. There remains a niche market for diesel where it will readily capture market share due to its high torque engine profile and substantially higher efficiencies. However, pricing of diesel fuel relative to gasoline will continue to work against increased penetration. Diesel engines cost significantly more than gasoline engines, although with high fuel prices, a favorable tax regime, and the better efficiency of diesel engines, diesels can be economically competitive with gasoline vehicles. These conditions are more supportive in Europe, but less in the U.S. and in most of the developing world.

The most notable trend will be the decline in absolute sales level and market share of “conventional” gasoline vehicles and the growth in vehicles utilizing some efficiency enhancing technology, be it diesel, hybridization, or electrification off the grid. While sales penetration of the new technologies is fairly rapid, the penetration of the vehicle stock is slower. Of the new vehicle types, hybrids dominate the car fleet, while diesels dominate the light truck fleet.

Diesel is forecast to remain the fuel for nearly half of European car VMT over the forecast period. In China, passenger cars are anticipated to remain overwhelmingly gasoline-powered due to their lower price point.

Electricity usage in transportation grows over the forecast period with regional variations driven by different fuel prices, driving patterns, and policy regimes. Europe has the highest uptake due to its fuel prices, with China at a slightly slower uptake, driven primarily by government policy.

Vehicle Fuel Efficiency

PIRA assumes a substantial improvement in fleet efficiency over the forecast period. New diesel car and light truck fuel efficiencies are expected to improve at rates of ~1-1.5% per year, with overall fleet efficiency improvement rates somewhat lower. Heavy vehicles are expected to improve at annualized rates of 0.5-1% driven by incremental technology improvements.

Among the overall LDV fleet (diesel and non-diesel), PIRA similarly expects significant improvements in vehicle efficiency, driven by
incremental improvements in conventional gasoline vehicles, increasing hybridization/electrification, and the uplift from the greater efficiency of diesel vehicles relative to gasoline as adoption broadens. Corporate average fuel economy (CAFE) standards, improvements in vehicle technology, and high fuel prices relative to history all support greater vehicle fuel efficiency.

Turnover of the heavy truck fleet is currently relatively slow. Capital costs are considered high relative to operating costs. Even so, there is potential for a more rapid advancement in heavy duty truck efficiencies. The turnover of delivery trucks such as FedEx and UPS is three to four years, and such entities are looking at alternative fueling of such vehicles. Whether they choose to continue using diesel fuel or switch to a pure electric or hybridized engine designs for vehicles not converted to natural gas could result in much faster efficiency improvement than PIRA currently assumes.

Technological Change Takes Time to Work Through Capital Stock Turnover

Assume (U.S.):
- Light vehicle (cars + trucks) fleet of 250 million
- New light vehicle sales of 17 million/yr (pre-recession), now 16 million
- Retirement of 14-15 million/yr or 5-6% of fleet/yr
- New technology provides 25-30% greater efficiency
- Penetrates new car sales at rate of 5%/year.
  (Note: Hybrid market share in U.S. ~3.2% in 2013 after 14 years)

Impact on average fleet fuel efficiency:
- Year 1: 0.1%
- Year 5: 1.2%
- Year 10: 4.1%
- Year 20: 15.1%

Turnover much slower for industrial plant, structures
- Median age of power plant ~30 years (lower in emerging markets)
- Median age of house ~40 years
Powertrain and Vehicle Transportation Technologies

Vehicle powertrain technologies are likely to be the most important single factor limiting overall oil demand growth over PIRA’s outlook period. The rise in vehicles that use electricity, natural gas, or more exotic alternatives such as hydrogen will supplant oil in fuels. More important, however, will be the rapid accumulation of oil-consuming vehicle technologies that marginally improve efficiency but are applied broadly throughout the entire conventional internal combustion engine (ICE) fleet, which in PIRA’s estimation will still comprise something on the order of 90% of LDVs on the road in the U.S. in 2030 (conventional gasoline and diesels, but excluding hybrids). The surprisingly low share of non-conventional vehicles in the fleet reflects the math described in the section above, in which a new technology—even with rapidly rising adoption—will take considerable time to penetrate the fleet given the pace of vehicle turnover.

One of the main drivers of improved vehicle technology is the high price of oil relative to the 1990s and early 2000s. With motor fuels at the pump today costing twice what they did in the mid-1990s in inflation-adjusted dollars, investing in additional efficiency-improving technologies upfront makes greater economic sense. In addition, the regulatory environment in most vehicle markets around the world is consistently requiring greater efficiency. Thus, automakers are investing in efficiency-improving R&D and deploying these technologies in more vehicles over time.

Light Vehicle Economics

Light vehicle economics for efficiency-improving technologies typically require a rapid payoff on the order of two or three years since these are the return horizons historically required to sell to individual consumers. Individuals often face uncertainty about their future driving needs and generally avoid new technology risk. In addition, experience has shown that it is very difficult for individuals to weigh vehicle life-cycle costs appropriately when evaluating a new purchase, although drivers have become increasingly cognizant of fuel efficiency in recent years.

In the U.S. the low price of gasoline relative to most other countries renders alternative vehicle technologies uneconomic at present. Tax credits and subsidies can alter economics over the short term, but the cost of electric vehicle (EV) batteries must decrease substantially over the long term for EVs to scale in the U.S.

In Europe, much higher fuel prices and the typically tax-advantaged status of diesel relative to gasoline often make diesels an economic purchase. EVs, however, are still uneconomic without subsidies, although attainable cost improvements will likely change this by 2020.

