ISLAMIC UNIVERSITY OF TECHNOLOGY

ANALYSIS AND OPTIMAZATION ON THERMAL EFFICIENCY OF AUTOMOBILE ENGINES

B.Sc. Engineering (Mechanical) THESIS

A THESIS PRESENTED TO THE DEPARTMENT OF MECHANICAL AND CHEMICAL ENGINEERING, ISLAMIC UNIVERSITY OF TECHNOLOGY, DHAKA IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF DEGREE FOR BACHELOR OF SCIENCE (B. Sc.) IN MECHANICAL ENGINEERING

Authors,

Araf Mahfuz
Department of Mechanical and Chemical Engineering,
Islamic University of Technology (IUT)
STUDENT NO: 141405

Ashik Ahmed
Department of Mechanical and Chemical Engineering,
Islamic University of Technology (IUT)
STUDENT NO: 141407

SUPERVISED BY,
Prof. Dr. Md. Nurul Absar Chowdhury
Dean, Faculty of Engineering and Technology
Islamic University of Technology (IUT)

Candidate's Declaration:

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature of the Candidates,

Araf Mahfuz

ID: 141405

Department of Mechanical and Chemical Engineering (MCE)

Islamic University of Technology (IUT), OIC Board Bazar, Gazipur, Dhaka

Ashik Ahmed

ID: 141407

Department of Mechanical and Chemical Engineering (MCE)

Islamic University of Technology (IUT), OIC Board Bazar, Gazipur, Dhaka

Certificate of Approval

The thesis titled "ANALYSIS AND OPTIMAZATION ON THERMAL EFFICIENCY OF AUTOMOBILE ENGINES" submitted by Araf Mahfuz, Student No 141405 & Ashik Ahmed, Student No 141407 has been found as satisfactory and accepted as partial fulfillment of the requirement for the degree of Bachelor of Science in Mechanical Engineering on 04th of November, 2018.

Signature of the Supervisor,

Prof. Dr. Md. Nurul Absar Chowdhury

Dean, Faculty of Engineering and Technology

Department of Mechanical and Chemical Engineering

Islamic University of Technology (IUT)

ACKNOWLEDGEMENTS:

We would like to begin by saying Alhamdullilah and grateful to Almighty Allah who made it possible for us to finish this project successfully on time. Equally say a big thank to our supervisor Professor Dr. Md. Nurul Absar Chowdhury, Dean, Faculty of Engineering and Technology , IUT for all his support, ideas about experiments, discussions, time and for explaining so patiently the hard topics and checking this thesis and papers above all his care and concern. These will ever remain in my memory. Thanks to our examiners for their constructive ideas, suggestions and double checking my work. Special thanks to all faculties for their support and encouragement throughout the period of our studies. Special thanks also to our Automobile lab Instructor Rabiul Hasan sir for his useful workshop support and cooperation which made it easier for us to carry out the experiments. WE will like to say a big thank you to the Head of Department Professor Dr. Zahid Hossian for his continues encouragement and support during the period of our studies. Finally, we will like to express our lasting gratitude to our family members and friends for their patience, support, encouragement, enthusiasm and prayers.

Table of Contents

ABSTRACT:

The thermodynamic limitation for the maximum efficiencies of internal combustion engines is an important consideration for the design and development of future engines. Knowing these limits helps direct resources to those areas with the most potential for improvements. Automobile engines are run by internal combustion. Most internal combustion engines are incredibly inefficient at turning fuel burned into usable energy. Using various resources which includes the first and second laws of thermodynamics, this study has determined the fundamental thermodynamics that are responsible for these limits. This Study is about how optimizations can be done to get the best thermal efficiency out of automobile engines and how they can be applied in practical life. First we will study about the different types of engines and their thermal efficiency. Then we will find their lackings and limitations. Based upon that we will make optimization on different aspects of engines and discuss about the ways to enhance their ability. There are various systems to enhance thermal efficiency of automobile engines, we tried to explore them as much as possible here and draw a clear line for the most efficient and optimum way for enhancing thermal efficiency. Better thermal efficiency will not only just save fuel, it will also reduce CO_2 emission and hence cause a positive impact on our environment.

INTRODUCTION:

Engine efficiency of thermal engines is the relationship between the total energy contained in the fuel, and the amount of energy used to perform useful work. There are two classifications of thermal engines-

1. Internal combustion (gasoline, diesel and gas turbine, i.e., Brayton cycle engines) and
2. External combustion engines (steam piston, steam turbine, and the Stirling cycle engine).

Automobile engines are run by internal combustion. Most internal combustion engines are incredibly inefficient at turning fuel burned into usable energy.

The efficiency by which they do so is measured in terms of "thermal efficiency", and most gasoline combustion engines average around 20 percent thermal efficiency. Diesels are typically higher--approaching 40 percent in some cases.

In other words, even when the engine is operating at its point of maximum thermal efficiency, of the total heat energy released by the gasoline consumed, about 60-80% is rejected as heat without being turned into useful work, i.e. turning the crankshaft. Approximately half of this rejected heat is carried away by the exhaust gases, and half passes through the cylinder walls or cylinder head into the engine cooling system, and is passed to the atmosphere via the cooling system radiator. Some of the work generated is also lost as friction, noise, air turbulence, and work used to turn engine equipment and appliances such as water and oil pumps and the electrical generator, leaving only about 20-40% of the energy released by the fuel consumed available to move the vehicle which is a huge waste of energy.

The development of high efficiency, low emission internal combustion engines continues to be a goal of engineers and scientists. An important aspect of this development is knowledge of the actual maximum possible efficiencies. Although the literature has numerous contributions to this topic, little if any of this previous

work has supplied specific results. The work presented here is directed at quantifying the maximum possible engine efficiencies. The maximum possible efficiencies
are due to the limitations imposed by the first and second laws of thermodynamics.
Ever since the first engines were produced, a goal has been to improve performance and efficiency.Because of this, numerous publications and presentations
have been produced over the years which discuss the potential maximum efficiencies of internal combustion engines. These papers and presentations, however, have generally only presented qualitative ideas. In addition, these previous works have not distinguished the different constraints for different engine application categories. The current work aims to address these previous weaknesses.

PREVIOUS WORKS RELATED TO THIS TOPIC:

Ever since the beginning of engine development, engineers have sought higher engine performance and efficiency. The following literature review is far from comprehensive, but is provided to illustrate the emphasis on higher engine performance and efficiency throughout the history of the development of the IC engine. This brief review includes those previous technical papers which discussed increasing engine efficiency or outlined the qualitative limits for higher efficiencies.

A few papers from the early years (1907–1959) and from the mid-years (1960–1999) will be cited first.These papers will be followed by descriptions of more recent work (2000–2016). Clerk in 1907 described the limits of thermal efficiencyfor internal combustion engines. He based his conclusions on the careful inspection of results from a number of engines and attempted to relate his findingsto the results from the simple Otto cycle analysis. In 1916, Sargent published a paper which recognized the need to improve the efficiency of the IC engine. Onesuggestion was to minimize the use of the throttle for part load operation and instead to use valve timing to provide for part load. In 1920, Gibson focused on theissue of fuel vaporization to achieve higher thermal efficiencies.Campbell et al.,4 in 1949, provided a summary report on the problems of increasing IC engine efficiencies.They concentrated on the limitations of increasing the compression ratio due to knock and the importance of providing fuels with greater knock resistance.

In the period 1960–1990, numerous technical papers were published which addressed engine efficiencies.Lucas in 1967 describes the development progress ofthe IC engine and outlines several future developments including lower exhaust emissions, overhead camshafts,and aluminum structures. Stratified charge engineswere considered an opportunity to improve an engine’s efficiency. An example of this work was reported by Turkish in 1975. Increased burn rates were another area pursued for increased efficiencies. Tuttle and Toepel reported on this in 1979. Turbocharging small displacement IC engines for improved fuel economy was presented by Emmenthal et al.8 in 1979. Muranaka described a study from 1987 which examined the factors that limit the thermal efficiency at higher compression ratios. They found that the heat transfer losses increased rapidly for the higher compression ratios.

Technical papers published in the 1990s which focused on engine efficiency included work by Zhechen. They completed a parametric study of SI engine efficiency using a cycle simulation. They concluded that increasing compression ratio is the most effective approach to increasing efficiencies.

Okamoto et al.11 in 1997 reported on the use of a Miller cycle with exhaust gas recirculation (EGR) to improve engine efficiency. In 1998, De Sousa proposed the use of EGR with increased compression ratio to increase the thermal efficiency of a SI engine. Thomas and Staunton13 in 1999 provided a review of possible technologies which could aid the competitiveness of light-duty, natural gas vehicles. They recommended SI, lean burn with turbocharging, and port fuel injection as a promising option. Also in 1999, Wambsganss published a paper on thermal management concepts for higher efficiency heavy-duty engines. More recent work includes a paper by Macek in 2005. He attempted to provide an overview of the thermodynamic limits of IC engine efficiencies. He considered realistic limits which included mechanical and thermal aspects as well as pollutant emissions. He included some discussion of low temperature combustion, downsizing, waste heat recovery, and regeneration concepts. Also in 2005, Kutlar reported on the use of stratified charge and variable displacement engines to improve part load efficiency. Ayala in 2006 reported on the limitations for higher engine efficiency. They concentrated on the importance of higher compression ratios in dilute engines for a range of loads.

Also, in 2006, Farrell provided the second law analyses for several specific engines: port fuel injection gasoline engine, lean burn engines, and homogeneous
charge compression ignition (HCCI) engines. They showed that lean burn strategies reduced exhaust and heat transfer losses, but increased combustion irreversibilities.
They also discussed the implications of the fuel choice for reducing the second law losses. In 2009, the National Academies of Sciences published a report which outlined the prospects for more efficient transportation engines.19 Tey et al.20,21 in 2008 published a two-part paper that considered the thermodynamic requirements for maximum engine efficiency with an emphasis on the results from the second law evaluations. They focused on developing options to minimize the exergy destruction during combustion. In 2010, Oak Ridge National Laboratory sponsored a colloquium to review and assess the current state of the efficiency of engines used for light- and heavy-duty transportation.

This summary report identified broad efficiency limitations and technology barriers to further advances. The report ended with near and longer term

research and development priorities to achieve higher efficiency engines. In 2012, Lavoie et al.23 reported on the thermodynamics of highly dilute, high-pressure gasoline engines with realistic burn durations, heat loss, boosting, and friction constraints. One of their conclusions was that dilution with either air or EGR provided benefits due to improved thermodynamic properties. Foster24 in 2014 published a concise summary of the thermodynamic
limitations of increasing the efficiency of engines. In terms of background, another topic that should be mentioned is the high efficiency of large, two-stroke marine engines.25 These engines are unique, operate at low speeds (;100 r/min), and have combustion chambers with low surface area to volume ratios. Also, these
engines utilize efficient turbochargers and use waste heat recovery devices. All of these features combine to result in brake thermal efficiencies on the order of 55%.

Since the focus of the current study does not include utilizing the exhaust gas energy, the technologies associated with these large marine engines are not considered in the following

.
The above brief review of the literature provides evidence of two major points:
(1) the desire for higher efficiency engines has persisted since the very beginnings
of engine development and
(2) very little quantitative information has been provided on the maximum possible
efficiencies.
This study is directed at providing this quantification.

ELABORATION:

There are 3 main cycles used in the automotive system; They are Otto cycle, Diesel Cycle and Atkinson cycle.

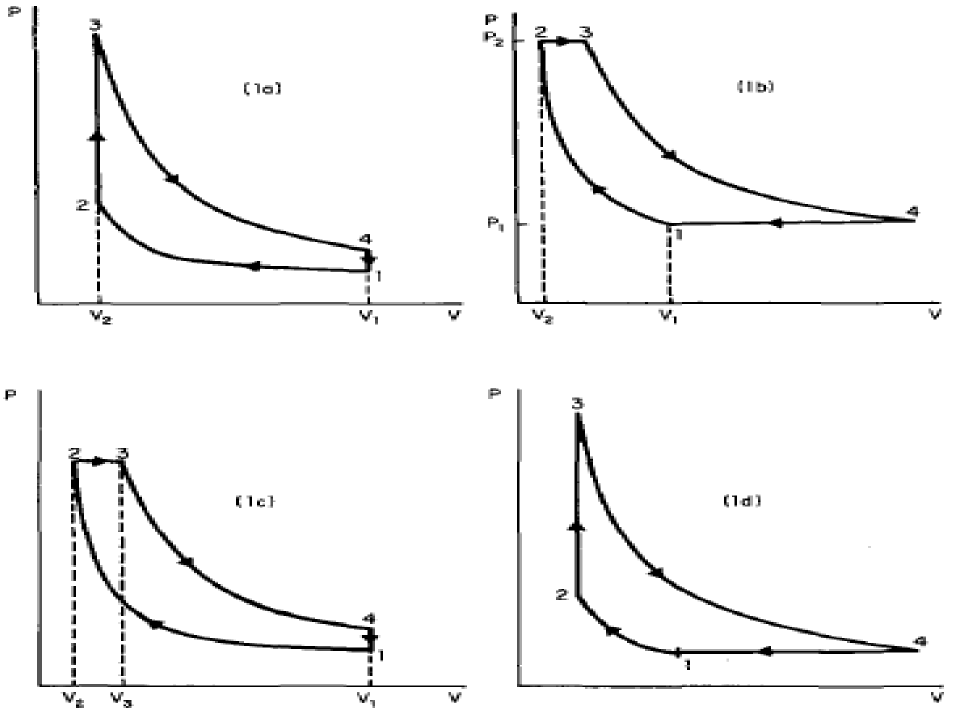


Fig. 1. Four reversible heat engine cycles. (a) Otto, (b) Joule–Brayton, (c) Diesel, and (d) Atkinson.

