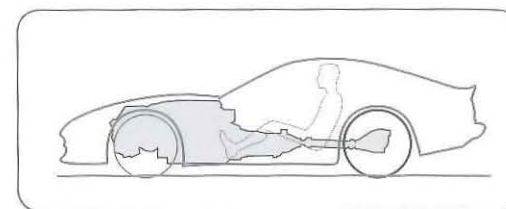


"The powertrain is one of the most influential systems on the architecture, due to its size and weight. Battery electric, hybrid and revolutionary powertrains create opportunities to reinvent architectures for more efficiently packaged vehicles."

POWERTRAIN ANATOMY

THE BASIC ANATOMY OF THE INTERNAL COMBUSTION ENGINE (I.C.E.) POWERTRAIN

The simplified graphic below shows a side view of a conventional, longitudinal, front-engine, rear-wheel-drive layout. Other internal combustion engine configurations can look completely different but contain the same basic elements.



THE ENGINE

These come in many different sizes and configurations but they are made up from similar components: the cylinder block, cylinder head, oil pan (sump), pistons, crankshaft, flywheel, induction system, exhaust manifold, starter motor, accessory drives and several other auxiliary components. Due to its size, weight and relationship to the wheels it is one of the most influential components in the package.

FUEL TANK

The volume will depend on the size and range of the vehicle. The main factor to consider for fuel-tank packaging is its protection during a high-speed impact.

TRANSMISSION

Manual or automatic transmissions are usually attached to the end of the engine to feed the power at various speeds to the final drive. The clutch (manual) or torque converter (automatic) is sandwiched between the engine and transmission.

COOLING

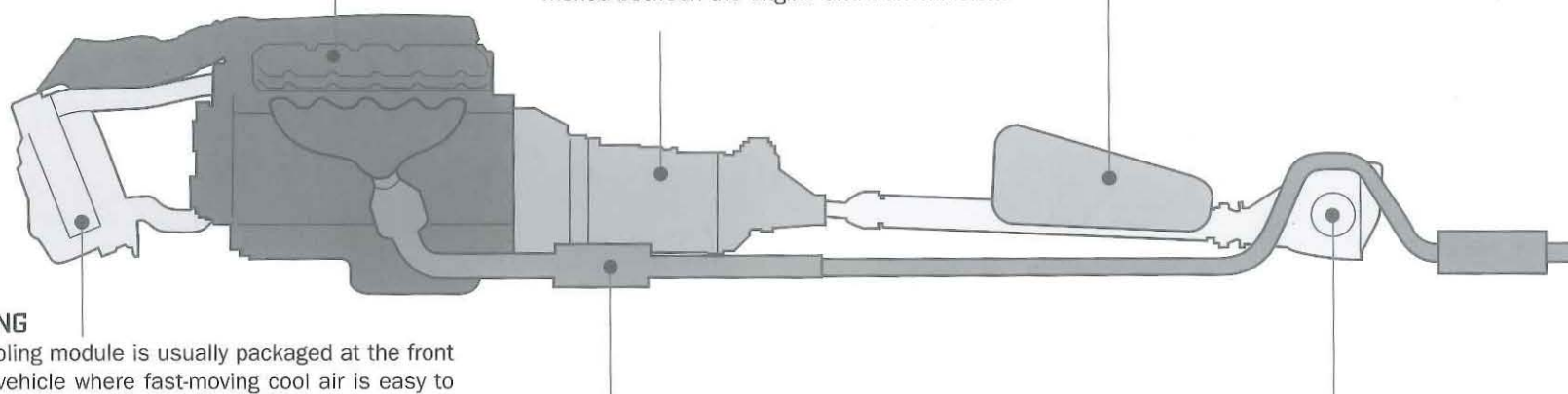
The cooling module is usually packaged at the front of the vehicle where fast-moving cool air is easy to access. Cooling modules are sized according to the engine power and loading capacity. Often other coolers for oil, air conditioning, transmissions and intercoolers are packaged together with the engine cooler, creating quite a large volume that needs to be placed where there is airflow.

EXHAUST

Exhaust packaging is not usually the focus of early package studies, but large components in the system such as catalytic converters and silencers should be given some thought.

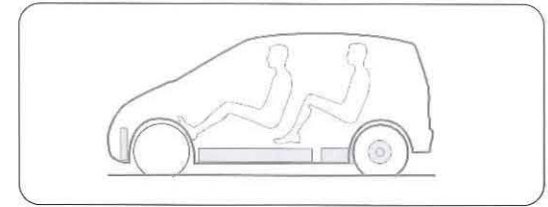
FINAL DRIVE

This comprises the drive shafts, differentials and transfer case (for 4WD). Their motion, linked to suspension travel, should be considered during the initial package study.



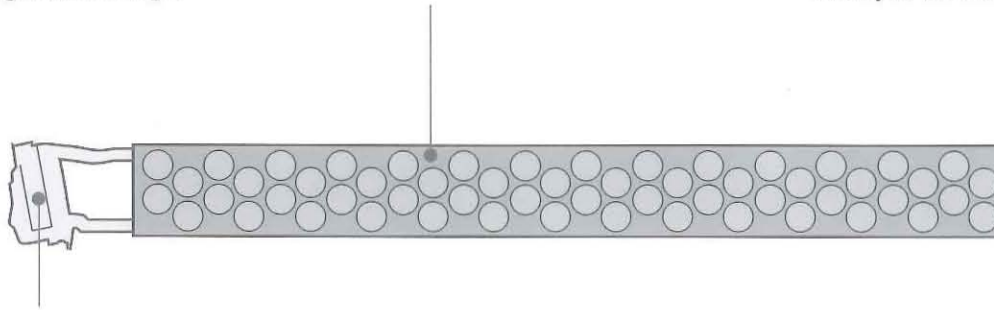
THE BASIC ANATOMY OF AN ELECTRIC POWERTRAIN

Packaging an electric system requires a different attitude to a conventional powertrain. Here the motors are relatively small but the energy or fuel-storage systems are quite large in comparison to those of internal combustion systems. The main thing to take advantage of is the low-profile potential for these components. If the system can be packaged under the floor, for instance, it allows the designer the opportunity to reduce the overall length of the vehicle and change the exterior proportions.



BATTERIES / FUEL CELL

The electric power can be stored in batteries or created by a fuel cell. The batteries can be made from various materials based on cost versus power density requirements. The fuel-cell system consists of several components including the fuel stack, compressor and hydrogen fuel storage.

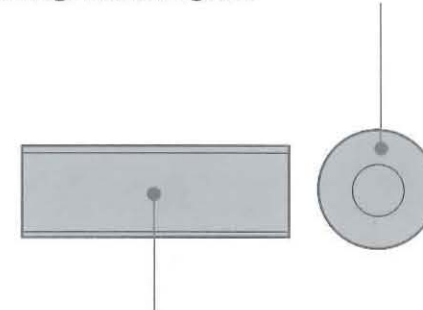


COOLING

Although electric systems are far more efficient than internal combustion engines, they still generate heat which needs to be dissipated.