Diesel

Diesel has been quite successful in Europe over the last 15 years to the point that new car sales are now about half diesels. Improvements in engine technologies and fuel specifications have brought about highly efficient diesel engines with good performance. This came out of a collaboration between regulators, fuel suppliers, and automakers to simultaneously provide a tax advantage for diesel versus gasoline, supply lower-sulfur, less polluting diesel fuel, and to build better small diesel engines capable of
providing good performance and high efficiency while limiting emissions. With these factors in place, diesel sales rose very rapidly, from less than 15% of new auto sales in the early 1990s to roughly half of sales by the mid-2000s.

Without a similar collaboration in the U.S. diesel uptake among LDVs has been far more limited. Within the light truck segment diesels have benefitted from their high torque, but overall model availability has been limited. Over recent years, however, automakers have brought more diesel models to market, even within the car segment. A lot of these vehicles are simply European automakers bringing some of their models over to the U.S., but domestic U.S. automakers are beginning to supply models as well. This push by automakers as well as the higher efficiencies of diesel vehicles should be supportive of diesel growth in the LDV fleet.

Gasoline

Given the large majority share of the current and expected future LDV fleet powered by gasoline, the most important trend right now in vehicle technology is the accumulation of technologies for conventional gasoline vehicles that provide marginal improvements in efficiency. Many of these technologies are currently undergoing rapid rollout as costs come down and fuel prices have increased. What is important about these technologies is that they can be applied to most vehicles in each automaker’s lineup rather than to a few specialized models as with more exotic technologies such as electric vehicles. Particularly noteworthy are improvements driven by better computer control technologies such as fuel injection, cylinder deactivation, and automatic transmission control, which have been made much more economic by plunging costs in small, powerful computers and lightweight sensors. Many of these technologies can also be applied to diesels. The key incremental technologies include:

- **Turbocharged engines.** Initially developed for diesels in Europe, turbocharging amplifies the power of lower-displacement engines which improves overall fuel efficiency by allowing vehicles to use smaller engines to obtain the same power output. In the last few years, this technology has begun to move to gasoline vehicles.
- **Improved direct fuel injection.** Although fuel injection technologies have been around for a long time, modern gasoline engines are increasingly using highly sophisticated computer-controlled direct injection where fuel is injected into the cylinder rather than the intake manifold. This allows for a leaner fuel mixture that is more precisely calibrated to the ambient conditions, reducing the fuel required to obtain the same performance. (Diesels already all use direct injection.)
- **Cylinder deactivation.** During highway driving, vehicles typically require much less than maximum power output. Cylinder deactivation shuts off the unneeded cylinders, saving fuel while cruising.
- **Variable valve timing.** Many automakers have been taking advantage of variable valve timing, which alters the timing of the intake and/or exhaust valves to better optimize combustion according to driving mode and environmental conditions.
- **Transmission improvements.** Advances in computer control have made modern automatic transmissions match or exceed the fuel efficiency of manual transmission vehicles driven by typical
drivers. Automakers have also been increasing the number of speeds in transmissions in an effort to improve efficiency, with 7- and 8-speed versions becoming increasingly common, and automakers developing transmissions with even greater numbers of speeds. In addition, continuously variable transmissions (CVTs), which smoothly shift between all gear ratios, are becoming increasingly common.

- **Lightweighting.** Automakers have become conscious of reducing unnecessary vehicle weight as a means of improving fuel efficiency via chassis designs that use less metal due to better design, replacement of steel with aluminum, and greater incorporation of lighter materials such as magnesium and composites.

- **Vehicle downsizing.** Improvements in internal vehicle layout accompanied by greater investment in comfort and entertainment features within smaller vehicles have made them more attractive. Luxury automakers such as BMW, Mercedes, and Audi all now offer premium smaller vehicles, and premium features are being increasingly incorporated into economy-plus small vehicles.

- **Micro-hybrids.** By incorporating a larger battery and a more powerful starter motor, micro-hybrids can shut the engine off instead of idling while stopped and still restart the engine quickly enough to provide good performance off the line. This improves fuel efficiency when stuck in start-stop traffic in urban driving.

Automakers have been incorporating these technologies into more of their models over the last decade, especially since 2007. For example, Ford's EcoBoost engine technology, which combines turbocharging and direct fuel injection to improve fuel economy 20% over a normal engine of equivalent performance, is now offered as an option on roughly 90% of the automaker's lineup, after first introduction in the 2010 model year.

**Hybrid Vehicles**

Hybrids offer an attractive alternative powertrain because they require no changes to driver behavior. From the customer perspective they're just normal gasoline cars (rarely diesel) that cost somewhat more up front but get much better mileage. Since the introduction of the Toyota Prius in Japan in 1997 and worldwide in 2000, hybrids have grown in popularity, particularly in the U.S. and Japan, driven by reductions in cost, performance improvements, and successful marketing that appeals to green-conscious, affluent drivers. There were about 45 hybrid models offered in 2013, roughly even with 2012, as automakers reshuffle hybrid offerings towards higher-volume models and retire niche models. U.S. 2013 hybrid sales were up roughly 14% over 2012, versus 7.5% for overall auto sales. Companies are rapidly adding additional models in certain categories. (Toyota plans 21 additional hybrids by end 2015.)