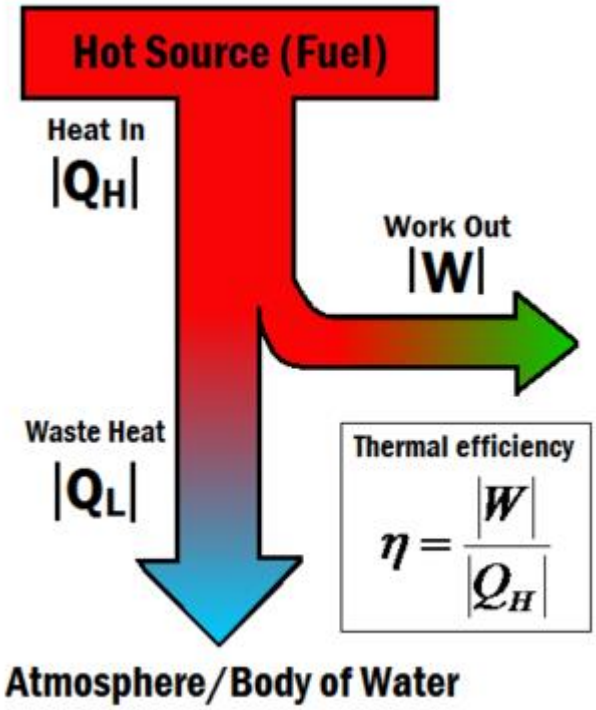
THERMAL EFFICIENCY

Heat engines turn heat into work. The **thermal efficiency** expresses the fraction of heat that becomes useful work. The thermal efficiency is represented by the symbol ηη, and can be calculated using the equation:

$$\eta = \frac{W}{Q_H}$$

Where:

W is the useful work and
QH is the total heat energy input from the hot source.
Heat engines often operate at around 30% to 50% efficiency, due to practical limitations. It is impossible for heat engines to achieve 100% thermal efficiency (η=1) according to the Second law of thermodynamics. This is impossible because some waste heat is always produced in a heat engine, shown in Figure 1 by the QL term. Although complete efficiency in a heat engine is impossible, there are many ways to increase a system's overall efficiency.



The Carnot cycle is reversible and thus represents the upper limit on efficiency of an engine cycle. Practical engine cycles are irreversible and thus have inherently lower efficiency than the Carnot efficiency when operated between the same temperatures and One of the factors determining efficiency is how heat is added to the working fluid in the cycle, and how it is removed. The Carnot cycle achieves maximum efficiency because all the heat is added to the working fluid at the maximum temperature and removed at the minimum temperature In contrast, in an internal combustion engine, the temperature of the fuel-air mixture in the cylinder is nowhere near its peak temperature as the fuel starts to burn, and only reaches the peak temperature as all the fuel is consumed, so the average temperature at which heat is added is lower, reducing efficiency.

An important parameter in the efficiency of combustion engines is the specific heat ratio of the air-fuel mixture, γ. This varies somewhat with the fuel, but is generally close to the air value of 1.4. This standard value is usually used in the engine cycle equations below, and when this approximation is made the cycle is called an *air-standard cycle*.

Otto cycle: The Otto cycle is the name for the cycle used in spark-ignition internal combustion engines such as gasoline and hydrogen fueled automobile engines. Its theoretical efficiency depends on the compression ratio *r* of the engine and the specific heat ratio γ of the gas in the combustion chamber.

$$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}}$$

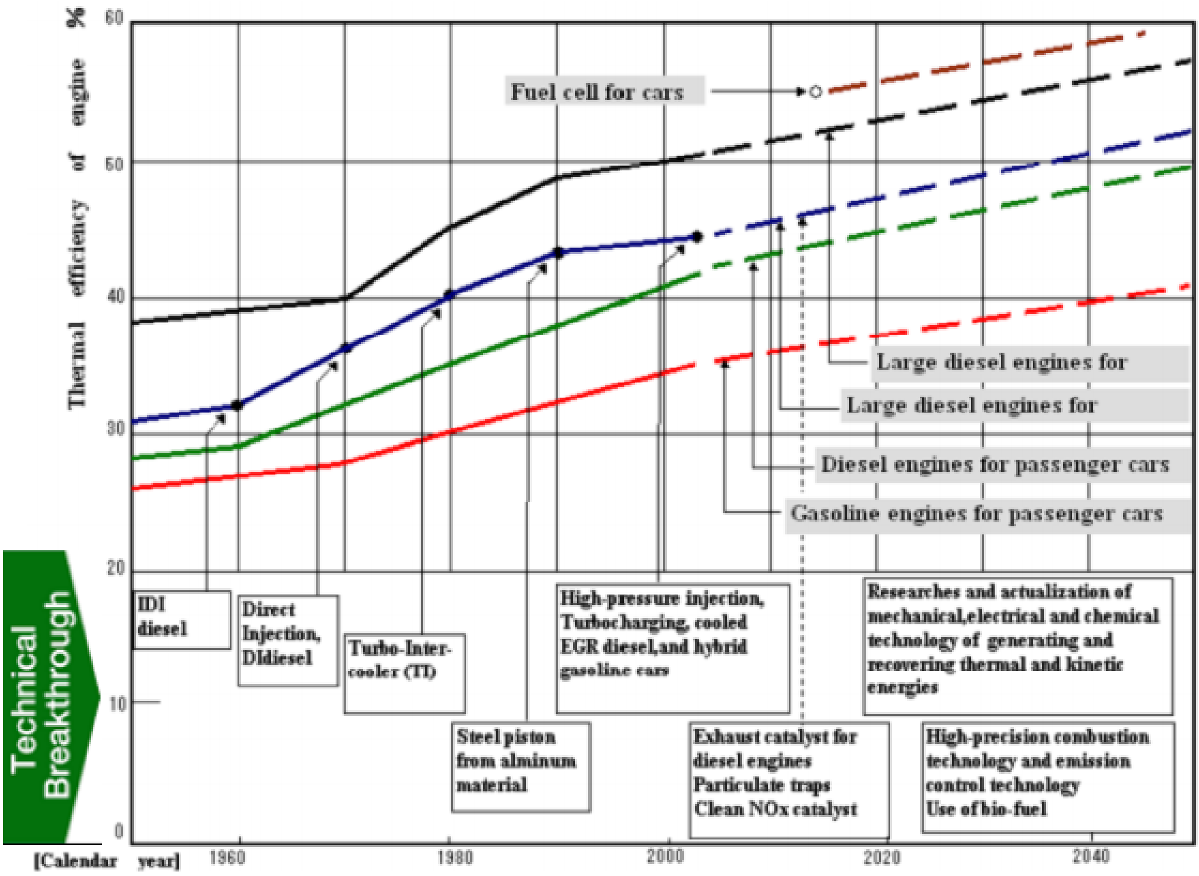
Thus, the efficiency increases with the compression ratio. However the compression ratio of Otto cycle engines is limited by the need to prevent the uncontrolled combustion known as knocking. Modern engines have compression ratios in the range 8 to 11, resulting in ideal cycle efficiencies of 56% to 61%.

Diesel cycle: Diesel cycle is used in diesel truck and train engines, the fuel is ignited by compression in the cylinder. The efficiency of the Diesel cycle is dependent on *r* and γ like the Otto cycle, and also by the *cutoff ratio*, r_c, which is the ratio of the cylinder volume at the beginning and end of the combustion process:

$$\eta_{th} = 1 - \frac{r^{1-\gamma}(r_c^{\gamma} - 1)}{\gamma(r_c - 1)}$$

The Diesel cycle is less efficient than the Otto cycle when using the same compression ratio. However, practical Diesel engines are 30% - 35% more efficient than gasoline engines. This is because, since the fuel is not introduced to the combustion chamber until it is required for ignition, the compression ratio is not limited by the need to avoid knocking, so higher ratios are used than in spark ignition engines.

DIFFERENT EFFICIENCIES FOR DIESEL AND OTTO CYCLE:



Vehicles powered by compression-ignition engines are more fuel efficient (upto 30%) than their gasoline counterparts. The reason is as follows :

1/ Volumetric Efficiency is the ratio of The Volume of air occupied in cylinder to The Total Volume of the cylinder.

Volumetric Efficiency = Volume of air in cylinder / Total volume of cylinder

If the volume of cylinder is 1-liter. During suction stroke, 1-liter of air should be enter into cylinder than the volumetric efficiency is 100%.

In Petrol engine, due to the presence of **THROTTLE BODY** there be a more resistance during air enters into engine cylinder. Due to this resistance the volume of air enter into cylinder gets lower. Hence Volumetric efficiency is considerably reduced.

In Diesel engine, there is **NO THROTTLE BODY** air enters directly to engine cylinder from air filter. Hence resistance of air flow is less. so more amount of air enters into engine cylinder volume(Diesel engine always running in the lean mixture). Hence volumetric efficiency is more in Diesel engines.

Turbocharger and Supercharger are the air compressing devices which considerably increase the Volumetric efficiency of the engine by sending compressed air to the engine cylinder during suction stroke. While sending forced air to the cylinder, volumetric efficiency can be increased by more than 100%.

2/ Diesel actually contains more carbon, which means more energy per gallon than gasoline.

The specific energy content of a fuel is the heat energy obtained when a certain quantity is burned (such as a gallon, litre, kilogram). It is sometimes called the heat of combustion. There exists two different values of specific heat energy for the same batch of fuel. One is the high (or gross) heat of combustion and the other is the low (or net) heat of combustion. The high value is obtained when, after the combustion, the water in the exhaust is in liquid form. For the low value, the exhaust has all the water in vapor form (steam). Since water vapor gives up heat energy when it changes from vapor to liquid, the liquid water value is larger since it includes the latent heat of vaporization of water. The difference between the high and low values is significant, about 8 or 9%. This accounts for most of the apparent discrepancy in the heat value of gasoline. In the U.S. (and the table) the high heat values have traditionally been used, but in many other countries, the low heat values are commonly used.

Fuel type	MJ/L	MJ/kg	BTU/imp gal	BTU/US gal	Research octane number (RON)
Regular gasoline/petrol	34.8	~47	150,100	125,000	Min. 91
Premium gasoline/petrol		~46			Min. 95
Autogas (LPG) (60% propane and 40% butane)	25.5–28.7	~51			108–110
Ethanol	23.5	31.1[3]	101,600	84,600	129
Methanol	17.9	19.9	77,600	64,600	123
Gasohol (10% ethanol and 90% gasoline)	33.7	~45	145,200	121,000	93/94
E85 (85% ethanol and 15% gasoline)	25.2	~33	108,878	90,660	100–105
Diesel	38.6	~48	166,600	138,700	N/A (see cetane)
Biodiesel	35.1	39.9	151,600	126,200	N/A (see cetane)
Vegetable oil (using 9.00 kcal/g)	34.3	37.7	147,894	123,143	
Aviation gasoline	33.5	46.8	144,400	120,200	80-145
Jet fuel, naphtha	35.5	46.6	153,100	127,500	N/A to turbine engines
Jet fuel, kerosene	37.6	~47	162,100	135,000	N/A to turbine engines
Liquefied natural gas	25.3	~55	109,000	90,800	
Liquid hydrogen	9.3	~130	40,467	33,696	

3/ Diesel engines have much higher compression ratios. Air in the cylinders gets superheated by all the squeezing, when the fuel is sprayed into the combustion chambers it instantly ignites and can extract more power from the fuel.

4/ Common-rail fuel injection and piezoelectric technology deliver very precise amounts of fuel into the cylinders at extremely high pressures, up to 29,000 PSI. Piezoelectric injectors can deliver as many as five squirts of fuel per combustion cycle.

5/ Diesel engines have no pumping losses as there are no restrictions in the throttle body. Diesel engines today have variable vane turbochargers. These advanced turbochargers alter the amount of boost they provide at different engine speeds giving an even delivery of torque.

6/ Low sulphur diesel availability has further enhanced the diesel advantage. Advanced after treatment systems like Selective catalyst reduction technology (SCR) injects a urea solution into the exhaust stream where it reacts breaking up dangerous NOx into harmless nitrogen and oxygen.

FACRORS BEHIND LOW THERMAL EFFICIENCIES:

Compression ratio:

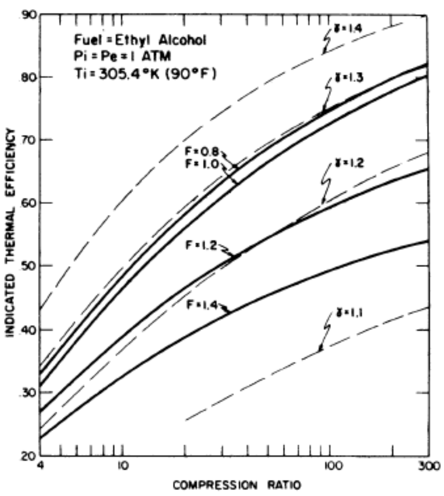
The efficiency of internal combustion engines depends on several factors, the most important of which is the expansion ratio. For any heat engine the work which can be extracted from it is proportional to the difference between the starting pressure and the ending pressure during the expansion phase. Hence, increasing the starting pressure is an effective way to increase the work extracted (decreasing the ending pressure, as is done with steam turbines by exhausting into a vacuum, is likewise effective).

