Chapter 3
(After 3/20/16 line Edits)

Where Does the Primary Energy Go?

The Petroleum Part of the Story!

The prior chapter was concerned primarily with where and how we consumed electrical energy in our homes, and only briefly with electrical energy used commercially and industrially. The production of electrical energy consumes the largest portion of all forms of primary energy, and next comes petroleum that accounts for about 36 per cent of all forms of primary energy (see Figure 1.1).

About ¾ of primary petroleum is consumed by all forms of transportation including car driving, trucking, many railroads, and flying. First I want to review the basic definition of petroleum used by the EIA.

“Petroleum: A broadly defined class of liquid hydrocarbon mixtures. Included are crude oil, lease condensates, unfinished oils, refined products obtained from the processing of crude oil, and natural plant liquids.”

The single word “petroleum” covers this very broad mixture of different hydrocarbon molecules that must be separated out before we can use them in our car or use them to heat our house. Many listings of petroleum imports just list crude oil and not the other hydrocarbons included by the EIA in their definition of petroleum. I will keep to the EIA definition of petroleum.

3.1 Refining Crude Oil

Crude oil pumped from the ground in Saudi Arabia has a different mixture of hydrocarbon molecules and impurities than crude oil pumped from a well in the Gulf of Mexico or most anywhere else in the world. Refineries are designed to process crude oil from a particular set of wells or regions of the...
world. The basic refining process consists of heating crude oil and then
separating the vapors of the different hydrocarbon molecular by their boiling
points. The gasoline we burn in our cars is one of the lightest vapors having a
relatively low boiling point. Gasoline is a blend of various hydrocarbons with
additional molecules added to enhance the combustion in automobile engines.
Also some of the biggest molecules of crude oil are catalytically broken into
smaller more useful molecules.

In the refining process crude oil is broken down into the following
separate fractions: liquefied petroleum gas (think propane for example), gasoline,
naphtha, kerosene and related jet fuels, diesel fuels, lubricating oils, paraffin
wax, asphalt and tar, petroleum coke, and sulfur. On average, less than half of
crude oil is refined into gasoline with the remainder composed of the products
just mentioned. The fraction of gasoline in a barrel of crude can be adjusted a bit
in the refinery process. Before our summer driving season our refineries are shut
down and slightly reconfigured to produce the maximum percentage of gasoline,
and in the fall the process is reversed as heating oil is needed in the Northeast.
The refinery process itself is energy intensive with efficiencies of only about 88
per cent. That is, additional energy in the form of natural gas, electricity, oil, and
hydrogen has to be added to the refining complex to produce the useful products
already mentioned. This need for large amounts of additional energy is an
important reason for locating refineries where primary energy is readily
available at low cost.

In recent years, newspaper articles have mentioned that most of the U.S.
refineries on the coast of the Gulf of Mexico were designed to process
Venezuela’s heavy crude oil and not the lighter and sweeter crude (lower sulfur
content) from the fracked wells in North Dakota. The lighter North Dakota
crude is generally sent by rail to refineries on the eastern seaboard where the
refineries were designed to treat that type of crude oil generally imported from
overseas.

1 The energy needed to refine crude oil is accounted for in the industrial category in the charts of Estimated
U.S. Energy Use in Appendix A.
Within the last decade the U.S.A. has almost doubled the amount of crude oil produced in the lower 48 states. This new production comes primarily from North Dakota, Colorado, Ohio, Texas, and Louisiana while existing refineries are mostly along the Gulf coast of Texas and Louisiana and the eastern seaboard. Before the new fracking revolution for oil and gas, refineries were located to handle imported crude oil and oil from the Gulf of Mexico and distribute gasoline and diesel fuel through existing pipelines. Pipelines and refineries are not now ideally located for our current U.S.A. crude oil and natural gas production and subsequent distribution, and by necessity some crude oil and refined products are now shipped long distances by rail.

3.2 Petroleum in Transportation

This chapter will focus primarily on the use of gasoline, diesel, and jet fuel in transportation. Transportation use of primary energy and its efficiency of use in 2010 is summed up in Figure 3.1, which is just a slice of the Energy Use chart for 2010 in Appendix A. The figure has primary petroleum in dark green; most of the petroleum going into Transportation, the box colored pink. The useful output work of the input petroleum is colored dark gray. The energy rejected in the process of converting primary petroleum in useful transportation is also an output of energy conversion process and it is colored light gray. Think of the ratio of the energy reject to the energy input as the inefficiency of transportation.

