Fuels used in IC engines & alternate fuels for IC engines

Internal combustion engines are seen every day in automobiles, trucks, and buses. The name internal combustion refers also to gas turbines except that the name is usually applied to reciprocating internal combustion (I.C.) engines like the ones found in everyday automobiles. There are basically two types of I.C. ignition engines, those which need a spark plug, and those that rely on compression of a fluid. Spark ignition engines take a mixture of fuel and air, compress it, and ignite it using a spark plug. Fig 1 shows a piston and some of its basic components. The name 'reciprocating' is given because of the motion that the crank mechanism goes through. The piston- cylinder engine is basically a crank-slider mechanism, where the slider is the piston in this case. The piston is moved up and down by the rotary motion of the two arms or links. The crankshaft rotates which makes the two links rotate. The piston is encapsulated within a combustion chamber. The bore is the diameter of the chamber. The valves on top represent induction and exhaust valves necessary for the intake of an air-fuel mixture and exhaust of chamber residuals.

Parts of the Engine Block
• Cylinder – the part of the engine block where the combustion takes place.
• Piston – a plunger with rings that fit against the inside cylinder walls and prevent air from leaking past
• Connecting rod – connects the piston to the crankshaft. Fastened by the wrist pin
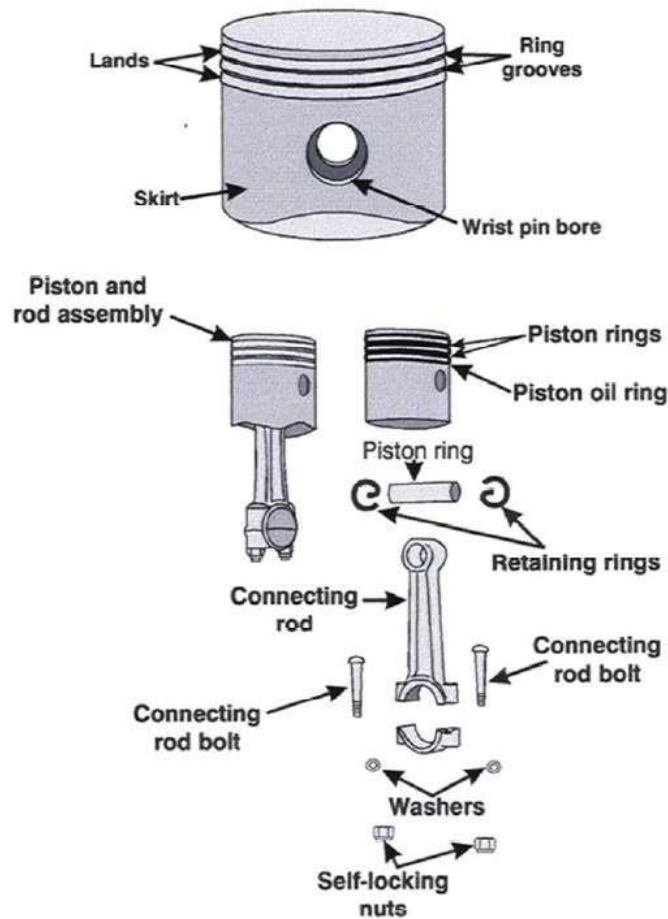• Crankshaft – shaft with offsets to which the connecting rods are attached

Bore and Stroke of a Cylinder
The Fig. 1. Shows the different parts viz., crankshaft, bore, connecting rod, piston, piston pin, cylinder wall
and the combustion pressure in the cylinder.
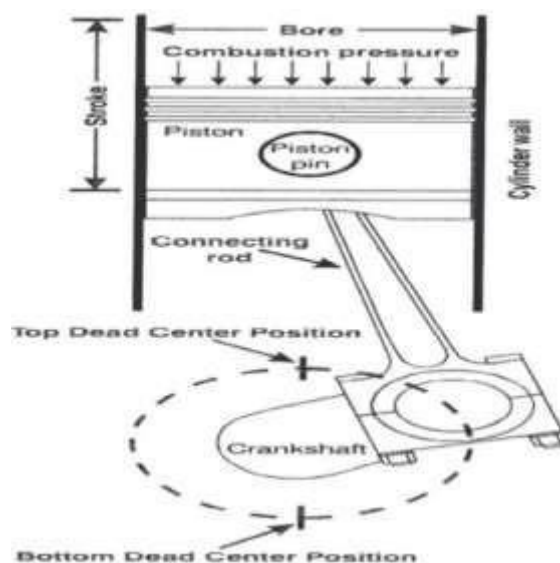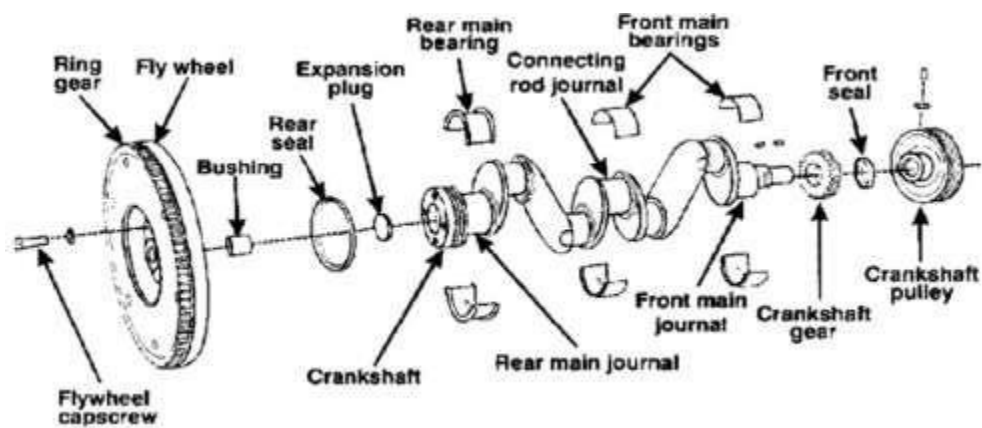

Parts of IC engine

Piston and Connecting rod

(Courtesy, Interstate Publishers, Inc.)

Piston and connecting rod

## *Crank Shaft assembly*

Crankshaft assembly

Conventional Fuel

Mobility is critical for sustainable development. The share of vehicles with internal combustion engines exceeds 95% globally (2014). The rest are electric engines and others. Therefore, engine fuels are one of most important energy sources. Internal combustion engines can be intermittent (eg, Otto engine, diesel engine) or continuous (aviation turbine), and these engines use different motor fuels to generate power. Gasolines are the main fuel for spark ignition internal combustion engines (Otto engines), diesel fuels are for compression ignition internal combustion engines (Diesel engines), marine fuels are for shipping, and aviation turbine fuels (JET fuels) are used for aviation turbines. 1.1. Energy Requirement of Vehicles for Transportation. The energy demand for transportation can be seen on Figure 1 (1).

It is approximately 23% of the total energy consumption; 53% of the crude oil consumption globally (2013). The change in energy demand for transportation by regions is shown in Figures 2 and 3 (1).
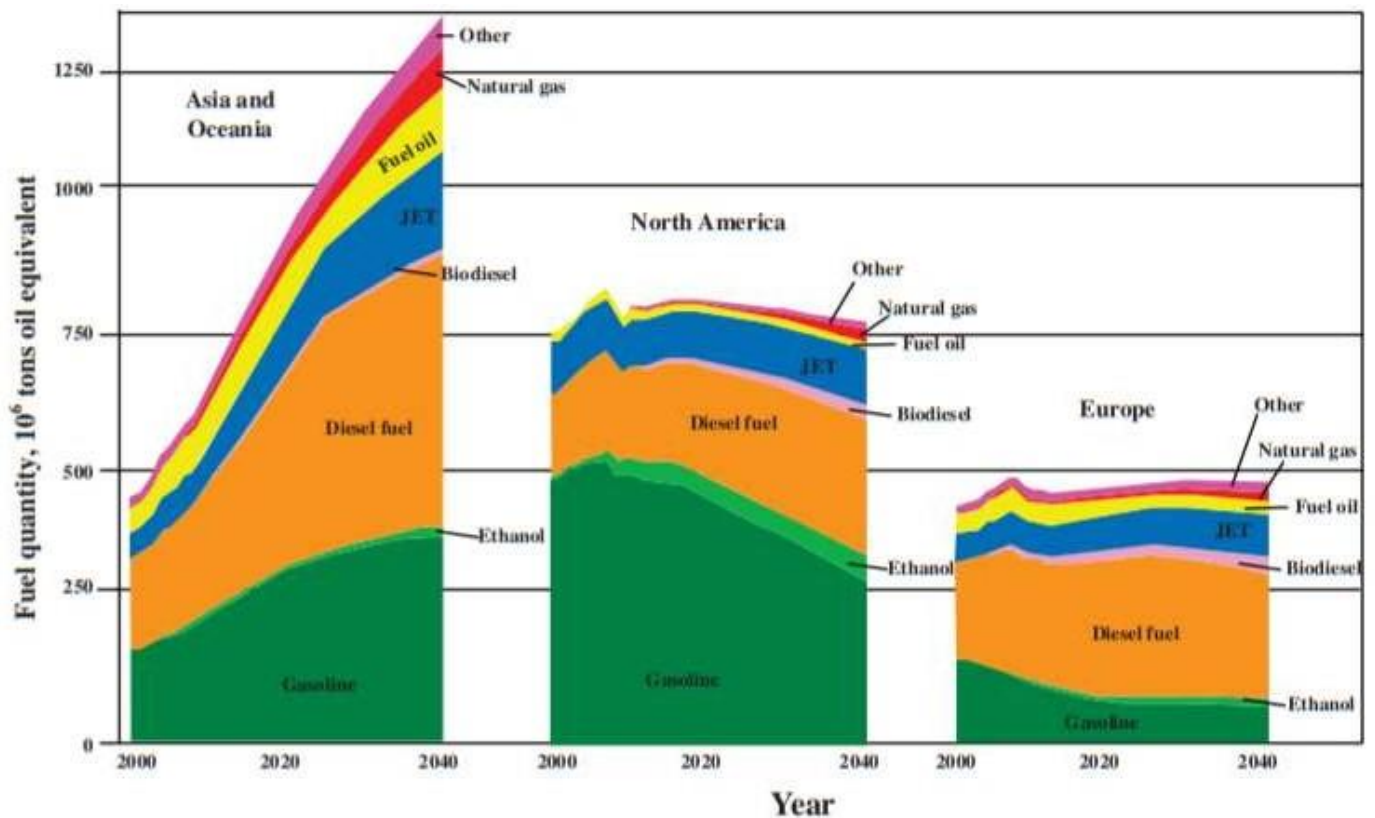
The current and prospected use of engine fuels by type is also shown in Figure 3 (1). Several types of fuels can be used in internal combustion engine, either alone or as a blending component.

• Types of Fuels: - Otto engines (gasolines, LPG, CNG, ethanol, etc) - Diesel engines (diesel fuels, CNG, dimethyl ether, etc) - Alternative driving (eg, electricity)

• Origin: - Produced from fossil energy carriers - Produced from renewable energy carriers (eg, biofuels based on biomass)

• Number of Feedstock Resources: - One resource (eg, fatty acid methyl esters from only triglyceride and/or fatty acid containing feedstocks) - Multiple resources (eg, ethanol; from sugar crops, from crops containing starch, lignocellulose, hydration of ethylene, etc).