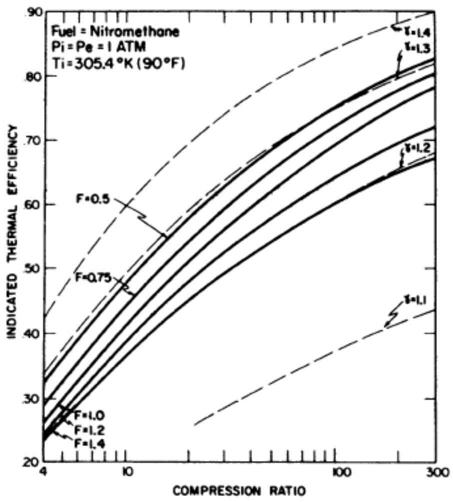
Most gasoline (petrol) and diesel engines have an expansion ratio equal to the compression ratio (the compression ratio calculated purely from the geometry of the mechanical parts) of 10:1 (premium fuel) or 9:1 (regular fuel), with some engines reaching a ratio of 12:1 or more. The greater the expansion ratio the more efficient is the engine, in principle, and higher compression / expansion -ratio conventional engines in principle need gasoline with higher octane value, though this simplistic analysis is complicated by the difference between actual and geometric compression ratios. High octane value inhibits the fuel's tendency to burn nearly instantaneously (known as *detonation* or *knock*) at high compression/high heat conditions. However, in engines that utilize compression rather than spark ignition, by means of very high compression ratios (14-25:1), such as the diesel engine or Bourke engine, high octane fuel is not necessary. In fact, lower-octane fuels, typically rated by octane number, are preferable in these applications because they are more easily ignited under compression.

Under part throttle conditions (i.e. when the throttle is less than fully open), the *effective* compression ratio is less than when the engine is operating at full throttle, due to the simple fact that the incoming fuel-air mixture is being restricted and cannot fill the chamber to full atmospheric pressure. The engine efficiency is less than when the engine is operating at full throttle. One solution to this fact is to shift the load in a multi-cylinder engine from some of the cylinders (by deactivating them) to the remaining cylinders so that they may operate under higher individual loads and with correspondingly higher effective compression ratios. This technique is known as variable displacement.

Some engines such as the Atkinson cycle or the Miller cycle achieve increased efficiency by having an expansion ratio larger than the compression ratio.

Diesel engines have a compression / expansion ratio between 14:1 to 25:1. In this case the general rule does not apply because Diesels with compression ratios over 20:1 are indirect injection diesels. These use a prechamber to make possible high RPM operation as is required in automobiles and light trucks. The thermal and gas dynamic losses from the prechamber result in direct injection Diesels (despite their lower compression / expansion ratio) being more efficient.





Friction:

An engine has many moving parts that produce friction. Some of these friction forces remain constant (as long as applied load is constant); some of these friction losses increase as engine speed increases, such as piston side forces and connecting bearing forces (due to increased inertia forces from the oscillating piston). A few friction forces decrease at higher speed, such as the friction force on the cam's lobes used to operate the inlet and outlet valves (the valves' inertia at high speed tends to pull the cam follower away from the cam lobe). Along with friction forces, an operating engine has *pumping losses*, which is the work required to move air into and out of the cylinders. This pumping loss is minimal at low speed, but increases approximately as the square of the speed, until at rated power an engine is using about 20% of total power production to overcome friction and pumping losses.

Oxygen:

Air is approximately 21% oxygen. If there is not enough oxygen for proper combustion, the fuel will not burn completely and will produce less energy. An excessively rich fuel to air ratio will increase unburnt hydrocarbon pollutants from the engine. If all of the oxygen is consumed because there is too much fuel, engine's power is reduced.

As combustion temperature tends to increase with leaner fuel air mixtures, unburnt hydrocarbon pollutants must be balanced against higher levels of pollutants such as nitrogen oxides (NOx), which are created at higher combustion temperatures. This is sometimes mitigated by introducing fuel upstream of the combustion chamber to cool down the incoming air through evaporative cooling. This can increase the total charge entering the cylinder (as cooler air will be more dense), resulting in more power but also higher levels of hydrocarbon pollutants and lower levels of nitrogen oxide pollutants. With direct injection this effect is not as dramatic but it can cool down the combustion chamber enough to reduce certain pollutants such as nitrogen oxides (NOx), while raising others such as partially decomposed hydrocarbons.

The air-fuel mix is drawn into an engine because downward motion of the pistons induces a partial vacuum. A compressor can additionally be used to force a larger charge (forced induction) into the cylinder to produce more power. The compressor is either mechanically driven supercharging or exhaust driven turbocharging. Either way, forced induction increases the air pressure exterior to the cylinder inlet port.

There are other methods to increase the amount of oxygen available inside the engine; one of them, is to inject nitrous oxide, (N_2O) to the mixture, and some engines use nitromethane, a fuel that provides the oxygen itself it needs to burn. Because of that, the mixture could be 1 part of fuel and 3 parts of air; thus, it is possible to burn more fuel inside the engine, and get higher power outputs.

Combustion irreversibilities :

The maximum possible thermal efficiency for reciprocating engines even with no heat losses or friction is limited by the combustion irreversibilities.
(Note that combustion irreversibilities are not related to incomplete combustion.) For the conditions examined in this work, these irreversibilities accounted for about 18%–33% of the fuel exergy. These irreversibilities are due largely to the chemical reactions, heat transfer, and mixing associated with combustion processes. Many studies have been completed to examine ways to minimize these irreversibilities. Within
the constraints of typical engines, however, no feasible approach has been identified. In fact, one study has shown that even if the irreversibilities could be reduced,the preserved exergy would not result in much if any additional work. The preserved exergy, however, would remain in the exhaust.

Heat transfer:

The cylinder heat transfer is a major reason for lower maximum efficiencies for IC engines. This has motivated many studies to seek low heat rejection engine designs.

For the most part, these attempts have not been successful.This topic is too immense to be discussed in this article, but a few summary comments are provided for
completeness. For today's materials and lubricants, cylinder heat transfer is necessary to prevent structural damage and deterioration of the lubricants. Using high-temperature materials (e.g. ceramics) and hightemperature lubricants to minimize the heat losses has
been attempted with mixed results. Furthermore, decreasing cylinder heat transfer increases the gas temperatures which decreases the ratio of specific heats.
This decreases the conversion of thermal energy into work. In general, the reduction of cylinder heat transfer results in minimal or zero increases of work, but increases the thermal energy of the exhaust. This higher energy of the exhaust may be useful, but designs will be
needed to take advantage of this energy.

Lean mixtures :

The use of lean mixtures has several advantages for higher engine efficiencies. First, operation with lean mixtures results in lower combustion temperatures. These lower temperatures result in less heat loss and higher ratios of the specific heats. The advantages of lean mixtures are greater than the slight penalty of higher combustion irreversibilities (due to the lower combustion temperatures). The disadvantages of the use of lean mixtures
are the higher inlet and cylinder pressures which are needed to achieve the required load.

Burn duration :

The use of short burn durations is advantageous for higher efficiencies since the expansion work is increased (for MBT combustion timing). The disadvantages of short burn durations are higher peak cylinder pressures, higher pressure rise rates, and increased engine noise.

Ratio of specific heats :

Although the effects are not easily separated, the ratio of specific heats during the combustion process is a significant property related to the thermal efficiency of engines. This is easily demonstrated with the simple Otto cycle analysis. Using the complete engine cycle simulation, this can also be demonstrated.31 In general, higher ratios of the specific heats increase the thermal efficiencies. In this work, the importance of the ratio of specific heats has been noted in several areas.

Engine size and design:

Although not specifically addressed in this work, engine size affects the maximum possible efficiencies. The main reason is the cylinder surface area and volume ratio which typically decreases as the engine size increases. This results in less relative heat loss if all else is the same. Briefly, as engine size increases, the surface area and volume ratio rapidly decrease, the relative cylinder heat transfer decreases (due largely to the decrease of the surface area and volume ratio) and the net indicated thermal efficiency increases largely due to the reduction of the relative cylinder heat transfer. Only a fraction of the energy retained due to the decrease of the relative cylinder heat transfer, however, converts to work. The remaining energy remains in the exhaust gases.

SUMMARY:

- Reducing cylinder heat transfer appears to have the potential to increase the thermal efficiencies. The minimization of the cylinder heat transfer, however, is not easily achieved. Even for reduced cylinder heat transfer, the increases of work are small or zero due to the difficulties of converting thermal energy to work. For most cases, exergy retained due to reduced heat transfer will mostly increase the exhaust exergy.

- Reducing the mechanical friction increases the brake thermal efficiencies with little or no disadvantages. This is a direct benefit and engine manufacturers continue to make progress in this area.

- The use of lean mixtures has several advantages toward improving the thermal efficiencies. These advantages include reductions of gas temperatures,reductions of heat losses and increases of the ratio of specific heats. The disadvantages include higher inlet and cylinder pressures.

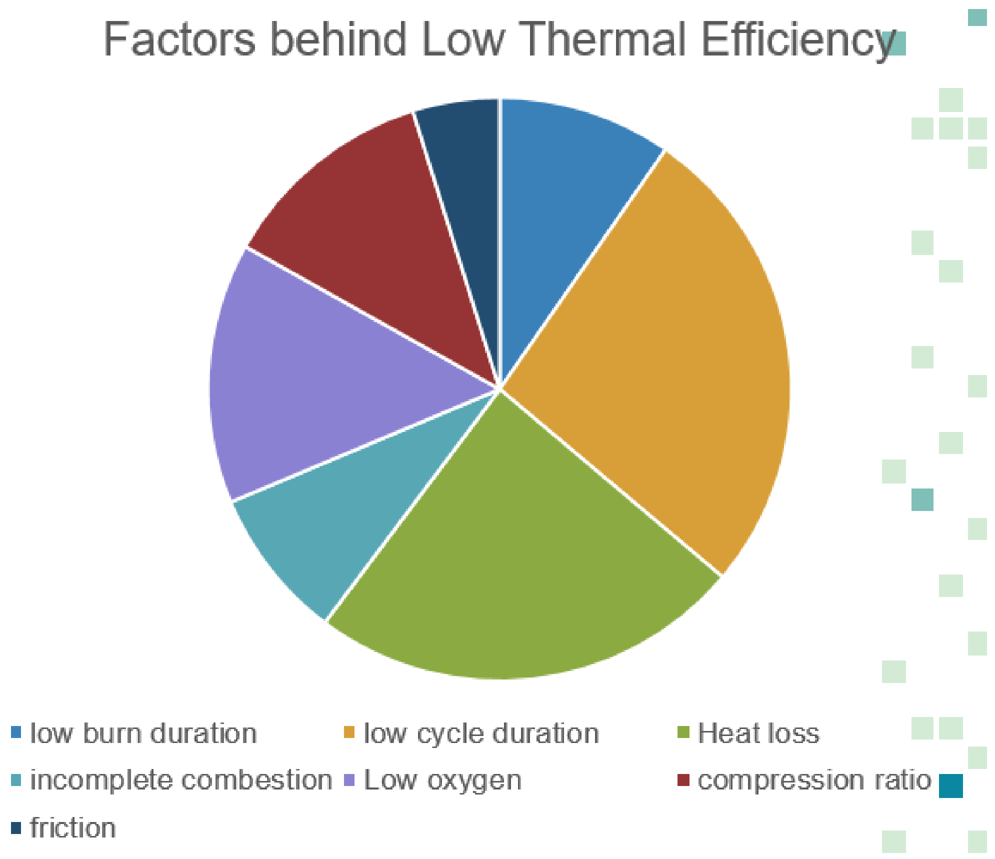
- The use of short burn durations provides higher thermal efficiencies largely due to the more effective expansion work. Short burn durations, however,usually result in higher peak cylinder pressures and higher pressure rise rates.

- Combustion phasing has a significant effect on efficiency.Results show that the CA50 occurs near TDC for MBT timing for the conditions of no heat transfer and short burn duration.

- Increases of the exhaust pressure relative to the inlet pressure decrease the efficiency—for the conditions examined, about 2.1% (absolute) decrease of efficiency was noted for an increase of the pressure difference from 10 to 40 kPa.

- Higher values of the ratios of specific heats during the combustion process are important for achieving higher thermal efficiencies.

- In general, the maximum possible thermal efficiency of an internal combustion engine depends on the constraints that are imposed. These constraints include the allowed values for compression ratio,heat transfer, friction, stoichiometry, peak cylinder pressure, and maximum pressure rise rate.