Figure 3.1 Primary Energy Flows in Transportation 2010.
Source: Lawrence Livermore National Laboratory – U.S Energy Flows 2010: numbers in Quads of BTUs

Some of the numbers of Quads are fairly difficult to read in this reproduction of the 2010 Energy Use chart, so I will mention the important ones. Total Petroleum is 35.97 Quad. The contribution from Biomass – the light green
flow - to transportation is 1.10 Quads; this includes the alcohol blended with our gasoline and biodiesel; the contribution to transportation from Natural Gas – the blue flow – is 0.68 Quads; the contribution from electricity – the yellow flow - is just 0.03 Quads; and finally the contribution from Petroleum, in all of its refined forms, to transportation is 25.65 Quads. Figure 3.1 estimates that only 6.86 Quads of useful work were done by all forms of transportation, and 20.59 Quads of energy were rejected as heat. Another way of saying that is (6.86/25.65)*100 or 26.7 is the percentage of useful work done by burning all of the primary energy-petroleum, natural gas, and alcohol. Clearly the energy efficiency of transportation in 2010 was low, even lower that the conversion of primary energy into electrical energy.

The gasoline engines of our cars do useful work, in the physics sense of work, by increasing the speed of the car. For example, having the car go from a stop to 60 mph increases the kinetic energy of the mass of the moving car. If the car is then braked to a stop, all of that kinetic energy of the car is converted into heat in the brakes and lost as heat. The lost energy in braking is what is partially recovered and converted into electrical energy and stored in batteries in hybrid cars. The stored energy is then later used to propel the car by an electrical motor. Again, there are energy inefficiencies in each of the steps of converting energy from one form to another. The fact that hybrid electric cars often achieve nearly twice the mileage per gallon of gasoline, as do conventional gasoline-powered cars of the same size, suggests just how energy inefficient cars with conventional internal combustion engines are.

There are many inherent energy inefficiencies in an internal combustion engine. The engine has to overcome internal friction due to the motion of the moving parts of the engine, and there is heat rejected to the air to keep the metal of the engine cool. I am often startled by the amount of heat rejected by my hybrid car’s gasoline engine. After parking in my driveway in the summer and walking around the front of the car there is a blast of hot air from the radiator—that hot air is a significant portion of the rejected energy.
Figure 3.1 give the overall flow of primary energy into all forms of transportation. While most people might think of gasoline as the major portion of refined crude oil, it is actually less than half. The history from 1993 of product yields of U.S. refineries is available on the EIA web site listed in the footnote: The percentage of a barrel of crude that is refined into distillate fuel oil – diesel fuel and home heat oil- varies with the month and the year, but in 2010 it was about 28 per cent and the yield of gasoline was about 46 percent. The yield of jet fuel in 2010 was about 9.3 percent. So the three major transportation fuels account for about 83 per cent of our refinery yield from crude oil. Diesel fuel is not used exclusively for transportation, for example mining equipment is generally diesel powered. Figure 3.1 shows that 25.65 Quads of petroleum are consumed by transportation, just 71 per cent of the total. Looking at the full Energy Use Chart for 2010 you will see that transportation is the biggest final consumer of U.S. primary energy.

3.2 Crude Oil Imports and Exports of Petroleum Products

The Energy Information Agency (EIA) of the Department of Energy publishes a Monthly Energy Review (MER) with detailed information about imports and exports of just about all of the petroleum products. The data reports the daily averages of barrels of each product produced in the U.S., imported, and exported. From an energy point of view, a barrel of gasoline has a different energy content than a barrel of diesel fuel. So rather than report the barrels of all petroleum products I will just look, for the most part of this chapter, at crude oil and refined motor fuels produced and imported into the U.S., and U.S. exports. These three items of petroleum cover most of the newspapers’ interests. Inputs to refineries include natural gas plant liquids, other liquids such as ethanol and biodiesel in addition to crude oil, but I will focus on just crude oil, the major input to refineries. Imports and exports of crude oil and total petroleum products are summarized in Table 3.1 for 3 year. In 2005 our imports peaked, 2010 is this book’s energy reference year, and 2014 is the latest year of LLNL’s Estimated U.S. Energy Use charts – see Appendix A.

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http://www.eia.gov/dnav/pet/pet_pnp_pct_dc_nus_pct_m.htm

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<table>
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<th>YEAR</th>
<th>Crude Oil</th>
<th>IMPORTS* Total Petroleum Products</th>
<th>EXPORTS* Petroleum Products</th>
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<tr>
<td>2005</td>
<td>10,126</td>
<td>13,714</td>
<td>1,165</td>
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<tr>
<td>2010</td>
<td>9,213</td>
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<tr>
<td>2014</td>
<td>7,331</td>
<td>9,221</td>
<td>4,180</td>
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</table>

*Imports and Exports in thousands of barrels per day

Table 3.1 Petroleum Trade U.S. Imports and Exports for Three Selected Years
Source – EIA Monthly Energy Review; Petroleum Section, Table 3.3b; June 2015

I have included the data for 2005 because that was the year of peak import of crude oil and petroleum products. It is a reference for what the U.S. petroleum situation was like before fracking of layers of shale for oil and natural gas in the lower 48 became significant. From 2005 to 2014 crude oil import dropped nearly 3 million barrels per day and total petroleum products imported dropped by over 4 million barrels per day.