• Spread: - Generally used conventional fuels (crude oil-based fuels) - Alternative fuels

• Phase: - Liquid - Gas

• Place of Mobility: - Fuels of inland vehicles (eg, gasoline, diesel fuel) - Fuels of aviation (eg, aviation gasoline, jet fuel) - Fuels of marine transportation (eg, gasoline, heavy diesel fuels, bunker oil)
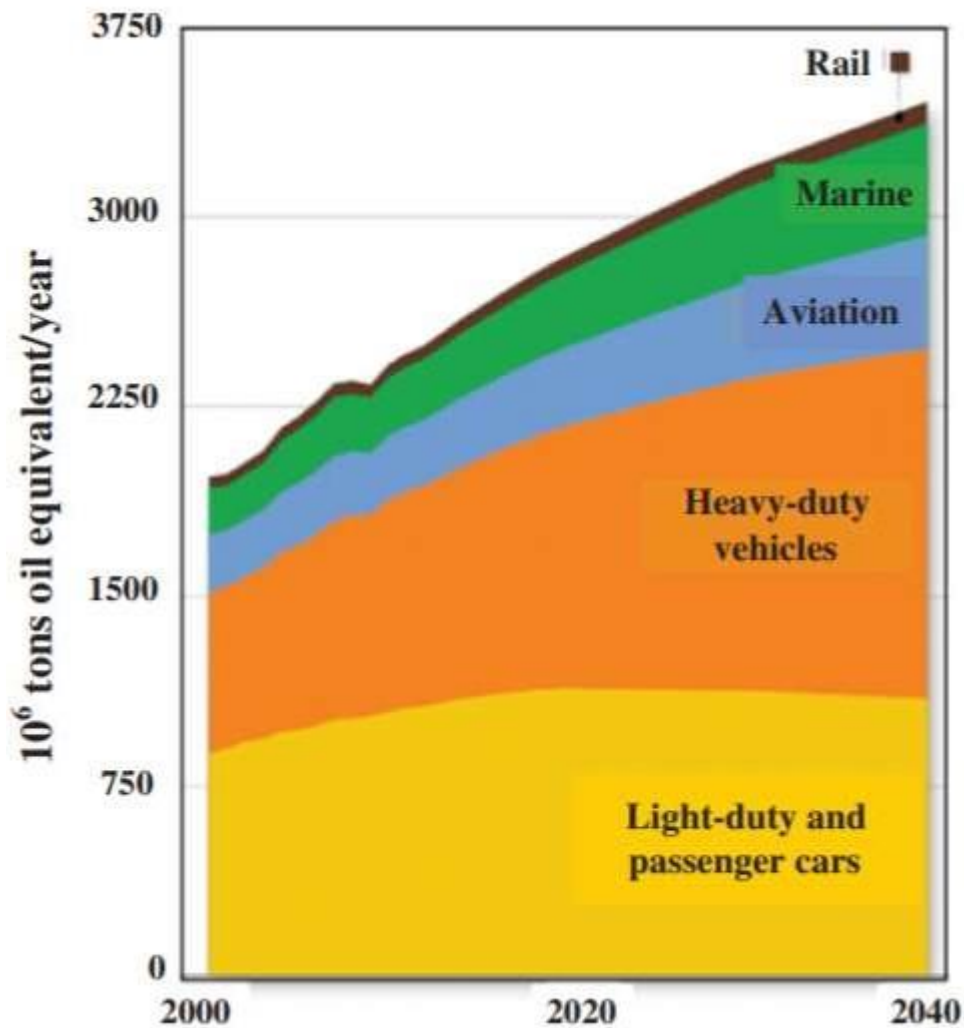
Energy demand of vehicles

• Storageability: - Long term (years)

 - Middle term (months)

- Weeks

– Days

 • Infrastructure (Supply Chain):

- Conventional (existent)

- Different from conventional (must be built up)

Fuel quantity, 10^6 tons oil equivalent

Asia and Oceania — Other, Natural gas, Fuel oil, JET, Biodiesel, Diesel fuel, Ethanol, Gasoline

North America — Other, Natural gas, Fuel oil, JET, Biodiesel, Diesel fuel, Ethanol, Gasoline

Europe — Other, Natural gas, Fuel oil, JET, Biodiesel, Diesel fuel, Ethanol, Gasoline

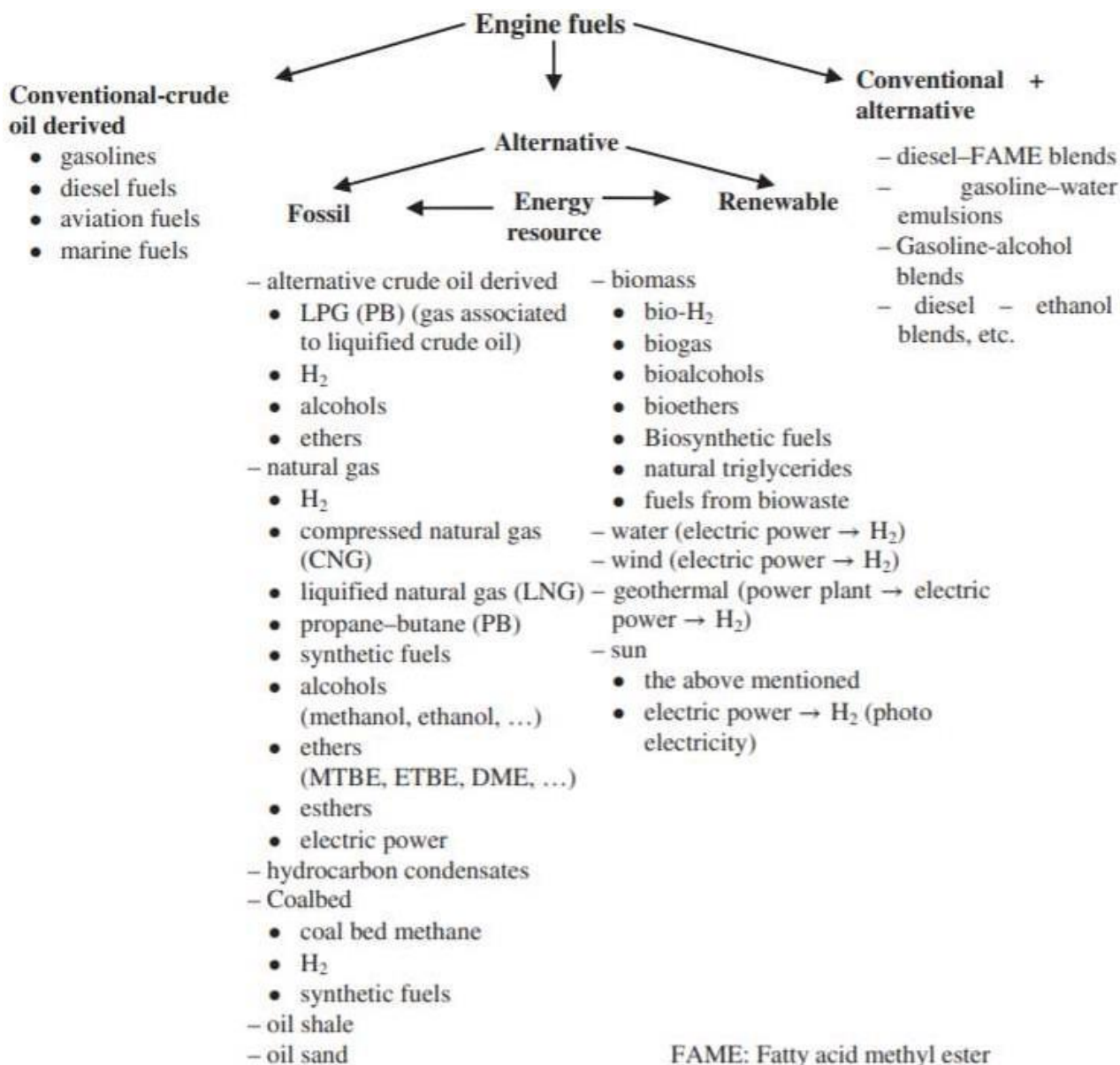Year

Project Global consumption

Conventional fuels are those derived from the liquid products of crude oil refining (gasoline, diesel fuel, jet fuel, marine fuel). Every other is named alternative fuel.

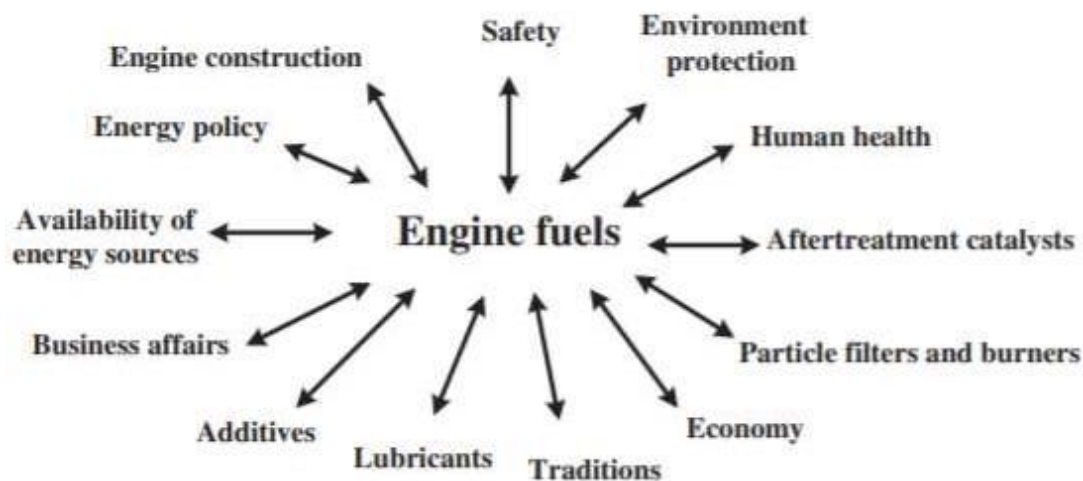### 1. Fuels for Vehicles Motor

fuels are blends of natural and/or synthetic materials and their derivatives, which must satisfy the following general requirements:

– meet energy demand of the specific engine;

– long-term availability in quantity and quality in every location throughout the world;

– environment-friendly during the total life cycle;

– affordable price.

Nowadays, low environmental burden during the total life cycle is one of the basic requirements. As a result, harmful effects, including acid rains, global warming, low and high atmospheric ozone problems, smogs, soil and water contamination, adverse health effects, endangering the flora and fauna, can be reduced or prevented. A large number of factors determine the suitability and quality of motor fuels of different engines). Fuels for internal combustion engines for inland mobility must meet many requirements: • high energy content, • easy recovery and production, • available in high and constant quantity, • contain no or very low amount of components hazardous to the environment (eg, sulfur content)

Engine fuels

Conventional-crude oil derived
- gasolines
- diesel fuels
- aviation fuels
- marine fuels

Alternative

Energy resource

Fossil ← → **Renewable**

Conventional + alternative
- diesel–FAME blends
- gasoline–water emulsions
- Gasoline-alcohol blends
- diesel – ethanol blends, etc.

– alternative crude oil derived
- LPG (PB) (gas associated to liquified crude oil)
- H_2
- alcohols
- ethers

– natural gas
- H_2
- compressed natural gas (CNG)
- liquified natural gas (LNG)
- propane–butane (PB)
- synthetic fuels
- alcohols (methanol, ethanol, …)
- ethers (MTBE, ETBE, DME, …)
- esthers
- electric power

– hydrocarbon condensates
– Coalbed
- coal bed methane
- H_2
- synthetic fuels

– oil shale
– oil sand

– biomass
- bio-H_2
- biogas
- bioalcohols
- bioethers
- Biosynthetic fuels
- natural triglycerides
- fuels from biowaste

– water (electric power → H_2)
– wind (electric power → H_2)
– geothermal (power plant → electric power → H_2)
– sun
- the above mentioned
- electric power → H_2 (photo electricity)

FAME: Fatty acid methyl ester
MTBE: Methyl tertiary buthyl ether
ETBE: Ethyl tertiary buthyl ether
DME: Dimethyl ether

Engine fuels

- Safety
- Environment protection
- Engine construction
- Human health
- Energy policy
- Availability of energy sources
- Aftertreatment catalysts
- Business affairs
- Particle filters and burners
- Additives
- Lubricants
- Traditions
- Economy
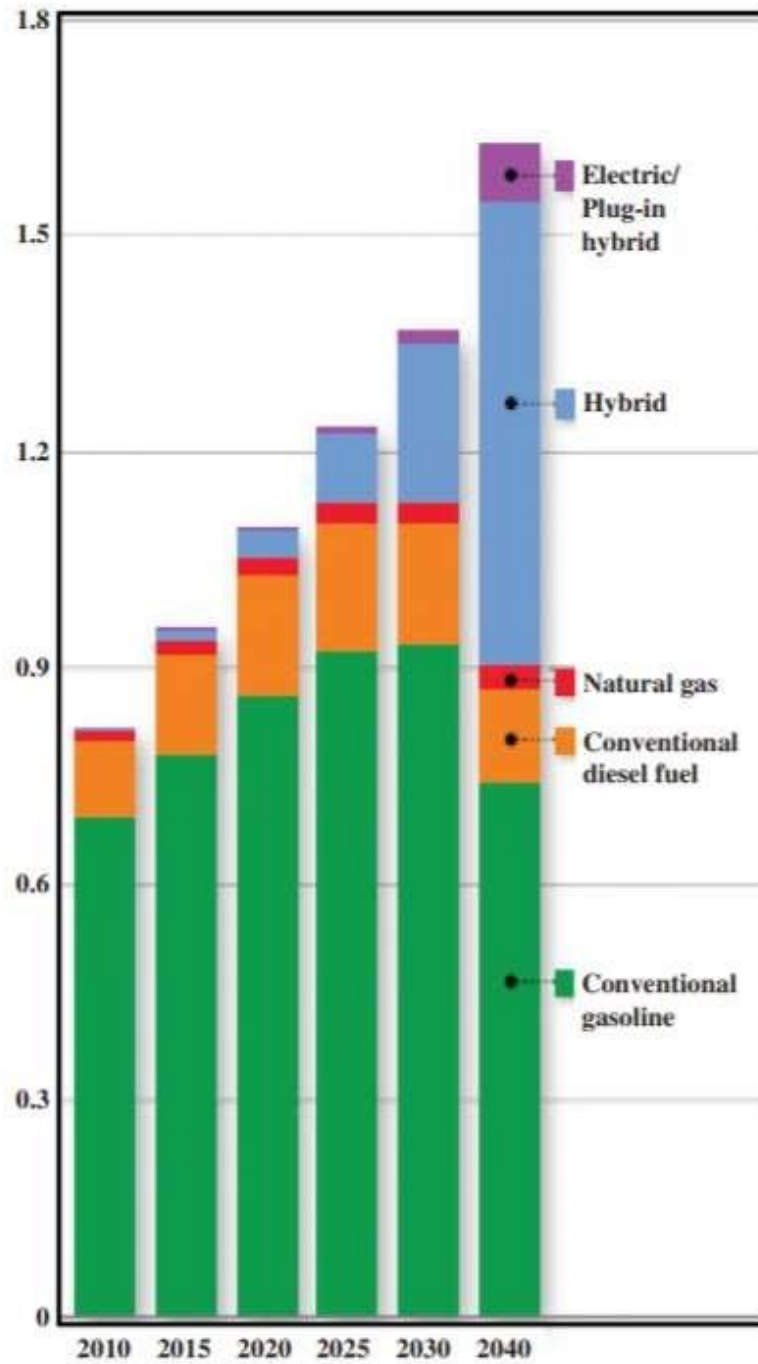
10^9 passenger cars

Projection of passenger car distribution by type of energy.

