ELECTRICAL AND HYBRID VEHICLES

by Dr. I. Prabhakar Reddy &
P.Ashok Kumar Reddy

IV B.Tech/I Sem
EEE

Unit-1

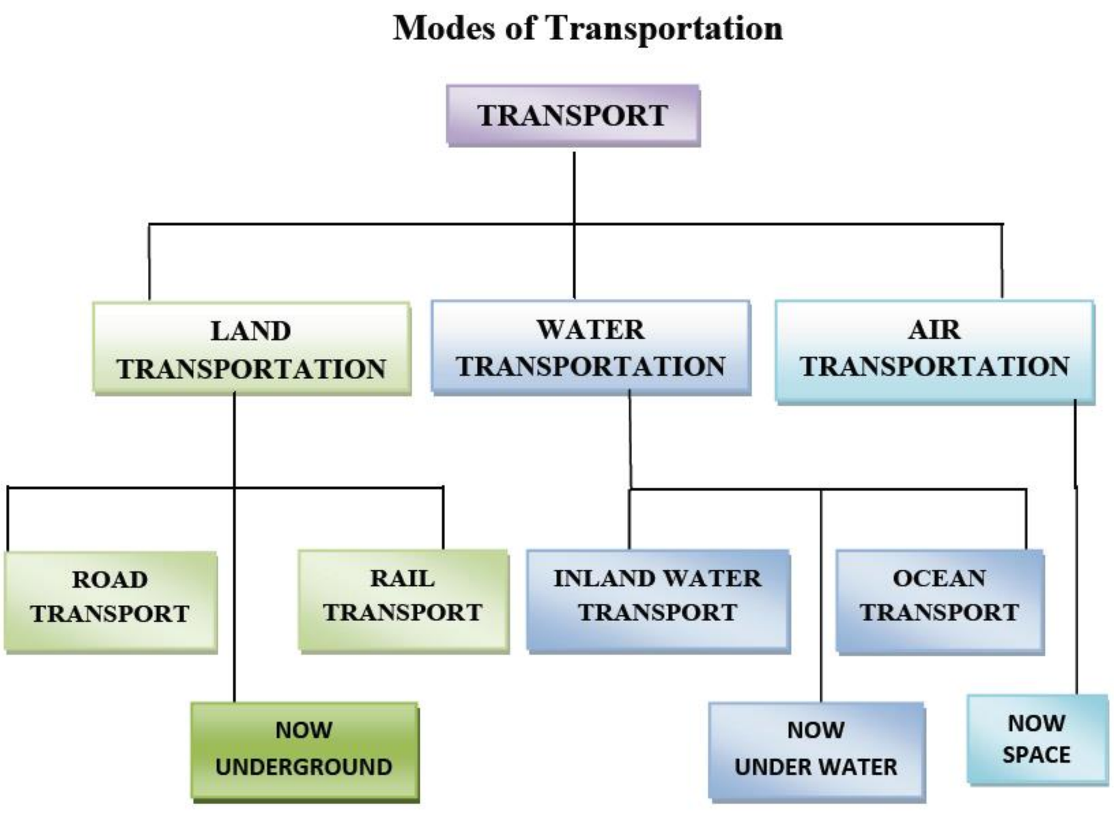
History of modern transportation

Transportation is defined as the movement of freight and passenger from one place to another.

Transportation is the movement of goods and persons from place to place and the various means by which such movement is accomplished. The growth of the ability—and need—to transport large quantities of goods or numbers of people over long distances at high speeds in comfort and safety has been an index of civilization and in particular of technological progress.
With the invention of wheel after fire, life changed tremendously for mankind. She / he could move faster and farther as a result could see more, conquer more and also exploit more resources.
To put things on wheels we have invented steam based automated engines followed by fossil fuel and new renewable energy resources.

<u>Modes of transportation:</u>

There are three modes of transportation namely,
1. Air Transport.
2. Water Transport.
3. Land Transport.



<u>Air transportation:</u>

Airways refer to the movement of goods and a person from one place to another through the air. It is quickest, comfortable and costlier means of transportation. It is suitable for carrying precious articles, mail and high class passengers. It does not require construction and maintenance of the tracks for its operations but it is most expensive because heavy investments are required for the construction of aero planes, air ports, hangers, repair shops, wireless and metrological stations, wind indicators, control towers, neon bacons, and flood light- houses etc. It requires the permission of other countries for flying over the air territories.

The potential of air transport in India was first realized in 1911, when an aircraft carried mail from Allahabad to Naini across the river Ganga. However it was only in 1924 after world war-I British Imperial Airways started the first regular air service to India to provide a link with UK. The first civil aviation company which was manned and managed by India was set up by TATA sons in 1932.

Today India has 125 airports including 11 International airports spread all the states of country. Indian airports handled 96 million passengers and 1.5 million tons of cargo in year 2006-07, an increase of 31.4% for passenger and 10.6% for cargo traffic over previous year. The dramatic increase in air traffic for both passengers and cargo in recent years has placed a heavy strain on the country's major airports. Passenger traffic is projected to cross 100 million and cargo to cross 3.3 million tons by 2010.

Water transportation:

Water transportation refers to the movement of goods and passengers on water through boats, steamers and ships. It has two kinds of transportation - Inland water transportation and Ocean transportation.

Two third of the world’s surface is covered by water. The use of boat as a means of transport is the oldest means of transport in the world. It is a natural means of transport and less expensive and slow and risky mode of transportation. Water transport is more flexible and uncertain in maintaining schedule times. Water transport has come for all nations but serves to limited areas.

Inland water is the cheapest mode of transport for certain kind of travels both long and short distances. This transportation which comprises canals, rivers and lakes had received a set-back in the past due to completion from the railway and road transport systems. Whereas Ocean transport was considered in olden days as a big hindrance, in modern times they are instrumental in promoting international trade. Up to 1824, sailing vessels were used. Now a day the importance of steamers and diesel ship has increased.

The advantages of waterways are that they are suitable for carrying bulky goods and heavy articles but not for public transportation due to its slow movements. It is cheaper than road and rail transport and it is relatively free from risks but it serves only limited areas.

India has a 7617 km coastline and there are 12 major ports and 187 minor/ intermediate ports. Nearly 95 per cent of the country’s foreign cargo moves by sea (Manorama, 2009).

Land transportation:

Under land transportation the prime factors to be taken into account is the configuration of soil or surface. Several kinds of carriage are used in road transport such as bicycles, bikes, Motor rickshaws, cars etc., but Road and Railways are considered two major land public transport system.

a) Railway transport:

Railway transport refers to the movement of goods and persons through trains. It is the most important means of land transport and suitable for carrying heavy and bulky articles over long distances.

In 1767 the first iron rails were laid at Coal brook dale and the first passenger railway start by Stockton to Darlington line, built by Stephenson in 1825. The line comprised 27 miles. Early railways were a combination of horse power, fixed steam engines and locomotives. The official opening of the first train was run between Liverpool to Manchester line in 1830.

The Indian railways have been a great integrating force during the last more than 150 years. It has bound the economic life of the country and helped in accelerating the development of industry and agriculture.

It is the world's fourth largest railway network after those of the United States, Russia and China. The railways traverse the length and breadth of the country and carry over 30 million passengers and 2.8 million tons of freight daily across 28 states and two union territories.

Indian Railways is the largest employer in the world with a work force of 14 lakhs employees of which 78, 989 are women as on March 31st 2007 it represents 6% of the total work force (Indian Railways Annual Report and Accounts 2006-07).

b) Road transport:

Road transport transportation refers to the movement of goods and persons through motor vehicles on road. It is very oldest and most universal mode of transport and it is sustainable for short distance service and light articles. Every part of the country can be easily reached by road transport and it is less expensive when compared to rail and air transport. The expenditure involved in the construction and maintenance of road is comparatively lower than railways.

Evolution of transport:

The transport system has evolved with the development of human culture. It has developed across several stages like the hunting stage, the pastoral, agricultural, industrial and commercial stages. Man has made many achievements in the development of transport and at the same time has also helped civilization to develop. In the olden days, before human civilization, roads did not exist, and people used to walk for their livelihood and social life. Long distance walking tracks developed as trade routes in Paleolithic times. In human history, the only form of transport apart from walking was by using domestic animals.

The first earth tracks were created by human was by carrying goods and following game trails. Tracks were naturally created at points of high traffic density. As animals were domesticated, horses, oxen and donkeys, dogs, camels etc, became an element in track creation. With the growth of trade, tracks were flattened and widened to accommodate animal traffic.

Thus different animals were used in different regions to local conditions for transport. Use of domestic animals for social life was a part of development of human culture (William, 1969: 425). Animal drawn wheeled vehicles developed in Europe and India in the 4th millennium B.C. and China is about 1700 BC. The elephant was tamed for transport is more conjectural in the 3rd millennium BC. Representation on seals show a close knowledge of the animals and part of elephants' skeleton has been found in a high level at Mohanjadoro.

Environmental Impact of Modern Transportation

The development of internal combustion engine vehicles, especially automobiles, is one of the greatest achievements of modern technology.

Automobiles have made great contributions to the growth of modern society by satisfying many of its needs for mobility in everyday life. The rapid development of the automotive industry, unlike that of any other industry, has prompted the progress of human society from a primitive one to a highly developed industrial society. The automotive industry and the other industries that serve it constitute the backbone of the word's economy and employ the greatest share of the working population.