Just how large is 1 million barrel of oil per day? I looked at Wiki for the capacity of the so-called super tankers and found that one of these tankers is capable of carrying 2,000,000 barrels of crude. The Wiki site states “by way of comparison the United Kingdom consumed about 1.6 million barrels (250,000 m³) of oil per day in 2009”¹. I have never seen a super tanker so I decided on a different description. Almost all of have seen a U.S. football field. The length of such a field between goal lines is 100 yards. Another way to imagine the size of 1,000,000 barrels is to calculate the height of a circular tank 100 yards in diameter that would hold all of the million barrels. I did that calculation and found the football field diameter tank would need to be 79.4 feet high to hold 1 million barrels. In fact you would need to put two football fields side by side to enclose a 100 yards diameter tank since a single football field is just 53 an 1/3 yards wide.

After calculating the size of a circular tank to hold a million barrels of crude oil, I thought I would see how large would be just one day of the world’s crude oil production if it were put in 1,000,000 barrels tanks stacked next to each

¹ https://en.wikipedia.org/wiki/Oil_tanker
other? Well the EIA’s MER of September 2015 reports that the world’s daily average production of crude oil was just a little shy of 78 millions barrels. So just one day’s crude oil could be put into 78 circular tanks, each 300 feet in diameter and 79 feet tall. Imagine such a wall of tanks 23,400 feet long and nearly 80 feet tall. And that would be the average amount of crude oil used by the world in just one day. The world’s yearly crude oil production in million barrel tanks would be a line of tanks 1,618 miles long and 79 feet high. That is the very large volume of crude oil we pump from below the earth’s surface each year, and then burned it in one way or another to support our lives.

Going back to Table 3.1 you see our exports of petroleum products have grown to be 4.180 millions barrels per day in 2014. And the products are almost all gasoline and diesel fuel – value added products refined in the U.S. This growth has been possible because of fracking of layers of shale for oil and gas.

3.3 Our Yearly Consumption of Gasoline, Diesel, and Jet Fuel

Chapter 2 detailed all of the improvements in energy efficiency of the electrical appliances used in our homes since the energy crisis of 1973-75. Now we can look and see how we are doing with petroleum transportation fuels. And we will need to look at the growth in the number of cars and light trucks we have and use. First though is the amount of fuel we use daily.

As always the fuel demand data comes from the EIA’s MER and I have to include the exact month of the MER used for the source of the data because the EIA revised the data as new information becomes available. The data for Table 3.2 below comes from MER, June 2015: Table 3.5. I think that there is little confusion about the meaning of the categories of Motor Gasoline and Jet Fuel, but Distillate Fuel Oil caused me to look to the Glossary at the back of every MER, and in this case the definition below is located on page 203.

“Distillate Fuel Oil: A general classification for one of the petroleum fractions produced in conventional distillation operations. It includes diesel fuels and fuel oils. Products known as No. 1, No. 2, and No. 4 diesel fuel are used in on-highway diesel engines, such as those in
trucks and automobiles, as well as off-highway engines, such as those in railroad locomotives and agricultural machinery. Products known as No. 1, No. 2, and No. 4 fuel oils are used primarily for space heating and electricity generation."

<table>
<thead>
<tr>
<th>Year</th>
<th>Motor Gasoline$^e$</th>
<th>Distillate Fuel Oil$^b$</th>
<th>Jet Fuel$^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>9,159</td>
<td>4,118</td>
<td>1,679</td>
</tr>
<tr>
<td>2010</td>
<td>8,993</td>
<td>3,800</td>
<td>1,432</td>
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<tr>
<td>2014</td>
<td>8,922</td>
<td>4,010</td>
<td>1,470</td>
</tr>
</tbody>
</table>

Table 3.2 Petroleum Fuels Consumed Daily in the U.S.
Source – EIA Monthly Energy Review; Petroleum Section, Table 3.3; June 2015

Now to avoid confusion about whether or not motor gasoline included ethanol, I am including the footnotes given in the source’s Table 3.5. I am using the same footnote reference labels e, b, and c used in the source table.

- $^e$ Finished motor gasoline. Through 1963, also includes special naphthas. Beginning in 1993, also includes fuel ethanol blended into motor gasoline
- $^b$ Beginning in 2009, includes renewable diesel fuel (including biodiesel) blended into distillate fuel oil.
- $^c$ Beginning in 1957, includes kerosene-type jet fuel. For 1952-2004, also includes naphtha-type jet fuel. (Through 1951, naphtha-type jet fuel is included in the products from which it was blended—gasoline, kerosene, and distillate fuel oil. Beginning in 2005, naphtha-type jet fuel is included in “other”).

Note in footnote c above, the category “other” refers to a separate column listing in the source Table 3.5.

With all of the details of the specifications of the petroleum products behind us, I will shift our discussion to the actual numbers in our Table 3.2 and their implications. First the total number of barrels of transportation fuel consumed daily in the U.S. amounts to between 14 and 15 million barrels of fuel. This is a very large amount, and the numbers of barrels in each category have only decreased marginally from year 2005 to 2014 in spite of our increased awareness of environmental concerns caused by engine exhausts. I am going to focus just on the motor gasoline, the fuel generally used in cars and light trucks.