Advanced technology improvements to improve fuel efficiency:

The most efficient machines for converting energy to rotary motion are electric motors, as used in electric vehicles. However, electricity is not a primary energy source so the efficiency of the electricity production has also to be taken into account. Currently railway trains can be powered using electricity, delivered through an additional running rail, overhead catenary system or by on-board generators used in diesel-electric locomotives as common on the US and UK rail networks. Pollution produced from centralised generation of electricity is emitted at a distant power station, rather than "on site". Pollution can be reduced by using more railway electrification and low carbon power for electricity. Some railways, such as the French SNCF and Swiss federal railways derive most, if not 100% of their power, from hydroelectric or nuclear power stations, therefore atmospheric pollution from their rail networks is very low. This was reflected in a study by AEA Technology between a Eurostar train and airline journeys between London and Paris, which showed the trains on average emitting 10 times less CO_2, per passenger, than planes, helped in part by French nuclear generation.

Modern world is looking for alternative fuel vehicles. This includes:

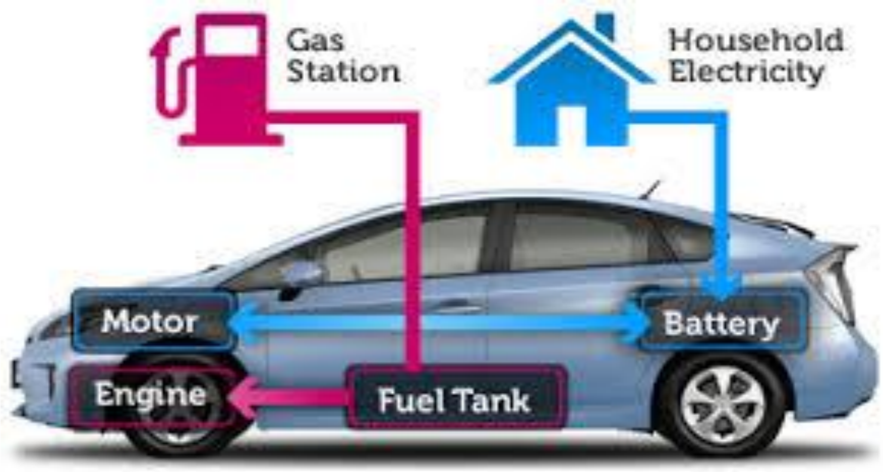
1. Plug in Hybrids
2. Full Electric Cars
3. Hydrogen Fuel Cells

Plug In Hybrid:

A **plug-in hybrid electric vehicle** (PHEV) is a hybrid electric vehicle whose battery can be recharged by plugging it into an external source of electric power, as well by its on-board engine and generator. Most PHEVs are passenger cars, but there are also PHEV versions of commercial vehicles and vans, utility trucks, buses, trains, motorcycles, scooters, and military vehicles.

Similarly to all-electric vehicles, plug-in hybrids displace emissions from the car tailpipe to the generators powering the electricity grid. These generators may be renewable, or may have lower emission than an internal combustion engine. Charging the battery from the grid can cost less than using the on-board engine, helping to reduce operating cost.

Mass-produced plug-in hybrids were available to the public in China and the United States in 2010. By the end of 2016, there were over 30 models of series-production highway legal plug-in hybrids for retail sales. Plug-in hybrid cars are available mainly in the United States, Canada, Western Europe, Japan, and China.



A plug-in hybrid's all-electric range is designated by PHEV-*[miles]* or PHEV*[kilometers]*km in which the number represents the distance the vehicle can travel on battery power alone. For example, a PHEV-20 can travel twenty miles (32 km) without using its combustion engine, so it may also be designated as a PHEV32km.
For these cars to be battery operated, they go through charging processes that use different currents. These currents are known as Alternating Current (AC) used for on board chargers and Direct Current (DC) used for external charging.

PHEVs are based on the same three basic powertrain architectures of conventional hybrids; a *series hybrid* is propelled by electric motors only, a *parallel hybrid* is propelled both by its engine and by electric motors operating concurrently, and a *series-parallel hybrid* operates in either mode. While a plain hybrid vehicle charges its battery from its engine only, a plug-in hybrid can obtain a significant amount of the energy required to recharge its battery from external sources.

The battery charger can be on-board or external to the vehicle. The process for an on-board charger is best explained as AC power being converted into DC power, resulting in the battery being charged.[11] On-board chargers are limited in capacity by their weight and size, and by the limited capacity of generalpurpose AC outlets. Dedicated off-board chargers can be as large and powerful as the user can afford, but require returning to the charger; high-speed chargers may be shared by multiple vehicles.

Using the electric motor's inverter allows the motor windings to act as the transformer coils, and the existing high-power inverter as the AC-to-DC charger. As these components are already required on the car, and are designed to handle any practical power capability, they can be used to create a very powerful form of on-board charger with no significant additional weight or size. AC Propulsion uses this charging method, referred to as "reductive charging"

Fuel efficiency and petroleum displacement:

Plug-in hybrids have the potential to be even more efficient than conventional hybrids because a more limited use of the PHEV's internal combustion engine may allow the engine to be used at closer to its maximum efficiency. While a Prius is likely to convert fuel to motive energy on average at about 30% efficiency (well below the engine's 38% peak efficiency), the engine of a PHEV-70 would be likely to operate far more often near its peak efficiency because the batteries can serve the modest power needs at times when the combustion engine would be forced to run well below its peak efficiency.The actual efficiency achieved depends on losses from electricity generation, inversion, battery charging/discharging, the motor controller and motor itself, the way a vehicle is used (its duty cycle), and the opportunities to recharge by connecting to the electrical grid.

Each kilowatt hour of battery capacity in use will displace up to 50 U.S. gallons (190 l; 42 imp gal) of petroleum fuels per year (gasoline or diesel fuels).[135] Also, electricity is multi-sourced and, as a result, it gives the greatest degree of energy resilience.

The actual fuel economy for PHEVs depends on their powertrain operating modes, their all-electric range, and the amount of driving between charges. If no gasoline is used the miles per gallon gasoline equivalent (MPG-e) depends only on the efficiency of the electric system. The first mass production PHEV available in the U.S. market, the 2011 Chevrolet Volt, with an EPA rated all-electric range of 35 miles (56 km), and an additional gasoline-only extended range of 344 miles (554 km) has an EPA combined city/highway fuel economy of 93 MPG-e in all-electric mode, and 37 mpg$_{\text{-US}}$ (6.4 L/100 km; 44 mpg$_{\text{-imp}}$) in gasoline-only mode, for an overall combined gas-electric fuel economy rating of 60 mpg$_{\text{-US}}$ (3.9 L/100 km; 72 mpg$_{\text{-imp}}$) equivalent (MPG-e). The EPA also included in the Volt's fuel economy label a table showing fuel economy and electricity consumed for five different scenarios: 30, 45, 60 and 75 miles

(121 km) driven between a full charge, and a never charge scenario.[138] According to this table the fuel economy goes up to 168 mpg_{-US} (1.40 L/100 km; 202 mpg_{-imp}) equivalent (MPG-e) with 45 miles (72 km) driven between full charges.

For the more comprehensive fuel economy and environment label that will be mandatory in the U.S. beginning in model year 2013, the National Highway Traffic Safety Administration (NHTSA) and Environmental Protection Agency (EPA) issued two separate fuel economy labels for plug-in hybrids because of their design complexity, as PHEVS can operate in two or three operating modes: all-electric, blended, and gasoline-only.[139][140] One label is for series hybrid or extended range electric vehicle (like the Chevy Volt), with all-electric and gasoline-only modes; and a second label for blended mode or series-parallel hybrid, that includes a combination of both gasoline and plug-in electric operation; and gasoline only, like a conventional hybrid vehicle.

The Society of Automotive Engineers (SAE) developed their recommended practice in 1999 for testing and reporting the fuel economy of hybrid vehicles and included language to address PHEVs. An SAE committee is currently working to review procedures for testing and reporting the fuel economy of PHEVs. The Toronto Atmospheric Fund tested ten retrofitted plug-in hybrid vehicles that achieved an average of 5.8 litres per 100 kilometre or 40.6 miles per gallon over six months in 2008, which was considered below the technology's potential.

In real world testing using normal drivers, some Prius PHEV conversions may not achieve much better fuel economy than HEVs. For example, a plug-in Prius fleet, each with a 30 miles (48 km) all-electric range, averaged only 51 mpg_{-US} (4.6 L/100 km; 61 mpg_{-imp}) in a 17,000-mile (27,000 km) test in Seattle,[143] and similar results with the same kind of conversion battery models at Google's RechargeIT initiative. Moreover, the additional battery pack costs US$10,000–US$11,000

Cost comparison between a PHEV-10 and a PHEV-40[147][149] (prices for 2010)							
Plug-in type by EV range	Similar production model	Type of drivetrain	Manufacturer additional cost compared to conventional non-hybrid mid-size	Estimated cost of battery pack	Cost of electric system upgrade at home	Expected gasoline savings compared to a HEV	Annual gasoline savings compared to a HEV(2)
PHEV-10	Prius Plug-in(1)	Parallel	US$6,300	US$3,300	More than US$1,000	20%	70 gallons
PHEV-40	Chevy Volt	Series	US$18,100	US$14,000	More than US$1,000	55%	200 gallons

FULL ELECTRIC CAR:

An electric car is a plug-in electric automobile that is propelled by one or more electric motors, using energy typically stored in rechargeable batteries.

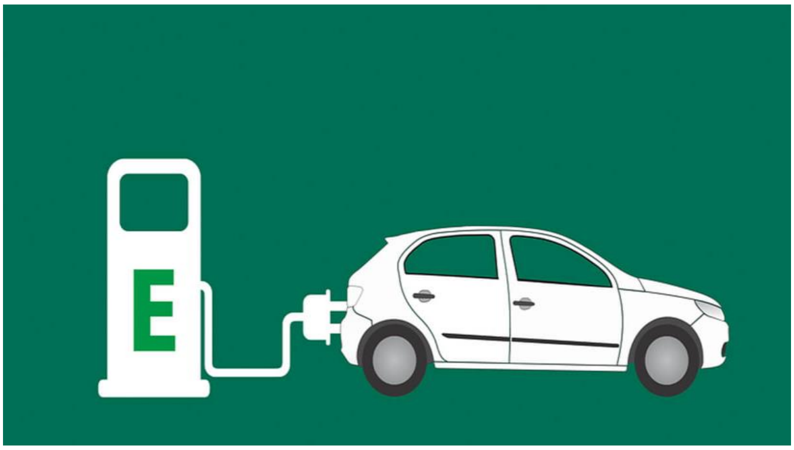
Since 2008, a renaissance in electric vehicle manufacturing occurred due to advances in batteries, concerns about increasing oil prices, and the desire to reduce greenhouse gas emissions.[1][2] Several national and local governments have established tax credits, subsidies, and other incentives to promote the introduction and adoption in the mass market of new electric vehicles, often depending on battery size, their electric range and purchase price. The current maximum tax credit allowed by the US Government is US$7,500 per car.[3] Compared with internal combustion engine vehicles, electric cars are quieter and have no tailpipe emissions, and, often lower emissions in general.[4]

Charging an electric car can be done at a variety of charging stations, these charging stations can be installed in both houses and public areas.[5] The two best selling electric vehicles, the Nissan Leaf and the Tesla Model S, have EPA ranges reaching 151 miles (243 km) and 335 miles (539 km) respectively.[6][7]

As of September 2018, there are over 4 million all- electric and plug-in hybrid cars in use around the world.[8][9][10] All-electric vehicles represent 64 % of the global volume.[11] The Nissan Leaf is the best-selling highway-capable electric car ever, with over 350,000 units sold globally by September 2018.[12] Ranking second is the Tesla Model S with 250,000 units sold worldwide through September 2018.

Electric cars are a variety of electric vehicle (EV). The term "electric vehicle" refers to any vehicle that uses electric motors for propulsion, while "electric car" generally refers to highway-capable automobiles powered by electricity. Low-speed electric vehicles, classified as neighborhood electric vehicles (NEVs) in the United States,[17] and as electric motorised quadricycles in Europe,[18] are plug-in electric-powered microcars or city cars with limitations in terms of weight, power and maximum speed that are allowed to travel on public roads and city streets up to a certain posted speed limit, which varies by country.

While an electric car's power source is not explicitly an on-board battery, electric cars with motors powered by other energy sources are typically referred to by a different name. An electric car carrying solar panels to power it is a solar car, and an electric car powered by a gasoline generator is a form of hybrid car. Thus, an electric car that derives its power from an on-board battery pack is a form of battery electric vehicle (BEV). Most often, the term "electric car" is used to refer to battery electric vehicles, but may also refer to plug-in hybrid electric vehicles (PHEV)



Electric motors can provide high power-to-weight ratios, batteries can be designed to supply the currents needed to support these motors. Electric motors have flat torque curve down to zero speed. For simplicity and reliability, many electric cars use fixed-ratio gearboxes and have no clutch.

Many electric cars have motors that have high acceleration, relative to comparable cars, however, Neighborhood Electric Vehicles may have a low acceleration due to their relatively weak motors. This is largely due to the relatively constant torque of an electric motor, which often increase the acceleration relative to a similar motor power internal combustion engine.