However, the large number of automobiles in use around the world has caused and continues to cause serious problems for the environment and human life. Air pollution, global warming, and the rapid depletion of the Earth's petroleum resources are now problems of paramount concern. In recent decades, the research and development activities related to transportation have emphasized the development of high efficiency, clean, and safe transportation. Electric vehicles, hybrid electric vehicles, and fuel cell vehicles have been typically proposed to replace conventional vehicles in the near future.

Air Pollution

At present, all vehicles rely on the combustion of hydrocarbon fuels to derive the energy necessary for their propulsion. Combustion is a reaction between the fuel and the air that releases heat and combustion products. The heat is converted to mechanical power by an engine and the combustion products are released into the atmosphere. A hydrocarbon is a chemical compound with molecules made up of carbon and hydrogen atoms. Ideally, the combustion of a hydrocarbon yields only carbon dioxide and water, which do not harm the environment. Indeed, green plants "digest" carbon dioxide by photosynthesis. Carbon dioxide is a necessary ingredient in vegetal life. Animals do not suffer from breathing carbon dioxide unless its concentration in air is such that oxygen is almost absent.

Actually, the combustion of hydrocarbon fuel in combustion engines is never ideal. Besides carbon dioxide and water, the combustion products contain a certain amount of nitrogen oxides (NO_x), carbon monoxides (CO), and unburned hydrocarbons (HC), all of which are toxic to human health.

Global Warming

Global warming is a result of the "greenhouse effect" induced by the presence of carbon dioxide and other gases, such as methane, in the atmosphere. These gases trap the Sun's infrared radiation reflected by the ground, thus retaining the energy in the atmosphere and increasing the temperature. An increased Earth temperature results in major ecological damages to its ecosystems and in many natural disasters that affect human populations. Among the ecological damages induced by global warming, the disappearance of some endangered species is a concern because it destabilizes the natural resources that feed some populations. There are also concerns about the migration of some species from warm seas to previously colder northern seas, where they can potentially destroy indigenous species and the economies that live off those species.

Global warming is believed to have induced meteorological phenomena such as "El Niño," which disturbs the South-Pacific region and regularly causes tornadoes, inundations, and dryness. The melting of the polar icecaps, another major result of global warming, raises the sea level and can cause the permanent inundation of coastal regions, and sometimes of entire countries.
Carbon dioxide is the result of the combustion of hydrocarbons and coal. Transportation accounts for a large share (32% from 1980 to 1999) of carbon dioxide emissions. The distribution of carbon dioxide emissions is shown in Figure 1.1.

Figure 1.2 shows the trend in carbon dioxide emissions. The transportation sector is clearly now the major contributor of carbon dioxide emissions. It should be noted that developing countries are rapidly increasing their transportation sector, and these countries represent a very large share of the world's population.

The large amounts of carbon dioxide released in the atmosphere by human activities are believed to be largely responsible for the increase in global Earth temperature observed during recent decades (Figure 1.3). It is important to note that carbon dioxide is indeed digested by plants and sequestrated by the oceans in the form of carbonates. However, these natural assimilation processes are limited and cannot assimilate all of the emitted carbon dioxide, resulting in an accumulation of carbon dioxide in the atmosphere.

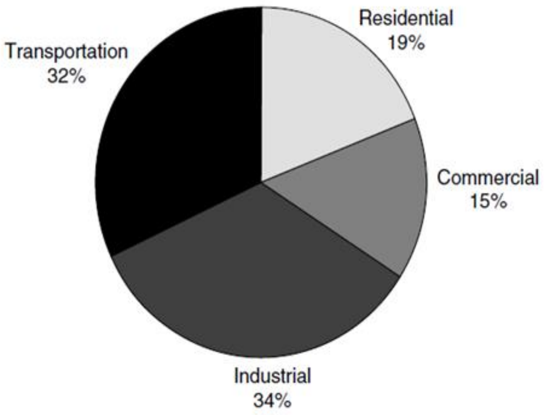


FIGURE 1.1
Carbon dioxide emission distribution from 1980 to 1999

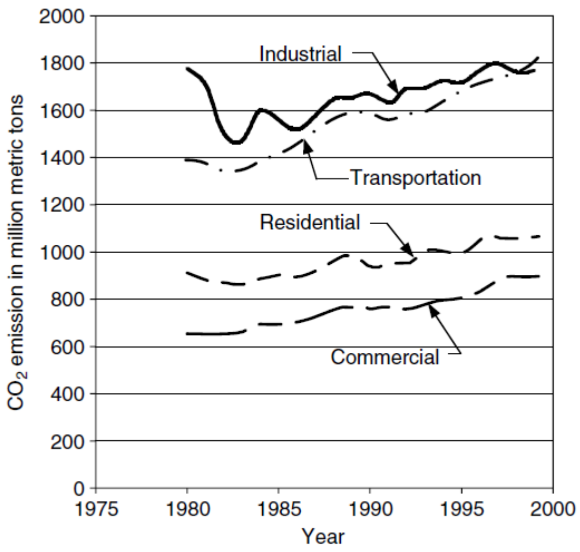


FIGURE 1.2
Evolution of carbon dioxide emission

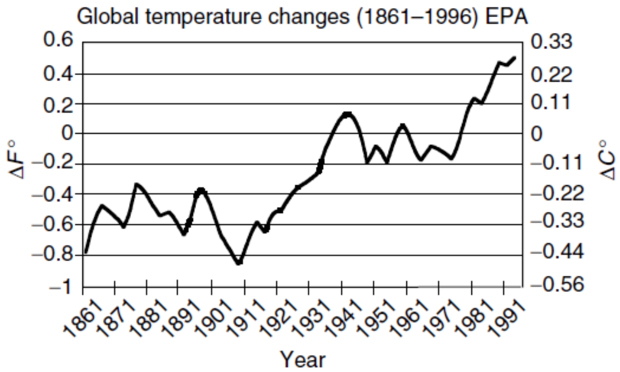


FIGURE 1.3
Global Earth atmospheric temperature. (*Source*: IPCC (1995) updated.)

Petroleum Resources

The vast majority of fuels used for transportation are liquid fuels originating from petroleum. Petroleum is a fossil fuel, resulting from the decomposition of living matters that were imprisoned millions of years ago (Ordovician, 600 to 400 million years ago) in geologically stable layers and fossil fuels are finite.

The amount of future oil discoveries is hypothetical, and the newly discovered oil will not be easily accessible. The R/P ratio is also based on the hypothesis that production will remain constant. It is obvious; however, that consumption (and therefore production) is increasing yearly to keep up with the growth of developed and developing economies.
Consumption is likely to increase in gigantic proportions with the rapid development of some largely populated countries, particularly in the Asia-Pacific region. The plot of Figure 1.4 shows the trend in oil consumption over the last 20 years.7 Oil consumption is given in thousand barrels per day (1 barrel is about 8 metric tons). Despite the drop in oil consumption for Eastern Europe and the former USSR, the world trend is clearly increasing, as shown in Figure 1.5. The fastest growing region is Asia-Pacific, where most of the world's population lives. An explosion in oil consumption is to be expected, with a proportional increase in pollutant emissions and carbon dioxide emissions.

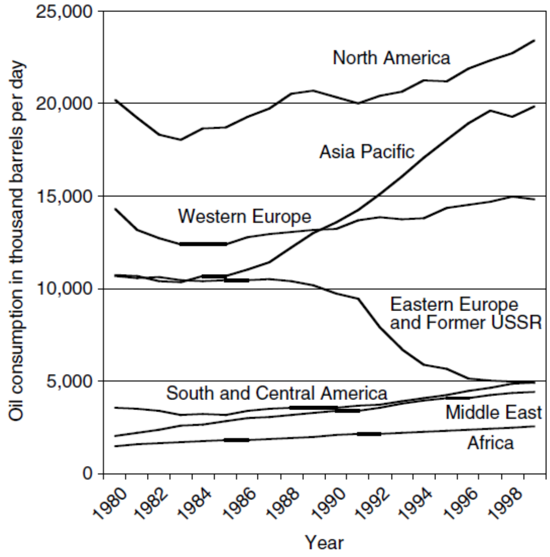


FIGURE 1.4
Oil consumption per region

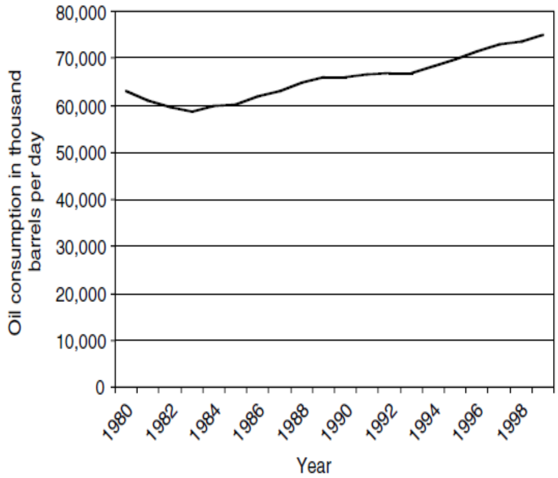


FIGURE 1.5
World oil consumption

Induced Costs

The problems associated with the frenetic combustion of fossil fuels are many: pollution, global warming, and the foreseeable exhaustion of resources, among others. Although difficult to estimate, the costs associated with these problems are huge and indirect,8 and may be financial, human, or both. Costs induced by pollution include, but are not limited to, health expenses, the cost of replanting forests devastated by acid rain, and the cost of cleaning and fixing monuments corroded by acid rain. Health expenses probably represent the largest share of these costs, especially in developed countries with socialized medicine or health-insured populations.