3.4 Use of Motor Fuel in the U.S.

We have just seen that we consume nearly 9 million barrels of motor fuel each day. Remember that a barrel of motor fuel has 42 gallons of fuel so we, as a
nation, consume about 378 million gallons of gasoline daily. That is more than 1 gallon of gasoline for each person in the country. How do we manage to do that? I am certain that we consume more motor fuel per capita than any other economically advanced country. And we have more cars and light trucks than any other country in the world. Fortunately Oak Ridge National Laboratory published a Transportation Energy Data Book (TEDB) and the latest release is Edition 34 (TEDB-34), which covers only up to 2013. So I can only include data for cars and light trucks for the three years 2005, 2010, and 2013, not the last year documented in fuel usage Section 3.3 because 2014 data is not available.

To begin I will start at the highest level, namely the number of vehicles per thousand population. For this discussion "light vehicles" includes cars, pickup trucks, SUV, Crossovers, and minivans since so many types of light vehicles are used primarily in private transportation. The United States had 808.6 vehicles per thousand of population in 2013. The only country that comes close is Canada with 646.1 vehicles per thousand of population in 2013; for comparison India, in 2013 had 26.6 vehicles and China had 88.6 vehicles per thousand of population. So it is not surprising with so many cars and light trucks we consumed more than a gallon of gasoline fuel daily for each person and even more for each vehicle in the country.

The first step the U.S. took to bring down our nation's consumption of gasoline was passing the Corporate Average Fuel Economy (CAFE) standard in 1975. This standard was in response to the Arab members of OPEC (the Oil Producing Exporting Countries) and Egypt and Syria proclaiming an oil embargo of the U.S., Canada, Japan, the Netherlands, and the United Kingdom. Regulations of gasoline mileage efficiency for new cars were first introduced in 1978 only for passenger cars, but fuel standards for light trucks were added in 1979. When the CAFE standard was passed in 1975 there were 106.7 million

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4 TEDA - 34, Table 3.5, page 3-10
5 The embargo was a response to American involvement in the 1973 Yom Kippur War. Six days after Egypt and Syria launched a surprise military campaign against Israel to regain territories lost in the June 1967 Six-Day War, the US supplied Israel with arms. In response to this, OPEC announced an oil embargo against Canada, Japan, the Netherlands, the United Kingdom and the US. Source 1973 Oil Crisis - Wikipedia.org

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passenger cars registered with an estimated average efficiency of 13.9 miles per gallon (mpg). In that same year there were 20.4 million light trucks registered with an estimated fuel efficiency of 10.5 average mpg. A light truck was defined as vehicle weighing less that 6,000 pounds and the limit was raised to 8,500 pounds in 1980.

As you will certainly imagine, the CAFE standards were accompanied by serious disagreements between the automobile manufacturers and the government, and there were many exceptions to the rules, but the growing average CAFE standards held up to 2007 when a new law, the Energy Independence and Security Act was signed by President George W. Bush. This is also the law that began the slow decline of our use of incandescent light bulbs. In 2007 the standard for new cars was 27.5 mpg and overall fuel efficiency of the fleet of car had increased to 22.5 mpg. But the fleet of all light vehicles in the U.S. also grew during the years from 1975 to 2007. The number of cars registered in 2007 grew to 135.9 million vehicles and the number of light trucks grew to 101.4 million vehicles with average fuel efficiency of cars being 22.5 mpg and that for light truck rising to 18.0 mpg.

Any new mandate increasing new vehicle fuel efficiency has to run the gauntlet of criticism and legal actions by environmental organizations who wish for stricter regulations and vehicle manufacturers who would generally wish less severe restrictions on their products. Finally in 2011 President Obama achieved an agreement to increase fuel efficiency to up to 54.5 mpg for small cars by model year 2025 that was supported by just about all car manufacturers, the UAW union, the state of California, but with Volkswagen opposed. This agreement covers fuel efficiency for cars and light trucks, with the most stringent fuel efficiencies for vehicles with the smallest footprint and less stringent requirements for larger and heavier vehicles. The details of the fuel efficiency mandate depend on the size of the vehicle, and for those interested, the WEB has

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* TEDB - 34, Table 4.1 and 4.2, pg. 4-2 and 4-3.
* Ibid. pg. 4-2 and 4-3
* Corporate Average Fuel Economy: Wikipedia, pg. 13 of 23
many sites covering all sides of the issue. The Center for Climate and Energy Solutions presents tables by years for various vehicles. If all goes as planned, in 2025 the combined car and light truck efficiency of new vehicles will be 48.7 mpg. There are provisions to cover the possibility that citizens might not purchase vehicles of the sizes imagined at the time these projections were made and allowance will be made to conform to reality of the market.

The future for reduced gasoline consumption seems bright. As a nation we are driving much more fuel-efficient vehicles. In 2013, the TEBD-34 estimates that the weighted average mpg of new cars was 27.6 mpg, and that for new light trucks was 19.8 mpg, to give a new vehicle fleet average of 24.1 mpg. This 2013 figure should be compared with the 13.1-mpg average in 1975. While there has been substantial progress in vehicle fuel efficiency since 1975, the fleet average is estimated to increase in 2025 to 48.7 mpg for new cars and light trucks.  