Internal combustion engines have thermodynamic limits on efficiency, expressed as fraction of energy used to propel the vehicle compared to energy produced by burning fuel. Gasoline engines effectively use only 15% of the fuel energy content to move the vehicle or to power accessories, and diesel engines can reach on-board efficiency of 20%, while electric vehicles have on-board efficiency of over 90%, when counted against stored chemical energy, or around 80%, when counted against required energy to recharge.[72]

Electric motors are more efficient than internal combustion engines in converting stored energy into driving a vehicle. Electric cars can not idle. Regenerative braking, which is most common in electric vehicles, can recover as much as one fifth of the energy normally lost during braking.[1][72]

Production and conversion electric cars typically use 10 to 23 kW·h/100 km (0.17 to 0.37 kW·h/mi).[73][74] Approximately 20% of this power consumption is due to inefficiencies in charging the batteries. Tesla Motors indicates that the vehicle efficiency (including charging inefficiencies) of their lithium-ion battery powered vehicle is 12.7 kW·h/100 km (0.21 kW·h/mi) and the well-to-wheels efficiency (if the electricity is generated from natural gas) is 24.4 kW·h/100 km (0.39 kW·h/mi)

Electric vehicles can also use a direct motor-to-wheel configuration which increases the available power. Having motors connected directly to each wheel allows the wheels to be used both for propulsion and as braking systems, thereby increasing traction.[66][67][68] When not fitted with an axle, differential, or transmission, electric vehicles have less drive-train inertia.

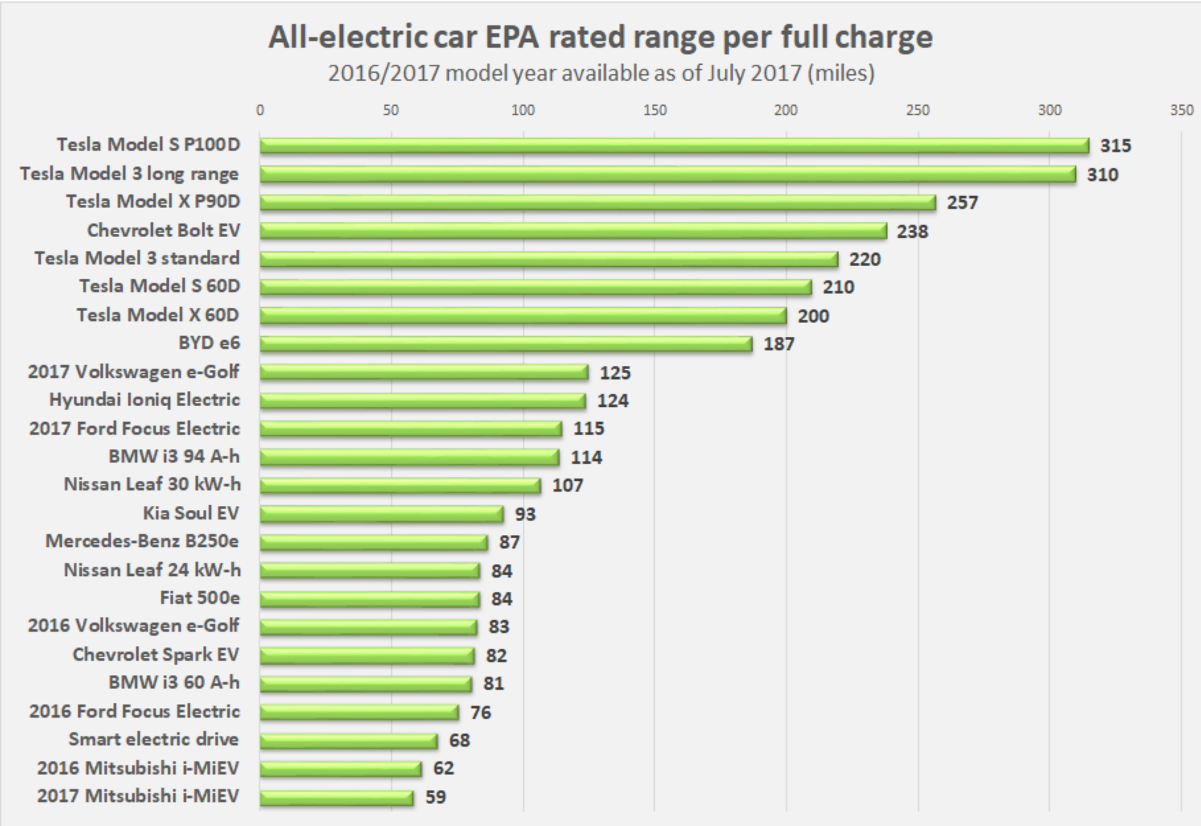
While heating can be provided with an electric resistance heater, higher efficiency and integral cooling can be obtained with a reversible heat pump. PTC junction cooling[76] is also attractive for its simplicity — this kind of system is used, for example, in the Tesla Roadster (2008).

To avoid using part of the battery's energy for heating and thus reducing the range, some models allow the cabin to be heated while the car is plugged in. For example, the Nissan Leaf, the Mitsubishi i-MiEV and the Tesla Model S can be pre-heated while the vehicle is plugged in.[77][78][79]

Some electric cars, for example the Citroën Berlingo Electrique, use an auxiliary heating system (for example gasoline-fueled units manufactured by Webasto or Eberspächer) but sacrifice "green" and "Zero emissions" credentials. Cabin cooling can be augmented with solar power, or by automatically allowing outside air to flow through the car when parked. Two models of the 2010 Toyota Prius include this feature as an option.

Lithium-based batteries are often chosen for their high power and energy density, although may wear out over a long period of time.[109]However, there are many emerging technologies trying to combat this issue.

There are also other battery types, such as Nickel metal hydride (NiMH) batteries which have a poorer power to weight ratio than lithium ion, but are cheaper. Several other battery chemistries are in development such as zinc-air battery which could be much lighter.

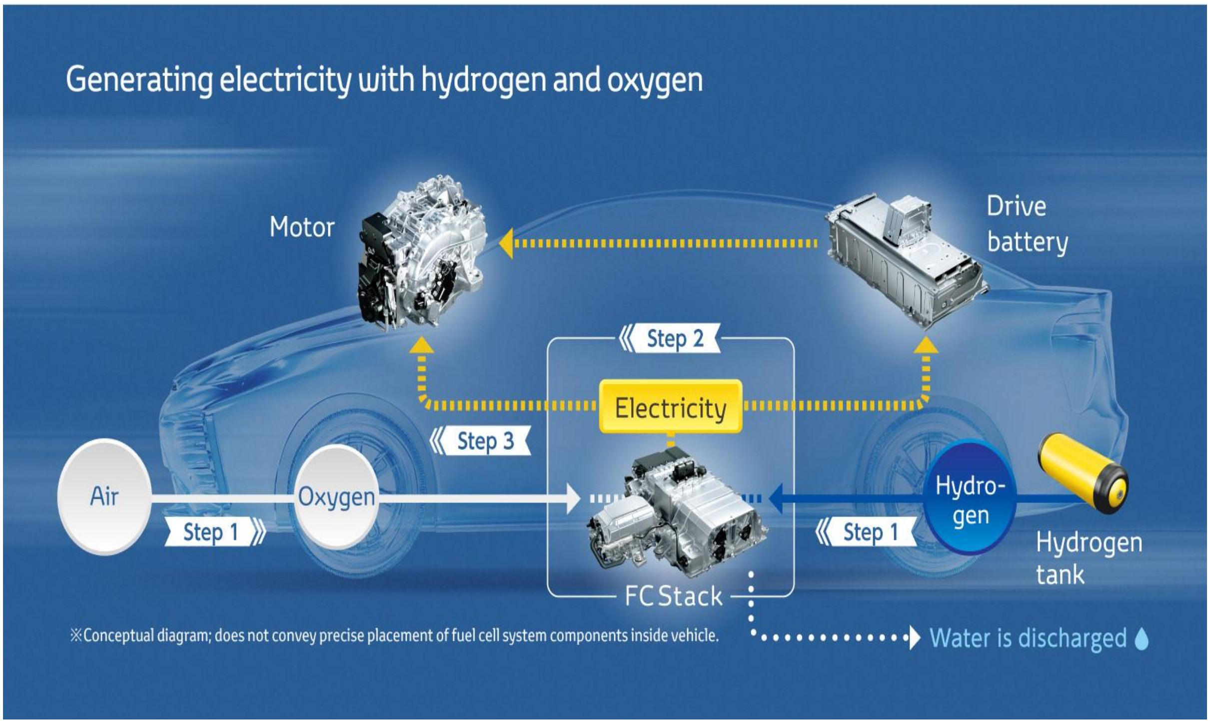


Hydrogen Fuel Cell Cars:

In the future, hydrogen cars may be commercially available. Toyota is test marketing hydrogen fuel cell powered vehicles in southern California where a series of hydrogen fueling stations has been established. Powered either through chemical reactions in a fuel cell that create electricity to drive very efficient electrical motors or by directly burning hydrogen in a combustion engine (near identically to a natural gas vehicle, and similarly compatible with both natural gas and gasoline); these vehicles promise to have near-zero pollution from the tailpipe (exhaust pipe). Potentially the atmospheric pollution could be minimal, provided the hydrogen is made by electrolysis using electricity from non-polluting sources such as solar, wind or hydroelectricity or nuclear. Commercial hydrogen production uses fossil fuels and produces more carbon dioxide than hydrogen.

Because there are pollutants involved in the manufacture and destruction of a car and the production, transmission and storage of electricity and hydrogen, the use of the label "zero pollution" should be understood as applying only to the car's conversion of stored energy into transportation.

In 2004, a consortium of major auto-makers — BMW, General Motors, Honda, Toyota and Volkswagen/Audi — came up with *"Top Tier Detergent Gasoline Standard"* to gasolinebrands in the US and Canada that meet their minimum standards for detergent content[17] and do not contain metallic additives. Top Tier gasoline contains higher levels of detergent additives in order to prevent the build-up of deposits (typically, on fuel injector and intake valve) known to reduce fuel economy and engine performance



Fuel cell vehicles use hydrogen gas to power an electric motor. Unlike conventional vehicles which run on gasoline or diesel, fuel cell cars and trucks combine hydrogen and oxygen to produce electricity, which runs a motor. Since they're powered entirely by electricity, fuel cell vehicles are considered electric vehicles ("EVs")—but unlike other EVs, their range and refueling processes are comparable to conventional cars and trucks.

Converting hydrogen gas into electricity produces only water and heat as a byproduct, meaning fuel cell vehicles don't create tailpipe pollution when they're driven. Producing the hydrogen itself can lead to pollution, including greenhouse gas emissions, but even when the fuel comes from one of the dirtiest sources of hydrogen, natural gas, today's early fuel cell cars and trucks can cut emissions by over 30 percent when compared with their gasoline-powered counterparts. Future renewable fuel standards—such as the requirements currently in place in California—could make hydrogen even cleaner.

Hydrogen fuel cell vehicles combine the range and refueling of conventional cars with the recreational and environmental benefits of driving on electricity.

Refueling a fuel cell vehicle is comparable to refueling a conventional car or truck; pressurized hydrogen is sold at hydrogen refueling stations, taking less than 10 minutes to fill current models. Some leases may cover the cost of refueling entirely. Once filled, the driving ranges of a fuel cell vehicle vary, but are similar to the ranges of gasoline or diesel-only vehicles (200-300 miles). Compared with battery-electric vehicles—which recharge their batteries by plugging in—the combination of fast, centralized refueling and longer driving ranges make fuel cells particularly appropriate for larger vehicles with long-distance requirements, or for drivers who lack plug-in access at home.

Like other EVs, fuel cell cars and trucks can employ idle-off, which shuts down the fuel cell at stop signs or in traffic. In certain driving modes, regenerative braking is used to capture lost energy and charge the battery.

Differences between fuel cell cars and other EVs:

Battery electric vehicles run off an electric motor and battery. This offers them increased efficiency and, like fuel cell vehicles, allows them to drive emissions-free when the electricity comes from renewable sources. Unlike fuel cell cars and trucks, battery electric vehicles can use existing infrastructure to recharge, but must be plugged in for extended periods of time.

Plug-in hybrid electric vehicles are similar to battery electric vehicles but also have a conventional gasoline or diesel engine. This allows them to drive short distances on electricity-only, switching to liquid fuel for longer trips. Although not as clean as battery electric or fuel cell vehicles, plug-in hybrids produce significantly less pollution than their conventional counterparts.

Conventional hybrids also have conventional engines and an electric motor and battery, but can't be plugged-in. Though cleaner than conventional cars and trucks, non-plug-in hybrids derive all their power from gasoline and diesel, and aren't considered electric vehicles.

	Hydrogen & Fuel Cells	Electricity & Batteries
Fuel lifecycle efficiency	Good for conventional Poor for electrolysis	Good for conventional V. Good for renewables
Technology cost	Costly for peak power Okay for average power	Cheap for peak and average power
Range	Independent of device	Dependent and Costly
Cost of fuel	Large variability	Cheap

Hydrogen fuel cells are relatively expensive to produce, as their designs require rare substances such as platinum as a catalyst,[56] In 2014, Toyota said it would introduce its Toyota Mirai in Japan for less than $70,000 in 2015.[12][57] Former European Parliament President Pat Cox estimates that Toyota will initially lose about $100,000 on each Mirai sold.