THE MOTOR & FINAL DRIVE

Electric motors are very powerful for their size and develop a lot of torque at low revs. This allows them to be packaged easily on the axle or at each wheel and also eliminates the need for a conventional transmission. The final drive (shafts) and differential can be attached directly to the motor through reduction gears.



ELECTRONIC CONTROLLERS

The energy from the power source (batteries, fuel cell or generator) must be processed and fed into the electric motors. The control systems that do this can be surprisingly bulky but they can be put somewhere conveniently out of the way.

SELECTING A POWERTRAIN

The powertrain is the system that provides and transmits power to the wheels. Historically, the vast majority of cars have used an internal combustion engine (I.C.E.) and some kind of mechanical system of gears and shafts that connect the engine to the driven wheels. In the future we may see a greater variety of powertrains available such as electric motors with batteries or hydrogen fuel cells or combinations of systems (hybrids).

Choosing a powertrain is often a complex task, so look closely at the functional objectives before laying out the engine, transmission, and final drive system. Give the following criteria close consideration:

What “type” of power is required to meet the functional objectives?

Some vehicles will require a lot of power, others only a little. High amounts of torque will be needed to tow or carry heavy loads, favoring large gasoline engines or diesels. Brake-horse-power (BHP) will be a priority for performance cars, sometimes requiring higher revving ability and efficiency rather than outright engine size. Luxury cars focus on quiet, smooth powertrains with good acceleration, while environmental concerns encourage powertrains that are clean and fuel-efficient.

What powertrains are available?

Developing internal combustion engines and transmissions takes a long time and is expensive, so each manufacturer generally already has their own limited but strategic range from which to choose. Sometimes a manufacturer will develop an engine with a competitor to save costs. As the industry moves away from internal combustion engines, it is likely that the manufacturers will source powertrains from their suppliers rather than develop them themselves.

What is the main priority for the package?

The functional objectives will influence the priorities of the package. For some cars, power and performance are a high priority so the powertrain may dominate the architecture. For others the passengers and cargo may be the most important consideration so the engine and transmission layout will be driven by package efficiency (see the opposite page).

What are the constraints of the package?

Powertrains take up a lot of space, particularly conventional internal combustion engines and mechanical transmissions, so finding room for them can be challenging. Some packages can be designed around large components but often dimensional constraints will limit the size of the engine and limit the final drive options.

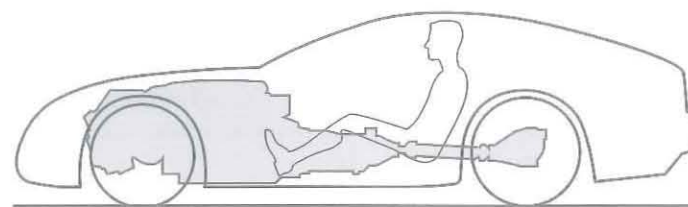
What are the traction requirements?

The final drive system distributes the power to the wheels, so this part of the powertrain will be influenced by traction requirements. Front-wheel-drive cars gain an advantage because the weight of the engine is directly over the wheels. Rear-wheel-drive cars work well when loaded or under acceleration but usually require the transmission to pass along the center of the vehicle, through the passenger compartment. Driving all four wheels is ideal but a more expensive and heavier solution. Vehicles designed for off-road use or for operation in hostile climates may require special all-wheel-drive (AWD or 4WD) configurations, which usually intrude into the occupant package more than a 2WD layout.

POWERTRAIN PRIORITIES

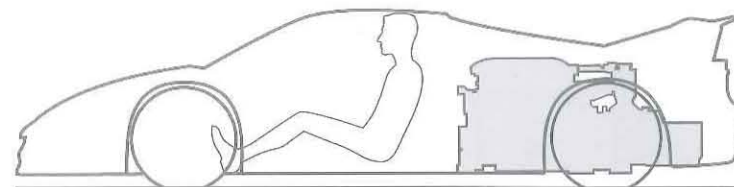
POWER

High-performance cars often use their engine to make a bold statement. In this package the power train dominates the side view and has a dramatic effect on the proportions, exterior design and occupant package.



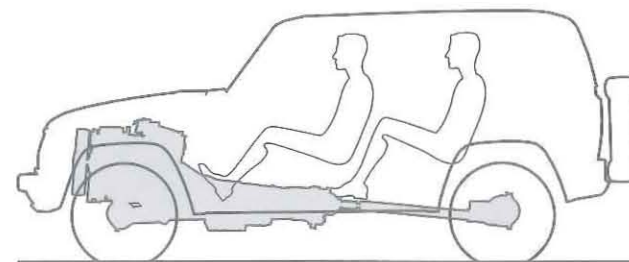
WEIGHT DISTRIBUTION & AERODYNAMICS

A mid-rear engine package works well when very high speeds and handling are critical. This layout allows the designer to distribute the weight of the major components closer to the middle of the wheelbase. This reduces the polar moment of inertia, allowing the car to change directions more quickly. Because there is no engine up front, the hood can be lowered for better air penetration and forward visibility.



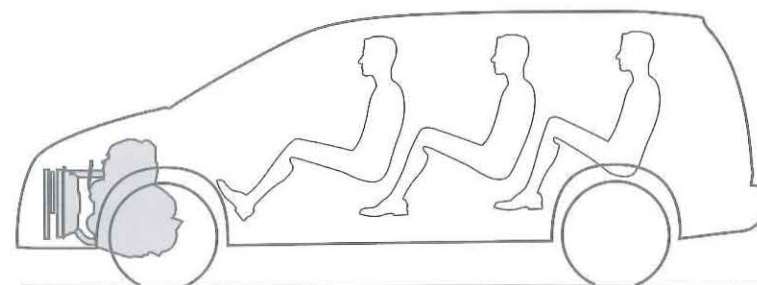
TRACTION & TORQUE

For serious off-road vehicles, traction takes a high priority, so durable 4WD systems coupled to motors with low speed/high torque characteristics are a requirement. This usually results in a tall powertrain with a large center tunnel between the front occupants.



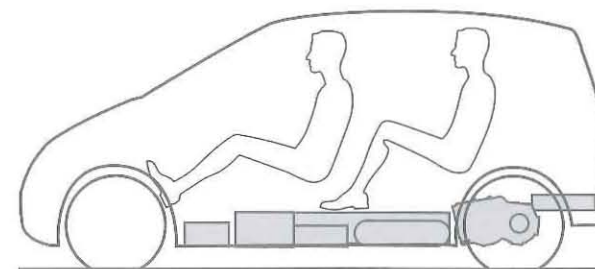
OCCUPANTS & CARGO

Minivans require a very efficient package and put great emphasis on the occupants. The transverse engine and transmission occupy only a small portion of the architecture. Because all of the powertrain components are in front of the occupants' feet, the entire floor can be designed flat.