3.5 Future of U.S. Motor Vehicle Efficiency

Is it really realistic to assume that the U.S will meet the overall light vehicle fleet average of 48.7 mpg in 2025? The National Research Council has commissioned a report from experts to explore what might be done and the resulting cost of more energy-efficient vehicles. The study group has issued a report that is available on-line at the National Academies Press site. Rather than trying to summarize the 466-page document I will just quote the description of the report directly from the Academies Web-site.

"The light-duty vehicle fleet is expected to undergo substantial technological changes over the next several decades. New powertrain designs, alternative fuels, advanced materials and significant changes to the vehicle body are being driven by increasingly stringent fuel economy and greenhouse gas emission standards. By the end of the next decade, cars and light-duty trucks will be more fuel efficient, weigh less, emit less air pollutants, have more safety features, and will be more expensive to purchase relative to current vehicles. Though the gasoline-powered spark ignition engine will continue to be the dominant powertrain configuration even through 2030, such vehicles will be equipped with advanced technologies, materials, electronics and controls, and aerodynamics. And by 2030, the deployment of alternative methods to propel and fuel vehicles and alternative modes of transportation.

9 http://www.c2es.org/federal/executive/vehicle-standards
10 TEBD-34, Table 4.10, pg. 4-10
11 The Bureau of Transportation Statistics shows higher mpg for passenger cars, but definition of cars and light trucks might vary among agencies -.

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including autonomous vehicles, will be well underway. What are these new technologies--how will they work, and will some technologies be more effective than others?

Written to inform the United States Department of Transportation's National Highway Traffic Safety Administration (NHTSA) and Environmental Protection Agency (EPA), Corporate Average Fuel Economy (CAFE) and greenhouse gas (GHG) emission standards, this new report from the National Research Council is a technical evaluation of costs, benefits, and implementation issues of fuel reduction technologies for next-generation light-duty vehicles. Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles estimates the cost, potential efficiency improvements, and barriers to commercial deployment of technologies that might be employed from 2020 to 2030. This report describes these promising technologies and makes recommendations for their inclusion on the list of technologies applicable for the 2017-2025 CAFE standards.

I, like many people, am reluctant to accept long reports from experts at face value, but in the summary of their long report the experts did include the figure reproduced below that give me great hope. From the figure you will see many popular cars have achieved efficiencies not expected until 2020.

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**Figure 3.2.** Certification fuel economy values of selected 2013 and 2014 model year cars, plotted on NHTSA CAFE target curves.

The long solid lines with two breaks in slope in the Figure 3.2 are the CAFÉ target curves for new light vehicles for specified model years. A vehicle's footprint is the area of the rectangle formed by the distance between the front and rear axel - the wheelbase - with the other length given by the distance between the center of left and right side tire tracks. To see how the car I drive – 2013 Ford C-MAX Hybrid 3,600 lb. wagon – measures up with the CAFÉ target curves I measured my car's footprint, and found it to be just over 45 square feet. The manufacturer reports that average mileage is 40 mpg, and I achieve somewhat better mileage, so my car is in the vicinity of the 2017 standard for new cars.

Looking at Figure 3.2 you see that the hybrids in general have achieved higher fuel efficiency and are years ahead of the mandated mpg for light vehicles of their footprint. I have looked at the report where I found Figure 3.2 and I did not find information about the two hybrid cars plotted in the figure. I assume that both cars must be plug-in hybrids to achieve such high mileage. All electric cars are off the chart too, but their impact on light vehicle fleet average mpg is very small since they comprise a very small fraction of the new vehicle fleet; most estimates of the total of all electric and hybrid cars are just 2 per cent of the new car fleet. There are no pickups, SUVs, or crossover vehicles plotted in Figure 3.2; just cars are plotted. I assume that pickups and the other bigger vehicles that are currently so popular would lie on the right hand horizontal portions of the CAFÉ plots. So the actual light fleet average fuel efficiency might be lower than expected.

3.6 New Developments that Cloud the Future of U.S. Motor Vehicle Fuel Efficiency

When President Obama had the automotive manufacturers together in 2011 and achieved their agreement on the new CAFÉ standard shown in Figure 3.2, gasoline was selling at an average price of $3.48 per gallon, and during November 2015, gasoline was selling for an average price of $2.20/gallon according to the AAA. The auto club estimates that drivers are spending about
$275 million less per day on gasoline compared to a year ago. This drop in gasoline prices and the increased employment in the national economy seem to have encouraged a record number of light-vehicles to be sold in 2015. Sales of cars dropped 2.2 per cent from 2014 to 7,740,912 units, but the number of light-duty trucks sold rose to 9,729,587 units, representing a 13.1 per cent increase over 2014, according to the Wall Street Journal’s Data Center of January 5, 2016. Sales of pickup trucks in 2015 grew by 9.7 per cent over the number sold in 2014, but the biggest growth in the light-duty truck category was in crossovers at 18.5 per cent and SUVs at 10.7 per cent.