Hybrids combine an internal combustion engine with a battery and one or more electric motors to take advantage of the strengths of both powertrain types and enhance fuel efficiency. In parallel hybrids like the Honda Insight, both the internal combustion engine (ICE) and the electric motor can drive the wheels, with the electric motor typically kicking in during periods of peak power demand to thereby allow for a smaller ICE. In series hybrids, the electric motor drives the wheels and is powered by a generator that is spun by the ICE, thereby allowing the ICE to run within its most efficient RPM range. In the series-parallel layout (like in the Prius), some combination of the two approaches is used, with the motor typically providing more power at low speeds where it's more efficient than the ICE, but also assisting the ICE at periods of peak power demand at higher speeds such as highway passing. One of the benefits of the hybrid layout (and even some micro-hybrids) is regenerative braking in which some of the energy of braking is actually converted back into electricity by the motor during deceleration rather than wasted as heat. This can considerably improve the efficiency of start-stop driving such as in traffic.
Electric Vehicles (EVs) and Plug-in Hybrid Vehicles (PHEVs)

EVs and PHEVs have gained a lot of interest over the last five years from automakers and governments as a means of dramatically reducing reliance on petroleum and limiting emissions of CO₂ and urban air pollutants.

Due to the greater efficiencies of turning stored electricity into motive power rather than burning gasoline, EVs have inherent MPG equivalent advantages of three to four times that of conventional ICE vehicles and about a 50% advantage once powerplant inefficiencies are taken into account. In terms of economics, the cost per mile is much lower for electricity than for gasoline, so with high enough fuel prices and low enough battery prices, EVs can attain economic competitiveness with ICE vehicles. In addition, many governments offer EV subsidies, although PIRA believes that over the longer term, budget constraints will largely prevent the mass-scale subsidization of EVs in the industrialized economies.

Pure EVs just contain a battery and a motor, while PHEVs are hybrids that can be recharged from the electrical grid, allowing the driver to use electricity for shorter trips, but then switch to the ICE drivetrain for longer trips without stopping. PHEVs typically have shorter all-electric ranges and are more expensive than equivalent EVs due to their greater drivetrain complexity. However, they can be driven like regular vehicles, whereas EVs are range-limited and must be recharged once their batteries are depleted.

Charging typically takes six to nine hours from a regular charger (home or work) and 45 minutes from public direct current quick chargers. Quick charging requires an expensive public station ($50,000+ but declining rapidly), can only bring the battery to 80% of full charge, and may cause more battery degradation due to the higher strain of rapid charging. Tesla, the CHAdeMO Consortium, and potentially other companies and groups, are in the process of rolling out quick charging networks across the U.S., Europe, and Asia to enable long-range driving among suitably-equipped EVs.

Home charge spots typically cost on the order of $2,000-3,000 installed, although many EVs can recharge directly from wall sockets at half the normal rate (so ~12-18 hours for a full charge). Several companies, such as Nissan and Qualcomm, are working on wireless chargers that can recharge a car from a coil placed below without the user needing to plug in, which makes the experience more convenient.

Battery technology is the main outstanding technological issue. At present, lithium-ion EV batteries cost in the vicinity of $300-500/kWh at the pack level, with a typical 24 kWh battery costing around $12,000. This puts a significant premium on the upfront cost of the vehicle, especially since that battery gives a real-world range of only ~80 miles. Longer-ranged vehicles such as those made by Tesla have much larger batteries, which cost more.

Manufacturing improvements and economies of scale suggest battery prices in the $200-300/kWh are possible in the 2017-2020 period, which would enable the production of 200 mile range EVs at a price point of around $35,000, potentially enabling much broader adoption.

Battery technology improvements are uncertain although there are several technologies in the laboratory today that could improve battery performance by a factor of two or more if commercialized. The most promising technologies today generally do one of three things:

1. Improve the density of lithium ion storage and/or the ability of lithium ions to move during charge/discharge by altering the cathode and/or the anode, typically with nanotechnology innovations.
2. Change the non-lithium materials in the battery, such as replacing the metal oxides in typical Li-ion batteries with sulfur (currently one of the most promising approaches).
3. Use non-lithium chemistries such as zinc-air (currently further out on the R&D roadmap).
However, due to the demanding safety and durability requirements within vehicles, technologies in the lab today are unlikely to be ready for mass vehicle use until near the end of the decade. Most estimates place annual improvements in EV batteries in the 6-8% range, which would mean a 50%-70% improvement by 2020. A step change improvement that nearly doubles capacity from today would roughly fit within this pattern, with intervening incremental improvements occupying the interim period.

Starting with the U.S. launch of Nissan Leaf EV and Chevy Volt PHEV in 2010, virtually every major automaker has an EV or PHEV in some level of development. Companies are moving forward with EV plans and refining and expanding EV offerings, much like how the hybrid rollout went in past years. Tesla has been particularly successful in selling a luxury EV to the premium market, but it remains to be seen whether this will carry over to the mass market segments required for EVs to have a noticeable impact on oil demand.

PIRA’s view is that EVs will face slow adoption over the rest of the decade due to limitations on battery technology and customer preference, although they will accelerate in importance post-2020. Overall, PIRA sees a series of incremental improvements gradually accumulating to the point where EVs begin to gain significant market share after 2020.

**Natural Gas**

PIRA is optimistic about the future of natural gas vehicles in the U.S., particularly in LNG trucks and CNG fleet vehicles (although not necessarily in personal vehicles). With shale gas offering the potential for low natural gas prices and abundant supply over the long term, NGVs look to have competitive economics for the foreseeable future.