ENVIRONMENT

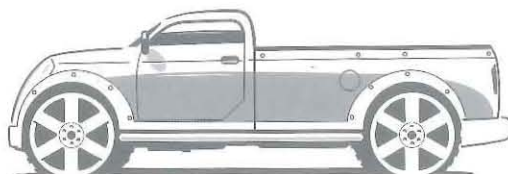
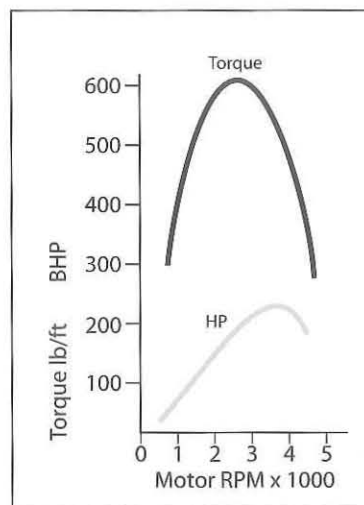
Alternative propulsion systems are being developed to help reduce harmful emissions, but their size and proportion also create new packaging opportunities. Generally, the motor and transmission are a fraction of the size of conventional internal combustion engine powertrains, but the fuel systems (batteries and fuel cells) are considerably larger compared with gasoline fuel tanks. Because no one component is large in all directions, the entire powertrain can usually be packaged under the floor.



POWER CHARACTERISTICS

Before specifying the engine and transmission, the power requirements should be studied. The type of power will depend of the type of functions the vehicle has to perform.

Engine power or torque is measured at the (rotating) crankshaft in pound/foot (lb/ft) or Newton meters (Nm). This is multiplied by the engine speed (revolutions per minute or RPM) to give the total power output which is measured in Horsepower (HP) or Kilowatts (kW).



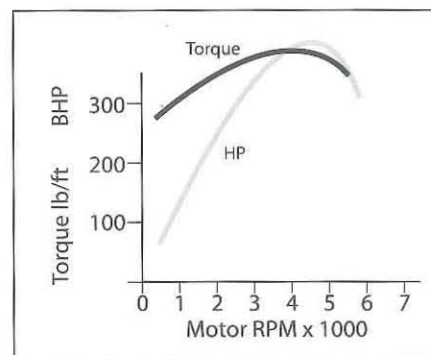
TYPICAL HEAVY-DUTY TRUCK ENGINE

Engine Size	7.0 liters - In-line 6
Max HP	250 @ 3500rpm
Max Torque	600 @ 2500rpm

Vehicle weight	6000kg
Towing capacity	8000kg
Acceleration 0-60mph	12 sec.

The curve graphs (below) illustrate the different power output characteristics of various motors. For a large vehicle to have smooth acceleration or carry heavy loads uphill, it needs an engine with high torque. To maintain a high speed, a higher revving engine is required with more brake horsepower (BHP).

Brake horsepower is the power as measured at the end of the crankshaft, at the engine; unlike horsepower which is the power measured at the wheels...or, historically, at the back end of a horse.



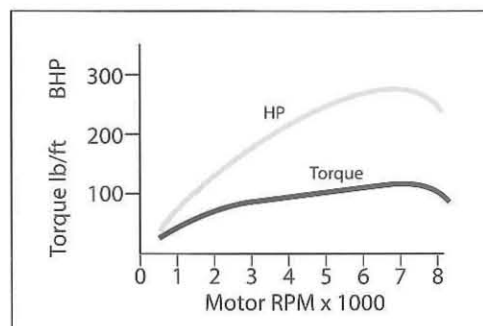
TYPICAL SUV / LARGE CAR ENGINE

Engine Size	5.0 liters - V8
Max HP	375 @ 5000rpm
Max Torque	350 @ 4000rpm

Vehicle weight	3500kg
Towing capacity	5000kg
Acceleration 0-60mph	8.0 / 6.0 sec.

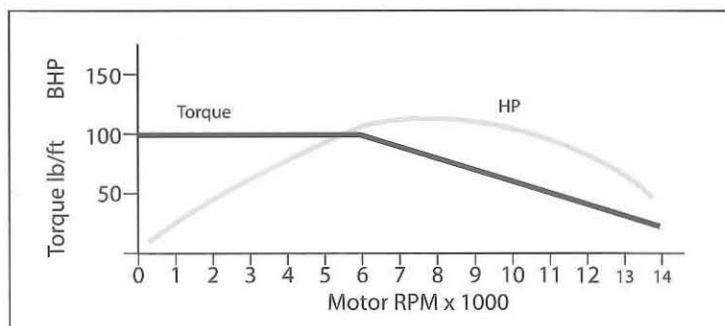
It is quite simple to choose an engine based on the vehicle function. A few other factors may also affect the engine choice such as package space, cost, fuel consumption, emissions, sound and smoothness.

The far-left graph illustrates a typical heavy-duty truck engine. It may be expected to carry and tow very heavy loads so it needs very high torque at low revs. The other graphs show how the relationship between torque and HP changes as the weight of the vehicle reduces and speed and handling become more important.



TYPICAL SMALL PERFORMANCE CAR ENGINE

Engine Size	2.0 liters - In-line 4
Max HP	250 @ 5000rpm
Max Torque	120 @ 4000rpm
Vehicle weigh	1200 kg
Towing capacity	n/a
Acceleration 0-60mph	6.0 sec.



TYPICAL ELECTRIC MOTOR

Engine Size	110 kW (peak)
Max HP	220 @ 8000rpm
Max Torque	200 @ 0-6000rpm
Vehicle weight	1200kg
Towing capacity	n/a
Acceleration 0-60mph	4.0 sec.

I.C. ENGINE CONFIGURATIONS

The number of cylinders and their configuration will depend on several factors. Cost, power, package space, weight distribution and vibration are the main considerations behind each selection.