With very low gasoline prices, a more healthy economy, and with low interest rates on vehicle loans, consumers were buying bigger light vehicles and fewer cars than they did in 2014, and the average fuel economy of these new vehicles is likely lower than it was in 2014 because of their bigger footprint. And sales of electric vehicles and hybrids were down. The New York Times reports that the 2015 sales of the all-electric Leaf fell 43 per cent from sales in 2014, and the sales of the leading hybrid model, the Toyota Prius, fell 11 per cent in 2015 from those of 2014.12 Despite the sluggish sales of electrical vehicles and hybrids the auto industry is moving forward with plans to introduce new all electric models with extended ranges of about 200 miles between battery recharges. Time will tell whether electric vehicle buyers are focused on lowering their carbon footprint by going electric or whether their focus is on other features such as distance between recharging. Meanwhile in Europe, with much higher fuel costs because of high taxes on fuel, mid 2015 sales of electric vehicles were reported up 78 per cent of 2014 sales.13

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12 Bill Vlasic, NYT; January 7, 2015
13 Michael Graham Richard@http://www.treehugger.com/cars/1lectric-car-sales-are-78-so-far-year-european-union.html

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3.7 New Developments in Spark Ignition Engines to Improve Fuel Efficiency

The auto industry is not giving up on the internal combustion engine and is pushing ahead with developments to make engines smaller, more environmentally friendly, and more fuel-efficient. *The Economist* in a recent article called *The incredible shrinking machine* describes some of the steps manufacturers have taken to achieve this shrinkage.¹

Perhaps the biggest contribution to fuel efficiency has come from turbocharging the air going into the cylinders and by directly injecting fuel into the cylinders. The article states: “The smallest member of the Ford’s EcoBoost family – a one-liter, three-cylinder device - delivers more power than a 1.6 liter, four-cylinder engine of the previous generation. This engine is now fitted into one in five of all Ford cars sold in Europe.” Other manufacturers are also turbocharging their engines, the article mentions: “BMW makes a 1.5 liter three-cylinder version – that increases acceleration 42% and reduces fuel consumption by 8% in the MINI Cooper as compared to the previous four-cylinder motor.”

The lifting of the intake and exhaust valves are now controlled in some engines by the engine’s electronic control system for better performance as power demand varies during driving. Some are using computer control systems to turn off cylinders when driving only requires low power output. It is reported that Nissan has developed a diamond-like carbon coating for the surface of moving parts of engines; the coating can reduce engine friction by 25%. Others are seeking to reformulate engine oils to reduce friction. Still others are exploring new materials that can better withstand the exhaust gas temperatures entering the turbocharger.

¹ *The Economist*; Dec. 12-18, 2013; page 74-75
The *Economist* article ends with this paragraph: “Just how far internal-combustion engines will shrink remains to be seen. But every improvement keeps them in the race with those who would shrink the number of cylinders to zero, and replace the whole lot with electric motors.”

### 3.8 Developments in Electric Vehicles (EV)

One often reads that electric vehicles (EV) including hybrids are only about 2 per cent of the new car market in the US, but more in the EU. Remember in the EU the retail price of gasoline is very much higher than it is in the US because of local government taxes that do not go down as the world price of petroleum products falls, as they have in 2014 and 2015. Since the auto market is a worldwide one, most of the automobile manufacturers have been working on EV and hybrid models. And this development was certainly started a while back when crude oil sold over a $100/barrel and the world market for high mpg equivalent vehicles certainly looked more promising then than it does now in this country. There is also the worldwide interest in reducing greenhouse gases (GHG) released from cars burning a fossil fuel – either gasoline or diesel fuel.

One of the knocks on EVs, beside their initial higher price, is that the electrical energy they require to recharge their batteries is most often generated by burning a fossil fuel and not from renewable energy. While that is certainly true, the thermal efficiency of electrical cars is so much greater than that of a gasoline-powered car that the overall energy used per mile is less for an EV than it is for a gasoline-burning car. In Norway where most of the electricity is generated by hydropower, there is a national push to lower GHG in their cities and encourage the purchase of EVs.

At the January 2016 Consumer Electronic Show, GM introduced the new all electric 2017 Chevrolet Bolt that is reported to be able to travel 200 miles between recharging. After a federal income tax rebate of $7,500 for purchasers of an all-electric vehicle or a plug-in-hybrid, the Bolt will have a manufacturer’s suggested net retail price (MSRP) of $30,000. The 2016 Nissan LEAF is
advertised to have a battery-only range of 84 to 107 miles, and a MSRP of the base model of $29,010. The EV most in the news is the Tesla Model S introduced in 2012. It was offered in 2015 in 5 model configurations with base models with MSRP from $69,900 to $85,000 and range from 208 to 270 miles.