The rollout of the 11.9L engine by the Cummins/Westport Innovations (CWI) joint venture should catalyze sales of LNG trucks since, unlike previous LNG truck engines, it is right-sized for heavy vehicle needs. Truck manufacturers that currently use or plan to incorporate the CWI 11.9L include Kenworth, Peterbilt, Freightliner, and Volvo. Based on PIRA’s relative price outlooks for gas and diesel it appears that the payback period for the extra upfront capital investment should be around two years (discussed more thoroughly below).

Currently, U.S. LNG infrastructure is immature, but it seems poised for expansion. Clean Energy’s America’s Natural Gas Highway currently has ~100 LNG fueling stations complete. Looking ahead, LNG refueling will ultimately expand from an initial expected corridor from California into the Southwest. Other high traffic early target areas will include the so-called “Texas Triangle” (Austin, Fort Worth, Houston, and San Antonio) and linkage between Louisiana-Texas, Chicago-Texas, and Chicago-Atlanta.

In U.S. CNG fleet vehicles, the engine technologies are well-developed. Fleets, whether cars, trucks, or buses, generally travel fixed routes, return to a base operating station and have fixed hours of operation. Such usage allows for minimal fueling points along a route. Additionally, fleets can utilize cheaper time-fill fueling infrastructure given the hours of operation and what generally are long windows of time during which vehicles are off-duty. These fueling stations simply require a drying unit and compressor after connection to existing natural gas pipes rather than more costly pressurized pumps that fuel CNG vehicles like traditional gasoline.
pumps. PIRA is less optimistic about CNG in passenger cars (and LNG tanks are too large for passenger vehicles). Only one commercially natural gas stock-made passenger vehicle is currently available and it sells in very low volumes.

Outside the U.S., CNG is used extensively in vehicles in Iran, Pakistan, Argentina, Brazil, and China, among others, often incentivized with subsidies and price controls on natural gas. CNG is particularly popular for urban driving and is frequently found in buses and taxis. LPG fueled vehicles are also increasing in popularity in selected markets. LNG is also likely to make gradual inroads into ship bunkering, driven by cost advantages and marine fuel sulfur limitations. Many of the largest railroads are also looking at gas as an alternative to diesel.

The life-cycle economics of heavy vehicles are typically more important relative to personal vehicles since most are purchased by businesses or independent operators using them for business. Such purchasers typically weigh life-cycle costs in their purchase decisions.

High-mileage LNG trucks in the U.S. face attractive economics, even with relatively conservative fuel pricing assumptions. The expected cost of a midsize truck powered by CWI's 11.9L spark-ignited engine will likely be $40,000-$45,000 above that of a comparable midsize diesel truck. Heavier duty LNG trucks, such as Westport's 15L engine, with high pressure direct injection (HPDI) have much higher price tags and some require a dual tank system given their extra weight. The 15L engine trucks carry incremental initial costs of $60,000 to $70,000 with a single tank system. The same engine with a dual tank system will push the incremental cost closer to $90,000.

Under the assumptions displayed in the box, operators can attain breakeven within two years, so the economics are quite supportive of LNG truck deployment—at least for usage in high-mileage vehicles. As the capital cost increment declines with volume and competition, the breakeven time should continue to decline potentially to under one year.

In the above section on diesel supply and trade, PIRA also explored a lower natural gas substitution scenario, reflecting limited infrastructure and high upfront natural gas vehicle cost premiums. This results in much lower natural gas substitution for diesel than the Reference Case (0.6 MMB/D oil equivalent in 2030 versus 1.3 MMB/D in the Reference Case). Regardless, the U.S. still remains a large net exporter of diesel fuel over the outlook.

**Hydrogen and Other Powertrain Technologies**

**Hydrogen.** PIRA is skeptical that hydrogen fuel cell vehicles (FCVs) will achieve material uptake over the outlook period. FCVs have been “10 years off” for several decades now, and catalyst costs have not come down anywhere near enough for the vehicles to approach economic competitiveness. In addition, FCVs would require hydrogen fueling infrastructure, which is a large financial deterrent to their rollout. Several of the major automakers have FCV programs that they continue to advance, including recent announcements from Toyota, Honda, and Hyundai, but PIRA sees these efforts as limited in scale.
Compressed air. A few startup companies are experimenting with compressed air as an energy storage technology, especially for small, short-range vehicles. Compressed air is a low energy density technology, and it is unlikely that it can be scaled to gain a material share of vehicle miles traveled (VMT).

Biofuels and Gas to Liquids (GTL) Technology

Ethanol. Although a gasoline blending component rather than a diesel substitute, growing ethanol usage decreases the demand for hydrocarbon gasoline, and thus indirectly may affect diesel. The U.S. uses a large amount of ethanol in its gasoline (currently ~0.9 MMB/D). Initially this was as a replacement for MTBE as it was phased out and more recently due to the blending mandates under the Renewable Fuel Standard (RFS2). This ethanol comes predominantly from corn, with a significant share of the U.S. corn crop going to ethanol. Despite substantial R&D investments in chemical and biological processes to produce cellulosic ethanol from waste materials, technological and economic hurdles have limited the success of these approaches to date, and the EPA has had to retroactively revise lower the cellulosic component of the biofuels mandate due to extremely limited actual production.