Importance of Different Transportation Development Strategies to Future Oil Supply

The number of years that the oil resources of the Earth can support our oil supply completely depends on the discovery of new oil reserves and cumulative oil production (as well as cumulative oil consumption). Historical data show that the new discovery of oil reserves occurs slowly. On the other hand, the consumption shows a high growth rate, as shown in Figure 1.6. If oil discovery and consumption follow current trends, the world oil resource will be used by about 2038.

It is becoming more and more difficult to discover new reserves of petroleum under the Earth. The cost of exploring new oil fields is becoming higher and higher. It is believed that the scenario of the oil supply will not change much if the consumption rate cannot be significantly reduced. As shown in Figure 1.7, the transportation sector is the primary user of petroleum, consuming 49% of the oil used in the world in 1997. The patterns of consumption of industrialized and developing countries are quite different, however. In the heat and power segments of the markets in industrialized countries, nonpetroleum energy sources were able to compete with and substitute for oil throughout the 1980s, and by 1990, oil consumption in other sectors was less than in the transportation sector.

Most of the gains in worldwide oil use occur in the transportation sector. In developing countries, the transportation sector shows the fastest projected growth in petroleum consumption, promising to rise nearly to the level of nontransportation energy use by 2020. In the developing world, however, unlike in industrialized countries, oil use for purposes other than transportation is projected to contribute 42% of the total increase in petroleum consumption. The growth in nontransportation petroleum consumption in developing countries is caused in part by the substitution of petroleum products for noncommercial fuels (such as wood burning for home heating and cooking).

Improving the fuel economy of vehicles has a crucial impact on oil supply. So far, the most promising technologies are hybrid electric vehicles and fuel cell vehicles. Hybrid vehicles, using current internal combustion engines (ICEs) as their primary power source and batteries/electric motors as the peaking power source, have much higher operation efficiency than those powered by ICEs alone. The hardware and software of this technology are almost ready for industrial manufacturing. On the other hand, fuel cell vehicles, which are potentially more efficient and cleaner than hybrid electric vehicles, are still in the laboratory stage and it will take a long time to overcome technical hurdles for commercialization.

Figure 1.8 shows the generalized annual fuel consumptions of different development strategies of next-generation vehicles. Curve a–b–c represents the annual fuel consumption trend of current vehicles, which is assumed to have a 1.3% annual growth rate. This annual growth rate is assumed to be the annual growth rate of the total vehicle number. Curve a–d–e represents a development strategy in which conventional vehicles gradually become hybrid vehicles during the first 20 years, and after 20 years all the vehicles will be hybrid vehicles. In this strategy, it is assumed that the hybrid vehicle is 25% more efficient than a current conventional vehicle (25% less fuel consumption). Curve a–b–f–g represents a strategy in which, in the first 20 years, fuel cell vehicles are in a developing stage while current conventional vehicles are still on the market. In the second 20 years, fuel cell vehicles will gradually go to market, starting from point b and becoming totally fuel cell powered at point f. In this strategy, it is assumed that 50% less fuel will be consumed by fuel cell vehicles than that by current conventional vehicles. Curve a–d–f–g represents the strategy by which the vehicles become hybrid in the first 20 years, and fuel cell powered in the second 20 years.

Cumulative oil consumption is more meaningful because it involves annual consumption and the time effect, and is directly associated with the reduction of oil reserves, as shown in Figure 1.6. Figure 1.9 shows the scenario of generalized cumulative oil consumptions of the development strategies mentioned above. Although fuel cell vehicles are more efficient than hybrid vehicles, the cumulative fuel consumption by strategy a–b–f–g (a fuel cell vehicle in the second 20 years) is higher than strategy a–d–e (a hybrid vehicle in the first 20 years) within 45 years, due to the time effect. From Figure 1.8, it is clear that strategy a–d–f–g (a hybrid vehicle in the first 20 years and a fuel cell vehicle in the second 20 years) is the best. Figure 1.6 and Figure 1.9 reveal another important fact: those fuel cell vehicles should not rely on oil products because of the difficulty of future oil supply 45 years later. Thus, the best development strategy of next-generation transportation would be to commercialize hybrid electric vehicles immediately and, at the same time, do the best to commercialize nonpetroleum fuel cell vehicles as soon as possible.

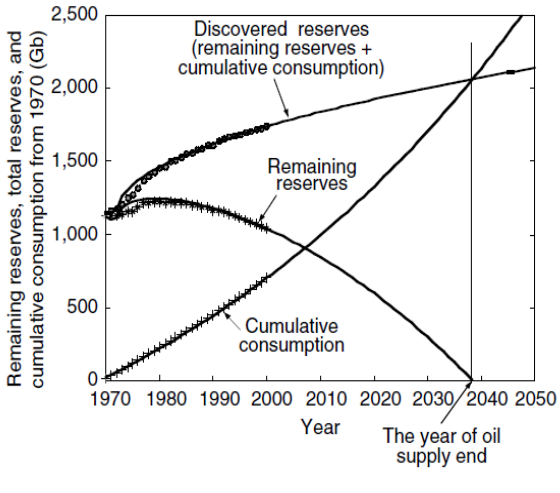


FIGURE 1.6
World oil discovery, remaining reserves, and cumulative consumption

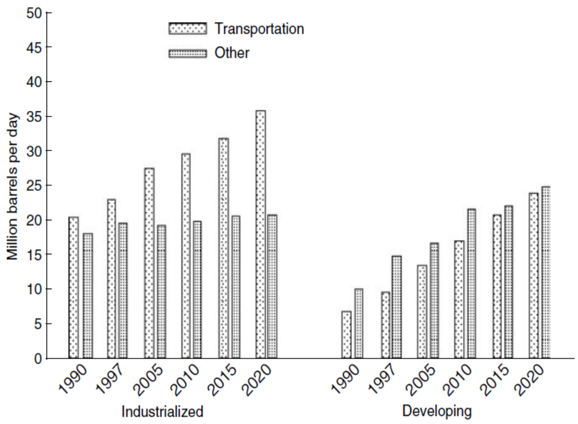


FIGURE 1.7
World oil consumption

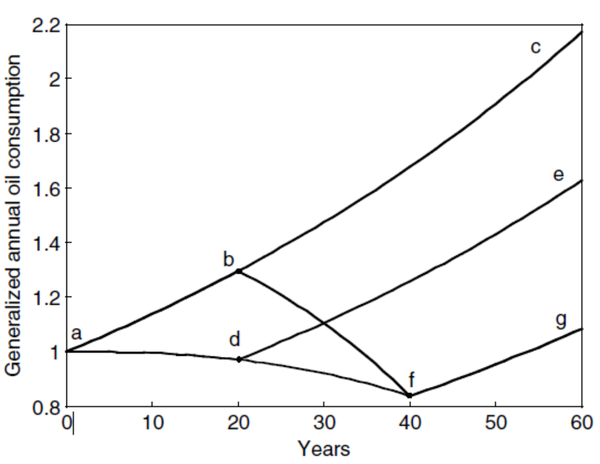


FIGURE 1.8
Comparison of the annual fuel consumption between different development strategies of the next-generation vehicles

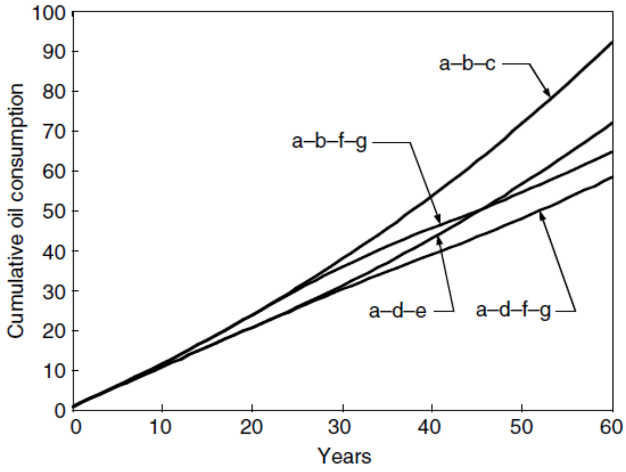


FIGURE 1.9
Comparison of the cumulative fuel consumption between different development strategies of next-generation vehicles

<u>Introduction of Electrical Vehicles:</u>

Electric vehicles (EVs) use an electric motor for traction, and chemical batteries, fuel cells, ultra capacitors, and/or flywheels for their corresponding energy sources. The electric vehicle has many advantages over the conventional internal combustion engine vehicle (ICEV), such as an absence of emissions, high efficiency, independence from petroleum, and quiet and smooth operation.

Electric vehicle is an automobile propelled by one or more **electric** motors, drawing power from an onboard source of **electricity**. **Electric cars** are mechanically simpler and more durable than gasoline-powered **cars.**

1. Why Electric Vehicles (EV)?

There are many reasons why people are moving to Electric Vehicles (EV) to get them to the places they need to be. These include:

1. EV's produce no smelly fumes or harmful greenhouse gases.
2. EVs are innovative and cool.
3. EVs only cost approximately $360 a year to operate compared to $3600 for a gasoline vehicle.
4. EVs are a smart and convenient choice.
5. EVs are fun to drive because they are fast and smooth.