Alternative Fuel

The large increase in number of automobiles in recent years has resulted in great demand for petroleum products. With crude oil reserves estimated to last only for few decades, there has been an active search for alternate fuels.

The depletion of crude oil would cause a major impact on the transportation sector. Of the various alternate fuels under consideration, biodiesel, derived from vegetable oils, is the most promising alternative fuel to conventional diesel fuel (derived from fossil fuels; hereafter just "diesel") due to the following reasons

• Biodiesel can be used in existing engines without any modifications.
• Biodiesel is made entirely from vegetable sources; it does not contain any sulfur, aromatic hydrocarbons, metals or crude oil residues.
• Biodiesel is an oxygenated fuel; emissions of carbon monoxide and soot tend to be reduced compared to conventional diesel fuel.
• Unlike fossil fuels, the use of biodiesel does not contribute to global warming as CO_2 emitted is once again absorbed by the plants grown for vegetable oil/biodiesel production. Thus CO_2 balance is maintained.
• The Occupational Safety and Health Administration classify biodiesel as a non-flammable liquid.
• The use of biodiesel can extend the life of diesel engines because it is more lubricating than petroleum diesel fuel.
• Biodiesel is produced from renewable vegetable oils/animal fats and hence improves fuel or energy security and economy independence.

A lot of research work has been carried out using vegetable oil both in its neat form and modified form. Studies have shown that the usage of vegetable oils in neat form is possible but not preferable . The high viscosity of vegetable oils and the low volatility affects the atomization and spray pattern of fuel, leading to incomplete combustion and severe carbon deposits, injector choking and piston ring sticking. Methods such as blending with diesel, emulsification, pyrolysis and transesterification are used to reduce the viscosity of vegetable oils. Among these, the transesterification is the most commonly used commercial process to produce clean and environmentally friendly fuel.

A large number of studies on performance, combustion and emission using raw vegetable oils and methyl/ethyl esters of sunflower oil, rice bran oil, palm oil, mahua oil, jatropha oil, karanja oil, soybean oil, rapeseed oil and rubber seed oil have been carried out on Compression Ignition(CI) engines. The purpose of this report is to review previous studies that look into the effect of bio-diesel on CI engine from the viewpoint of performance, combustion and emissions.

Production of biodiesel

Vegetable oils are chemically complex esters of fatty acids. These are the fats naturally present in oil seeds, and known as tri-glycerides of fatty acids. The molecular weight of these tri-glycerides would be of order of 800 kg/m3or more. Because of their high molecular weights these fats have high viscosity causing major problems in their use as fuels in CI engines. These molecules have to be split into simpler molecules so that they have viscosity
and other properties comparable to standard diesel oils. Modifying the vegetable oils (to make them lighter) can be achieved in many ways, including; Pyrolysis, Micro emulsification, Dilution and Transesterification. Among these, transesterification is the most commonly used commercial process to produce clean and environmentally friendly
light vegetable oil fuel i.e. biodiesel.

ALTERNATIVE FUELS FOR
INTERNAL COMBUSTION ENGINES

This section focuses on physical and chemical characteristics, applications, and production pathways of biofuels including biodiesel and bioalcohols. In addition, there will be a brief introduction to other nonbiofueld ICE alternative fuels.

Biodiesel
Among various AFs under consideration, biodiesel is the most promising substitute for conventional fossil
fuels due to the following reasons:
• Biodiesel can be used in existing IC engines without any modifications.
• Biodiesel is made entirely from renewable sources including plants and animal fats, and it does not
contain sulfur, aromatics, metals, or crude oil residues.
• Biodiesel is an oxygenated fuel. Emissions of HCs, CO, and soot tend to be substantially reduced compared to ordinary diesel fuel.
• Unlike fossil fuels, the life cycle CO_2 emission of biodiesel is significantly reduced (w70%e80%
reduction). CO_2 emitted is once again absorbed by the oil production plants. Thus, CO_2 balance is maintained.
• Biodiesel is classified as a non-flammable liquid.
• The use of biodiesel can extend the life of diesel engines because it is more lubricating than petroleum
diesel fuel.
• Biodiesel is produced from renewable vegetable oils/ animal fats and hence improves energy security and economy independence.

Standards and properties of biodiesel

The US biodiesel industry began in the early 1990s in order to produce renewable fuels, reducing dependence on imported crude oil from energy safety consideration, and environmental impacts as well as adverse health effects from sustainable development concern.

The American Society of Testing Materials Standards (ASTM) defines biodiesel as "a fuel comprising mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats"

The first specification for pure biodiesel (B100) was approved by ASTM D6751 in 2001. Soon after, stakeholders expressed a need for standards involving blending pure biodiesel with finished fuel. ASTM approved up to 5 vol% (denoted as B5) biodiesel blending with conventional diesel fuel (ASTM D975) and burner fuel (ASTM D396) in 2008. A separate standard, ASTMD7467, was adopted for 6e20 vol% blends (B6 to B20) for on- and offroad diesel fuel in the same year. ASTM is still improving biodiesel standards because of conventional fuel specification and equipment changes. The increase of biodiesel blending levels in the market also requires standards modification. In 2003, a more restrictive specification for biodiesel, that is, EN 14214, was approved by the European Committee for Standardization in Europe. Updates made in 2008 and 2014 were added to current EN 14214 specification.

the common properties of biodiesels when compared with conventional diesel can be listed as follows:

• **Higher kinematic viscosity**: one of the major problems associated with biodiesel is that its viscosity is usually much higher than that of diesel fuel. Biodiesel can be once or twice as viscous as petroleum diesel. Higher viscosity leads to poorer fuel atomization and vaporization and therefore poorer combustion condition. Nonuniform atomization may result in the fuel-rich pocket and subsequent soot production. Thus, the US ASTM D6751-08 and EN 14214 standards limit the biodiesel viscosity in the range of 1.9e6.0 and 3.5e5.0 mm2/s, respectively. In general, the viscosity of all esters decreases with increasing level of unsaturation or shorter ester chain length.

• **Higher density**: fuel density is a key property affecting engine performance. Both air-fuel ratio and energy content within the combustion chamber are influenced by fuel density. ASTM D6751 does not specify the fuel density range. However, according to the EN 14214 standard, biodiesel should have a density of 860e900 kg/m. Generally, densities of biodiesel fuels are slightly higher than those of petroleum diesel. Blending biodiesel with conventional diesel can increase fuel density
The density is reported to be affected by the degree of unsaturation and chain length, where higher unsaturation and lower chain length lead to increased density

.• **Poorer cold flow properties**: low-temperature performance is one of the most important considerations for the application of biodiesel. However, the low-temperature parameter has not been clarified in the EN 14214-2005 and ASTM D6751- 08 standards. General assessment of fuel cold flow properties includes cold filter plugging point (CFPP), cloud point (CP), and pour point (PP). Poor cold flow properties result from the presence of long chains and saturated fatty acid esters in biodiesel. Longer carbon chain and higher saturated degree contribute to poorer fuel low-temperature performance.

• **Higher flash point**: the flash point is inversely related to fuel volatility. The higher flash point makes biodiesel safer in terms of storage, handling, and transformation. ASTM D6751 is the most restrictive specification with respect to the minimum flash point
of biodiesel. ASTM D6751 states that B100 must have a flashpoint greater than 130 C, whereas the European norm, EN 14214, sets a minimum value of 120C .

• **Higher CN**: CN is the measure of a fuel's autoignition characteristics. Since biodiesels mainly consist of long, straight chain hydrocarbons (with virtually no branching or aromatic structures), it typically has a higher CN than petroleum diesel. Increasing blending level of biodiesel increases the CN . Generally, a minimum CN of 47 can meet the ASTM standard. CN ranges between 48 and 67 for biodiesels from different feedstocks. Some literature reported that increasing degree of unsaturation leads to
decreasing CN. Biodiesel produced from feedstocks rich in saturated fatty acids (such as tallow and palm) has higher CN than fuels produced from less saturated feedstocks (such as soy and rapeseed).

• **Lower heating value**: biodiesels have lower massenergy density than petroleum diesel because of their higher oxygen content. With increasing fatty acid carbon chain length (for a constant unsaturation level), the mass fraction of oxygen decreases, and therefore the heating value increases. The heating value of biodiesel is reported to decrease with increasing unsaturation level. Neither ASTM nor EN standard includes heating value requirement.

Production pathways
Currently, the feedstocks for biodiesel include plant oils, such as soybean oil, sunflower oil, corn oil, olive oil, rapeseed oil, castor oil, lesquerella oil, milkweed (Asclepias) seed oil, Jatropha curcas, mandarin seed, Pongamia glabra (karanja), Madhuca indica (Mahua), and Salvadora oleoides (Pilu), Calophyllum inophyllum, palm oil, linseed oil, algae, etc., and animal fats, such as bovine fat, fish oils, pig fat, duck, beef tallow, etc., and used cooking oil iodiesel can be produced from these oils in four different ways, namely pyrolysis/ cracking, dilution with hydrocarbons (blending), microemulsification, and transesterification.

Pyrolysis
Pyrolysis, or thermal cracking, is the decomposition of one organic substance into a variety of small molecules by heating with or without the aid of a catalyst. Vegetable oils and animal fats are mostly composed of triglycerides. The mechanism of triglycerides thermal decomposition is depictedyrolyzed vegetable oils possess acceptable amounts of sulfur, water, and sediment, as well as acceptable copper corrosion
values. Many researchers have also indicated that pyrolysis of triglycerides can produce suitable products for diesel engines. Though biodiesel fuel produced through pyrolysis is suitable for diesel engines, the removal of oxygen can degrade oxygenated fuels' environmental benefits in terms of combustion products consumption. Besides, pyrolyzate (product of pyrolysis) has lower viscosity, flash point, and PP than petroleum diesel fuel. Furthermore, other undesirable properties such as lower heating value, volatility, and instability can restrict the application of pyrolysis biodiesel. Pyrolysis requires complex apparatus including distillation equipment and is also energy consuming, which all make pyrolysis a relatively expensive production pathway
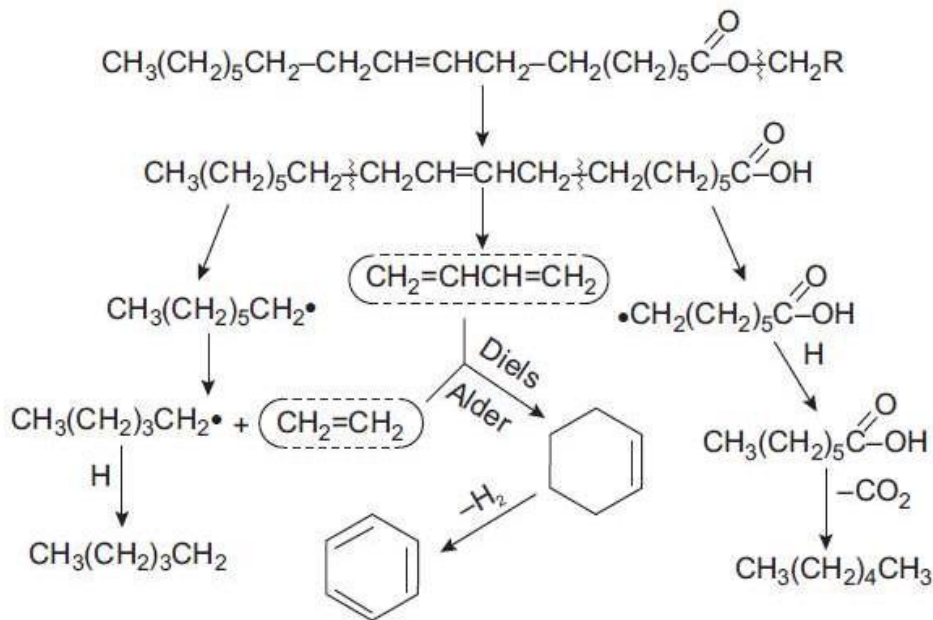
The mechanism of thermal decomposition of triglycerides.

Dilution with hydrocarbons (blending)

The second pathway is dilution with hydrocarbons (blending). Burning vegetable oils are generally considered
unsatisfactory and impractical for both direct and indirect injection diesel engines. Oil deterioration and incomplete combustion are the two severe problems
associated with the direct use of vegetable oils in diesel engineso solve these problems, vegetable oils are usually diluted with diesel, solvent, or ethanol to reduce oil viscosity and improve engine performance. This method does not require any chemical process. For practical short-term use, a blending ratio of 1:10e2:10 oil to diesel fuel has been found to be successful. However, long-term performance tests always failed because of the following reasons:
• High viscosity, acid composition content, and free fatty acid content.
• Gum formation due to oxidation and polymerization
during storage and combustion.
• Carbon deposits and lubricating oil thickening
Accordingly, to use vegetable oils in diesel engines requires significant engine modifications, including changing of piping and injector construction materials.
Otherwise, engine maintenance costs would increase due to more severe wear as well as the danger of engine failure.