The level of ethanol in U.S. gasoline has been increasing sharply over the past several years, to the point that well over 95% of U.S. gasoline contains ethanol, largely at a 10% level. Moving beyond 10% is difficult in the near term given vehicle- and distribution-system component compatibility issues, among many other logistics factors. To do so will require growing usage of gasoline blends with ethanol fractions higher than 10% such as E15 and E85. Engine technology to handle these blends is well-developed (most post-2001 vehicles can generally use E15 and so called “flex-fuel” vehicles can use E85), but there are concerns about warranty issues and the impact on older vehicles that weren’t designed for the higher ethanol blends.

Biodiesel. Biodiesel is largely used in Europe, but the U.S. also has growing consumption. Compared to ethanol it is easier to blend biodiesel into the motor fuels pool since it generally has similar properties to regular diesel. There are a variety of approaches to manufacturing biodiesel, but most begin with some sort of vegetable oil and then treat it to produce a final product. Biodiesel is typically more expensive than comparable hydrocarbon diesel, so regulatory mandates play a large role in biodiesel growth. In terms of the technology roadmap, most innovations appear more of the incremental sort, so PIRA expects relatively moderate growth in biodiesel production over the outlook, both in the U.S. and abroad. Of the total diesel consumption in the U.S., biodiesel should grow somewhat from the roughly 90 MB/D in 2013 to around 160 MB/D in 2030 due to expansion of blending mandates. With biodiesel expected to remain more expensive than hydrocarbon diesel, biodiesel demand growth will be a regulatory-driven phenomenon in the U.S., making exact long-term volumes uncertain.

Gas-to-liquids (GTL). GTL technologies typically use various chemical processes (often Fischer-Tropsch or some variant) to convert natural gas into liquid fuels, often diesel and jet. Given the significant price discount of gas versus oil on an energy equivalent basis in the U.S., in some Middle Eastern countries, and elsewhere, economics can be attractive. However, GTL technologies typically involve very high capital expenditures, and several of the GTL plants constructed so far around the world have come in significantly over-budget and behind schedule. Currently, only a few GTL plants are in operation and producing significant amounts; they are as follows: Mossgas in South Africa, Shell’s Bintulu in Malaysia, Oryx in Qatar, and Shell’s Pearl in Qatar, with Escravos in Nigeria set to come online in 2014. Given the abundance of shale gas in the U.S., several companies have planned projects, but it remains to be seen whether any large-scale plants will be constructed given the high capital expenditures required and long construction periods. One potentially attractive alternative is smaller plants, which can be constructed quickly and can be placed in areas with cheap, stranded natural gas (e.g. the Bakken oil field in North Dakota, where natural gas gathering and transmission infrastructure is limited).
Methanol. In addition to its use in the chemicals industry, methanol is used in some places around the world as a vehicle fuel, either via conversion to additives like MTBE, or directly. Several Chinese provinces blend methanol produced from coal into gasoline, and growing shale production in the U.S. could support greater global methanol production. However, methanol and its derivatives face challenges due to lower energy density (half that of gasoline) and potential water contamination hazards. Concerns about toxicity and water table contamination have essentially prevented the use of methanol within the U.S. gasoline pool.

Non-Powertrain Technologies Relevant to Transportation

Mobility services. One interesting recent development is the growing prominence of mobility services like car sharing in urban environments. Companies like ZipCar allow people to rent cars from conveniently located spots. This transforms personal vehicle usage from a high fixed cost but low marginal cost activity into a service that is nearly all marginal cost, potentially reducing car travel. Other services like Uber, which allows users to hail personal drivers from smartphones, may also reduce the need for car ownership in the future.

Telecommuting. Significant improvements in remote communications have enabled a greater share of workers to work from home. Over the forecast period, there is room for substantial IT innovation that could dramatically enhance this trend, potentially reducing the need for commuter transportation.

Telematics in delivery vehicles. Telematics systems with in-vehicle GPS have improved dramatically over the past decade, and are being tightly integrated into supply chain management systems. This technology increases the efficiency of a given delivery vehicle by reducing the miles it must drive in order to deliver a given set of goods, thereby saving fuel.

Self-driving cars. In the last couple years, artificial intelligence programs have become able to drive cars without human input under certain conditions. Automakers are beginning to implement limited autonomous vehicle technologies to build safety features such as automatic braking to avoid accidents. Over time these technologies may grow in prominence, with several automakers targeting fully self-driving cars around 2020. However, there are a large number of legal and policy challenges that must be resolved for these technologies to enter adoption beyond niche applications.
Policy Factors Affecting U.S. and International Diesel Demand

One of the most important factors influencing fuel demand over time is government policy. Governments can influence consumers with fuel taxes/subsidies, vehicle taxes, and bonus/minus schemes. They can influence fuel suppliers with emissions regulations. And they can impose fuel efficiency or alternative drivetrain requirements on vehicle manufacturers. All of these can collectively lead to substantial changes in the volume and composition of fuels demand.

This section discusses some of the key policies influencing diesel and overall fuel demand in the U.S. and elsewhere, as well as PIRA’s outlook for how these policies will evolve over time. In general, PIRA assumes broad continuation of existing policies, with some tightening of efficiency requirements and emissions regulations around the world.

**Fuel Taxation**

By imposing different excise taxes on different fuels, governments can influence the composition of fuel demand. In Europe and some other countries, taxes are lower on diesel than on gasoline, thereby incentivizing greater use of diesel via economic pressure. In Europe, this is one of the main drivers behind the rapid growth in diesel passenger vehicle usage over the last two decades. In the U.S., diesel is typically taxed slightly more per gallon than gasoline, and PIRA assumes that this doesn’t change over the outlook period.