2. How far can drive EV before to recharge

The first question many ask is how far an Electric Vehicle travel before it needs to be recharged. Firstly, when was the last time you ran out of gas in your vehicle? For most people the answer is never, because they watch the fuel gauge and fill up their tank when it is almost empty. It's the same with an EV, you can pull into one of the 450 public charging stations to "top up" or plug your car in each night at home just like you do with your cell phone and always leave home with a full battery. The average daily drive in BC's urban regions is 30km and all electric vehicles today can drive at least 100km's before needing to be recharged.

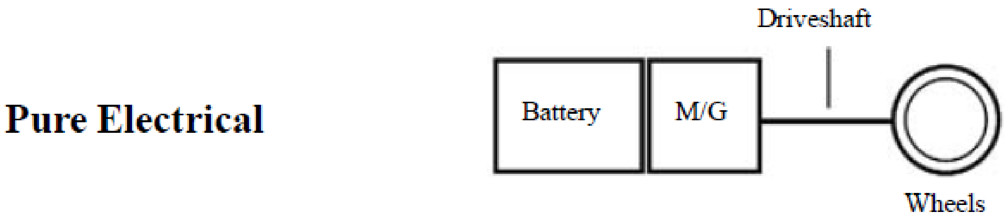
Some BEVs that can drive up to 426km. Hybrid vehicle which also has a gasoline engine that can be used once the battery runs out.

3. What is the difference between an Electric Vehicle and a Hybrid?

There are 3 types of electric vehicle: Battery Electric Vehicle (BEV), Plugin Hybrid Electric Vehicle (PHEV) and Hybrid Electric Vehicle (HEV) and each are described in more detail below.

Battery Electric Vehicle (BEV)

A battery electric vehicle (BEV) runs entirely using an electric motor and battery, without the support of a traditional internal combustion engine, and must be plugged into an external source of electricity to recharge its battery. Like all electric vehicles, BEVs can also recharge their batteries through a process known as regenerative braking, which uses the vehicle's electric motor to assist in slowing the vehicle, and to recover some of the energy normally converted to heat by the brakes.



Pros

1. No emissions
2. No gas or oil changes
3. Ability to conveniently charge at home
4. Fast and smooth acceleration
5. Low cost of operation - about $30 a month.

Cons

1. Shorter range than gasoline vehicles although most people drive well within the range of today's BEV and could rent a hybrid for the rare long trips.
2. Slightly more expensive than their gasoline equivalent although the gasoline savings pay off the difference in typically 2-3 years.

Plug-in Hybrid Electric Vehicle (PHEV)

Plug-in hybrids (PHEVs) use an electric motor and battery that can be plugged into the power grid to charge the battery, but also has the support of an internal combustion engine that may be used to recharge the vehicle's battery and/or to replace the electric motor when the battery is low. Because Plug-in Hybrids use electricity from the power grid, they often realize more savings in fuel costs than tradition hybrids electric vehicles (HEV).

Pros

a. Longer range than BEV
b. Less gas consumption than gas only vehicle
c. Fewer emissions
d. Very simple mechanics, less to go wrong.

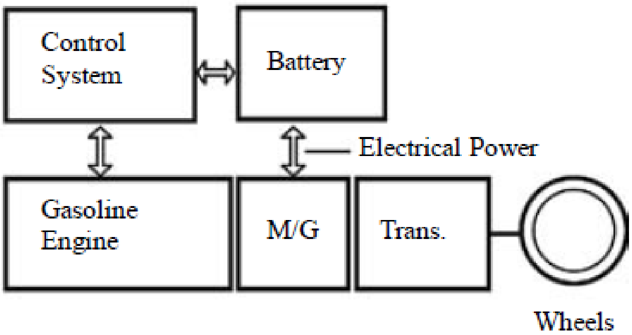
Cons

a. Produces tailpipe emissions
b. Needs gas and oil changes
c. More expensive to operate than Battery Electric Vehicle (BEV) but less than traditional hybrid vehicle (HEV).

Hybrid Electric Vehicle (HEV)

Hybrid Electric Vehicles (HEVs) have two complementary drive systems: a gasoline engine with a fuel tank; and an electric motor with a battery. Both the engine and the electric motor can turn the transmission at the same time, and the transmission then turns the wheels. HEVs cannot be recharged from the electricity grid – all their energy comes from gasoline and from regenerative braking

Hybrid



Pros

a. Longer range than BEV
b. Less gas consumption than gas only vehicle
c. Fewer emissions than gas only vehicle

Cons

a. Still produces emissions
b. Complex mechanics – Gasoline + Electric
c. Expensive to operate (8-10 times more expensive than BEV) but less than traditional gasoline vehicle.
d. No ability to conveniently charge at home.
e.

4. How do we charge EV?

Now that you have chosen the EV that best fits your needs, how do you charge it up? Well it's as easy as charging your phone and can be done in the comfort of your home or at the 500+ public charging stations in BC plus more in the US.

a. It's easy to charge every night they so EV drivers don't need as much one-time range as a typical gas-engine car driver who may refuel once a week or once a month.
b. When we charge at home we can always leave with a full battery.
c. With more than 500 EV charging stations in BC there is a good chance we can charge our EV while we are at work, shopping, at the movies, at the mall, at the doctor or dentist, etc so we can probably drive further than we think.

EV's will also charge themselves whenever you brake or go downhill so sometimes you will have more range available at the bottom of the hill than you did at the top.

5. Mobile Apps for your EV

Many EVs today are technically advanced and have mobile apps that can provide you with information on your car such as how far you can drive given your current battery charge and even allow you to control your car like locking the doors or pre heating your car on a winter day. Be sure to check the app store of your mobile device for apps for your EV, for example **Leaf Spy** and **VERNetwork**

<u>History of hybrid and electric vehicles</u>

Historical development (root) of Automobiles

In 1900, steam technology was advanced. The advantages of ***steam-powered cars*** included high performance in terms of power and speed. However, the disadvantages of steam-powered cars included poor fuel economy and the need to "fire up the boiler" before driving. Feed water was a necessary input for steam engine, therefore could not tolerate the loss of fresh water. Later, Steam condensers were applied to the steam car to solve the feed water problem. However, by that time Gasoline cars had won the marketing battle.

Gasoline cars of 1900 were noisy, dirty, smelly, cantankerous, and unreliable. In comparison, electric cars were comfortable, quiet, clean, and fashionable. Ease of control was also a desirable feature. Lead acid batteries were used in 1900 and are still used in modern cars. Hence lead acid atteries have a long history (since 1881) of use as a viable energy storage device. Golden age of ***Electrical vehicle*** marked from 1890 to 1924 with peak production of electric vehicles in 1912. However, the range was limited by energy storage in the battery. After every trip, the battery required recharging. At the 1924 automobile show, no electric cars were on display. This announced the end of the Golden Age of electric-powered cars.

The range of a ***gasoline car*** was far superior to that of either a steam or an electric car and dominated the automobile market from 1924 to 1960. The gasoline car had one dominant feature; it used gasoline as a fuel. The modern period starts with the oil embargoes and the gasoline shortages during the 1970s which created long lines at gas stations. Engineers recognized that the good features of the gasoline engine could be combined with those of the electric motor to produce a superior car. A marriage of the two yields the hybrid automobile.

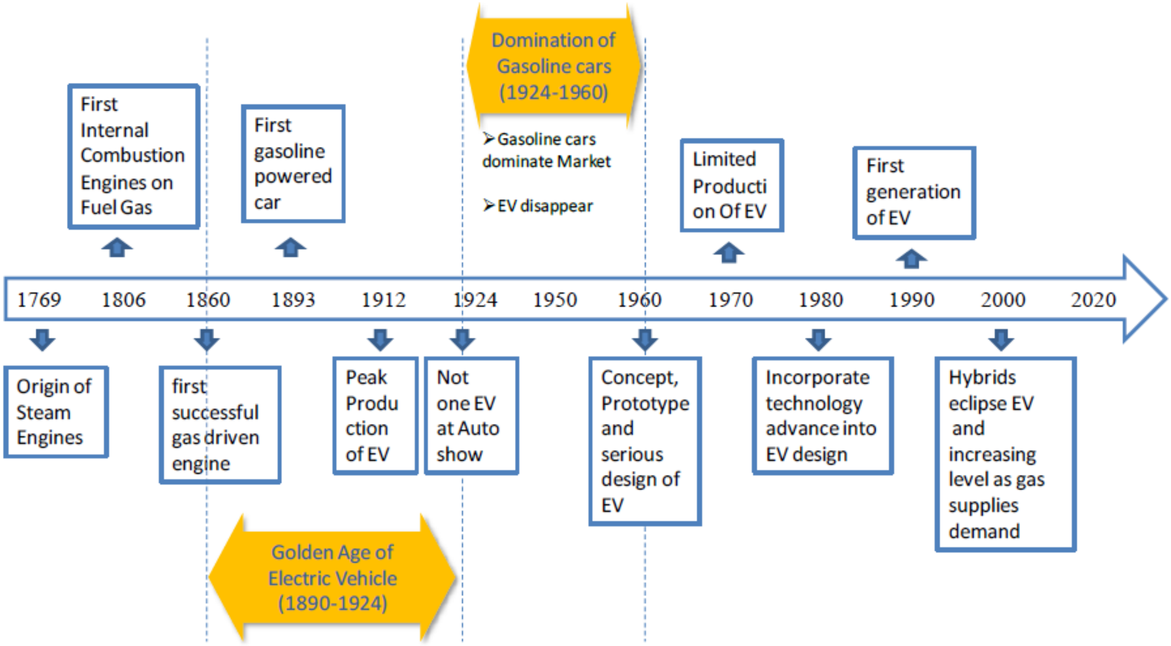


Figure 3: Historical development of automobile and development of interest and activity in the EV from 1890 to present day. Electric Vehicle merged into hybrid electric vehicle.