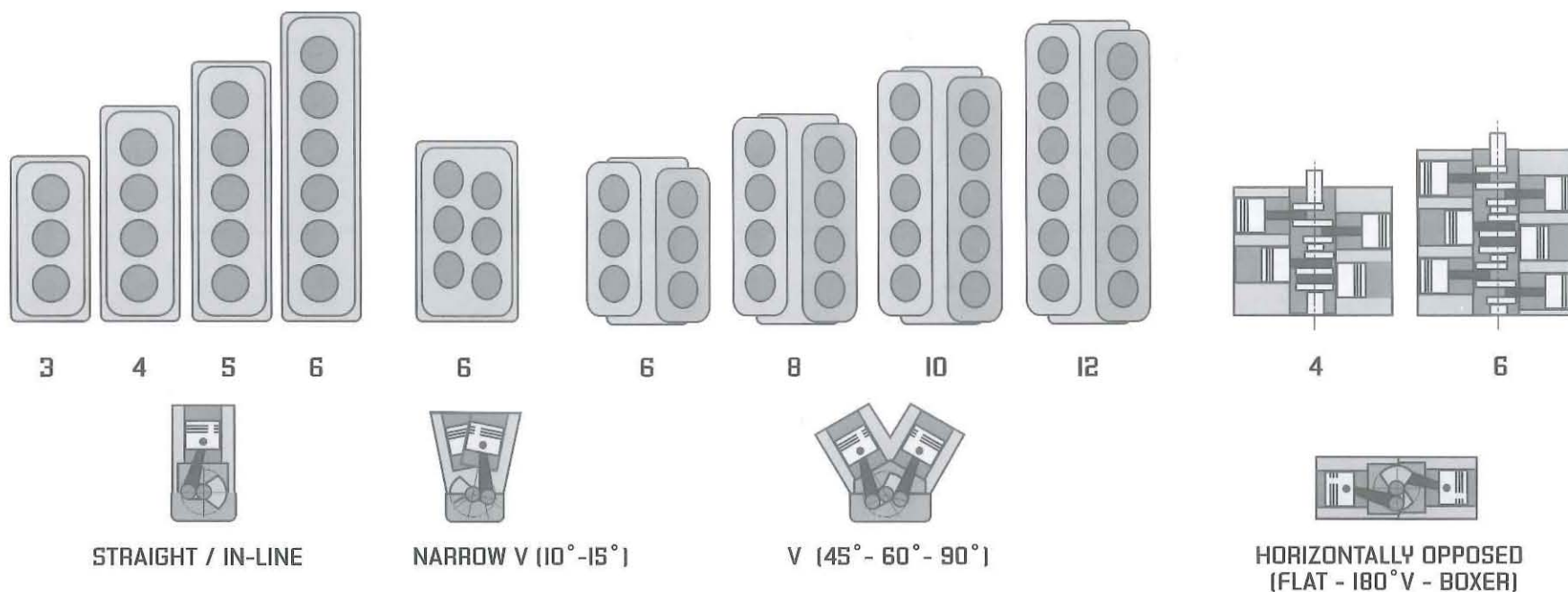
Smaller engines tend to have fewer cylinders, which are usually arranged in straight-line configurations (in-line). As engines get larger to produce more power, the number of cylinders increases, keeping the piston size to a minimum. With an increase in cylinders the configuration may change from in-line to a "V" formation to minimize the engine length. Some engines flatten the V out to become

"horizontally opposed" or "boxer" engines. This not only shortens the engine but decreases its height which is very useful to help lower the center of gravity and hood or deck height.

Short engines (in-line fours and V sixes) are often used in transverse applications (mounted across the car) where the designer is trying to keep the vehicle length short. The longer engines (straight sixes and V eights) usually need to be placed in a longitudinal orientation generally requiring them to drive the rear wheels.

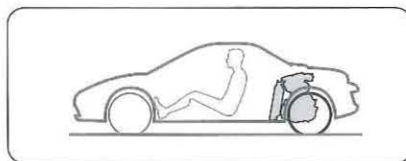
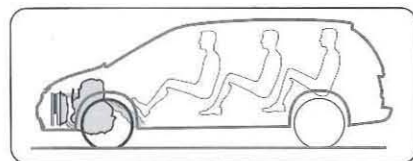
CYLINDER & BLOCK CONFIGURATIONS

The blocks are configured to help the vehicle meet its functional objectives by either improving the package, performance or comfort. Larger engines have more cylinders to minimize the size and reciprocating mass of the pistons.



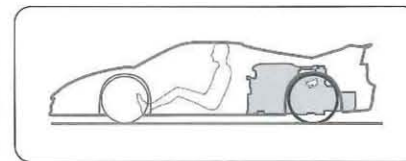
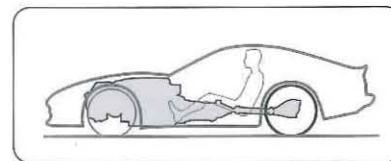
PROPORTIONS INFLUENCED BY ENGINE LENGTH

Below are four examples illustrating how the number of cylinders and engine length may influence the overall size and proportions.



TYPICAL SHORT ENGINE APPLICATIONS

In-line four or V-six engines are often used on vehicles where package efficiency or minimizing overall size is a priority.

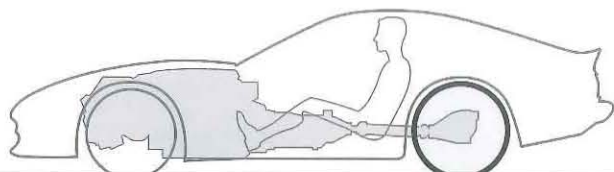


TYPICAL LONGER ENGINE APPLICATIONS

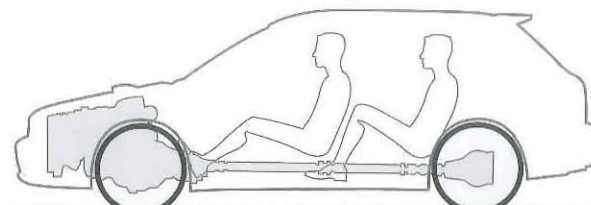
Larger engines are used when power is a priority. The vehicle proportions are quite different to the cars with smaller engines.

POWERTRAIN LOCATIONS AND ORIENTATION

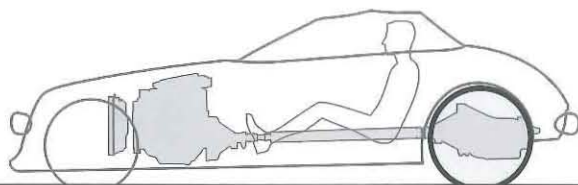
The internal combustion engine has been used in just about every possible location and orientation. Each configuration has its strengths and weaknesses being chosen to meet specific functional objectives like power, package efficiency, traction or weight distribution. Here are some examples of typical production-vehicle solutions.



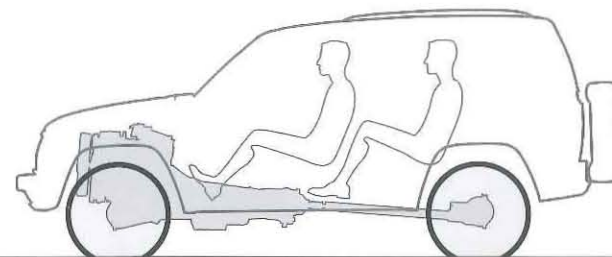
Mid-Front Longitudinal Engine - RWD



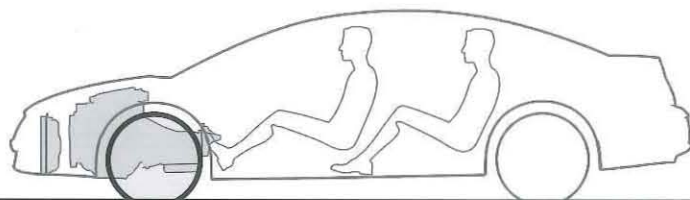
Front Longitudinal Engine - AWD



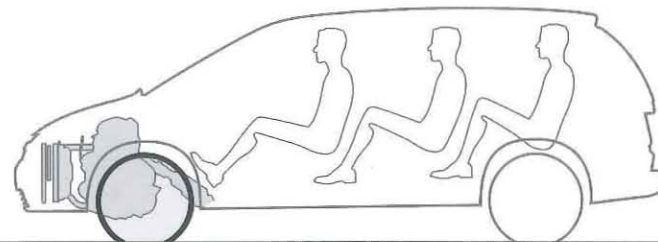
Mid-Front Longitudinal Engine - RWD
(Rear Transmission)