In addition to the relative taxes between different types of fuels, the absolute levels of fuel taxes or any applied subsidies are an important influence on vehicle fuel efficiency and driving patterns. In Europe, where fuel taxes are very high, vehicles are smaller and more efficient. In areas that heavily subsidize motor fuels such as Venezuela and the Arab Gulf countries, vehicles are typically larger with less importance attached to efficiency, and people drive more for a given level of income. Some of these countries may be forced to reduce subsidies as oil exports fall.

**Vehicle Fuel Efficiency**

The Department of Transportation (DOT) and Environmental Protection Agency (EPA) standards require new sales of passenger vehicles to attain an average of 34.1 mpg by 2016, rising to a blended average of 54.5 mpg by 2025 (48.7-49.7 mpg after exemptions for things like improved air conditioners). Heavy vehicles standards for 2014-2018 culminate in a 20% reduction in fuel usage per mile from the current baseline. PIRA’s Reference Case assumes that actual vehicle efficiency continues to improve, reaching 34.4 mpg by 2020 and 40 mpg by 2030 for new LDVs, but it will fall somewhat short of the standards, depending on how CAFE offsets and credits are calculated. This is primarily due to lower electric vehicle (EV) uptake than anticipated, consumer resistance to smaller vehicles, technological difficulties, and reduced policy pressure resulting from lower U.S. oil imports.

Outside of the U.S., Canada’s 2011-2016 fuel economy regulations are harmonized with the U.S. CAFE standards, and Canada’s published 2017-2025 standards are similar to the U.S. requirements. The E.U. currently has emissions targets for both cars and light-duty vehicles. The fleet average for all new cars must be 130 grams
CO₂/km by 2015, with a 2021 target of 95 grams CO₂/km. For comparison, the U.S. light vehicle standards correspond to 199 grams CO₂/mi (124 g/km) in 2021 and 163 grams CO₂/mi (101 g/km) in 2025 if all emissions reductions are achieved via efficiency improvements.

In late 2012, India proposed standards requiring fuel economy improvement of about 10% by 2015, and 25% by 2020. These dates have since been pushed back to 2017 and 2022 in the final rulemaking. In China there are proposals to improve fuel efficiency standards. The government has a CAFE-type program with manufacturer average required efficiencies equivalent to 34 mpg in 2015 and 47 mpg in 2020. Overall, PIRA expects to see continued tightening of fuel efficiency requirements around the world.

**Biofuels**

The U.S. Renewable Fuel Standard (RFS), which requires 36 billion gallons (2.3 MMB/D) of biofuels use by 2022 (including 16 billion gallons of cellulosic biofuels), became law in 2007. However, consumption has been limited by lower gasoline manufacture and the E10 blend wall. While E15 is approved for standard 2001 model and newer cars, E15 demand is expected to grow slowly, as many fuel suppliers and service stations will be reluctant to offer the blend without liability protection. Growth in the use of higher blends, such as E85 is slow as well. The lack of capacity to produce the mandated cellulosic, advanced and total biofuels, as well as the lack of ability to consume biofuels due to the blend wall, have made the current law extremely problematic in its present form.

The EPA has the authority to revise the mandate on an annual basis, while Congress is responsible for major revisions to the legislation. The cellulosic biofuels component has been routinely revised lower by the EPA due lack of availability, and in fact the 2012 mandate was vacated. In November 2013 the EPA proposed to reduce the mandate for total renewable fuels in 2014 to 15.21 billion ethanol-equivalent gallons (1.0 MMB/D), down significantly from 18.15 billion in RFS2 (1.2 MMB/D). PIRA expects more changes before the 2014 requirements are finalized later this year. PIRA’s Reference Case assumes that the total RFS for biofuels is revised lower with significant reductions to the advanced biofuels and cellulosic requirements.

Outside of the U.S., Canada has national mandates of 5% for ethanol and 2% for biodiesel. In addition, several provinces have their own mandates and incentives for biofuels. The E.U. Renewable Energy Directive (RED) includes a target of 10% renewable fuels in the transportation sector by 2020, primarily composed of various biofuels. PIRA believes that the E.U. will fall somewhat short of the 10% target.

Brazil is the second largest ethanol producer after the U.S. and produces its ethanol from sugarcane. Ethanol is used in two ways: anhydrous mandated from 18% to 25% in gasoline in standard cars and 100% hydrous ethanol in flexible fuel vehicles. After rapid growth from 2000-2008, the production and use of ethanol has been relatively stagnant over the last few years.

In China several provinces and cities have a 10% ethanol mandate, but due to food shortages edible feedstock is banned from new ethanol production. Concern with food price inflation is considerable and likely to provide a barrier to expansion.

Other countries, including Argentina, Colombia, India, Indonesia, the Philippines, and Thailand, also have ethanol and/or biodiesel targets. These targets serve to somewhat reduce the demand for refinery-produced fuels.

**Vehicle Electrification**

Due to their high battery costs, EVs are currently reliant on subsidies to be economically competitive with conventional vehicles, a situation likely to persist to around 2020. EVs currently benefit from a $7,500 federal tax credit, as well as a variety of state incentives totaling up to $6,000 in certain states. Over the longer term it is
doubtful that the government can provide subsidies to support high EV sales due to fiscal constraints, so the vehicles will likely face continued headwinds in moving beyond a niche product for some time. However, EVs have shown recent traction in the premium vehicle segment, and it remains to be seen whether they can succeed in migrating this strength into mass market appeal as battery costs decline.