1769

The ***first steam-powered vehicle*** was designed by Nicolas-Joseph Cugnot and constructed by M. Brezin that could attain speeds of up to 6 km/hour. These early steam-powered vehicles were so heavy that they were only practical on a perfectly flat surface as strong as iron.

1807

The next step towards the development of the car was the invention of the internal combustion engine. Francois Isaac de Rivaz designed the ***first internal combustion engine*** in, using a mixture of hydrogen and oxygen to generate energy.

1825

British inventor Goldsworthy Gurney built a steam car that successfully completed an 85 mile round-trip journey in ten hours time.

<u>History of electric vehicles</u>

- In 1834 the first no-rechargeable battery operated EV (Tricycle) was built by Thomas Davenport.
- After invention of Lead – acid battery, a rechargeable battery based EV was built by David Salomons in 1874.
- Twelve years – later, First electric trolley systems was built by Frank Sprague in 1886.
- In 1900, among 4200 automobiles sold in USA, 38% were EV, 22% were ICEV and 40% Steam powered vehicles.

Several companies in US, England and France made EVs by 1900.

- Electric Carriage and Wagon company, US [1894] 'Electrobat'
- Pope manufacturing company, US [500EVs by 1898] 'Columbia'
- Riker Electric Motor company, US 'Victoria' [1897]
- London Electric Cab Company England [started 1897]
- Bouqquet, Garcin and Schivre (BGS), France [1899 – 1906]
    - BGS EVs in 1900 had world record of 290 Km/Charge.
- An EV named 'Jamais Contente' captured a record of 110Km/Hr in May, 1899.
- By 1912, nearly 34,000 EVs were registered in US.

EVs disappeared by 1930s

- First development was that,, Henry Ford mass produced 'Ford Model T' in 1925, and reduced its price by over 1/3rd to its price in 1909.
    - This made EVs costlier compared to ICEV.
- The second development was invention of automobile starter motor, by Charie Keetering; that helped remove manual cranking required in ICEV, and enabled electric ignition and start
    - This made ICEV user friendly compared to EVs.

Resurgence of EVs

- Reasons that led resurgence of EVs in 1970s.
- The Arab oil embargo of 1973 increased demands for alternate energy sources.
- Increased air pollution led to worst fog in London in 1950s and in California in 1960s/70s retriggered strict emission regulations
    - In 1976, Congress enacted Public Law 94-413,, the Electric and Hybrid vehicle Reasearch, Development and Demonstration Act. This Act authorized a federal program

to promote electric and hybrid vehicle technologies and to demonstrate the commercial feasibility of EVs.

- In 1990, California Air Resource Board (CARB) established rules that 2% of all vehicles sold in California in 1998 should be ZEV (zero emission vehicles) and it should be 10% by 2003.
  - In 1968, "Great Electric Car Race" was organized between Boston (MIT) and Pasadena (Caltech) and covered a distance: 3, 490 miles with 53 recharging stations to recharge the batteries of EVs.

This gives a very good initiation for academic universities to invent new electrical vehicles.

Many automakers especially in US, Japan and Europe started development of EVs due to the strict implementation rules & acts and attracting subsidies.

- In Us, General Motors, Ford,, Chrysler, US Electricar and Solectria etc.
- In Japan, Toyota, Nissan, Honda, Mazda, Daihstsu, Mitsubishi, Suzuki, Isuzu, Subara etc.
- In Europe, PSA Peugeot, Renault, BMW, Mercedez Benz, Audi, Volvo, Opel, Volkswagen, Fiat, Bedford etc.

➢ GM built number of experimental EVs, such as Electrovai in 1966, Electrovan in 1968,, Electrovette in 1979 etc.
  - SCR based SE DC Motor,, with Ni-Zn Batteries, 60 miles/Hr, 80 Km range.

➢ Ford EV projects resulted in Fiesta EV, Escort EV, Aerostar, Ecostar etc in 1970s.

➢ Nissan development work includes EV-4, EV-Resort, President EV and Cedric-EV in 1970s/80s.

➢ Toyota produced series in EVs named EV-10 to EV-40 in 1980s.

➢ Fiat experimental EVs were X1/23,, Y10 in 1980s and Elettra in 90s

➢ BMW produced early convertibles such as E30E,, E36e in early 90s and E1 in mid 90s.

Some of Popular EVs in 1990s/Early2000

- GM EV1 [100KW IM,, VRLA, 0-100Km/Hr in 9 sec, 144 Km]
- Nissan Altera EV [62 KW, PMSM, Co-Li, 120 Km/Hr, 192 KM]]
- NIES Luciole [72 KW, in-wheel PMSM, VRLA, 130 Km/Hr, Solar]
- HKU U2001 [45 KW, PMSM, NI Cd, 110 Km/Hr, 176 Km]
- Reva Etc [13 KW, SE DC, VRLA, 65 Km/Hr, 80 Km]

➢ Popular HEVs in 1990s
  - Tpyota Prius [52 KW ICE, ## KW PMSM, Ni mH,, 160 Km/Hr]
  - Honda insight etc. [50 KW ICE, 10 KW PMSM, Ni mH, 26-30 Km/Hr]]

➢ Popular FCEV in 1990s/Early 200
  - Ford P2000
  - Daimier-Benz NECAR - 3 etc.

Some of Current popular EVs

- Tesla Roadstar (2007), Model-S(2012), Model-X(2015), Model-3(2017)
- Nissan Leaf
- Chevy Bolt
- BMW i3 etc

➢ Current popular HEVs are mostly PHEVs variants
  - Honda Accord hybrid
  - Toyota Camry, Prius hybrid
  - Ford Fusion hybrid
  - Lexus Rx 450h
  - Volvo XC60 T8
  - BMW 740e xDrive etc.

Some of EVs from 1880s

Gustave Trouvé's tricycle (1881), world's first electric car

Electric car built by Thomas Parker, photo from 1895

Thomas Edison and an electric car in 1913

The Honda EV Plus, one of the cars introduced as a result of the CARB ZEV mandate

The General Motors EV1, one of the cars introduced due to the California Air Resources Board mandate, had a range of 260 km (160 miles) with NiMH batteries in 1999.

The Mitsubishi i-MiEV was launched in Japan in 2009

Retail deliveries of the BMW i3 began in Europe in November 2013. The i3 ranked as the third best selling all-electric car in 2014.

Global sales of the Renault Zoe, released in 2012, achieved the 50,000 unit milestone in June 2016.

The Tesla Model S was the top-selling plug-in electric car worldwide in 2015 and 2016.

The first Chevrolet Bolt EVs were delivered to customers in the San Francisco Bay Area in December 2016

The Nissan Leaf listed as all-time best selling plug-in electric passenger car until December 2019, with 450,000 global sales.

Environmental Impact of Hybrid and Electric Vehicles

Over the last decade, there's been an increase in the purchasing of electric vehicles (EV). There are many_reasons why one might consider making the switch to an EV – electric cars are higher efficiency than gas-powered cars, can reduce your dependence on fossil fuels require less maintenance than most cars and Reduce car emissions to help the environment, to name four popular reasons.

One draw for many people who decide to buy an electric car is that EVs are often considered to be one of the most sustainable forms of transportation. Unlike hybrid vehicles or gas-powered cars, EVs run solely on electric power – depending on how that electric power is produced, your EV can be run 100% on sustainable, renewable resources.

There are four factors to consider when evaluating the impact of electric cars on the environment: tailpipe emissions, well-to-wheel emissions, the energy source that charges the battery, and the car's efficiency.

Electric car emissions: tailpipe and well-to-wheel

When an electric vehicle is running on electricity, it emits no tailpipe (also known as direct) emissions. When evaluated on that factor alone, EVs are a lot more eco-friendly than conventional gasoline-powered vehicles on the market today.

However, when evaluating the eco-friendliness of an electric vehicle, you also need to take the "well-to-wheel" emissions into account. This is an overarching term that includes greenhouse gas and air pollutants that are emitted to produce and distribute the energy being used to power the car. Electricity production results in a varying amount of emissions depending on the resource. While "being green" in the act of driving your electric vehicle is a start, if your primary goal in purchasing an electric vehicle is to reduce your greenhouse gas and pollutants emissions, you should also prioritize using zero-emissions electricity wherever possible.

When taking well-to-wheel emissions into account, all-electric vehicles emit an average of around 4,450 pounds of CO_2 equivalent each year. By comparison, conventional gasoline cars will emit over twice as much annually. The amount of well-to-wheel emissions your EV is responsible for is largely dependent on your geographic area and the energy sources most commonly used for electricity. For example, if you live in California, your electricity likely comes from natural gas. This doesn't hold true if your electric vehicle is being used and charged in New Hampshire, as the state sources most of its electricity from nuclear power plants.