Microemulsification

Microemulsification is a potential solution for solving the problem of high vegetable oil viscosity by forming
microemulsions (cosolvency). A microemulsion is a colloidal equilibrium dispersion of optically isotropic fluid microstructures formed spontaneously from two normally immiscible liquids and one or more ionic or nonionic amphiphiles Microemulsions are clear,
stable isotropic fluids with three components: an oil phase, an aqueous phase, and a surfactant. The components
of a biodiesel microemulsion include diesel fuel, vegetable oil, alcohol, and surfactant and cetane improver in suitable proportions. Alcohols, such as

methanol and ethanol, are used as viscosity lowering additives, higher alcohols are used as surfactants, and alkyl nitrates are used as cetane improvers. All microemulsions with butanol, hexanol, and octanol can meet the maximum viscosity limitation for diesel engines
. The oil droplet dimension is generally within 1e150 nm range. Microemulsification can improve
spray properties by explosive vaporization of the low boiling constituents in the micelles. Microemulsion reduces
biodiesel viscosity and improves spray performance,and increases CN as well. However, continuous use of microemulsified diesel in engines
causes problems such as irregular injector needle sticking,heavy carbon deposits, and incomplete combustion

Transesterification

Transesterification (also called alcoholysis) is the reaction of a fat or oil with an alcohol to form esters and glycerol, which is the most common biodiesel production
technology. Oils and fats (triglycerides) are converted to alkyl esters through transesterification, with reduced
viscosity to near diesel fuel levels. Thus, the product has similar properties to petroleum-based diesel fuel,
enabling its use as a drop-in fuel, that is, usage in existing petroleum diesel engines without any modification.

The first step is the conversion of triglycerides to diglycerides, which is followed by the conversion of
diglycerides to monoglycerides and of monoglycerides to glycerol, yielding one methyl ester molecule from
each glyceride at each step. A triglyceride has a glycerin molecule as its base with three long-chain fatty acids attached. The characteristics of the oil/fat are determined
by the nature of the fatty acids attached to the glycerin. The nature of the fatty acids can, in turn, affect the characteristics of the biodiesel he general chemical reaction depicting transesterification
of triglycerides.

Bioethanol

Bioethanol is a promising renewable and sustainable liquid fuel for tackling today's global energy crisis and
the worsening environment quality. During the early 1900e1970s, bioethanol was ignored because of its high production cost compared to petrol. The outbreak
of oil crisis and technology development made it a promising AF for SI and CI engines. Bioethanol is commercially used in some countries, presenting several advantages in relation to gasoline, mainly concerning engine performance and efficiency. The physicochemical properties of bioethanol are summarized in
 and the favorable properties of this bioalcohol are listed below:
• Bioethanol has a higher octane number, preventing
engine knocking and early ignition and leading to high antiknock value
• Its higher oxygen content allows cleaner combustion and reduces soot, CO, and HC emissions compared to fossil fuels .

• It helps to reduce up to 80% life cycle CO2 emission compared to fossil fuels .
• It has broader flammability limits, higher flame speed, higher heat of vaporization and shorter ignition timing, which enhance fuel combustion compared to fossil fuels.
• It is biodegradable and does not contain aromatics, olefins, and diolefin.

However, bioethanol also has several disadvantages:
• It is miscible with water and therefore it is corrosive to engine components.
• It can increase internal wear and generate a spark, which is undesirable to electric fuel pumps.

Fuel property	Unit	Bio-ethanol $[C_2H_5OH]$
Density at 15°F	Kg/m^3	790
Kinetics viscosity at 40°F	mm^2/s^1	1.13
Oxygen	Mass %	34.7
Cetane number	—	5,8
Octane number	—	110
Latent heat of vaporization	MJ/kg^1	0.91
Lower calorific value	MJ/kg^1	25.22,26.70
Flash point	°C	13
Autoignition temperature	°C	332.8366.0
Water content	Mg/kg^1	2024
Stoichiometric fuel/air ratio	—	1/9.01

Biobutanol

Biobutanol is another promising renewable fuel that presents several advantages for use in ICEs. Butanol can be used as gasoline additives, presenting straightchain
or branched structures, corresponding to nbutanol, isobutanol, and tert-butanol. Applications of butanol-gasoline blends and neat butanol have also been demonstrated on engines without modifications. Normal butanol occupies the best compatibility with gasoline. Biobutanol could be an option in terms
of blending with diesel to reduce soot and other hazardous
emissions.
Compared to most commonly used lower-carbon bioalcohol fuels, n-butanol has some beneficial features.
Some of the main physical and chemical properties of gasoline, diesel, methanol, ethanol, and n-butanol are listed.
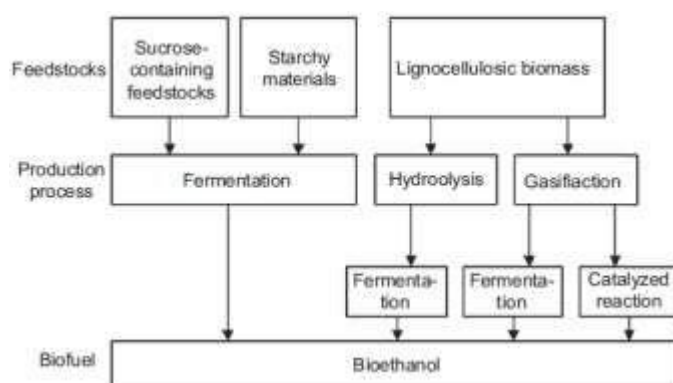
Advantages of n-butanol are listed below

• Higher heating value: butanol has around 50% higher volumetric energy density than that of ethanol. In practice, it means that lower fuel consumption rate
and better mileage can be achieved.
• Lower volatility: the volatility of alcohols decreases with increasing carbon number. It means that nbutanol is less likely to vaporize and its flash point is higher compared to ethanol. These two characteristics

|	Gasoline	Diesel	Methanol	Ethanol	n-Butanol
Molecular formula	C_4-C_{12}	$C_{12}-C_{25}$	CH_3OH	C_2H_5OH	C_4H_9OH
Molecular weight	111.19	198.4	32.04	46.06	74.11
Cetane number	0–10	40–55	3	8	25
Octane number	80–99	20–30	111	108	96
RON	88–99	0	109	109	98
MON	80–88	0	89	90	85
Oxygen content (wt%)	–	–	50	34.8	21.6
Density (g/mL) at 20°F	0.72–0.78	0.82–0.86	0.796	0.79	0.808
Autoignition temperature (°C)	300	210	470	434	385
Flash point (°C) at closed cup	−45 to −38	65–88	12	8	35
Lower heating value (MJ/kg)	43.7	42.5	19.9	26.8	33.1
Boiling point (°C)	25–215	180–370	64.5	78.4	117.7
Stoichiometric ratio	14.7	14.3	6.49	9.02	11.21
Latent heating (kJ/kg) at 25°F	380–500	270	1109	904	582
Flammability limits (vol%)	0.6–8	1.5–7.6	6.0–36.5	4.3–19	1.4–11.2
Saturation pressure (kPa) at 38°F	31.01	1.86	31.69	13.8	2.27
Viscosity (mm²/s) at 40°F	0.4–0.8 (20°F)	1.9–4.1	0.59	1.08	2.63
Energy density (MJ/L)	32	35.86	16	19.6	29.2

Liquefied petroleum gas(LPG)

As an alternative to gasoline, liquefied petroleum gas (LPG) is extracted from crude oil during refining process
of petroleum and from natural gas alternatively. It is also obtained from oil/gas mining as a byproduct. LPG
composition varies significantly globally, but it is primarily a mixture of four species: propane, propylene, isobutane, and n-butane . LPG has a lower carbon
content, higher heat value, octane number, and flame propagation speed. These favorable properties can reduce gaseous and PM emission levels compared to
gasoline fuel. Many studies reported that LPG was a clean-burning fuel and could be used in SI engines without modification.
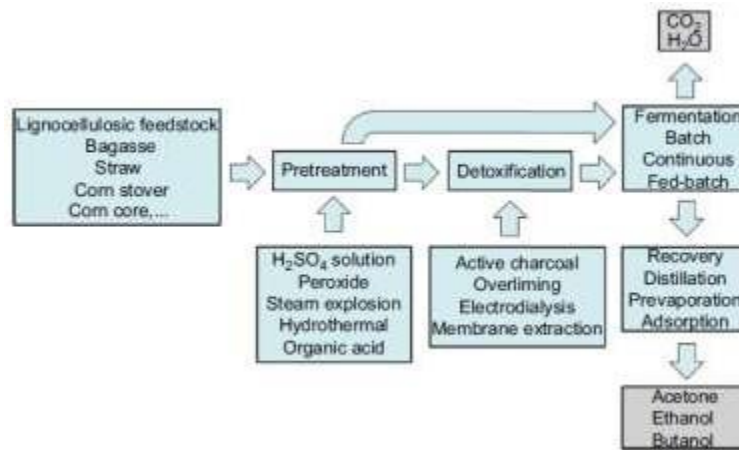
Schematic of biobutanol production process

Hydrogen (H2)

H2 is widely used over a wide range of industries due to the following reasons:

• The high octane number of H2 provides the opportunity to increase the compression ratio and the engine efficiency.

• Its high energy density in mass basis.

• Its wide flammability limits also enable unthrottled operation with lean combustion.

• H2 combustion does not produce carbon-related emissions, such as CO, CO2, and PM, due to the absence of C atoms. The favorable properties of H2 attract many researchers' attention trying to commercialize H2 usage in ICEs. However, there are still some disadvantages and technical barriers by now:

• The greater heat transfer losses through the cylinder wall with H2 fueled engines.

• Backfire and preignition, which are critical issues for H2-fueled engines.

• The immature technology of production, storage, and transportation of H2.

Coal-to-liquid (CtL)

CtL as an alternative fuel to diesel is considered to be one of the technology options to reduce petroleum consumption in on-road transportation. The CtL technology includes coal pyrolysis technology, direct coal liquefaction technology, and indirect coal liquefaction technology (F-T synthesis). Compared to the first two technologies, indirect coal liquefaction technology features high conversion ratio and high adaptability of coal. For indirect liquefaction, coal is firstly gasified into the mixture of H2 and CO, which is then converted
to oil through F-T synthesis . The CtL pathway offers the benefit of complete compatibility with existing infrastructure and vehicle fleet, which implies a near zero transition cost
However, from the fuel production perspective, CtL production technology
still faces the uncertainties of energy efficiency,environmental impacts, and economic feasibility. Compared with the alcohols pathways, the water consumption
and CO2 emissions of CtL pathway are generally higher.

Hydrocarbons

In organic chemistry, a hydrocarbon is an organic compound consisting entirely of hydrogen and carbon. Hydrocarbons are examples of group 14 hydrides. Hydrocarbons from which one hydrogen atom has been removed are functional groups called hydrocarbyls. Hydrocarbons are generally colorless and hydrophobic with only weak odors. Because of their diverse molecular structures, it is difficult to generalize further.
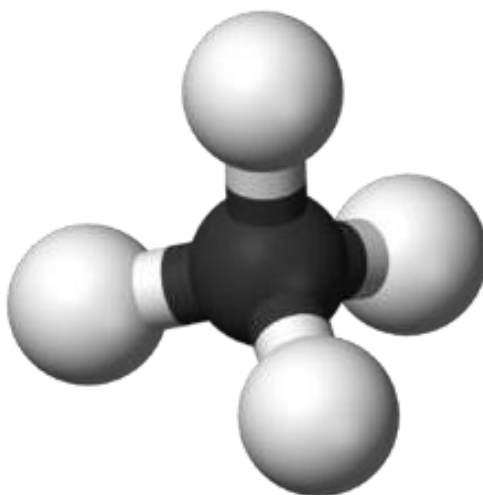
Ball-and-stick model of the methane molecule, CH_4. Methane is part of a homologous series known as the alkanes, which contain single bonds only.

ORIGIN

The vast majority of hydrocarbons found on Earth occur in petroleum, coal, and natural gas. Petroleum (literally "rock oil" – petrol for short) and coal are generally thought to be products of decomposition of organic matter. In contrast to petroleum, is coal, which is richer in carbon and poorer in hydrogen. Natural gas is the product of methanogenesis.

A seemingly limitless variety of compounds comprise petroleum, hence the necessity of refineries. These hydrocarbons consist of saturated hydrocarbons, aromatic hydrocarbons, or combinations of the two. Missing in petroleum are alkenes and alkynes. Their production requires refineries. Petroleum-derived hydrocarbons are mainly consumed for fuel, but they are also the source of virtually all synthetic organic compounds, including plastics and pharmaceuticals. Natural gas is consumed almost exclusively as fuel. Coal is used as a fuel and as a reducing agent in metallurgy.