Electric Turbo Compounding (ETC)

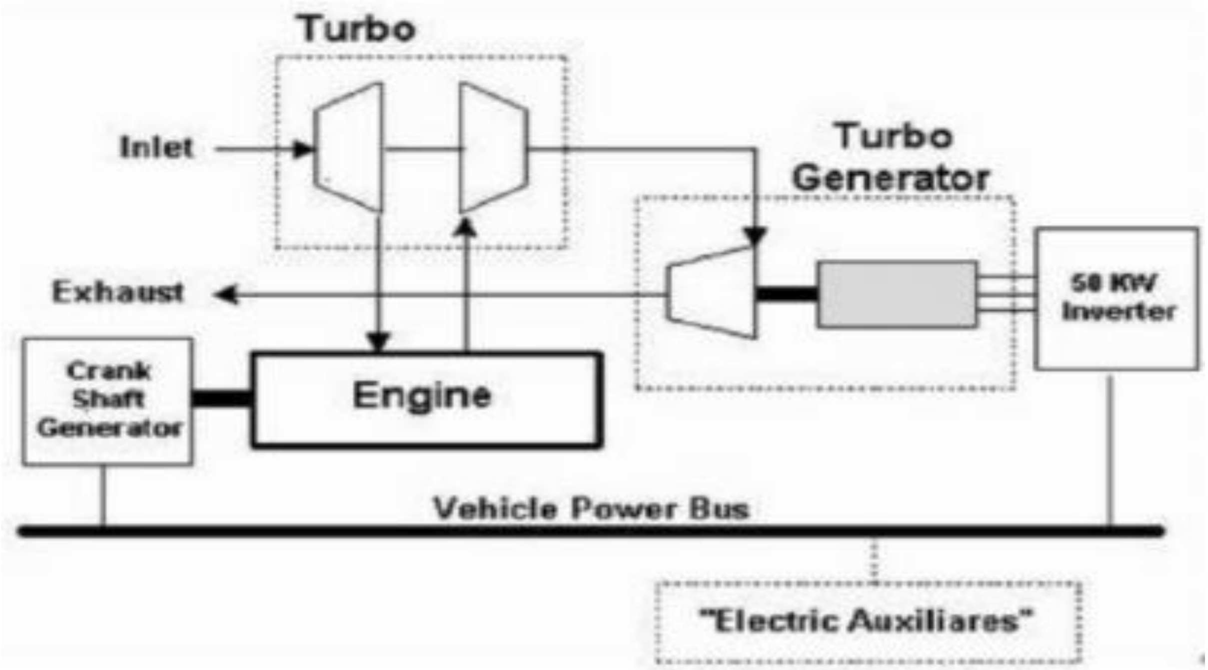
Electric Turbo Compounding (ETC) is a technology solution to the challenge of improving energy efficiency for the stationary power generation industry.

Fossil fuel based power generation is predicted to continue for decades, especially in developing economies. This is against the global need to reduce carbon emissions, of which, a high percentage is produced by the power sector worldwide.

ETC works by making gas and diesel-powered gensets (Electric Generators) work more effectively and cleaner, by recovering waste energy from the exhaust to improve power density and fuel efficiency.[19]

An **electric turbo compound** (ETC) system is defined where a turbine coupled to a generator (turbogenerator) is located in the exhaust gasflow of a reciprocating engine to harvest waste heat energy and convert it into electrical power.

An example of an ETC system is where a turbogenerator is located downstream of a turbocharger turbine of an Internal Combustion Engine (ICE). The power generated from the ETC system can be used to feed into an electrical grid or provide power to local electrical loads such as engine auxiliaries



Advantages of using ETC

- Helps developing economies with unreliable or insufficient power infrastructure. [20]
- Gives independent power providers (IPPs), power rental companies and generator OEMs (original equipment manufacturers) a competitive advantage and potential increased market share.
- Improves overall efficiency of the genset, including fuel input costs and helping end-users reduce amount of fuel burned. [21]
- Typically 4-7% less fuel consumption for both diesel and gas gensets. [22]
- Fewer carbon emissions.
- Increased power density. [23]
- Capability to increase power output and capacity, with improved fuel efficiency.
- ETC system integration offers a step change in efficiency without increasing service or maintenance requirements.
- The cost of generating power through waste heat recovery is substantially less than burning more fuel, even with low diesel prices.[24]

Disadvantages of using ETC

- Upfront costs incur an additional expense for businesses.

- The need to update existing turbomachinery and recertification of the unit adds additional costs and can be time consuming.[25]
- There will be additional weight to add an ETC to a current unit.
- Process still uses fossil fuels, thus still has a carbon footprint in a renewable age.
- They are bespoke to each generator so the design, build and implementation can be a lengthy process.
- There are challenges with high speed turbo generators such as high stress in the rotors, heat generation of the electrical machine and rotordynamics of the turbo generator system.

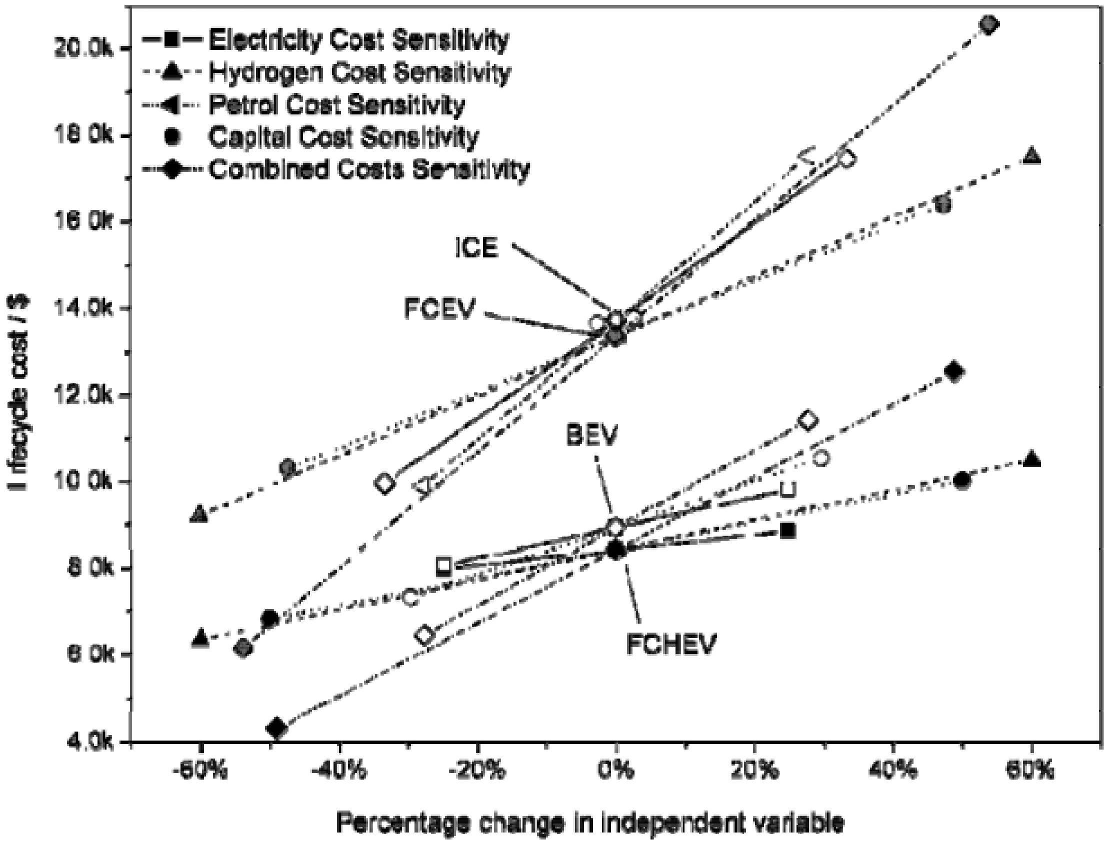
The operating cost of an ICE can be very significant, for example, a continuously operated 1 MWe diesel generator set may have an annual fuel bill which could represent more than five times the capital cost of the generator set.

The exhaust gas of an ICE contains 30% to 40% of the chemical fuel energy as heat.[8][9] As a consequence, even a limited recovery of this energy would represent a significant contribution in terms of overall system efficiency improvement.

Turbo Compound systems have been used for piston aircraft engines since the late 1950s until superseded by turboprop and turbojet engines. In the 1980s the mechanical turbo compound was applied in motorsport racing cars and in the 1990s in heavy truck diesel engines. In 2001, Caterpillar launched a program to develop an Electric Assisted Turbocharger (EAT) for truck applications. In 2004, the first ETC prototype was created for the heavy truck industry by Bowman Power Ltd in partnership with John Deere.

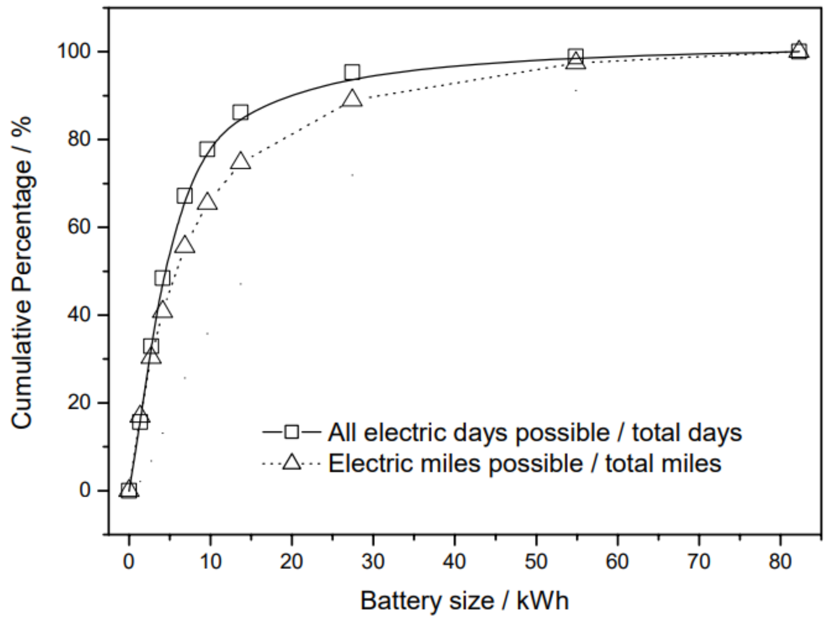
In 2009, Bowman Power Ltd developed an ETC system for the power generation industry. In 2010, Controlled Power Technologies (CPT) designed an ETC system called TIGERS for passenger car applications (Green cars congress reference2010). In 2014, F1 includes heat recovery technology to complement kinetic energy recovery under the name MGU-H to boost the engines power output.

Comparison Between Alternate Fuel Engines:

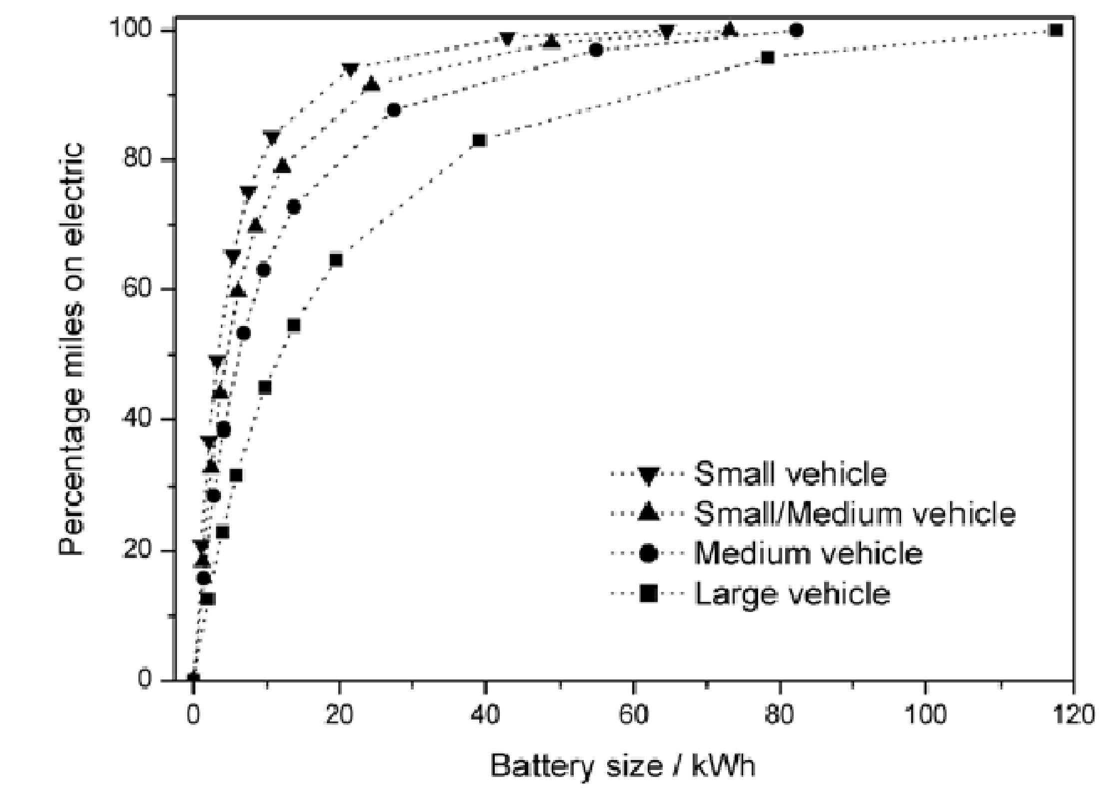


Offer G.J. et al., Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system.