Natural gas provides the majority of electricity in the United States, followed closely by coal. It is often considered to be the "cleanest" fossil fuel, because it emits 50 to 60 percent less carbon dioxide than coal. Coal is responsible for around 65 percent of carbon dioxide emissions by the electric power sector in the U.S. That being said, even if your electricity is primarily from a coal plant, driving an EV will likely still overall have lower or similar well-to-wheel emissions when compared to a conventional car. In most places in the United States today, the mix of resources used to generate your electricity mean that driving an electric vehicle will produce lower well-to-wheel emissions than a traditional car.

How to maximize the environmental benefits of your electric car

An electric vehicle will produce fewer emissions than a comparable gasoline-powered car. However, if you are looking to generate as close to zero well-to-wheel emissions as possible, not all electricity sources are created equal. If your primary motive in purchasing an electric vehicle is to be green, you should consider powering your car with a renewable energy source that you can generate at your home (such as solar, wind, or geothermal energy).

When purchasing an electric vehicle, homeowners often consider pairing it with a solar panel system on their roof to charge their car. An average home with a 5 kW installation pays around $10,465 for their solar panel system. Payback period varies depending on your location, but most homes throughout the country break even on the investment of solar panels by year seven.

Even if you can't generate your own renewable energy at your property for your EV to use, you can look into subscribing to a community solar share or changing your electricity supplier to a "green power" option that uses renewable energy sources. Community solar is rapidly expanding across the country, and the majority of utility companies today also have options to specifically purchase electricity from renewable resources.

Efficiency of electric cars

Outside of the resource used to produce your power, another reason why electric vehicles are considered more sustainable than traditional vehicles is because electric car efficiency is higher. When the gasoline in conventional vehicles combusts to power the car, approximately 17 to 21 percent of the energy is converted into power for the car. EVs, on the other hand, are able to convert 59 to 62 percent of the electric energy to power for the vehicle.

When comparing an EV option to a conventional gasoline vehicle (or even a hybrid option), car shoppers also often evaluate MPGe, otherwise known as miles per gallon equivalent (of gasoline). The Environmental Protection Agency (EPA) calculates MPGe by representing the number of miles a vehicle can go given the same (or equivalent) amount of energy that would be contained in one gallon of gasoline. The average MPG of a typical gasoline-powered car is around 24.7 miles per gallon. While that's much more efficient than in the past, it's not much when compared to the MPGe of electric vehicles on the market today. Electric vehicles available now can have a comparable "fuel economy" of as high as 100 MPGe – more than quadruple the efficiency of conventional vehicles

Challenges in the deployment of electric vehicle fleets

A number of factors can hamper or attenuate a larger scale deployment of electric vehicles. They can be grouped into factors that influence on the one hand the attractiveness of the EV for potential customers and subsequently the field experience of the EV users, and on the other hand the commercial interest of the industry to invest in EV development, manufacturing, sales as well as in re-charging and maintenance networks.

The customer interest will be amongst others determined by:

- Purchase price or lease costs
- Total cost of ownership
- Market offers (brands, models, trim levels etc.)
- Driving experience
- Convenience of re-charging
- Safety perception
- Familiarity with EV technology

The commercial interest of the industry will be constrained by:

- Potential EV market size and its uncertainty
- Profit margin
- Investment needs
- Supply risks
- Risk averseness.

Most experts are in agreement that the technology costs and here mainly the battery costs make the currently offered EVs uncompetitive for the mainstream market when compared with conventional vehicles, even when total cost of ownership (TCO) is taken into consideration. Once, this initial barrier can be overcome learning effects and further technology progress could lead to acceptable payback periods for rational customers in the long term. An important factor for the TCO is the residual value of the car. The residual value of EVs is strongly influenced by the expected durability and lifetime of the batteries. Appropriate warranty schemes can help to alleviate related customer concerns. As many private customers do not necessarily perform a TCO calculation but focus very much on the purchase price during their purchase decision, the higher purchase price will remain an attenuating factor in the longer term.

Driving range limitations of fully electric vehicles are a critical factor when comparing to conventional vehicles. Although this factor might not play a big role in the urban and sub-urban context for most of the vehicle users today, it can prevent potential customers from choosing an EV if they are unwilling to compromise vis-à-vis current conventional vehicle ranges. Fast charging or battery swapping could be one possibility to overcome this negative aspect of today's EVs. Other driving aspects like limited top speed and other typical characteristics of EV driving are not expected to create major acceptance problems for EVs, in particular in the urban and sub-urban context.

EVs are a new vehicle propulsion technology that requires the set-up of a new re-fuelling or in this case re-charging infrastructure in parallel to the vehicle technology deployment. Research work by Flynn (2002), and Struben and Sterman (2008) have studied in more detail the interaction between infrastructure and vehicle deployment. The main lessons that can be learned from these studies are that a strong synchronization is needed regarding an adequate coverage of re-charging points and the deployment of electrified vehicles. As electricity distribution systems are abundant especially in urban and sub-urban areas, the main challenges remain with the actual set-up of re-charging points and associated to this the setting up of standardized re-charging interfaces, vehicle to grid communication protocols as well as billing procedures and payment schemes. All these aspects need to be carefully addressed to ensure convenient EV re-charging for the EV user. In the urban context adequate re-charging solutions need to be found for city dwellers that have no possibility to re-charge their EV at home.

An important aspect for the potential EV users is that the EVs fulfill the same high safety standards as the conventional vehicle options. The fact that the recently launched EVs fulfill all pertinent safety standards for vehicles and also achieved a high European New Car Assessment Programme (EURO-NCAP) rating should positively influence the safety perception of EVs. Nevertheless, some further work needs to be done on improving or creating EV safety, electromagnetic interference and health standards.

Before a larger deployment of EVs is reached, the familiarity of the broader public with this new propulsion technology can be a challenge. The familiarity can be increased through dedicated marketing and media campaigns before a critical mass of EVs is on the road and word of mouth enhances further the public attention.

The future market size of EVs is unknown and predictions are highly uncertain. In the past, there have been examples of unsuccessful attempts to bring BEVs into the market. Some of these attempts were accompanied by optimistic outlooks on the future deployment of electromobility; however, a broader EV roll-out did not become reality (Frery, 2000). This uncertainty reduces the willingness of the industry to invest into EV and its related infrastructure. As the automotive industry and the needed infrastructure investment is capital intensive, the industry players are rather risk adverse in this context.

The profit margin for the first EVs will be low. As a matter of fact, it can be expected that the first generation of EVs that are currently deployed will constitute a negative business case for the industry that can be justified as an upfront investment into a potential future growth market. Many manufacturers are preparing for entering the EV market; they will try to limit their investment risk by deploying a limited number of models in the beginning. This limits the offered choices and can turn away potential customers that have a certain affinity to specific brands or models. Another possibility for the manufacturers to limit their investment needs in the beginning is to share common component sets across brands (e.g. Mitsubishi i-MIEV, Citroen C-Zero, Peugeot iOn) or to focus their deployment on selected lead-markets. The latter option will on the one hand limit the necessary investments in the dealer and maintenance network, but on the other hand also reduce the number of potential customers. The re-charging infrastructure providers will also want to ensure an adequate return on their investment which could potentially lead to unsatisfactory infrastructure coverage in the beginning.

Supply chains need to be built up for the new EV specific technologies and components. This can slow down the ramp-up of the EV deployment in the beginning but should not lead to a sustained supply bottleneck. Material bottlenecks are expected to become an issue for permanent magnet motors (e.g. neodymium) and some cathode materials for lithium ion batteries (e.g. Cobalt).

Common definitions and Specifications of PHEVs, BEVs, EVs

AMP

Short for ampere, this is a unit of electricity that refers to the steady current produced by one volt applied across a resistance of one ohm.

BATTERY

An essential EV component, this is an electric storage unit in which chemical energy is converted into electricity and used as a source of power. Federal regulations require automakers to cover EV batteries under warranty for at least eight years or 100,000 miles (whichever comes first).

LITHIUM-ION BATTERY

This is a type of high-energy rechargeable battery, used in EVs and other products like laptop computers, that leverages lithium ions as a key component of its electrochemistry.

CHARGING

The process of replenishing an electric vehicle's battery with electricity; this can either be accomplished at home via a standard wall outlet or a 220-volt line, or via a public or workplace-based charging station.

STATE OF CHARGE

Also known by the acronym SOC, it refers to the meter on an EV's instrument panel that displays the current battery level as a percentage.

LEVEL 1 CHARGING

The slowest way to charge an electric vehicle, Level 1 charging uses a standard 110-volt wall outlet. Depending on the model it may take between 8-24 hours to fully replenish a drained battery.

LEVEL 2 CHARGING

Level 2 charging, accomplished via a dedicated 240-volt electric circuit like those used for large electric appliances, roughly slashes charging time in half over Level 1 charging. You can have a Level 2 unit installed by a professional electrician at home, and it's the type of charging used most often in public and workplace charging stations.

LEVEL 3 CHARGING

This is the quickest way to replenish an EV's battery, though it's limited to what is still a relative handful of public charging stations. Also called DC Fast Charging, it's able to bring a depleted battery up to an 80% charge in around a half hour. If you're taking an extended road with an EV, you'll want to plan the route around the availability of Level 3 pubic charging stations.

EV

Short for "electric vehicle," it refers to any mode of transportation that uses one or more electric motors powered a rechargeable battery for propulsion. It's alternatively called BEV, for "battery electric vehicle."