During the second week of January 2016 there was the annual North American International Auto Show in Detroit, MI. The show is described quite differently by the NYT and the WSJ. For example, the NYT reports that even though the new vehicle fleet is only 2 per cent electric, the show was focused primarily on electric vehicles even though gasoline was selling for less than $2/gallon. The article says: “The federal government has mandated corporate average fuel economy of 54.5 miles per gallon by 2025. But the companies need to meet an interim standard of about 37 mpg by next year.”\textsuperscript{25} The WSJ describes the same auto show in a different way.\textsuperscript{26} Even though pickup, SUV, and crossovers were 60 per cent of the new vehicle sold in December 2015, they played a minor role in the Detroit Show. Plans for the show were many years ago when gasoline sold for about $3.50/gallon. Also the auto companies wanted to show that that they are competitive with the tech firms that are exploring driverless cars.

Both newspaper descriptions are likely true. The CAFÉ standard for 2025 allows for an interim discussion before 2025 between the automakers and the federal government if fuel-efficient vehicles are available but buyers prefer other vehicles. In January 2016 with gasoline selling below $2 a gallon, many new car buyers seem not to focus on the possibility that gasoline will sell at a much higher price during the long life of the vehicle. During early 2016 the top selling vehicles are pickups, SUVs, and crossovers. And while the fuel efficiency of these vehicles now is much greater than such vehicles were a decade ago, the efficiency is substantially below that of new passenger cars, especially any of the various types of electric vehicles.

\textsuperscript{25} Automakers Go Electric, Even If Gas Is Cheap; NYT Jan.12, 2016: p. B1
\textsuperscript{26} Truck to Take Back Seat to Passenger Vehicles at Show: Auto makers try to prove their relevance, as tech giants tread on their turf; Jeff Bennett and John D. Stoll: WSJ Jan. 11, 2016: p. B4
The all-electric passenger car (EV) face three major hurdles before they become top selling cars. 1) In general, the retail price of an EV is high primarily because of the initial cost of the energy storage batteries, and the fact that the batteries might not last the lifetime of an average passenger car. The larger the battery pack of an EV the greater the range of the vehicle, that is, the distance before exhausting the energy stored in the batteries. 2) In general, the bigger the battery pack, measured in kWh, the longer the time - in hours – needed to fully charge the batteries. 3) And lastly, recharging stations are not nearly as ubiquitous as are gasoline stations. It is true that recharging stations are appearing in some parking garages and in motels, but not nearly enough. Tesla has software to report the location of their closest super recharging station. The super-stations dramatically shorten the recharging time.

Hybrids and plug-in-hybrids do not suffer from any of the 3 listed disadvantages of the EV. But they do burn a fossil fuel, gasoline. The Toyota Prius is the top sell hybrid: in 2014 Toyota sold 207,372 Prius cars in the U.S., dropping to 184,794 in 2015.\(^7\) Toyota had sold over 7 million hybrid cars worldwide by September 2014.\(^8\) Now, after the 2016 Detroit auto show it seems that most if not all the most-popular automobile manufacturers will offer hybrids and plug-in-hybrids in 2016. Many will offer new EVs cars too. If more electrical vehicles of all types are sold in the near future, then the cost of batteries will fall and more charging stations will appear in urban areas.

There are two important additional factors influencing the total yearly mileage of cars and light trucks driven in the U.S. and that is the average age of the U.S. population of people with driver licenses is rising, and the corresponding decreased interest on the part of many younger people even to obtain driver licenses. The population of the U.S. is getting older, and older people tend to drive fewer miles per year than they did when they were younger.


The U.S. Department of transportation estimated that the total highway vehicle miles reached a peak in 2007 and has fallen from there until 2012 when it began to rise slightly. The total highway miles driven in 2013 are nearly identical to what they were in 2005.\footnote{http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_35.html; visited Feb. 2016} And now the University of Michigan’s Transportation Research Institute has released a report titled: \textit{Recent Decreases in the Proportion of Persons with Driver’s License Across All Age Groups} by M. Sivak and B. Schoettle.\footnote{http://www.umich.edu/~umtriswt/publications.html; visited Feb. 2016} The title of the paper tells the story, namely a smaller percentage of our population below the age of 54 in 2014 had driver licenses than was the case in 1983. The difference is most pronounced in teenagers. In 2014 about 20 percent fewer people in the age group from 16 to 19 had drivers licenses than was the case in 1983. Even in the age group from 30 to 34, the percentage of the population with licenses has fallen from 96.5 in 1983 to only 86.6 per cent in 2014.

So our national use of gasoline might fall in the future because new light vehicles are now more fuel-efficient than they had been, because the population is aging and driving less as they get older, and because many younger people no longer seem compelled to get a drivers license.