Outside the U.S., many E.U. countries have subsidies or tax breaks for the purchase of EVs and PHEVs. In addition, other member nations waive vehicle purchase taxes on plug-in vehicles, which, in the case of Denmark, total between 105-180% of the cost of a vehicle. Although not an E.U. member, Norway has among the most generous EV benefits of any country, with a variety of benefits that can add up to $8,000/year in value. Many E.U. cities offer subsidies for recharging infrastructure and access to preferred parking locations as an additional incentive to EV ownership. Longer term, fiscal pressure on the E.U. will make it increasingly difficult for governments to maintain large-scale EV subsidy programs.

In China there has been a strong government push for vehicle electrification, with official targets of 500,000 sales per year by 2015 and 5 million “advanced vehicles” per year by 2020. China offers subsidies of RMB 60,000 ($9,800) with certain provinces and cities offering additional credits. Moreover, cities such as Shanghai, Beijing, and Guangzhou have offered exemptions to vehicle registration quotas for EVs. That said, initial sales of EVs have been extremely disappointing due to quality and battery technology issues, as well as the still-high price of EVs compared to regular vehicles, even after the application of subsidies. PIRA assumes that China will fall significantly short of these EV targets, although a recent effort to better coordinate subsidies and require significant purchases of EVs for government vehicle fleets could increase numbers somewhat.

In Japan the government has worked closely with automakers to facilitate the spread of EVs and has in the past provided significant EV subsidies. As of 2014 most subsidies have ended. Nissan, Toyota, Honda, and Mitsubishi all have active EV programs, and the government has worked closely with them and electrical utilities like the Tokyo Electric Power Company (TEPCO) on joint testing and demonstration projects. In addition, EVs have been seen by the government as a potential technology for providing grid-connected electrical storage to help manage the impact of nuclear shutdowns.

Natural Gas Vehicles

Although President Obama’s 2014 State of the Union Address proposed support for natural gas refilling stations, PIRA’s Reference Case assumes that any federal government infrastructure support will not be sufficient to enable widespread adoption of natural gas consumer vehicles. The lack of infrastructure makes it difficult for CNG light vehicles to penetrate the market beyond fleets. Lack of government support matters less for heavy duty LNG trucks due to their superior economics.

PIRA expects more significant government support in China for NGVs and refueling infrastructure, especially if China is successful in developing its shale gas reserves. Over the longer term, PIRA sees significant upside potential for Chinese natural gas demand in vehicles because of the high level of control of the government over both vehicle manufacture and infrastructure. So far government support for NGVs has mostly taken the form of local assistance for infrastructure such as natural gas filling stations.

Other countries with significant NGV penetration include Argentina and India. Historically Argentina had excess natural gas but was short gasoline, so the government encouraged CNG vehicle adoption by setting the regulated price of natural gas low. Over the past few years, Argentina has been forced to import natural gas due to declining production and increased demand, so the government responded by quadrupling the CNG price for vehicles in August 2012. In India the Supreme Court ruled in 1998 that all public vehicles in Delhi must be powered by CNG, although implementation took many years after the ruling. This requirement has been
broadened to additional cities since the first ruling. At present, India has over one million CNG vehicles on its roads with government planning to increase this number over time with subsidies.

In general NGVs compete more directly with diesel than electrics do, and NGV policies around the world can have an influence on the global diesel balance, especially in places where cheap natural gas is available.

**Marine (Bunker) Fuels**

Bunker fuels consumed in Emission Control Areas (in the Baltic and North seas and within 200 miles of the coasts of the U.S. and Canada) have already been restricted in sulfur content, with further reductions scheduled to take place at the beginning of 2015. The initial sulfur reduction, implemented in 2010, was a relatively minor cut from 1.5% sulfur to 1.0%, which could be met with low sulfur residual fuel. The upcoming reduction, to 0.1%, will essentially require diesel fuel or potentially LNG. But bunker consumption in the Emissions Control Areas is only ~300 MB/D, a small percentage of the global total.

The larger challenge to bunker fuels demand and to global diesel production in general comes from planned changes in international bunker fuels specifications. The International Marine Organization (IMO) has issued regulations that will require the adoption of a maximum 0.5% sulfur limit in global bunker fuels effective in 2020-2025. The exact timing will be determined upon a review to be completed by 2018. Although the outcome of that review will likely be to delay implementation, and some countries will probably object to any implementation, it is likely that some significant amount of fuel oil will change specifications beginning in 2020. For example, the European Union has stated that it will change in 2020 regardless of whether the IMO delays implementation elsewhere.

In order for the market to meet the 0.5% sulfur spec, PIRA expects that a significant re-purposing of refinery operations will be required to effectively destroy a large amount of higher sulfur residual fuels (e.g. in coking) and replace that with lower sulfur residual fuels along with gasoil blending components into the bunker pool. This will tighten global distillate balances.

<table>
<thead>
<tr>
<th>Maximum Sulfur Content</th>
<th>Implementation Date</th>
<th>Comments</th>
<th>Price Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to 2010</td>
<td>2010-2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emission Control Areas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5%</td>
<td>July 2010</td>
<td>LS residual fuel oil and/or distillate</td>
<td>Minor widening of LSFO-HSFO spread</td>
</tr>
<tr>
<td>0.1%</td>
<td>Jan 2015</td>
<td>Essentially all distillate</td>
<td>Moderate widening of gasoil – HFO spread</td>
</tr>
<tr>
<td>Global</td>
<td>Jan 2012</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>0.5% (Or equivalent with exhaust scrubbers)</td>
<td>Jan 2020</td>
<td>Review in 2018; Likely defer to 2025</td>
<td>Significant widening of gasoil – HFO spread</td>
</tr>
</tbody>
</table>

* Formerly known as SECA's. Currently limited to Baltic Sea, North Sea and English Channel; The United States and Canada ECA's effective August 2012
Consumer Behavior

Driver behavior plays an important role in vehicle fuel demand, influencing both vehicle miles traveled (VMT) and vehicle purchase decisions (vehicle size and fuel type).