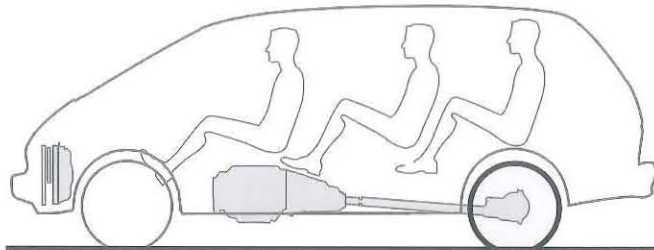
Front Longitudinal Engine - 4WD



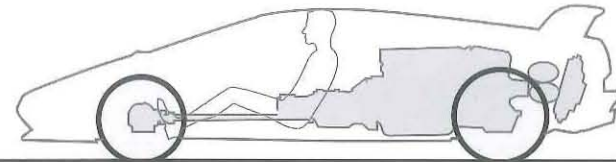
Front Longitudinal Engine - FWD



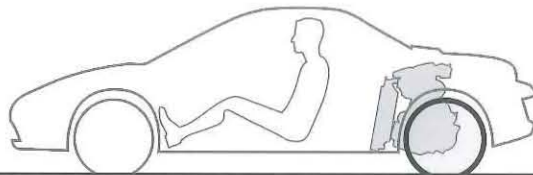
Front Transverse Engine - FWD



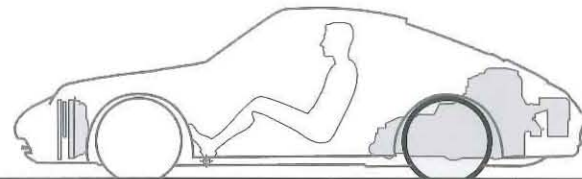
Under Floor Longitudinal Engine - RWD



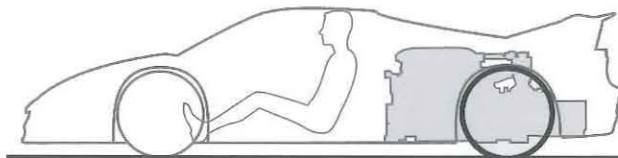
Mid Longitudinal Engine - AWD



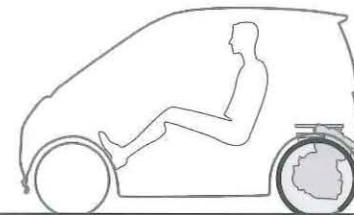
Mid Transverse Engine - RWD



Rear Longitudinal Engine - RWD



Mid Longitudinal Engine - RWD



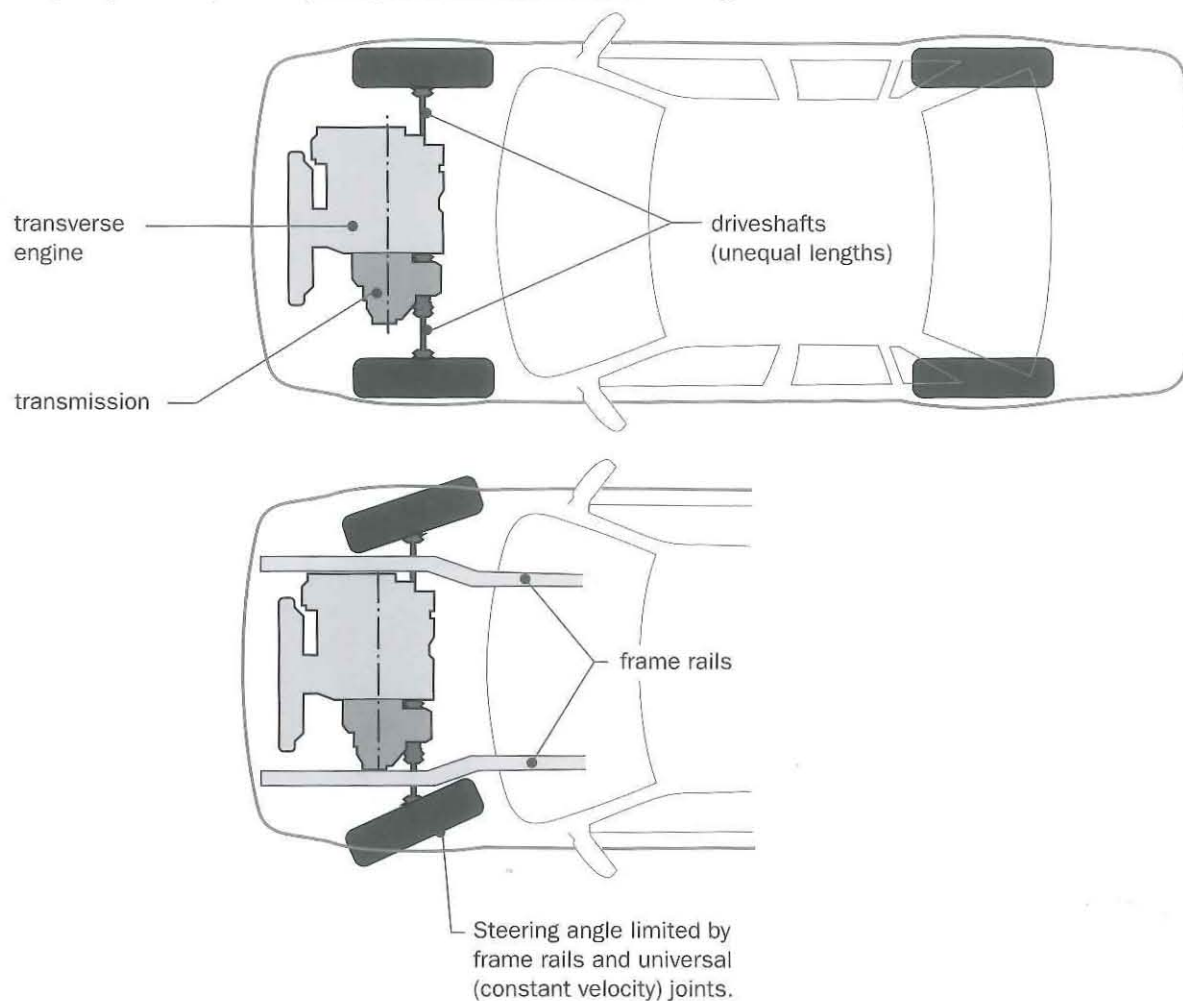
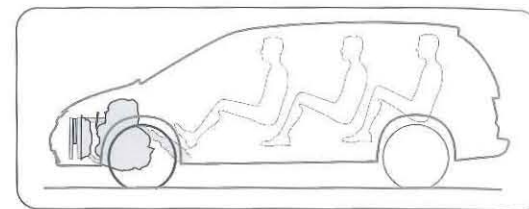
Rear Transverse Engine - RWD

FRONT TRANSVERSE ENGINE - FRONT-WHEEL DRIVE

One of the most popular configurations for passenger cars over the last 25 years. This is a very space-efficient layout, which can be mounted to the body with the powertrain and suspension pre-assembled. It is ideal for small economy cars or large minivans where passenger space is a priority. This layout is also used on most standard midsize cars.