TYPES OF HYDROCARBONS

As defined by IUPAC nomenclature of organic chemistry, the classifications for hydrocarbons are:

1. Saturated hydrocarbons are the simplest of the hydrocarbon species. They are composed entirely of single bonds and are saturated with hydrogen. The formula for acyclic saturated hydrocarbons (i.e., alkanes) is C_nH_{2n+2}. The most general form of saturated hydrocarbons is $C_nH_{2n+2(1-r)}$, where r is the number of rings. Those with exactly one ring are the cycloalkanes. Saturated hydrocarbons are the basis of petroleum fuels and are found as either linear or branched species. Substitution reaction is their characteristics property (like chlorination reaction to form chloroform). Hydrocarbons with the same molecular formula but different structural formulae are called structural isomers. As given in the example of 3-methylhexane and its higher homologues, branched hydrocarbons can be chiral. Chiral saturated hydrocarbons constitute the side chains of biomolecules such as chlorophyll and tocopherol.

2. Unsaturated hydrocarbons have one or more double or triple bonds between carbon atoms. Those with double bond are called alkenes. Those with one double bond have the formula C_nH_{2n} (assuming non-cyclic structures). Those containing triple bonds are called alkyne. Those with one triple bond have the formula C_nH_{2n-2}.

3. Aromatic hydrocarbons, also known as arenes, are hydrocarbons that have at least one aromatic ring.

Hydrocarbons can
be gases (e.g. methane and propane), liquids (e.g. hexane and benzene), waxes or low melting solids (e.g. paraffin wax and naphthalene)
or polymers (e.g. polyethylene, polypropylene and polystyrene).

The term 'aliphatic' refers to non-aromatic hydrocarbons. Saturated aliphatic hydrocarbons are sometimes referred to as 'paraffins'. Aliphatic hydrocarbons containing a double bond between carbon atoms are sometimes referred to as 'olefins'.

Simple hydrocarbons and their variations

Number of carbon atoms	Alkane (single bond)	Alkene (double bond)	Alkyne (triple bond)	Cycloalkane	Alkadiene
Variations on hydrocarbons based on the number of carbon atoms					
1	Methane	—	—	—	—
2	Ethane	Ethene (ethylene)	Ethyne (acetylene)	—	—
3	Propane	Propene (propylene)	Propyne (methylacetylene)	Cyclopropane	Propadiene (allene)
4	Butane	Butene (butylene)	Butyne	Cyclobutane	Butadiene
5	Pentane	Pentene	Pentyne	Cyclopentane	Pentadiene (piperylene)
6	Hexane	Hexene	Hexyne	Cyclohexane	Hexadiene
7	Heptane	Heptene	Heptyne	Cycloheptane	Heptadiene
8	Octane	Octene	Octyne	Cyclooctane	Octadiene
9	Nonane	Nonene	Nonyne	Cyclononane	Nonadiene
10	Decane	Decene	Decyne	Cyclodecane	Decadiene
11	Undecane	Undecballene	Undecyne	Cycloundecane	Undecadiene
12	Dodecane	Dodecene	Dodecyne	Cyclododecane	Dodecadiene

GASOLINE SPECIFICATIONS

FUEL SPECIFICATION: Fuel specifications define requirements for physical properties and chemical composition of the fuels, and are meant to ensure that commercial fuels are of sufficient quality and compatible with engine and emission control technologies that will be required to meet BS VI emission standards.

From an emissions and air quality perspective, the most important parameter defined in the fuel quality specifications is the maximum sulphur content of gasoline and diesel fuels. In both cases, sulphur content is limited to a maximum of 10 ppm in the proposed BS VI regulation, which matches global best practices. Low sulphur fuels enable the use of advanced aftertreatment control technologies, which greatly reduce emission rates of pollutants that have a significant human health burden, such as particulate matter (PM) and nitrogen oxides (NOX).

While proposed BS VI fuel specifications largely follow European regulations, proposed limits for several commercial gasoline and diesel fuel parameters in India differ from EU values. These parameters include octane number and olefin content for regular grade gasoline; and density, 95% distillation boiling point (T95), and polycyclic aromatic hydrocarbon (PAH) content for diesel. This working paper details these differences in fuel specifications for commercial gasoline and diesel fuels in India and the EU, and assesses potential air pollutant emission impacts of these differences.

The proposed BS VI regulation specifies requirements for two grades of commercial gasoline, regular and premium. Table 1 compares proposed Indian gasoline specifications with those set in other countries and regions with stringent motor vehicle emission control requirements. For the parameters discussed here, octane number and olefin content, specifications for premium grade BS VI gasoline match Euro 6 values. For regular grade BS VI gasoline, a lower octane number and higher olefin content is permitted.

OCTANE NUMBER: The octane number of gasoline provides a measure of the fuel's ability to resist auto-ignition, which can cause engine knock and engine damage. The octane number is determined from laboratory testing and, depending on the test method used, expressed as a Research Octane Number (RON) or Motor Octane Number (MON). In some regions, octane rating is expressed using an anti-knock index (AKI), which is equal to the average of the RON and MON of the fuel.

OLEFIN CONTENT: Olefins are a class of hydrocarbon compounds characterized by the presence of at least one carbon-carbon double bond. The presence of this double bond makes olefins more reactive than other gasoline components such as paraffinic or aromatic compounds. This reactivity has several implications for combustion dynamics and air pollutant emissions. Generally, increased olefin content improves combustion efficiency, which may lower hydrocarbon (HC) emissions and increase NOX emissions. Increased olefin content may also result in increased emissions of the air toxic 1,3-butadiene, which is a product of the incomplete combustion of olefin precursors.4 Because of their reactivity, olefins also tend to have higher ozone formation potentials than other hydrocarbon components in gasoline fuels.

TABLE 1

Comparison of fuel specifications for selected gasoline specifications

Fuel parameter	BS VI	Euro 6	EPA RFG average (2005)	EPA convetional gasoline average (2005)	Japan	South Korea	Worldwide Fuel Charter (Category 4)
Sulfur, ppm, max.	10	10	30 ppm (Tier 2) 10 ppm (Tier 3)	30 ppm (Tier 2) 10 ppm (Tier 3)	10	10	10
Research Octane (RON), min.	91/95	95[a]	NS	NS	89/96	91/94	91/95/98
Motor Octane (MON), min.	81/85	85[a]	NS	NS	NS	NS	82.5/85/88
Anti-Knock Index (AKI), min.	NS	NS	87/87/91	87/87/91	NS	NS	NS
Olefins, vol%, max.	21/18	18	11.2-11.9	11.6-12.0	NS	16-19[b]	10

NS = Not specified; / used to separate specifications for different gasoline grades; AKI = (RON+MON)/2
[a]Member states are permitted to allow regular grade gasoline with MON of 81 and RON of 91.
[b]Either aromatics 24 vol.% max and olefins 16 vol.% max or aromatics 21 vol.% max and olefins 19 vol.% max.

Comparison of Indian Gasoline Specification required meeting Bharat Stage II, III, & IV and VI Emission Norms.

India's current gasoline standards took effect on 1 Apr 2010. These standards required marked improvements from pre-2010 levels. Benzene limits were reduced from 3% in previously BS III cities and 5% elsewhere to 1% nationwide. The aromatic content limit, which was unregulated under Bharat II, stands at 42% under Bharat III norms and 35% under Bharat IV. Olefins, which were also unregulated under Bharat II, now stand at 21% and 18% for regular unleaded and premium unleaded, respectively, under Bharat III and Bharat IV regulations. Higher olefin content, along with higher Reid vapor pressure (RVP), tends to create more evaporative emissions, which leads to the formation of ozone (O_3) and other toxins in the atmosphere. Sulphur content was lowered to 150 ppm nationwide and 50 ppm in Bharat IV compliant cities in 2010. Under BS II, the octane number had been increased to 88 and 93 for regular and premium, respectively. It was further increased to 91 and 95 for regular and premium, respectively, under BS III and beyond. With the exception of reduced fuel sulphur content, the gasoline fuel quality mandated by BS VI is similar to that of BS IV fuel.

With respect to gasoline sulphur content, India presently lags behind international best practices. At the start of 2013, 23 cities required no more than 50 ppm sulphur in gasoline, while in the rest of the country up to 150 ppm sulphur was allowed. As of 2016, nearly half of the country requires 50 ppm gasoline. India will meet international best practices with the implementation of BS VI, which will require 10 ppm sulphur gasoline.

Characteristics	Unit	Bharat Stage II	Bharat Stage III	Bharat Stage IV	Bharat Stage VI
Implementation date		2001 (selected cities), 2005 (nationwide)	2005 (selected cities), 2010 (nationwide)	2010 (selected cities),2017 (nationwide)	2020[*](nationwide)
Density 15°C	Kg/m^3	710-770	720-775	720-775	720-775
Research Octane Number (RON)	min	88	91	91	91/95[†]
Anti-Knock Index (AKI) or Motor Octane Number (MON)	min	84	81	81	81/85[†]
Sulphur, max	ppm	500	150	50	10
Lead, max	g/L	0.013	0.005	0.005	0.005
Benzene, max	% volume	3 (metro), 5 (nationwide)	1.0	1.0	1.0

Aromatics, max	% volume	–	42	35	35
Olefin, max	% volume	–	21/18	21/18	21/18[†]
Oxygen Content, max	% mass	–	2.7	2.7	2.7

Internal Combustion Engine generally operates within a useful range of speed. Some engines are made to run at fixed speed by means of a speed governor which is its rated speed. At each speed within the useful range the power output varies and it has a maximum usable value. The ratio of power developed to the maximum usable power at the same speed is called the load. The specific fuel consumption varies with load and speed. The performance of the engine depends on inter-relationship between power developed, speed and the specific fuel consumption at each operating condition within the useful range of speed and load.

The following factors are to be considered in evaluating the performance of an engine:

- Maximum power or torque available at each speed within the useful range of speed.
- The range of power output at constant speed for stable operation of the engine. The different speeds should be selected at equal intervals within the useful speed range.
- Brake specific fuel consumption at each operating condition within the useful range of operation.
- Reliability and durability of the engine for the given range of operation.

Engine performance is really a relative term. It is represented by typical characteristic curves which are functions of engine operating parameters. The term performance usually means how well an engine is doing its job in relation to the input energy or how effectively it provides useful energy in relation to some other comparable engines.

Some of the important parameters are speed, inlet pressure and temperature, output, air-fuel ratio etc. The useful range of all these parameters is limited by various factors, like mechanical stresses, knocking, over-heating etc. Due to this, there is a practical limit of maximum power and efficiency obtainable from an engine. The performance of an engine is judged from the point of view of the two main factors, viz., engine power and engine efficiency.

Besides the overall efficiency, various other efficiencies are encountered when dealing with the theory, design and operation of engines.

Engine Performance Characteristics

Engine performance characteristics are a convenient graphical presentation of an engine performance. They are constructed from the data obtained during actual test runs of the engine and are particularly useful in comparing the performance of one engine with that of another. In this section some of the important performance characteristics of the SI engines are discussed. It is to be noted that there is a certain speed, within the speed range of a particular engine, at which the charge inducted per cylinder per cycle will be the maximum. At this point, the maximum force can therefore be exerted on the piston. For all practical purposes, the torque, or engine capacity to do work will also be maximum at this point. Thus, there is a particular engine speed at which the charge per cylinder per cycle is a maximum, and at approximately this same speed, the torque of the engine will be a maximum.

As the speed of the engine is increased above this speed the quantity of the indicated charge will decrease. However, the power output of the engine increases with speed due to more number of cycles are executed per unit time. It should be noted that the air consumption will continue to increase with increased engine speed until some point is reached where the charge per cylinder per stroke decreases very rapidly than the number of strokes per unit time is increasing. Engines are so designed that the maximum air consumption point is not reached within the operating speed of the engine. Increase in air consumption means that increased quantities of fuel can be added per unit time increasing the power output. In fact, the ip produced in the cylinder is almost directly proportional to the engine air consumption. The relationship between air charge per cylinder per cycle and torque, as well as air consumption and ip is illustrated in Fig. Note that the maximum torque occurs at a lower speed than the maximum ip.
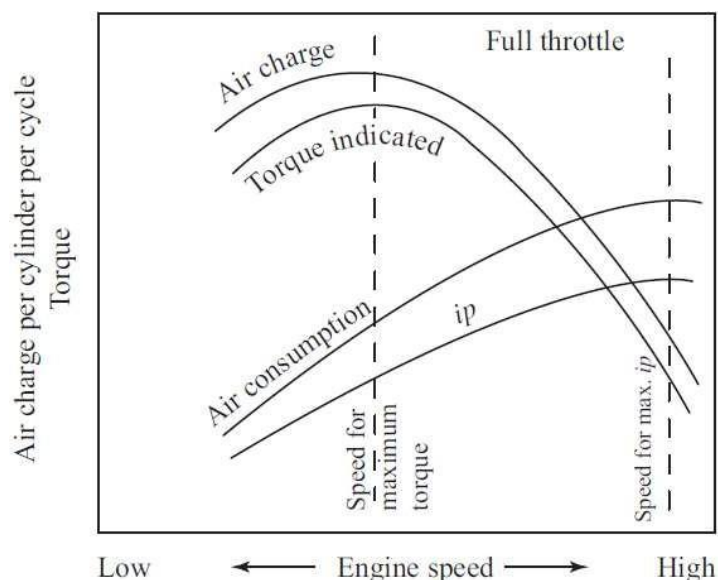
Figure shows some of the other important performance characteristics for a typical SI engine. In this figure, torque, ip, bp and fp are plotted against engine speed throughout the operating range of the engine, at full throttle and variable load. The difference between the ip produced in the cylinder, and the bp realized at the drive-shaft, is the fp. At low engine speeds, the fp is relatively low, and bp is close to ip. As engine speed increases, the fp increases at a greater rate. At engine speeds above the usual operating range, fp increases very rapidly. Also, at these higher speeds, ip will reach a maximum and then fall off. At some point, ip and f p will be equal, and bp will then drop to zero. Note that the torque reaches a maximum at approximately 60% of the rated rpm of the engine, while the ip has not reached maximum even at the rated speed.
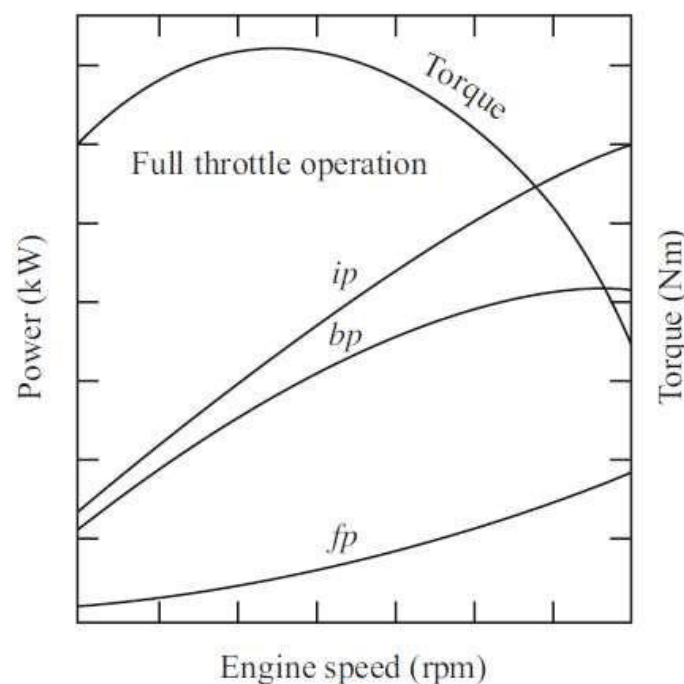
Typical SI Engine Performance Curves