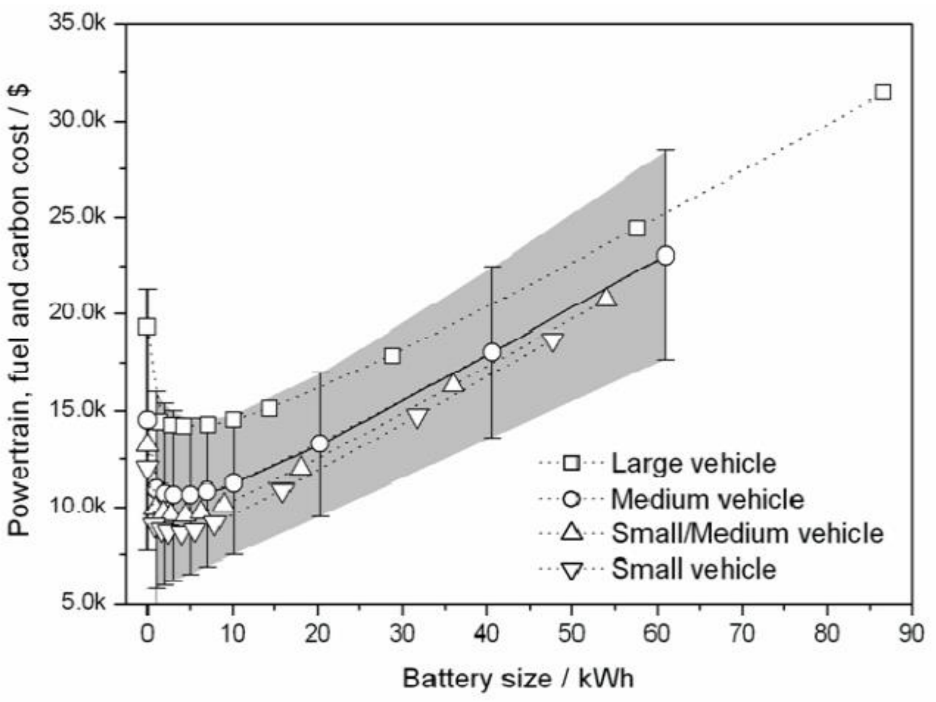
Hybrid Battery Size generation:



Different vehicle type – battery size :

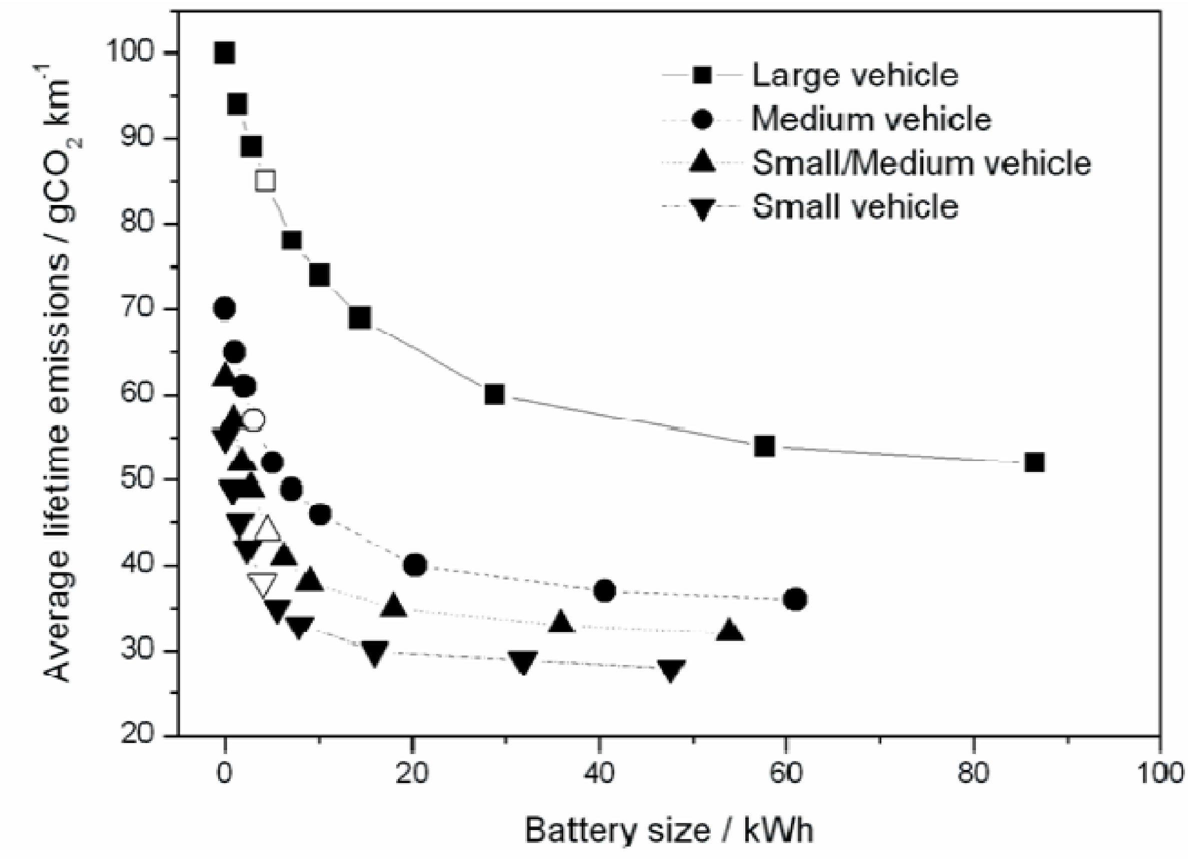


Different vehicle types :



$$Cost = f\Big(\big(C_{H_2}.C_E.C_{FF}\big)\big(C_{Batt}.C_{FC}.C_{ICE}\big)\big(B_{Size}.FC_{Size}\big)\big(C_{CO_2}.f(E_{Gen})\big)\big(f(behaviour).f(vehicle)\big)\Big)$$

Different vehicle type - emissions



Gathering data we can get the average power consumption for electric cars and internal combustion engine cars. Plotting them in graph we get,

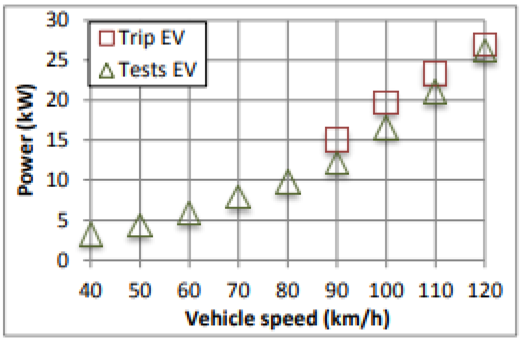


Fig. 16. Average power for the short & long trip (EV).

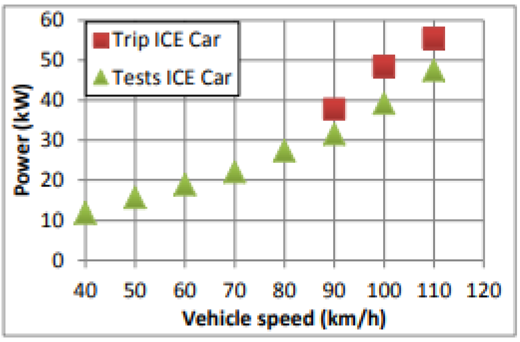


Fig. 17. Average power for the short & long trip (ICE car).

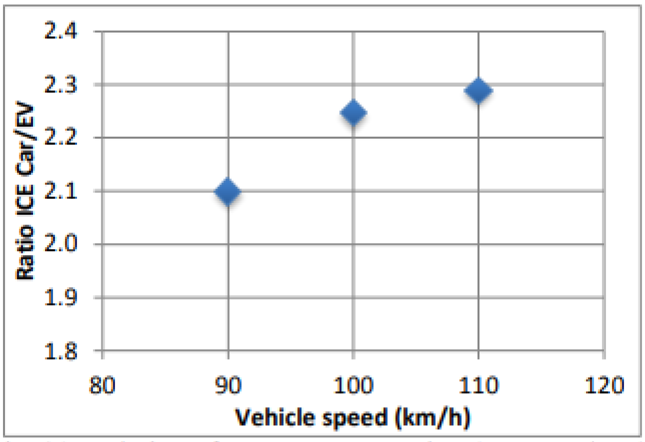


Fig. 20. Relation of energy consumption (ICE Car / EV).

Here we can see the relationship between energy consumption of ICE car and EV car for different vehicle speed. With more speed ICE car's energy consumption rises.

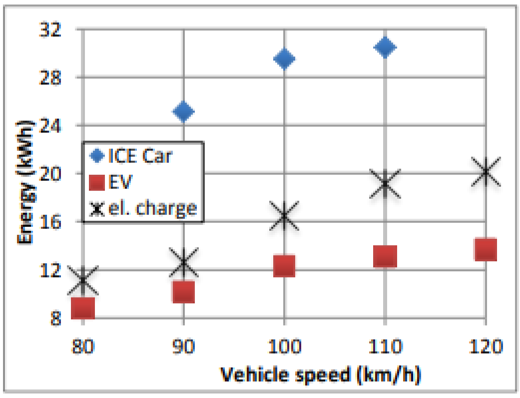


Fig. 27. Energy spent in EV and ICE cars, compared with electricity charged on EV.

From here we can see that even if we consider the electricity needed to charge the EV,still energy consumption in electric vehicle is much less than that of IC engine cars.

OTHER SCOPES OF RESEARCH FOR INCREASING THERMAL EFFICIENCY:

There are some more works going on this to improve thermal efficiencies.The following may be promising breakthrough technologies for improving the thermal efficiencies of reciprocating engines:

(1) New combustion systems for reducing NOx and PM simultaneously like pre-mixed compression ignition combustion.

(2) Friction-reduced by lubricant oil

(3) Synthetic fuel featuring improved thermal efficiency

(4) Mechanical, electrical and chemical technology of generating and recovering thermal and kinetic energies

(5) Transfer from fossil fuel to biomass fuel.

(6) A new system for better thermal exhaust heat recovery

(7) advanced injection timing in diesel engines

(8) Variable piston motion engines

(9) variable nozzle superchargers

(10) Electronic-controlled and high-pressure fuel injection

The fuel cell is an important breakthrough technology currently under examination. It is expected to be put into practical use from 2015 to 2020.

CURRENT BREAKTHROUGH ENGINES AND THEIR WORKING PRINCIPLE:

Formula I engines are the most efficient ones. Mercedes F1 team is usually at the technological forefront. Their latest 1,6-litre V6 turbo hybrid produces over 900 bhp and achieves more than 45 percent thermal efficiency. It can even harness heat energy in the exhaust downstream by sophisticated waste heat recovery system, thus achieving more than 50 percent efficiency.

To demonstrate how impressive this figure is, modern gasoline engines have usually a maximum thermal efficiency of 25% to 30%. That means a Formula I engine can extract almost twice as much useful energy from fuel than a conventional car engine!

As for serial production engines, latest Toyota engines are particularly impressive. Toyota exhibited a 2,8-litre diesel engine named “1GD-FTV” in 2015, achieving an efficiency of 44%. This is considered to be the highest in the world the biggest problem with the internal combustion engine is that most of the energy generated by combustion is wasted as heat rather than converted propulsion for the vehicle. Toyota's new Dynamic Force Engine has made a breakthrough in thermal efficiency in being 40 percent efficient as a conventional engine and 41 percent efficient in hybrid form. Most internal combustion engines are only 20 percent thermally efficient, according to *Green Car Reports*.

In addition to heat, the various systems required to run the engine all take energy that could potentially be put to use propelling the vehicle. In the Dynamic Force Engine, the sides of the pistons have been polished to a smooth mirror surface to reduce friction, with narrow grooves cross cut in it to improve scuff resistance. The cylinder head has been designed with a high-efficiency intake port. A high-power ignition coil is used to burn every last droplet of gas from the multi-hole direct injector. This engine uses a new version of Toyota's D-4S direct injection system, which has already been used on the Toyota 86 and Subaru BRZ twins for years.

Besides the obvious benefit of improved fuel economy, another major benefit of this engine is its enhanced torque. Not only does it produce more torque than the modern equivalent 2.0-liter engine, it begins generating that torque at a lower engine rpm. Horsepower numbers make flashy headlines, but high torque at low rpm is extremely useful in real-world driving, getting you off the line more quickly and easily.

Toyota has not yet said in what vehicles we can expect to see this engine equipped in the future. A fair bet may be anything economy-minded that currently runs a similarly sized engine, such as the Corolla.

The new 2.0-litre petrol engine, which peaks at 169bhp, will also offered with hybrid electric power. In this guise, it will match the Prius's 41% thermal efficiency but offers more performance thanks to its larger capacity.
This hybrid powertrain is expected to be introduced via the upcoming Auris, which is scheduled for reveal at the Geneva motor show next week.
It will be one of two hybrid powerplants offered in the new Auris, with the existing 1.8-litre hybrid powertrain remaining as the entry point, albeit in an updated form.