The width between the front frame rails can limit the length of the engine, making this layout unsuitable for luxury cars. The offset transmission also causes the driveshaft length to be shortened on one side, limiting suspension travel. The shorter driveshaft also requires the spindle location to be close to the transmission output shaft in side view so the engine location is governed by the front wheel center.

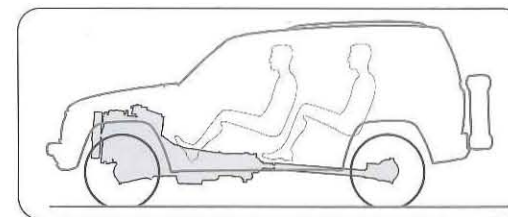
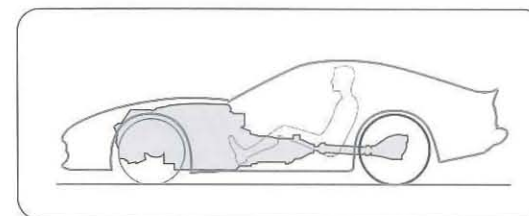
This configuration is easily adapted to a parallel hybrid system with little overall size change.



FRONT LONGITUDINAL ENGINE - REAR-WHEEL DRIVE & 4WD

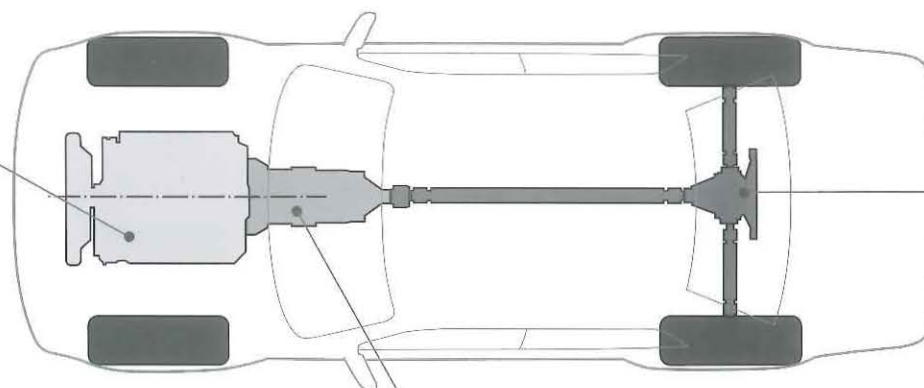
This traditional layout was introduced in the late 1800s and is still used on the vast majority of pickup trucks, luxury passenger cars and sports cars. The longitudinal orientation allows for larger (longer) engines to be installed between the frame rails without restricting the steering angles, helping to reduce turn circles on vehicles with longer wheelbases. Because the engine is not linked directly to the driven wheels it can be positioned for optimum weight distribution. The manual gear shift can also be directly linked to the transmission for crisp gear changes.

Final drive can be through a fixed differential or articulating solid axle. Four-wheel drive is achieved through a transfer case and additional driveshaft to the front axle. The longer driveshafts also allow for greater suspension articulation for off-road vehicles.



RWD

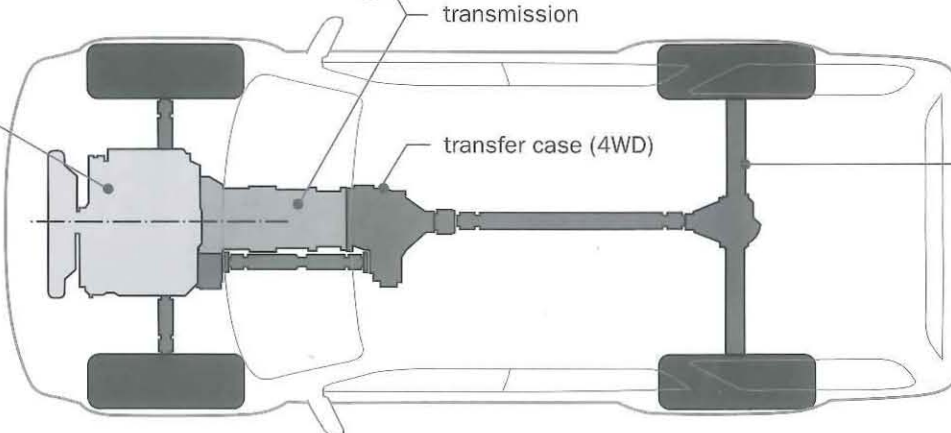
longitudinal engine



fixed differential

4WD

longitudinal engine



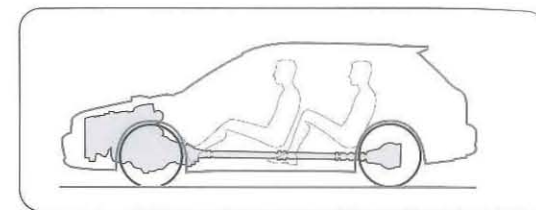
transmission

transfer case (4WD)