ICE

Short for "internal combustion engine," this acronym describes any vehicle that runs on fossil fuels.

HORSEPOWER

This is a measurement of an engine or motor's maximum power output; an electric motor's output can also be expressed in terms of kilowatts (kW).

KILOWATT

A measurement of electrical power, usually abbreviated as "kW." When used to express an electric motor's maximum output, this is roughly equivalent to 1.34 horsepower.

KWH

Short for "kilowatts per hour," this is a measurement of electricity that's equivalent to the amount of energy expended in one hour by one kilowatt of power. An EV's battery capacity is expressed in terms of kWh. The Environmental Protection Agency uses the number of kilowatts per hour needed to run a vehicle for 100 miles (shortened to "kWh/100 mi") to express an EV's energy consumption.

MPGE

This is a miles-per-gallon equivalent measurement the Environmental Protection Agency created to help consumers compare an electric car's energy consumption with those that run on fossil fuel. MPGe is calculated based on a conversion factor of 33.705 kilowatt-hours of electricity equaling one gallon of gasoline.

RANGE

The number of miles an EV can travel before the battery becomes fully depleted.

REGENERATIVE BRAKING

A system used in EVs (and hybrid-powered cars) that recovers energy otherwise lost during deceleration and braking and sends it back to the battery pack to help maintain a charge. Some EVs, like the Chevrolet Bolt EV and Nissan Leaf, can maximize the regenerative braking effect to slow down – and even bring the vehicle to a stop – without using the brakes. This is commonly called "one pedal" driving.

REX

Also called a "range-extended electric vehicle," this refers to an EV with a small gasoline engine that kicks in to run a generator that, in turn, operates the motor once the battery becomes depleted. At that point the vehicle's operating range is limited only by the amount of gas in the tank. This effectively eliminates worry over being stranded at the side of the road with a dead battery, which is often called "range anxiety." The BMW i3 is available as both a pure EV and a REX.

TORQUE

Torque is officially defined as the twisting force that causes rotation. It's the force you feel when you're pressed into your seat as a vehicle accelerates aggressively. Electric motors deliver 100% of their available torque instantaneously, which enables fast launches and strong passing abilities. Having a higher torque rating otherwise makes an engine or motor with limited horsepower feel quicker.

ZEV

This abbreviation stands for "zero emissions vehicle," which means it produces no tailpipe emissions. All pure electric vehicles are of the ZEV variety

Examples for EV:

• BMW i3 EV: 170 HP - 125 kW • Range on a single charge:	• KIA Niro EV: 200 HP -149 kw • Range on a single charge:

180 km - 112 miles / 33.2 kWh • Time to charge from empty: L1- 16 hrs L2- 5 hrs L3- 80% 30 min • Acceleration: 0-100 km/h or 0-60 mph in 7.3 sec • Top Speed: 150 km/h or 93 mph	384 km - 239 miles / 64 kWh • Time to charge from empty: L1- 59 hrs L2- 9 hrs L3- 80% 60 min • Acceleration: 0-100 km/h or 0-60 mph in 7.8 sec • Top Speed: 167 km/h or 104 mph

Example for PHEV:

Company: HYUNDAI
Model: IONIQ PHEV Entry
Engine: 1.6 litre 16 valve DOHC 4 cylinder petrol engine
Transmission: 6-speed Dual Clutch Transmission (DCT)
Fuel system: Petrol
Maximum power (kW/rpm): 77 kW / 5,700 rpm
Maximum torque (Nm/rpm): 147 Nm / 4,000 rpm
Electric power: 44.5 kW
Electric torque: 170 Nm
High voltage battery: 8.9 kWh lithium ion polymer
Electric only driving range (WLTP rating): 52 km

Plug-in Hybrid Characteristics

Vehicle characteristics

There are a number of hybrid vehicles available in the U.S. currently, however none of these have plug-in capability. These vehicles have battery capacities of 1-2 kWh and can only travel a few kilometers at relatively low speed. Higher capacity batteries could allow the vehicle to travel further. Various proposals include distances of 20, 40, or 60 miles using battery only. There are further permutations on whether a vehicle would run solely on battery until a discharge level was reached and then use a combination of the engine plus battery as in current hybrids, or whether the car would use both engine and battery from the start in order to optimize battery life. In addition, allowing the vehicle to run at highway speed solely on battery power requires a more powerful electric motor that increases the cost of the vehicle.

If solely the battery is used until a preset discharge level is reached, then batteries are likely to be more thoroughly discharged upon the completion of their trips, thereby allowing more energy to be delivered from the grid rather than gasoline. True optimization depends upon the objective function, be it lowest total or operating cost, best performance, longest life, reduced emissions, or a combination of objectives. It would require knowledge of the relative cost of gasoline and electricity, battery lifespan reduction from increased discharge, cost of the battery replacement, vehicle performance requirements, emissions restrictions, etc. The objectives and constraints could conceivably be different for each owner, and vehicle manufacturers will likely only be able to provide limited lternatives, but these alternatives could have a large impact on the charging requirements of a PHEV.

Charging characteristics

A key factor to understand about PHEV is that the power demand on the grid will be a function of the voltage and amperage of the connection to the grid. The capacity of the battery will then determine the length of time it will take to recharge the battery, given the connection strength.

EPRI has conducted several studies on PHEV capabilities and issues. One presentation by Dr. Mark S. Duvall at the DOE Plug-in Hybrid Electric Vehicles Workshop provided several characteristics for evaluating PHEV impacts on the grid (Duvall 2006). As the presentation shows, there are an array of options for the connection between the vehicle and the grid. At 120 volts AC, a 15 amp circuit would be about a 1.4 kW load, while a 20 amp circuit would be about 2.0 kW. If the user instead uses a 208/240 volt and 30 amp circuit, then the load could be as much as 6 kW.

A comparison of time required for recharging is given in Table 1. This table, from the Duvall report, shows the amount of time for vehicles that have a 20-mile battery range (PHEV 20) to recharge from 20% to 100% of State of Charge (SOC). Large battery packs (longer distance) would increase the time required while higher voltage or amperage would reduce the time.

Table 1. Charging requirements for PHEV-20 vehicles (Duvall 2006)

PHEV 20 Vehicle	Pack Size	Charger Circuit	Charging Time 20% SOC
Compact Sedan	5.1 kWh	120 VAC / 15 A	3.9 – 5.4 hrs
Mid-size Sedan	5.9 kWh	120 VAC / 15 A	4.4 – 5.9 hrs
Mid-size SUV	7.7 kWh	120 VAC / 15 A	5.4 – 7.1 hrs
Full-size SUV	9.3 kWh	120 VAC / 15 A	6.3 – 8.2 hrs

1.2 – 1.4 kW power, 1 or 2 hours conditioning

Using the average number of hours from Table 1 times a power level of 1.4 kW, the amount of energy needed and schedule for recharging each PHEV would be approximately as in Table 2.

Table 2. Power requirements by hour for PHEV-20 vehicles at 120 V / 15A

Hour	1	2	3	4	5	6	7	8	kWh Demand
Compact Sedan	1.4	1.4	1.4	1.4	0.91	0	0	0	6.51
Mid-size Sedan	1.4	1.4	1.4	1.4	1.4	0.21	0	0	7.21
Mid-size SUV	1.4	1.4	1.4	1.4	1.4	1.4	0.35	0	8.75
Full-size SUV	1.4	1.4	1.4	1.4	1.4	1.4	1.4	0.35	10.15

Assuming a constant energy requirement for fully charging the battery, higher voltages or current would shrink the time required to fully charge, as shown for mid-size sedans in Figure 1. The actual demand curves would vary more as the battery approached full charge and be dependent on other factors. Any battery charging will vary the amperage as the battery approaches full state of charge, such that the power needs will fluctuate and tail off towards the end of the charging time. This is approximated in the table and calculations by having the last hour being only a partial charge. Our analysis only requires hourly values to match against hourly utility demand levels, as discussed below.

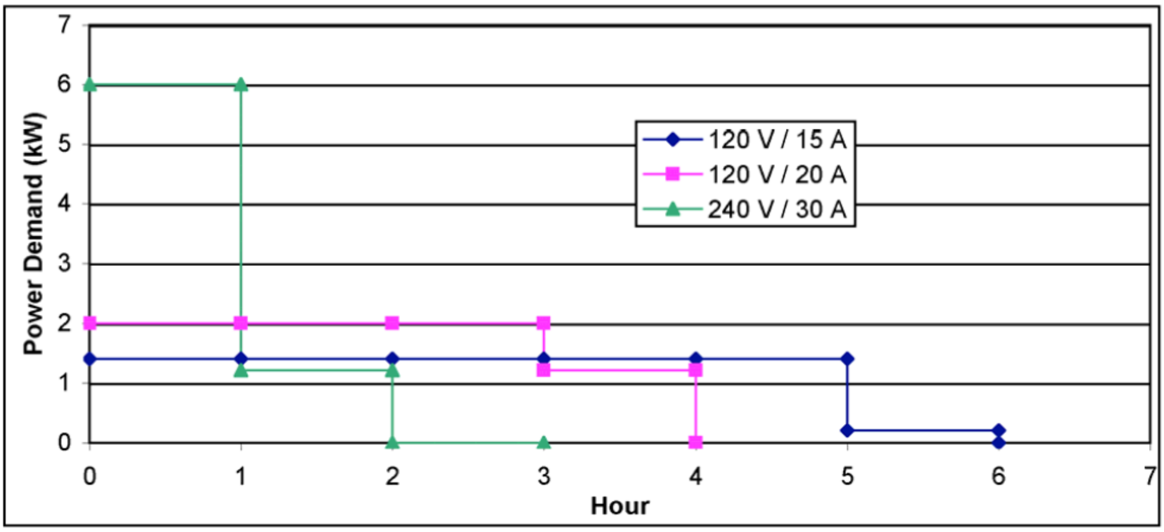


Figure 1. Hourly demand for PHEV-20 mid-size sedan at different voltages and currents

Many cars will not be fully discharged (at 20% SOC) at the time they are plugged in. Also, the owners may need to unplug them for travel before they are fully charged. These added complications are important, but will not be considered in this preliminary analysis.