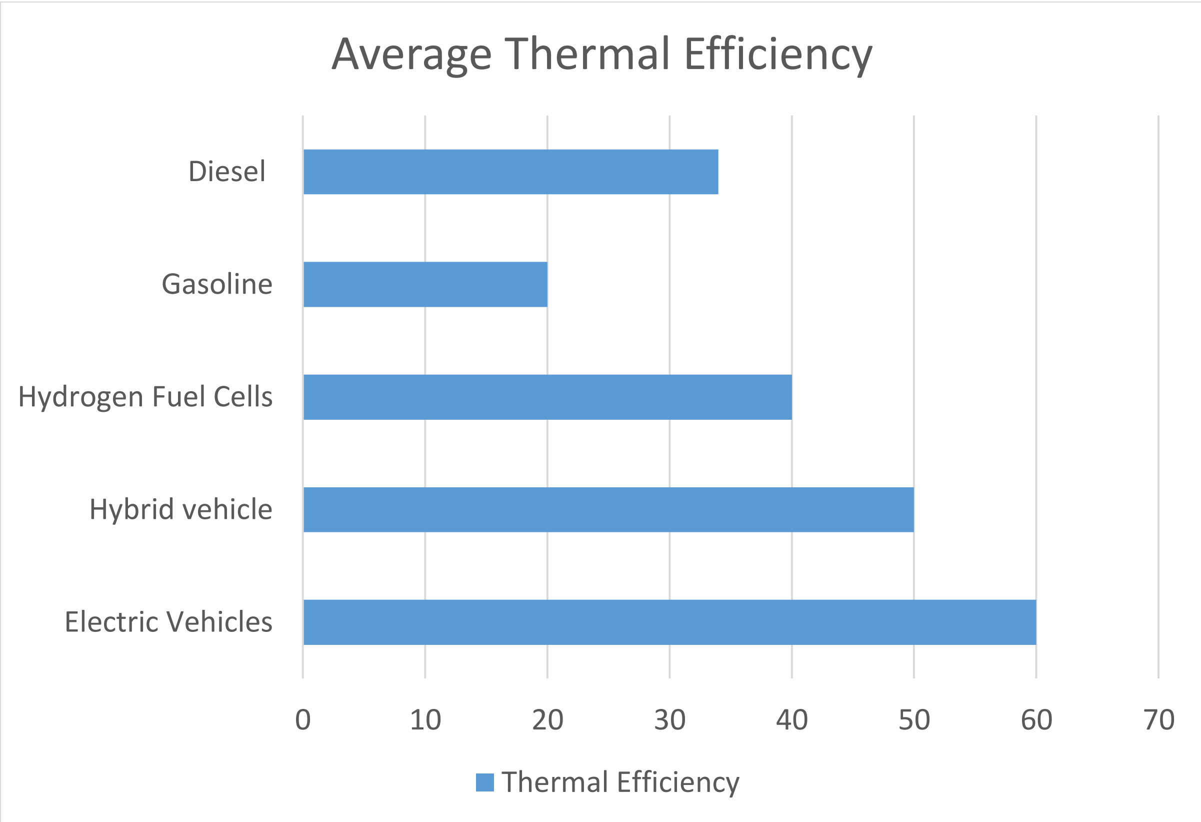
The expanded hybrid line-up created by the new 2.0-litre engine should partially fill the void left by the departed diesel Auris. Toyota dropped the diesel version of the Auris last year amid low demand, with just 651 examples sold in 2017.

Toyota has also developed a more efficient CVT gearbox that uses the world's first gear drive for initial acceleration. This essentially gives the gearbox the quicker off-the-line response of a standard automatic but enables the higher efficiency of a CVT when moving.

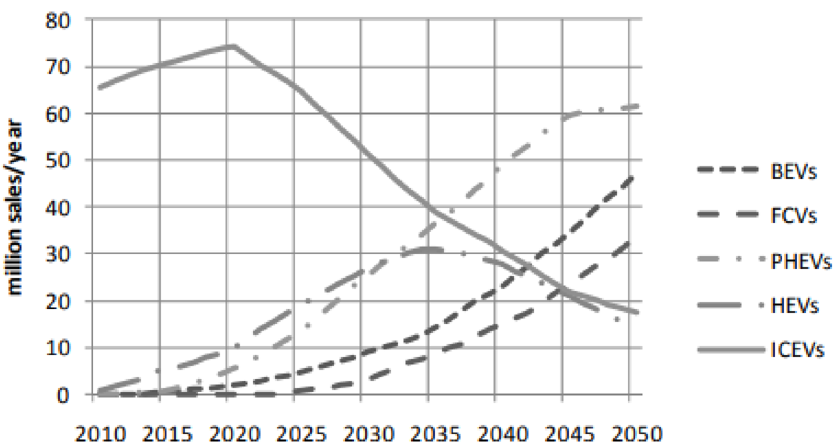
Meanwhile, Toyota has created a torque vectoring system for petrol all-wheel-drive models that can decouple the front axle for pure rear-drive. This system will be introduced into Toyota's all-wheel-drive and off-road models in the near future, with claims of improved fuel economy.

CONCLUSION:

From our study and analysis we have seen automobile engine performance for different kinds of engines. From the derived data we have found out the thermal efficiency of these engines.



So from this chart we can see that currently electric vehicles has the maximum thermal efficiency which is upto 60%. Calculating these data according to their weighted average value we can easily estimate the future of automobile industry is electric vehicles.



This graph clearly shows us an estimation of what is going to happen in next 30 years. The sales of internal combustion engine is going to fall rapidly, and a sharp rise will take place in the sales of Electric cars.Hydrogen fuel cars also can be a good alternative for their high thermal efficiency.

From our study we have also found out that another big scope to increase thermal efficiency is by using ELECTRIC TURBO COMPOUNDINGS. It can recover upto 30% of the lost heat and thus can enhance thermal efficiency significantly. Other factors like piston design, Intake nozzle design and Engine design can also help to increase thermal efficiency but due to metallurgical limitations and engine specifications they can not play a big role in increasing thermal efficiencies.

As global warming shows rapid progress at present, improvement of the engine thermal efficiency directly related to CO_2 reduction will possibly be accelerated by stronger external impacts. Thus, researchers and engineers in this field should be ready to take proper means of improving thermal efficiency at any time as society requires. Taking an example of passenger cars, if the thermal efficiencies of a car at operating-area in the case of fuel economy at 15 km/L is doubled, the car will run at 30 km/L with the same quantity of fuel, and CO_2 emission is halved. In 2025, new fuel cell cars and hybrid cars will be used widely, exhaust emissions will become cleaner, and CO_2 emissions from cars will be reduced by 20 to 30 %. As global warming shows rapid progress at present, needs for improvement of the engine thermal efficiency directly related to CO_2 reduction will become greater. Technical innovation in this field may progress earlier than prediction. But the main problem for research on this field is the difference between software analysis and practical happenings. Because engine efficiency depends on numerous practical factors which can’t be correctly and exactly replicated in software analysis, so research on this field is highly practical, mostly based on road tests. Nevertheless, We expect that more active discussions and researches will be done on this topic. Thus one day maybe we can reach our desired goal of getting a engine with minimal thermal energy loss.

References:

1. Clerk D. Limits of thermal efficiency in internalcombustion engines. J Am Soc Nav Eng 1907; 19(2): 494–499.

2. Sargent BE. Increasing automobile-engine thermal efficiency. SAE paper 160040, 1926.

3. Gibson HC. Bettering the efficiency of existing engines. SAE paper 200005, 1920.

4. Campbell JM, Caris DF and Withrow LL. Increasing the thermal efficiencies of internal-combustion engines. SAE paper 490202, 1949.

5. Lucas AG. Spark ignition engine progress. SAE paper 670199, 1967.

6. Turkish MC. Prechamber and valve gear design for 3-valve stratified charge engines. SAE paper 751004, 1975.

7. Tuttle JH and Toepel RR. Increased burning rates offer improved fuel economy-NOx emissions trade-offs in spark-ignition engines. SAE paper 790388, 1979.

8. Emmenthal KD, Hagemann G and Hucho WH. Turbocharging small displacement spark ignition engines for improved fuel economy. SAE paper 790311, 1979.

9. Muranaka S, Takagi Y and Ishida T. Factors limiting the improvement in thermal efficiency of S. I. engine at higher compression ratio. SAE paper 870548, 1987.

10. Zhecheng L, Brun M and Badin F. A parametric study of SI engine efficiency and of energy and availability losses using a cycle simulation. SAE paper 910005, 1991.

11. Okamoto K, Zhang F-R, Shimogata S and Shoji F. Development of a late intake-valve closing (LIVC) miller cycle for stationary natural gas engines: effect of EGR

utilization. SAE paper 972948, 1997.

12. De Sousa MT, Vianna JN and Fraga AG. Study of an engine operating with exhaust gas recirculation at different compression ratios. SAE paper 982895, 1998.

13. Thomas JF and Staunton RH. What fuel economy improvement technologies could aid the competitiveness of light-duty natural gas vehicles. SAE paper 1999-01-1511, 1999.

14. Wambsganss MW. Thermal management concepts for higher-efficiency heavy vehicles. SAE paper 1999-01-2240, 1999.

15. Macek J. Limits of internal combustion engines efficiency. J KONES Int Combust Engine 2005; 12: 201–209.

16. Kutlar OA, Arslan H and Calik AT. Methods to improve efficiency of four stroke spark ignition engines at part load. Energ Convers Manage 2005; 46: 3202–3220.

17. Ayala FA, Gerty MD and Heywood JB. Effects of combustion phasing, relative air-fuel ratio, compression ratio, and load on SI engine efficiency. SAE paper 2006-01-0229, 2006.

18. Farrell JT, Stevens JG and Weissman W. A second law analysis of high efficiency low emission gasoline engine concepts. SAE paper 2006-01-0491, 2006.

19. National Academy of Sciences. Real prospects for energy efficiency in the United States. Washington, DC: The National Academies Press, 2009.

20. Tey K-Y, Miller SL and Edwards CF. Thermodynamic requirements for maximum internal combustion engine cycle efficiency: part 1: optimal combustion strategy. Int J Engine Res 2008; 9: 449–465.

21. Tey K-Y, Miller SL and Edwards CF. Thermodynamic requirements for maximum internal combustion engine cycle efficiency: part 2: work extraction and reactant preparation strategies. Int J Engine Res2008; 9: 467–481.

22. Daw CS, Graves RL, Wagner RMand Caton JA. Report

on the transportation combustion engine efficiency colloquium.
Report no. ORNL/TM-2010/265, March 2010.

23. Lavoie GA, Ortiz-Soto E, Babajimopoulos A, Martz JB and Assanis DN. Thermodynamic sweet spot for highefficiency, dilute, boosted gasoline engines. Int J EngineRes 2013; 14(3): 260–278.

24. Foster DE. Pragmatic efficiency limits for internal combustion engines. Technical reports, readout no 42, July 2014. Kyoto, Japan: HORIBA.25. Lustgarten GA. The latest Sulzer marine diesel enginetechnology. SAE paper 851219, 1985.

[25]L.Jian, H.Xue, G.Xu, X.Zhu, D.Zhao, Z.Y.Shao, “Regulated Charging of Plug-in Hybrid Electric Vehicles for Minimizing Load Variance in Household Smart MicroGrid,” IEEE Transactions on Industrial Electronics, vol. 60, pp. 3218-3226, Aug. 2013.

[26]V. Monteiro, H. Gonçalves, João L. Afonso, “Impact of the Electric Vehicles on the Power Quality in a Smart Grid Context,” IEEE EQPU 11th International Electrical Power Quality and Utilization Conference, Lisbon Portugal, pp. 1-6, Oct. 2011.

[27]J. McDowall, “Conventional battery technologies-present and future,” IEEE Power Engineering Society Summer Meeting, pp. 1538-1540, 2000.

[28]A.Emadi, Y.J.Lee, K.Rajashekara, “Power Electronics and Motor Drives in Electric, Hybrid Electric, and Plug-In Hybrid Electric Vehicles,” IEEE Transactions on Industrial Electronics, vol. 55, pp. 2237-2245, 2008.

[29]V. Monteiro, J. C. Ferreira, G. Pinto, D. Pedrosa, João L. Afonso, “iV2G Charging Platform,” IEEE ITSC 13th International Conference on Intelligent Transportation Systems, Madeira Portugal, pp. 409-414, Sept. 2010.

[30]W. Kempton and J. Tomic, “Vehicle-to-grid power fundamentals: Calculating capacity and net revenue,” Journal of Power Sources, vol. 144, pp. 268-279, 2005.

[31]B. Kramer, S. Chakraborty, and B. Kroposki, “A review of plug-in vehicles and vehicle-to-grid capability,” IECON 2008 - 34th Annual Conference of IEEE Industrial Electronics, pp. 2278-2283, 2008.

[32]V. Monteiro, H. Gonçalves, J. C. Ferreira, João L. Afonso. “Batteries Charging Systems for Electric and Plug-In Hybrid Electric Vehicles,” New

Advances in Vehicular Technology and Automotive Engineering, 1st ed., J.P.Carmo and J.E.Ribeiro, Ed. InTech, 2012, pp. 149-168, ISBN 978-953-51-0698-2, http://dx.doi.org/10.5772/2617.

[33]Bimal K. Bose, “Energy, Environment, and Advances in Power Electronics,” IEEE Transactions on Power Electronics, vol. 15, pp. 688-701, July 2000.

[34]S. G. Wirasingha, R. Gremban, A. Emadi, “Source to Wheel (STW) Analysis of Plug in Hybrid,” IEEE Transactions on Smart Grids, vol. 3, pp. 316-331, Mar. 2012.