Figure shows fuel consumption and bsfc plotted against the engine speed, for the same engine operating under the same conditions. The quantity of fuel consumed increases with engine speed. The bsfc, on the other hand, drops as the speed is increased in the low speed range, nearly levels off at medium speeds, and increases in the high speed range, At low speeds, the heat loss to the combustion chamber walls is proportionately greater and combustion efficiency is poorer, resulting in higher fuel consumption for the power produced. At the high speeds, the f p is increasing at a rapid rate, resulting in a slower increase in bp than in fuel consumption, with a consequent increase in bsfc.
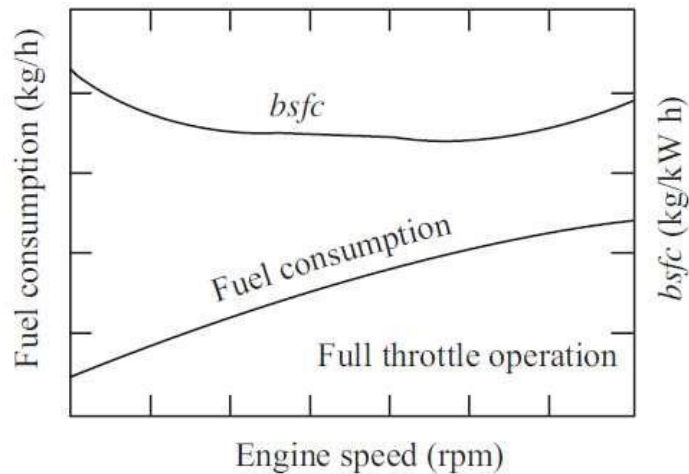
Typical Fuel Consumption Curves for an SI Engine

The bsfc curve of Fig. is for full throttle, variable speed operation. At any one speed, it represents the bsfc which will result when the engine is carrying its maximum load at that speed. By reducing throttle opening and load, that same speed may be obtained, but at loads less than the maximum. A family of curves for various speeds can be obtained, each showing the effect on bsfc of varying the load at constant speed. Under these conditions of constant speed and variable load, and at a constant air-fuel ratio, the bsfc will rise consistently and rapidly as the load (and throttle opening) is decreased. Figure illustrates the general shape of the curve for any given rpm. The reason for the rapid increase in bsfc with the reduction in throttle opening is that the fp remains essentially constant, while the ip is being reduced. The bp drops more rapidly than fuel consumption, and thereby the bsfc rises.
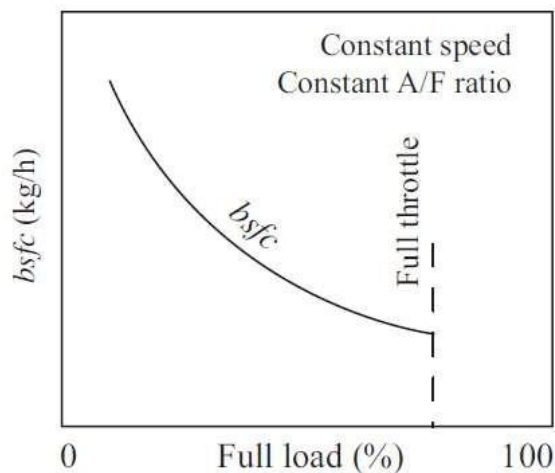

Bsfc Curve at Constant Speed and Variable Load

Fuel Injection system for SI engines

1. Carburetion

Spark-ignition engines normally use volatile liquid fuels. Preparation of fuel-air mixture is done outside the engine cylinder and formation of a homogeneous mixture is normally not completed in the inlet manifold. Fuel droplets, which remain in suspension, continue to evaporate and mix with air even during suction and compression processes. The process of mixture preparation is extremely important for spark-ignition engines. The purpose of carburetion is to provide a combustible mixture of fuel and air in the required quantity and quality for efficient operation of the engine under all conditions.
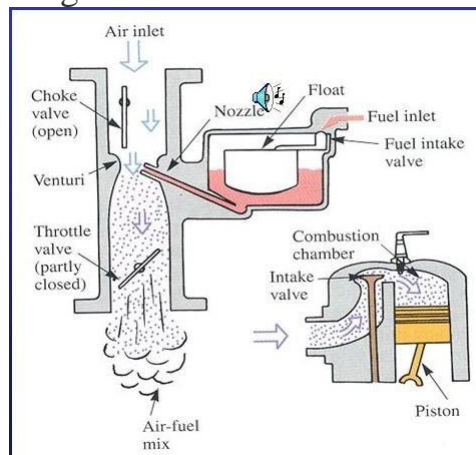
Definition of Carburetion

The process of formation of a combustible fuel-air mixture by mixing the proper amount of fuel with air before admission to engine cylinder is called carburetion and the device which does this job is called a carburetor.

Definition of Carburetor

The carburetor is a device used for atomizing and vaporizing the fuel and mixing it with the air in varying proportions to suit the changing operating conditions of vehicle engines.

Factors Affecting Carburetion

Of the various factors, the process of carburetion is influenced by
i. The engine speed
ii. The vaporization characteristics of the fuel
iii. The temperature of the incoming air and
iv. The design of the carburetor

Principle of Carburetion
Both air and gasoline are drawn through the carburetor and into the engine cylinders by the suction created by the downward movement of the piston. This suction is due to an increase in the volume of the cylinder and a consequent decrease in the gas pressure in this chamber.

It is the difference in pressure between the atmosphere and cylinder that causes the air to flow into the chamber. In the carburetor, air passing into the combustion chamber picks up discharged from a tube. This tube has a fine orifice called carburetor jet that is exposed to the air path.

The rate at which fuel is discharged into the air depends on the pressure difference or pressure head between the float chamber and the throat of the venturi and on the area of the outlet of the tube. In order that the fuel drawn from the nozzle may be thoroughly atomized, the suction effect must be strong and the nozzle outlet comparatively small. In order to produce a strong suction, the pipe in the carburetor carrying air to the engine is made to have a restriction. At this restriction called throat due to increase in velocity of flow, a suction effect is created. The restriction is made in the form of a venturi to minimize throttling losses.

The end of the fuel jet is located at the venturi or throat of the carburetor. The geometry of venturi tube. It has a narrower path at the center so that the flow area through which the air must pass is considerably reduced. As the same amount of air must pass through every point in the tube, its velocity will be greatest at the narrowest point. The smaller the area, the greater will be the velocity of the air, and thereby the suction is proportionately increased

As mentioned earlier, the opening of the fuel discharge jet is usually loped where the suction is maximum. Normally, this is just below the narrowest section of the venturi tube. The spray of gasoline from the nozzle and the air entering through the venturi tube are mixed together in this region and a combustible mixture is formed which passes through the intake manifold into the cylinders. Most of the fuel gets atomized and simultaneously a small part will be vaporized. Increased air velocity at the throat of the venturi helps he rate of evaporation of fuel. The difficulty of obtaining a mixture of sufficiently high fuel vapour-air ratio for efficient starting of the engine and for uniform fuel-air ratio indifferent cylinders (in case of multi cylinder engine) cannot be fully met by the increased air velocity alone at the venturi throat.
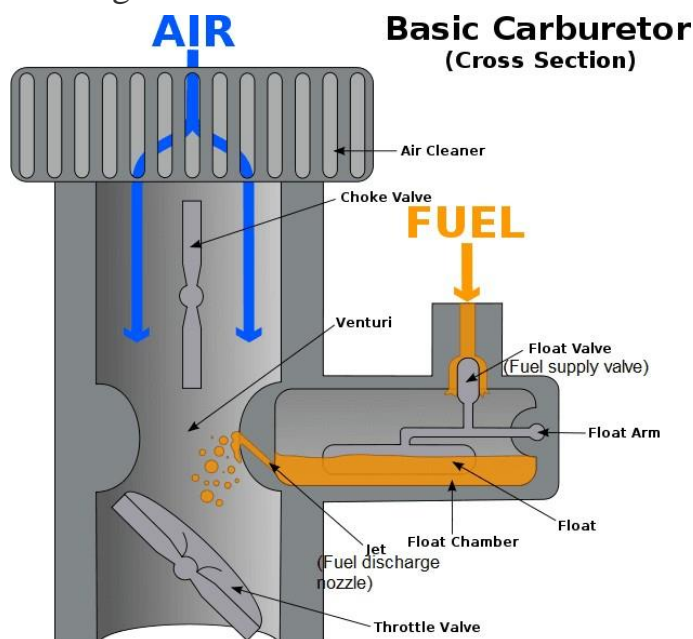
2. The Simple Carburetor
Carburetors are highly complex. Let us first understand the working principle bf a simple or elementary carburetor that provides an air fuel mixture for cruising or

normal range at a single speed. Later, other mechanisms to provide for the various special requirements like starting, idling, variable load and speed operation and acceleration will be included.

The simple carburetor mainly consists of a float chamber, fuel discharge nozzle and a metering orifice, a venturi, a throttle valve and a choke. The float and a needle valve system maintain a constant level of gasoline in the float chamber. If the amount of fuel in the float chamber falls below the designed level, the float goes down, thereby opening the fuel supply valve and admitting fuel. When the designed level has been reached, the float closes the fuel supply valve thus

stopping additional fuel flow from the supply system. Float chamber is vented either to the atmosphere or to the" upstream side of the venturi.During suction stroke air is drawn through the
venturi.

As already described, venturi is a tube of decreasing cross-section with a minimum area at the throat, Venturi tube is also known as the choke tube and is so shaped that it offers minimum resistance to the air flow. As the air passes through the venturi the velocity increases reaching a maximum at the venturi throat. Correspondingly, the pressure decreases reaching a minimum. From the float chamber, the fuel is fed to a discharge jet, the tip of which is located in the throat of the venturi. Because of the differential pressure between the float chamber and the throat of the venturi, known as carburetor depression, fuel is discharged into the air stream.

Basic Carburetor
(Cross Section)

AIR — Air Cleaner — Choke Valve — FUEL — Venturi — Float Valve (Fuel supply valve) — Float Arm — Float — Jet (Fuel discharge nozzle) — Float Chamber — Throttle Valve

The fuel discharge is affected by the size of the discharge jet and it is chosen to give the required air-fuel ratio. The pressure at the throat at the fully open throttle condition lies between 4 to 5 cm of Hg, below atmospheric and

seldom exceeds8 cm Hg below atmospheric. To avoid overflow of fuel through the jet, the level of the liquid in the float chamber is maintained at a level slightly below the tip of the discharge jet. This is called the tip of the nozzle. The difference in the height between the top of the nozzle and the float chamber level.

The gasoline engine is quantity governed, which means that when power output is to be varied at a particular speed, the amount of charge delivered to the cylinder is varied. This is achieved by means of a throttle valve usually of the butterfly type that is situated after the venturi tube.

As the throttle is closed less air flows through the venturi tube and less is the quantity of air-fuel mixture delivered to the cylinder and hence power output is reduced. As the" throttle is opened,

more air flows through the choke tube resulting in increased quantity of mixture being delivered to the engine. This increases the engine power output. A simple carburetor of the type described above suffers from a fundamental drawback in that it provides the required A/F ratio only at one throttle position.