Driving Patterns

The decline in U.S. VMT since 2007 has stimulated discussion as to whether this is a temporary dip brought on by economic factors or in fact a deeper structural shift in the long-term fundamentals of vehicle transportation. PIRA has explored the relationship between VMT and disposable personal income, fuel prices, and the unemployment rate, and has found that these factors largely explain the presently low VMT since 2007.

Over the longer term, however, demographic factors could suggest structurally slower VMT growth, but the timescale over which this would occur is unclear. Data from the National Household Travel Survey (NHTS) seem to indicate that younger people—the “Millennials”—are driving less than their counterparts a decade ago, although the ultimate cause of this is unclear. People between 20 and 34 drove roughly 2,000 VMT less per year in 2009 versus 2001. Increased urbanization, the rising use of social media as a replacement for in-person interaction, and reduced economic prospects have all been cited as reasons for the reduction in driving among young people.

Another cause of potentially lower VMT is the large shift of Baby Boomers into their mid-60s and older, an age at which people typically begin to drive considerably less. People 65 and above drive more than 4,000 VMT less per year than those in the 55-64 age range, on average.

PIRA expects VMT growth to improve as the economy grows. This is a critical assumption and a major uncertainty to the outlook. The current slowdown in VMT growth is deemed to be largely temporary, and with renewed economic growth PIRA assumes a return to VMT growth, although at lower rate than it was at pre-2000.

Vehicle Size and Configuration

Throughout the 1990s and early 2000s customers showed a growing preference for light trucks versus cars, reflected in a rising sales share. This had the effect of decreasing overall average fleet MPG over time all else being equal, due to the larger average light duty vehicle. Starting around the middle of last decade, the share of...
An Assessment of the Diesel Fuel Market

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cars began to rise again, driven by rising fuel prices and then by the recession. Since 2010 the sales shares have stayed approximately constant. Today the top two best-selling vehicles in the U.S. are light trucks (the Ford F-150 and the Chevy Silverado).

Light trucks are far more likely to be diesels than cars, so the relative share between the two vehicle formats is important for forecasting long-term diesel demand in the LDV fleet. PIRA assumes that the split remains more-or-less stable over the outlook period, with sales roughly evenly composed of cars and light trucks. By 2030 PIRA has about 22% of new light truck sales being diesel and 7% of new cars being diesel (making diesels 14% of total LDV sales), reflecting substantial growth in both groupings.
Conclusions

With improved diesel engines coming to market in the U.S. and greater diesel model availability from automakers, the share of diesels is likely to rise within the U.S. vehicle fleet. However, diesels will increasingly have to compete with new technologies for market share. In the case of personal vehicles, this competition will largely be from electrification in its various forms (hybrids, plug-in hybrids, and pure electrics) as these vehicles improve over time. In the case of heavy vehicles, natural gas is likely to play an increasing role once the engine technologies become cheaper and more widely available and the refueling infrastructure is built out.

Among the light duty vehicle fleet, diesel demand is expected to grow from less than 0.3 MMB/D at present to 1 MMB/D in 2030 as diesels gain market share. Due to competition from natural gas, and growing vehicle efficiency, diesel in the heavy duty vehicle segment is expected to shrink by 0.7 MMB/D to 2030. And other sources of diesel demand should decline in aggregate due to efficiency improvements and substitution. Thus, on an overall basis, U.S. diesel demand should decline from a near-term peak of roughly 4 MMB/D in 2015 to 3.5 MMB/D in 2030.

At a global level, diesel will be one of the strongest-growing fuels in terms of demand, driven by industrialization in emerging markets as well as by increased use of diesel in global shipping fuels to meet tightening sulfur specifications, particularly post-2020. This trend will be somewhat offset by declines in stationary diesel demand for non-transportation uses, resulting in a net increase in global diesel demand of more than 6 MMB/D from 2013 to 2030.

The U.S. is currently a large net exporter of diesel (around 1 MMB/D), and this is likely to grow over time due to rising U.S. refinery runs, increasing biodiesel/GTL-type production, and somewhat lower domestic demand, resulting in net diesel exports of 1.8 MMB/D by 2030 in PIRA’s outlook. This large surplus of diesel in the U.S. market should ensure supply availability even if domestic demand is substantially higher. In addition, the long-term ability of U.S. refiners to shift product yields provides additional flexibility.

On a global basis, refiniers should be able to meet anticipated diesel demand to 2030 while keeping yields essentially constant. Diesel and jet fuel are likely to remain premium products, and individual refiniers around the world will face economic incentives to maintain or increase their middle distillate yields.

Overall, PIRA’s assessment is that the U.S. is very well positioned to supply its own domestic fuel needs while also playing a growing role as a global product exporter. With growth in shale oil and gas, a flexible and highly advanced refining sector, and increasing biofuels production, the U.S. should be able to adapt to a wide variety of changing energy circumstances over the outlook period.