\section*{3.8 Developments in Commercial Aviation}

Each of us can take steps if we wish to decrease the petroleum we use driving around by purchasing a more fuel-efficient vehicle, but there is nothing we can do to decrease fossil fuel used in commercial aviation, except to collectively fly fewer miles. But if we were to know the fuel efficiency of various commercial airliners we could approach picking a flight with something more in mind than just cost, whether extra luggage is free, and the number of frequent flier miles for the trip. Fortunately a WSJ reporter wrote such an article in August 2012.\footnote{http://www.wsj.com/articles/SB10001424127887324383604571647043124322580?mod=WSJNewsPage; visited Aug 25, 2012} The article said that the Department of Transportation reported the average commercial airline flew a “seat”, occupied or not, 64 miles on a
gallon of jet fuel. So for better fuel efficiency it is better to fly than to drive a car without a passenger or two.

The article mentions that Alaska and JetBlue airlines had efficiencies of 75.9 and 71.7 seat mpg in 2009, and the least efficient were United, American, and Delta with efficiencies of 62.1, 60.5, and 60.4 seat mpg of jet fuel. For comparison the article reported the Chevy Suburban achieved just 19-vehicle mpg of gasoline while the Toyota Prius achieved 50 mpg of gasoline. A seat on a newer plane with newer engines on a long flight will get significantly better mileage that an older plane powered by older engines flying on a short flight on the congested east coast.

The four biggest jet engine manufacturers supply the engines for the world’s commercial aviation, and two of them are located in the U.S., namely GE and Pratt and Whitney. Our two manufacturers and Rolls Royce in England and CFM International – a joint venture of the French and GE - all have continuously introduced new more fuel-efficient models with a wide range of values of thrust. Jet engines are designed to meet particular civilian and military aircraft needs. For civilian aviation the engines must not only provide thrust to get the plane off the ground, but minimize the jet noise at and near airports. Such engines are high-bypass turbofan engines. The large diameter multi-bladed fan we see at the front of aircraft engines supplies much more air flow than what is needed to burn the jet fuel, which in turn provides the fan power and some of the jet propulsive force of a jet engine. The excess air provides thrust and bypasses the compressor, combustion chamber, and high-pressure turbine of a jet engine. The by-pass air also surrounds the high velocity jet exhaust in order to reduce engine exhaust noise. The remainder of the air passes through the portions of the engine that provides the turbine power to drive the fan, the compressor, and provide propulsive jet thrust.

Fuel efficiency of a jet engine increases when the gas temperature in the combustion chamber and in the high-pressure turbine increases. The blades of the turbine are grown from a single crystal of a super alloy for high strength at
high temperatures. In addition the blades have internal passages for air-cooling. The blades have a protective oxide coating, since the gas temperature from the combustion chamber is at or near the bare metal’s melting point. Holes are laser “drilled” along the leading and trailing edges to allow for more air-cooling through the blades and to envelop the blade in a somewhat cooler film of air.

The fabrication of jet engine turbine blades is at the peak of our metallurgical achievement, and naturally the details of their manufacture are important trade secrets. Rolls-Royce recently published an article describing the general development of single crystal blades. The title of the article says how important the technology is: *Jewel in the crown: Rolls-Royce’s single-crystal casting foundry.*

A jet engine industry expert told me that a single jet engine turbine blade likely would retail for about $5,000; the retail price is a good measure of the sophistication of the production process. The Rolls-Royce article has a picture of a person holding a single blade between his thumb and index finger; the blades are quite small.

Because aircraft fuel cost is such a major contributor to airline operating expenses, commercial airlines take advantage of newer aircraft with more efficient engines whenever they can afford to do so. In 2015 Boeing and Airbus delivered to the commercial market a few more than a combined total of 1,300 new aircraft. Naturally new aircraft are paired with new and improved engines, and in many cases the airplane makers have substituted lighter carbon based materials for metal parts where they can. There is every indication that the number of passengers flying will increase each year. There are estimates on the WEB that over 3 billion passenger flights were taken in 2014 with more than 100,000 daily flights worldwide. With ever increasing air travel, the airlines and engine manufacturers are making efforts to increase their fuel efficiency. In late 2015 Boing introduced a new airplane, the 737 MAX, with new wing tips designed to increase aerodynamic efficiency. The new Boeing plane is paired

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23 *The Economist*; Jan.16–22, 2016:p71
with the new CFM LEAP-1B engine. Boeing states that the new plane and engine will have 8 per cent lower operating cost than does its commercial competition.\textsuperscript{a}

Airbus has already delivered a version of its new single-aisle plane, the A320neo, to Deutsche Lufthansa in late 2015. This new plane will be offered with a choice of engines, the CFM LEAP-1A or the new fuel-efficient Pratt and Whitney’s Geared Turbofan Engine.\textsuperscript{a} The competition between Airbus and Boeing and that among the rival engine manufacturers GE, Pratt and Whitney, CFM, and Rolls Royce ensure that Western commercial airlines will fly the world’s premier commercial aircraft with the most fuel-efficient engines for many years to come.

\textsuperscript{a} [http://www.boeing.com/commercial/737max/; visited Feb. 2016]

\textsuperscript{b} Airbus Shifts Plans on Pratt Engine, R. Wall and J. Astrower; WSI, Feb. 8, 2016; p B 3