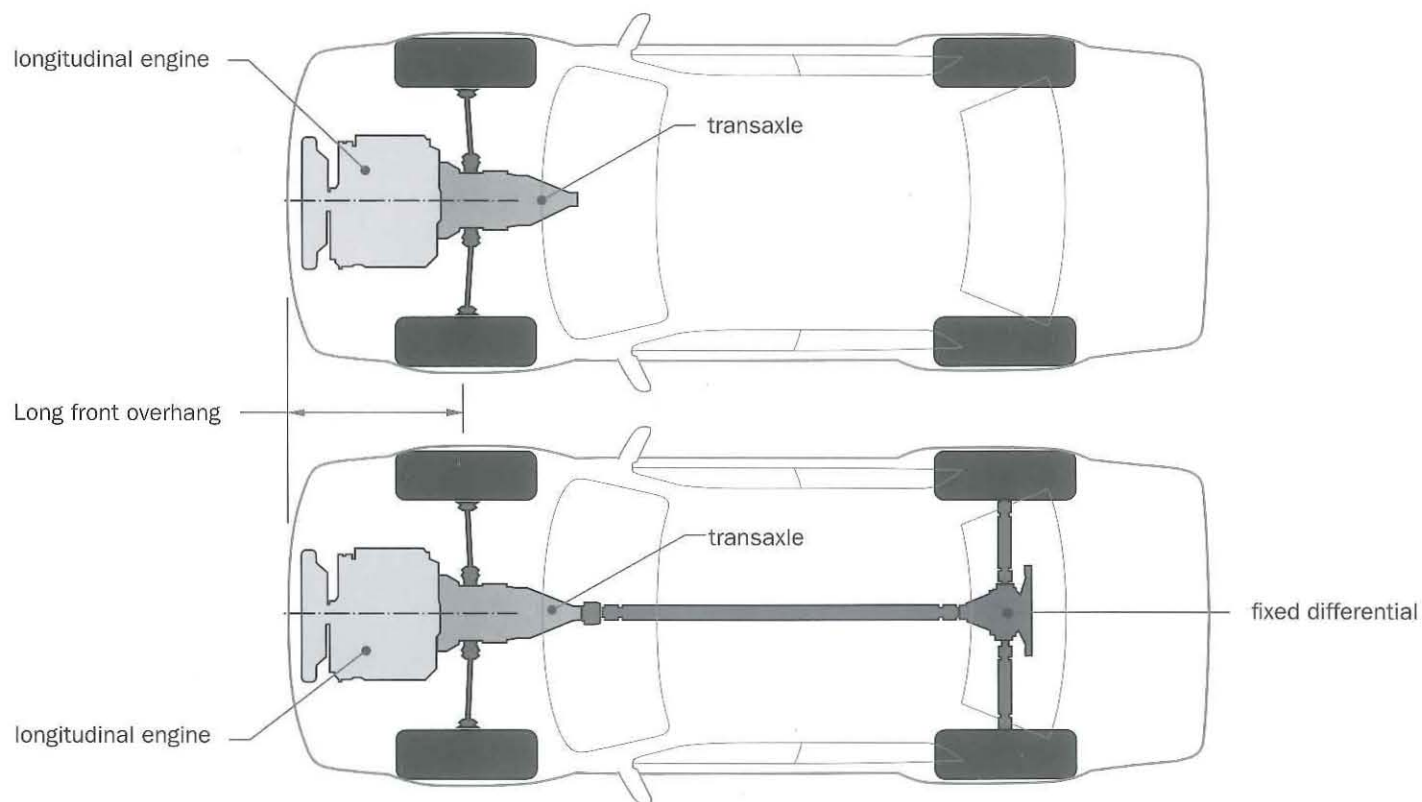
solid live axle

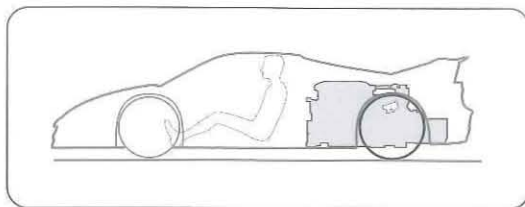
FRONT LONGITUDINAL ENGINE - FRONT-WHEEL DRIVE & AWD

This configuration is usually adopted by manufacturers who specialize in AWD passenger cars. It provides a lightweight, efficient way of getting drive to all four wheels. The main drawback of this configuration is the long front overhang caused by the relationship of the transmission to the front spindle. Unlike the transverse engine, the driveshafts are equal lengths and longer, allowing for more flexibility in engine location, but driveshaft angles are still limited.



The fixed differential reduces the "unsprung weight," helping to improve handling over solid axle configurations.

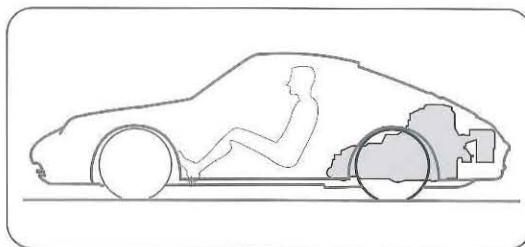




MID-REAR LONGITUDINAL ENGINE REAR-WHEEL DRIVE & AWD

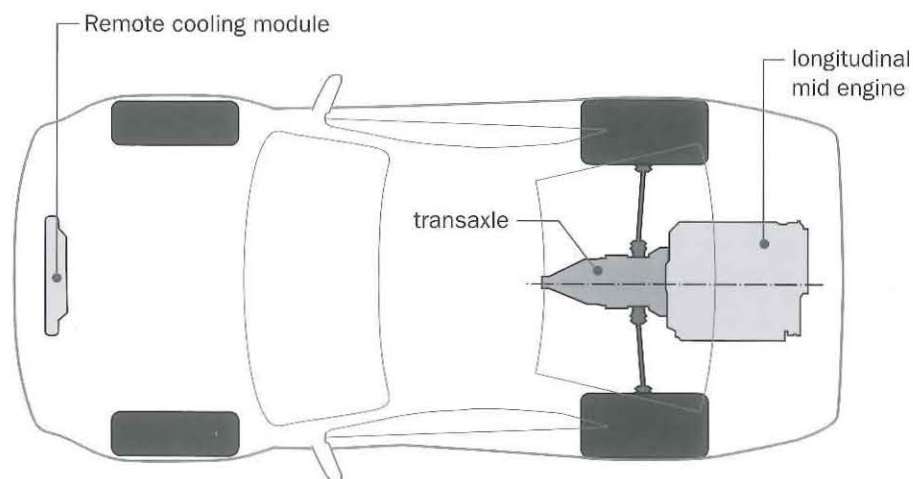
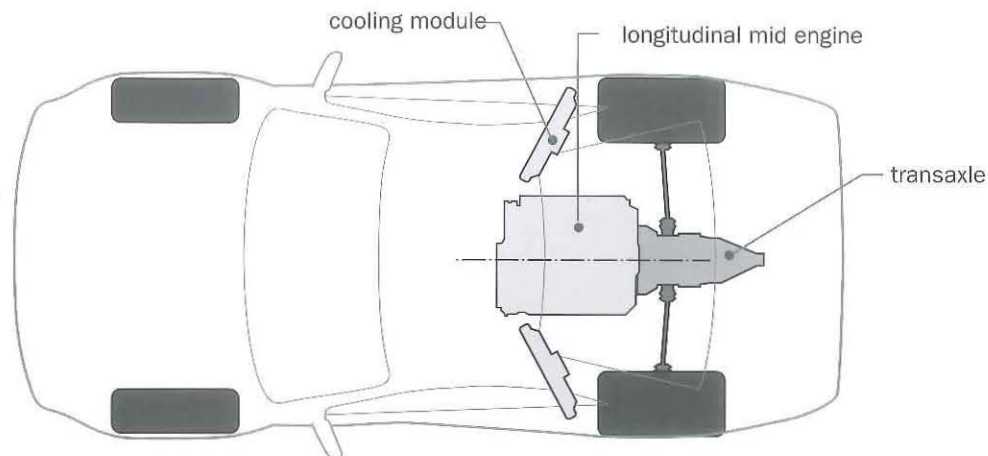
This configuration is best suited to high-performance sports cars. Having the engine mounted longitudinally ahead of the rear wheels optimizes the weight distribution for handling and cornering capabilities but eliminates the possibility of rear passengers. All-wheel drive is also possible with this layout.

When the powertrain is located toward the rear of the vehicle, the cooling modules can be located remotely at the front or adjacent to the engine, usually in front of the rear tires. This will affect the location of the breathing apertures which will significantly affect the exterior design.