Timing of plug-in

A key question is when would consumers recharge their vehicles? The optimum time for electricity providers is typically at night when demand is low and low-cost plants are the marginal producers. Any additional generation would come from these low-cost plants and not strain the existing transmission and distribution (T&D) system. However, for consumers the preferred time (absent any incentives to change their preference) is likely to be as soon as they are within easy access to a plug. These both are most convenient since they are at the vehicle already, and also improve their options since they may need the vehicle soon and would prefer a more fully charged battery.

There are various options for utilities to modify customer choices, including pricing schemes favoring nighttime charging or regulatory fiats on vehicle charging. Technically, it may be through smart chargers that know the price of power and/or driving habits of the owner. The intelligence could be in the charger or in the vehicle itself. Such questions are fertile areas for more extensive analysis but are beyond the scope of this white paper.

Other charging patterns may be for consumers to recharge at their place of work, giving them additional range. Employers may offer such options as benefits to employees or local governments may offer this to reduce afternoon air pollution levels (since battery power would then be used more on the trips home.) The utility and businesses could even install the infrastructure to allow consumers to plug in anywhere and have the cost of purchased power added to their bill.

There is also the idea of allowing the vehicles to provide power from their engines or batteries to feed the grid at times of peak demands. Further analysis is needed on the cost to consumers, the electric provider, and the environment by allowing this. Additional circuitry would be required in vehicles, interconnection issues would be difficult to address, and the pollution impact of the vehicles on the local air quality would have to be addressed. It may be that operating the vehicles to provide electricity to the grid may be more expensive and dirtier than building additional power plants.

The future of electric vehicles

Electric vehicles are not just the wave of the future, they are saving lives today. Ten things to know about electric vehicles — and how you can make the future electric.

1. Electric vehicles now include cars, transit buses, trucks of all sizes, and even big-rig tractor trailers that are at least partially powered by electricity.

Electric vehicles fall into three main categories:

- **Battery electric vehicles** are powered by electricity stored in a battery pack.
- **Plug-in hybrids** combine a gasoline or diesel engine with an electric motor and large rechargeable battery.
- **Fuel cell vehicles** split electrons from hydrogen molecules to produce electricity to run the motor.

It's more than just passenger cars now — from New York to Mississippi, you may find yourself on a quiet, zipping electric transit bus. The first electric fire truck in the nation will be welcomed by Angelenos in 2021 — and in the coming years, electric sanitation trucks will be quietly gliding through neighborhoods to pick up garbage and recycling, and more electric trucks will be delivering packages from warehouses to homes, air pollution-free.

2. Electric vehicles are saving the climate — and our lives. Here's how.

The largest source of climate pollution in the United States is Transportation. To solve the climate crisis, we need to make the vehicles on our roads as clean as possible. We have only a decade left to change the way we use energy to avoid the worst impacts of climate change.

Emissions from cars and trucks are not only bad for our planet; they're bad for our health. Air pollutants from gasoline- and diesel-powered vehicles cause asthma, bronchitis, cancer, and premature death.

The long-term health impacts of localized air pollution last a lifetime, with the effects borne out in asthma attacks, lung damage, and heart conditions.

3. Electric vehicles have a smaller carbon footprint than gasoline-powered cars, no matter where your electricity comes from.

The electricity to battery electric and plug-in hybrid vehicles comes from power grids, which rely on a range of sources — from fossil fuels to clean renewable energy.

Energy grids can vary from one state to another, which means that the carbon footprint of driving an electric vehicle ranges depending on the source of its electricity.

Earth justice attorneys are working across the country to bring 100% clean energy, but on our way there (consumption of renewable energy recently surpassed coal), a portion of the electricity in this country will continue to be generated by the burning of fossil fuels.

Electric vehicles are more efficient in converting energy.

Running electric or hybrid cars on the grid in any state has lower greenhouse gas emissions than gasoline-powered cars, as revealed in a study by experts at the Union of Concerned Scientists. And as states clean up their energy grids, the benefits of electric vehicles become stronger.

4. Through their entire lifetime, electric cars are better for the climate.

In the manufacturing process, electric vehicles will produce more global warming emissions than the average gasoline vehicle, because electric cars' large lithium-ion batteries require a lot of materials and energy to build. (For example, manufacturing a mid-sized electric car with an 84-mile range, results in 15% more emissions.)

However, once the vehicles get on the road, it's a whole different energy story.

Electric vehicles make up for their higher manufacturing emissions within, at most, eighteen months of driving — and continue to outperform gasoline cars until the end of their lives

The average electric car on the road today has the same greenhouse-gas emissions as a car getting 88 miles per gallon — which is far greater than the average new gasoline-powered car (31 mpg) or truck (21 mpg), according to analysis by the Union of Concerned Scientists.

5. Electric vehicles can charge up at home, at work, while you're at the store.

One advantage of electric vehicles is that many can be recharged wherever they make their home, whether that's your home or a bus terminal. This makes electric vehicles a good solution for truck and bus fleets that return regularly to a central depot or yard.

As more electric vehicles hit the market and are used more broadly, new recharging solutions — including adding more public charging locations in shopping centers, parking garages, and workplaces — will be required for people and businesses without the same access at home.

"Workplace charging is one key element of democratizing access to electric cars, and we need to move aggressively if we are going to meet this challenge. Electric utilities have a big role to play."

6. Planning now by states and utilities to build infrastructure for charging electric vehicles will go a long way.

Figuring out how to charge these vehicles will become an increasingly important problem to tackle.

Utilities in California are investing more than $1 billion to build the charging infrastructure necessary for electric cars, trucks, and buses throughout the state. These kinds of infrastructure investments will become increasingly important for public transit agencies, businesses, and people who want to purchase an electric car but are unable to install a charger at home.

7. Transit buses, that reliable fixture rumbling through our towns and cities, may just be the key to the electric vehicle revolution.

Buses are the workhorse of our transit system, providing affordable transportation to anyone and everyone. They are a cornerstone of daily life in many cities, making them an important step to getting big electric vehicles into the broader transportation market.

8. Electric trucks — delivering goods from warehouses to homes — can make a big, clean difference. We need more of them.

While diesel and gas trucks only make up a small portion of the vehicles on our roads and highways, they generate massive amounts of climate and air pollution. In the most impacted communities, these trucks create diesel "death zones" with more severe respiratory and heart problems.

It is now time for major manufacturers to start producing electric trucks on a larger scale.

9. Through all our electric vehicle work, Earth justice aims to ensure that the people who are most impacted by pollution have the option to use truly clean and zero-emissions vehicles.

In US, Earth justice endorsed the Electric Vehicle Freedom Act, introduced by Representatives Andy Levin (D-MI) and Alexandria Ocasio-Cortez (D-NY). The bill proposes establishing a network of electric charging stations alongside public roads, to encourage the adoption of electric vehicles by the wider public.

Meanwhile, Earthjustice attorneys are working to help our nation's transportation sector transition away from gasoline combustion to zero emissions, including:

• Electric Trucks: We've been working to increase the number of electric trucks in California — together with 20,000 residents, we asked the California Air Resources Board to enact the nation's first electric truck manufacturing standard.

• Charging Infrastructure: And Earthjustice is working with the Public Utilities Commission in California and other states to build more charging infrastructure. This would relieve one of the biggest barriers to having an all-electric vehicle for those who do not have a garage or a driveway, through either workplace charging, or centralized electric vehicle fast charging.

• Zero-Emissions Vehicles: We're in court defending the ZEV mandate, which is essentially the California state mandate that a certain percentage of vehicle purchases in the state be zero emissions. Ten states have adopted the ZEV mandate through California's special legal authority in the Clean Air Act.

"The Trump administration is trying to protect the oil and gas industry by slowing the transition to electric vehicles," said Earthjustice attorney Adrian Martinez of the Right to Zero campaign.

"Fortunately, there's a lot of opportunity at the local level to bring electric transportation into communities because inherently, a lot of the decisions are local. It's city councils, it's mayors, it's state legislatures that are making these decisions."

10. You can help make the future electric (even if you're car-free).

From cars to buses to trucks, electric vehicles are transforming how we move goods and ourselves, cleaning up our air and climate — and your voice can help advance the electric wave.

- **Urge your city to invest in electric buses, trucks, and charging infrastructure.** Speak with your local elected officials and write letters-to-the-editors.
- **If you (or your friends) are in the market for a car, buy electric.** Check, if your local utility offers rebates or other incentives for installing electric vehicle charging stations at your home.
- **Enlighten your friends.** Share the amazing electric facts you've learned. Encourage your friends to find out how much carbon pollution they could save by going electric.