At the other throttle positions the mixture is either leaner or richer depending on whether the throttle is opened less or more. As the throttle opening is varied, the air flow varies and creates a certain pressure differential between the float chamber and the venturi throat. The same pressure differential regulates the flow of fuel through the nozzle. Therefore, the velocity of flow of air II and fuel vary in a similar manner.

Engine performance is often characterized by the engine operating behavior in the speed–load domain, for example, the behavior of emissions, fuel consumption, noise, mechanical and thermal loading. Engine performance maps refer to the constant value contour plots of a given performance parameter in the speed–torque domain.

Vehicle performance represented by maximum speed, gradeability, and acceleration is completely determined by the vehicle tractive effort developed by the engine or electric motor and the resistance in the vehicle motion direction. Figure illustrates the forces acting on a vehicle, which is running uphill.
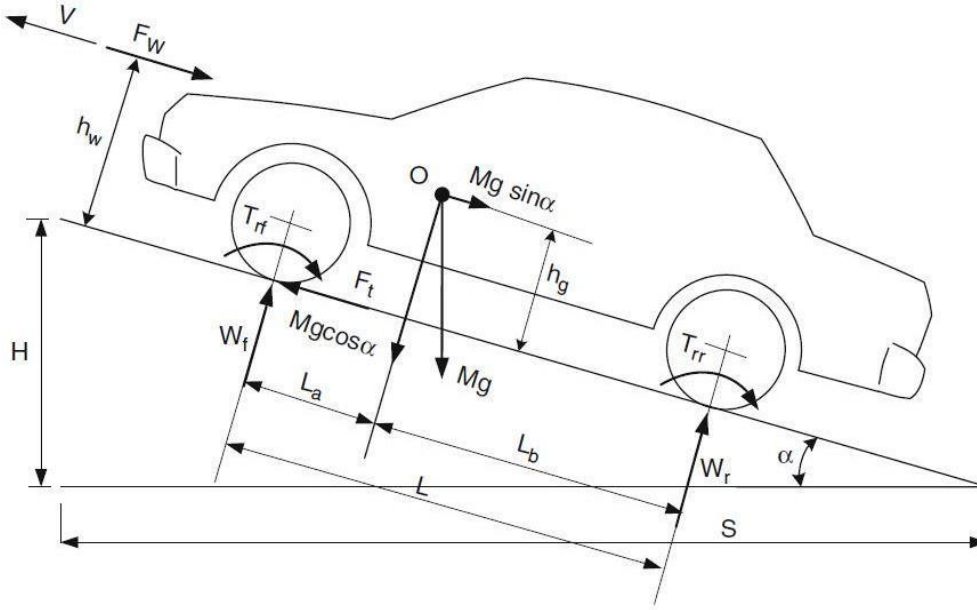
FIGURE(1)

The forces acting on the vehicle in the vehicle moving direction are tractive effort, Ft, and resistances including rolling resistance, aerodynamic drag, grading resistance, and inertial force induced by acceleration.

All these forces are always in a balanced state, which can be described by

$F_{t} = F_r + F_w + F_i + F_a$ -(1)

or more detail

$$\frac{T_e\, i_0\, i_g \eta_t}{r} = M g f_r \cos \alpha + \frac{1}{2} C_D \rho_a A_f V^2$$
$$+ M g \sin \alpha + M \delta \frac{dV}{dt}. \qquad - \qquad (2)$$

When grade angle α is small, $\cos\alpha \approx 1$ and $\sin\alpha \approx \tan\alpha = i$.
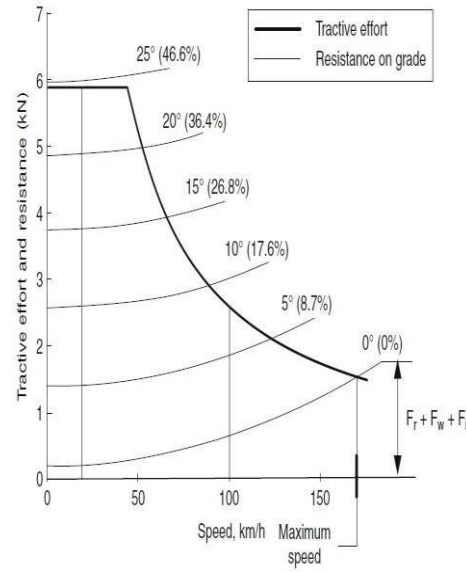
Equation (1) can further be written as

$$\frac{T_e\, i_0\, i_g \eta_t}{r} = M g f_r + \frac{1}{2} C_D \rho_a A_f V^2 + M g i + M \delta \frac{dV}{dt} \qquad - (3)$$

Equation (2) or (3) interprets the general operation behavior of a vehicle and is used to analyze vehicle performance. Depicting (3) using a tractive effort versus rolling resistance and aerodynamic drag on grade road is very helpful for vehicle performance analysis as shown in Figures below
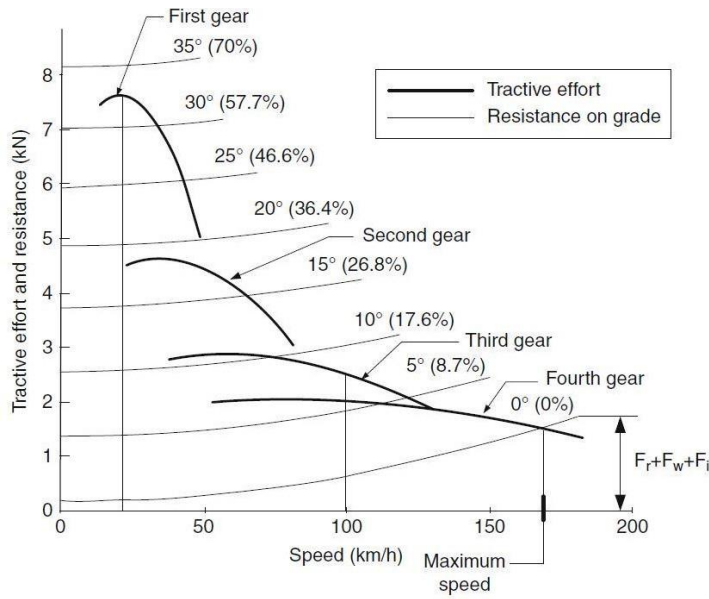
FIGURE(2)   FIGURE(3)

1. Maximum vehicle speed

The maximum speed of a vehicle is defined as the speed that can be reached when the power plant operates with its maximum capability (full open throttle for an IC engine and maximum current for an electric motor) on a flat road. Running on its maximum speed, no grading resistance and inertia force exists. Thus, (3) becomes

$$\frac{T_e \, i_0 \, i_g \eta_t}{r} = M g f_r + \frac{1}{2} C_D \rho_a A_f V^2.$$
-(4)

On the diagrams of Figs. 2 and 3, maximum speed of vehicle can be obtained as the intersection of the tractive effort curve and the resistance curve at zero grade road.

2. Gradeability

Gradeability of a vehicle is defined as the road grade or grade angle that the vehicle can overcome at a specified speed, for example, 100 km/h, or the maximum grade at low speed. While running on an uphill grade with constant speed, 2 and 3 become

$$\frac{T_e \, i_0 \, i_g \eta_t}{r} = M g f_r \cos\alpha + \frac{1}{2} C_D \rho_a A_f V^2 + M g \sin\alpha \qquad (5)$$

AND

$$\frac{T_e \, i_0 \, i_g \eta_t}{r} = M g f_r + \frac{1}{2} C_D \rho_a A_f V^2 + M g i \qquad (6)$$

The gradeability can be directly obtained by reading Figs. 2 and 3. For instance, for the gasoline engine–powered vehicle, running at 100 km/h, gradeabilities of 5.5 (9.6%) for fourth gear, 7.5 (13%) for third gear, and 32.5 (63.7%) at speed of about 20 km/h are obtained. Similarly, for the electric motor–powered vehicle, around 8 (14%) at the speed of 100 km/h and 24 (44.5%) at speeds lower than 50 km/h are obtained.

3. Acceleration performance

Acceleration performance of a vehicle is interpreted by the time used for accelerating the vehicle from a low speed (general zero speed) to a specified high speed (e.g., 100 km/h) on a level road. The acceleration time can be calculated by

$$t = \int_0^{V_f} \frac{1}{a} dV. \qquad (7)$$

where V_f is the specified final speed and a is the acceleration rate in m/s2, which can be obtained from (2) as

$$a = \frac{dV}{dt} = \frac{\frac{T_e i_0 i_g \eta_t}{r} - M g f_r + \frac{1}{2} C_D \rho_a A_f V^2}{M \delta} \qquad (8)$$

The distance covered during acceleration canbe calculated by

$$d = \int_0^{t_a} V dt \qquad (9)$$

A digital integration method may be used to solve (7)–(8). Figures 4 and 5 show the acceleration time and distance for a gasoline engine–powered and electric motor–powered vehicle.
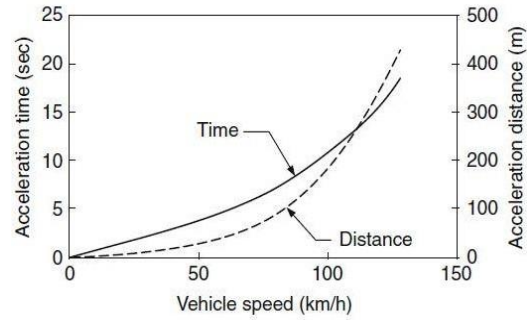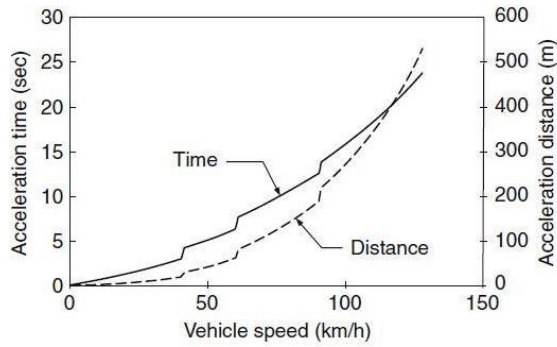
OVERVIEW

This assignment presents an overview of the efforts to figure out Road performance and fuel economy. This assignment reviews the principles involved in determining the external loads on vehicles from longitudinal and lateral accelerations, aerodynamic drag, rolling resistance, and various grades. Examples of loads measured in the field and related dynamometer tests for selected vehicles for fuel consumption and air contaminant emissions are provided.

HIGHWAY FACTORS AFFECTING FUEL ECONOMY

The elements influencing vehicle efficiency that fall inside the territory of the expressway creator incorporate essentially (an) interstate math and structure and (b) vehicle activity (speed versus separation) as impacted by expressway math, traffic signals, and interstate environmental factors. For a given vehicle, increasing speeds (i.e., speeds up) can force the biggest requests in fuel stream rate; the second-biggest effect on the prompt fuel rate is street level (longitudinal slant). Significant optional contemplations material to every one of these operational factors regularly are neglected: for increasing speeds, the level of complete working time that is spent quickening and the overall greatness of increasing speed rates, and for grades, both the level of slant and (generally significant) regardless of whether a similar change in height is to be cultivated on every one of at least two distinct evaluations.

After levels, the second mathematical component of roadways that most influence efficiency and air contamination emanations is even arrangement or ebb and flow. On the off chance that the street must alter course, the main controls left to the architect are the span of bend, superelevation (cross over "banking"), and configuration speed. By and large, it is attractive to evade or limit speed changes in light of the fact that these will in general decline mileage and can mess wellbeing up. Besides keeping the bend span sufficiently long to give safe driving, what amount does bend sweep impact mileage and air contamination discharges, are the connections unsurprising, and would they be able to be summed up over a scope of vehicles? This undertaking showed that the impacts of

bend span and speed can be estimated, are numerically nonstop over a wide scope of the two boundaries, and can be summed up for a scope of vehicle types.

Street surface harshness is another thruway "include" that can influence efficiency and air contamination emanations. The data assembled regarding this matter during this venture demonstrated that most streets conveying any critical volume of traffic presumably would be reemerged for reasons of security and client comfort before the unpleasantness effect on steady speed efficiency drew nearer around 4 to 5 percent on the particular patches of harshness. Note that, if an unpleasant spot makes drivers delayed down (particularly by slowing down) and afterward to quicken, this speed change can build fuel utilization.

Past these elements over which the roadway architect has some control, varieties in the conduct of various drivers expand the scope of mileage esteems that can be normal from a given vehicle. This was illustrated, at a steady speed on open parkways, by a restricted test exertion under this venture. Consequently, it was inferred that the reasons for this venture didn't request the furthest extent of loyalty in repeating the fuel utilization qualities of a specific vehicle that had been tried; those test boundaries would be impacted by different sums in the possession of various drivers. Or maybe, the roadway execution estimations should reflect with sensible precision the general impacts of various interstate plan highlights on the presentation of the vehicles examined.

Road Performance Curves: Acceleration, Gradability and Drawbar Pull

Traveller car performance depends on increasing speed, capacity to go up a slant, maximum velocity, efficiency, clamor level, and sturdiness. Transmission outfitting is intended to give the greatest quickening at low speed by holding the driving wheel force yield at the purpose of approaching wheel turn. As wheel turn happens, the quickening diminishes from the greatest. Likewise, the apparatus is intended for most extreme mileage when the motor is creating 80% of its greatest force as the car is moving at a steady speed. This gives 20% extra force for

increasing speed. The force needed to drive car increments as the 3D square of the speed for example it takes multiple times the ability to twofold the speed. At the point when the force accessible matches the force needed to push the vehicle, the speed gets steady. Overabundance power is required for quickening and slope climbing. Greatest speed is arrived at when there is no abundance of power remaining. The figure beneath delineates the variety of max speed power accessible at the wheels for four rigging proportions with street speed. A bend, demonstrating the force required by a vehicle at different street speeds is additionally introduced.

At any speed, the distinction of ordinates of intensity accessible and power required by vehicle gives the overflow power, which can be used either for increasing speed or for drawbar pull or for slope climbing. Or, in all likelihood the excess force might be shared by all the three things as and when required.
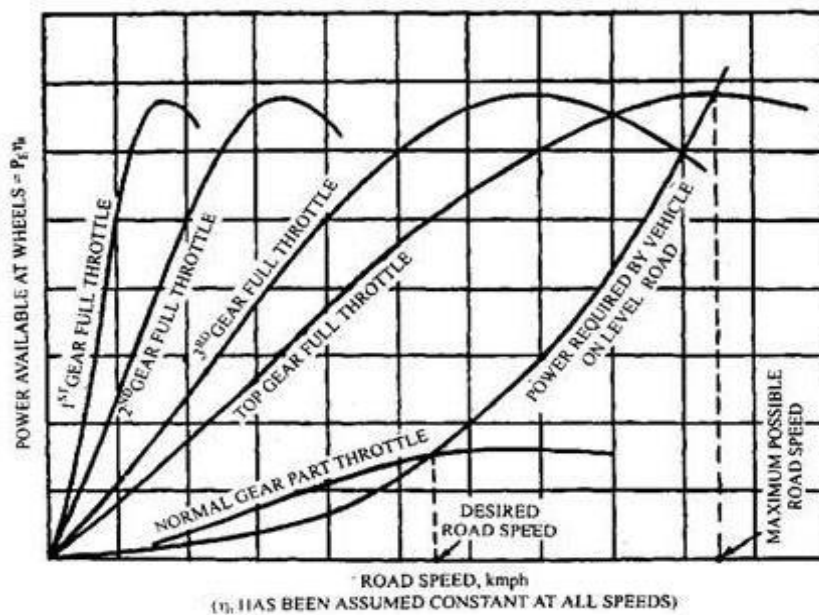

Figure 1

By utilizing the recipe given in segment 31.3, the force is accessible as demonstrated in Fig. 31.3 can be changed over into the tractive exertion. Henceforth tractive exertion execution bends for four rigging proportions can be plotted against street speed as in Fig. 31.4. In this figure, a street obstruction bend is additionally introduced. The distinction between the

ordinates of tractive exertion and street obstruction at any street speed gives the excess tractive exertion, which is used for increasing speed, drawbar pull, and slope climbing.
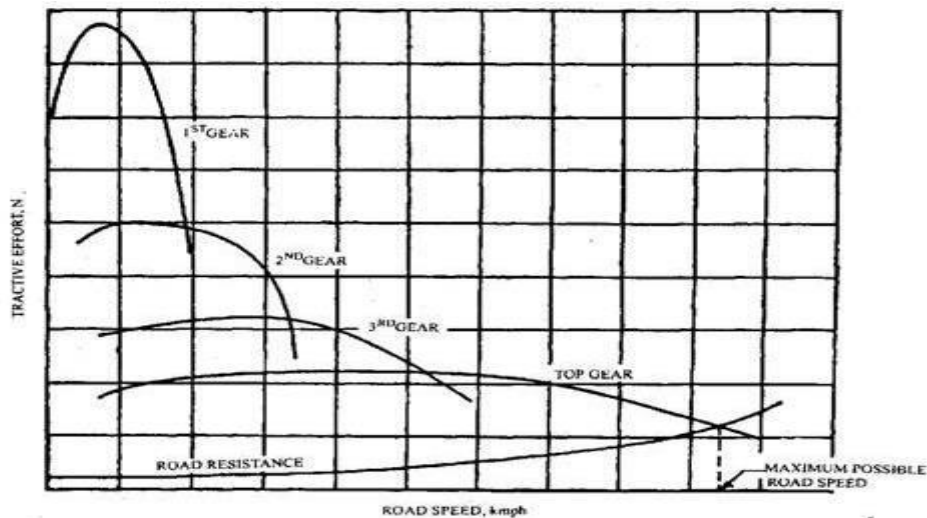

Fig. 31.4. Road speed vs tractive effort.
31.5.1.

Acceleration

When the vehicle is accelerated, its rotating parts are also accelerated depending upon their moments of inertia and the gear ratio in the drive line. Due to this, the weight of the vehicle is increased from W to We. This increased weight, We, is called the 'effective weight' of the vehicle. When surplus power, i.e. surplus tractive effort is fully utilized to acceleration, then

Surplus or excess power $= W_e f = \dfrac{V}{3600}$, kW

or, maximum acceleration, $\qquad f = \dfrac{1}{W_e} (\text{surplus power}) \dfrac{3600}{V}$

$\qquad = \dfrac{1}{W_e} (P_e - P_R)\, \eta_t\, \dfrac{3600}{V}$

$\qquad = \dfrac{1}{W_e} (P_e\, \eta_t - P_V)\, \dfrac{3600}{V}$

$\qquad = \dfrac{1}{W_e} (\text{Tractive effort} - \text{Road resistance})$

$= \dfrac{1}{W_e} (F - R).$

Gradability

The maximum percentage grade, which a vehicle can negotiate with full rated condition, is known as 'gradability'. Hence,

$$\text{Surplus power} = \frac{W \times \text{Gradability} \times V}{100 \times 3600}$$

$$\text{Therefore, Gradability} = \frac{100}{W}(P_e\,\eta_t - Pv)\frac{3600}{V}$$

$$= \frac{100}{W}(\text{Tractive effort} - \text{Road resistance}) = \frac{100}{W}(F - R).$$

Drawbar Pull

When the excess power is fully utilized for pulling extra load attached to vehicle then,

Maximum drawbar pull = Tractive effort—Road resistance = (F— R).

Road resistance in this section is made up of rolling resistance and air resistance.

Figures 31.3 and 31.4 show that maximum surplus power and hence maximum surplus tractive effort are provided at very low speeds of the vehicle. Therefore, for acceleration from start, for climbing steeper gradient and for large drawbar pull, first gear is best suited.

Maximum road speed is achieved in the gear when power available equals to power required and tractive effort becomes equal to level road resistance.

If the vehicle is desired to run at a lower speed, the throttle is adjusted accordingly so that the part throttle power available curve intersects the power required curve at the desired road speed.

2.0 Fuel Economy in Automobiles

The fuel economy of a car relates separation went by a vehicle and the measure of fuel expended. Utilization can be communicated as far as volume of fuel to travel a separation, or the separation voyaged per unit volume of fuel devoured. Since fuel utilization of vehicles is a huge factor in air contamination, and since importation of engine fuel can be a huge aspect of a country's unfamiliar exchange, numerous nations force prerequisites for mileage. Various techniques are utilized to inexact the genuine presentation of the vehicle. The vitality in fuel is needed to defeat different misfortunes (wind obstruction, tire drag, and others) experienced while pushing the vehicle, and in giving influence to vehicle frameworks, for example, start or cooling. Different methodologies can be utilized to decrease misfortunes at every one of the changes between the compound vitality in the fuel and the dynamic vitality of the vehicle. Driver conduct can influence mileage; moves, for example, unexpected speeding up and hefty slowing down waste vitality.

Electric vehicles don't straightforwardly consume fuel, thus don't have efficiency fundamentally, yet comparability measures, for example, miles per gallon gas identical have been made to endeavor to think about them.

Speed and fuel economy studies

Fuel economy at consistent paces with chosen vehicles was concentrated in 2010. The latest study shows more noteworthy eco-friendliness at higher paces than prior investigations; for instance, a few vehicles accomplish better efficiency at 100 km/h (62 mph) as opposed to at 70 km/h (43 mph), in spite of the fact that not their best economy, for example, the 1994 Oldsmobile Cutlass Ciera with the LN2 2.2L motor, which has its best economy at 90 km/h (56 mph) (8.1 L/100 km (29 mpg-US)), and improves economy at 105 km/h (65 mph) than at 72 km/h (45 mph) (9.4 L/100 km (25 mpg-US) versus 22 mpg-US (11 L/100 km)). The extent of driving on fast streets changes from 4% in Ireland to 41% in the Netherlands.
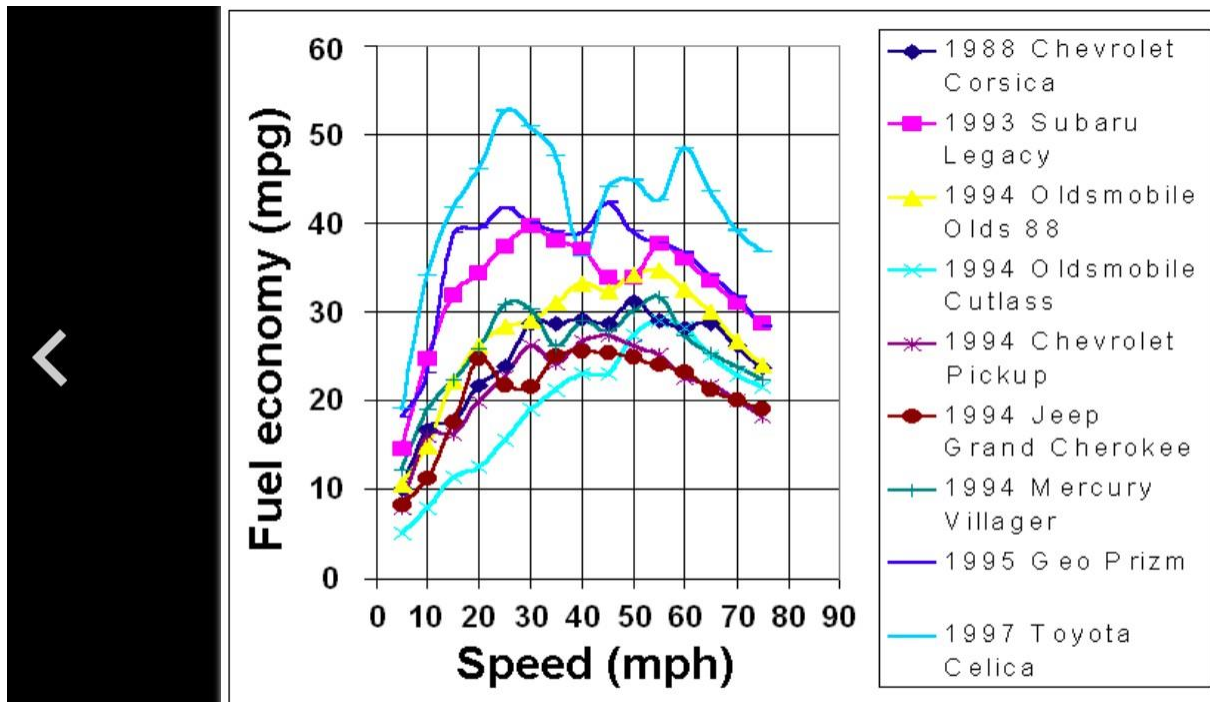
1997 fuel economy statistics for various US models

At the point when the US National Maximum Speed Law's 55 mph (89 km/h) speed limit was ordered from 1974 to 1995, there were grumblings that efficiency could diminish rather than increment. The 1997 Toyota Celica showed signs of improvement eco-friendliness at 105 km/h (65 mph) than it did at 65 km/h (40 mph) (5.41 L/100 km (43.5 mpg-US) versus 5.53 L/100 km (42.5 mpg-US)), albeit far superior at 60 mph (97 km/h) than at 65 mph (105 km/h) (48.4 mpg-US (4.86 L/100 km) versus 43.5 mpg-US (5.41 L/100 km)), and its best economy (52.6 mpg-US (4.47 L/100 km)) at just 25 mph (40 km/h). Different vehicles tried had from 1.4 to 20.2% better eco-friendliness at 90 km/h (56 mph) versus 105 km/h (65 mph). Their best economy was reached at velocities of 40 to 90 km/h (25 to 56 mph) (see diagram).

Authorities trusted that the 55 mph (89 km/h) limit, joined with a restriction on fancy lighting, no fuel deals on Sunday, and a 15% cut in gas creation, would decrease absolute gas utilization by 200,000 barrels per day, speaking to a 2.2% drop from annualized 1973 gas utilization levels.[14][b] This was incompletely founded on a conviction that vehicles accomplish

greatest proficiency somewhere in the range of 65 and 80 km/h (40 and 50 mph) and that trucks and transports were generally productive at 55 mph (89 km/h).

In 1998, the U.S. Transportation Research Board footnoted a gauge that the 1974 National Maximum Speed Limit (NMSL) diminished fuel utilization by 0.2 to 1.0 percent.[17] Rural interstates, the streets most obviously influenced by the NMSL, represented 9.5% of the U.S' vehicle-miles-went in 1973,[18] however such free-streaming streets ordinarily give more eco-friendly travel than ordinary streets.