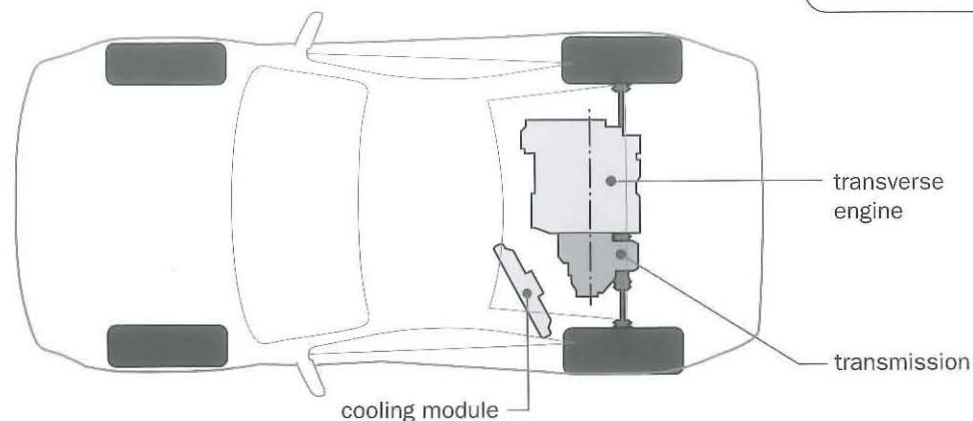
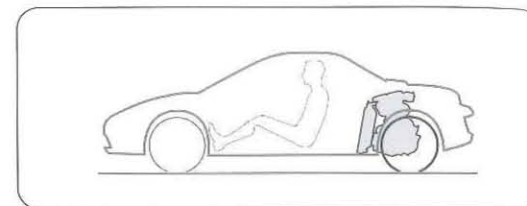
REAR LONGITUDINAL ENGINE REAR-WHEEL DRIVE & AWD

Once favored by many European makers for low-powered family cars, this layout is rarely used today. The rear-weight bias can make for tricky handling at the extreme, although electronic traction controls and tire technology have made rear-engine cars more forgiving to drive. Traction for acceleration though, is supreme. All-wheel drive is easy with this layout. Luggage accommodation under the hood and some rear passenger space are possible with this configuration.



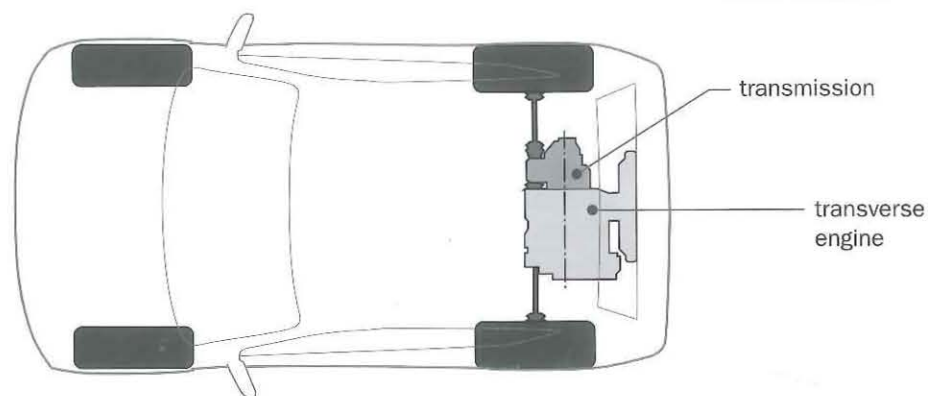
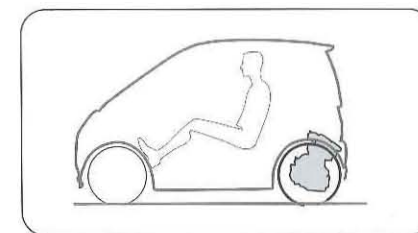
MID TRANSVERSE ENGINE - REAR-WHEEL DRIVE

The mid transverse layout is often used on small sports cars. Engine size is limited by the track width, so these are usually found in lightweight, performance cars. The powertrains are often adapted from front-wheel drive vehicles. This provides great weight distribution in a car with a short wheelbase.



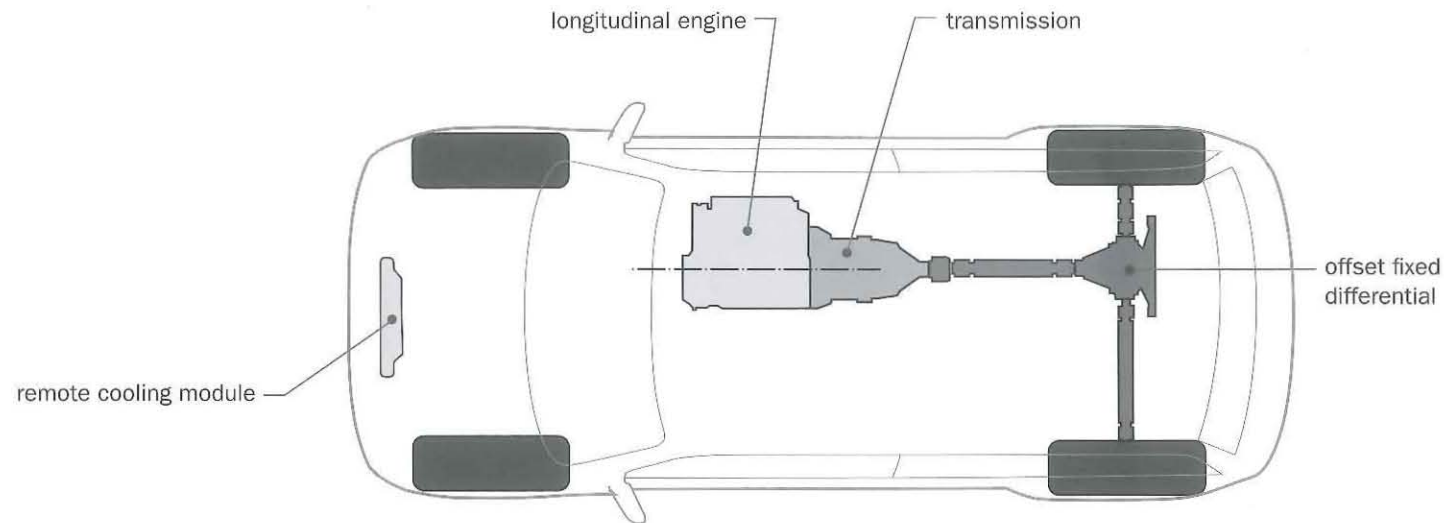
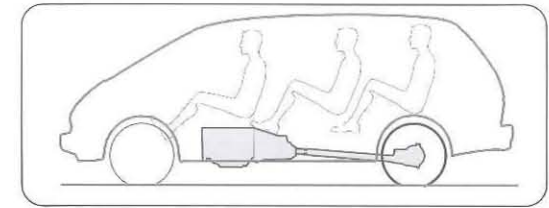
REAR TRANSVERSE ENGINE - REAR-WHEEL DRIVE

Rear transverse engine layouts are applied when space (length) is critical. It is ideal for micro cars where the engine size is small enough to package behind/under the driver seat, helping to reduce the length of the vehicle in front of the driver's feet. Frontal impact targets require vehicles to have free crush space between the bumper and driver's feet. Taking the engine out of the crush zone helps to create a more efficient package.



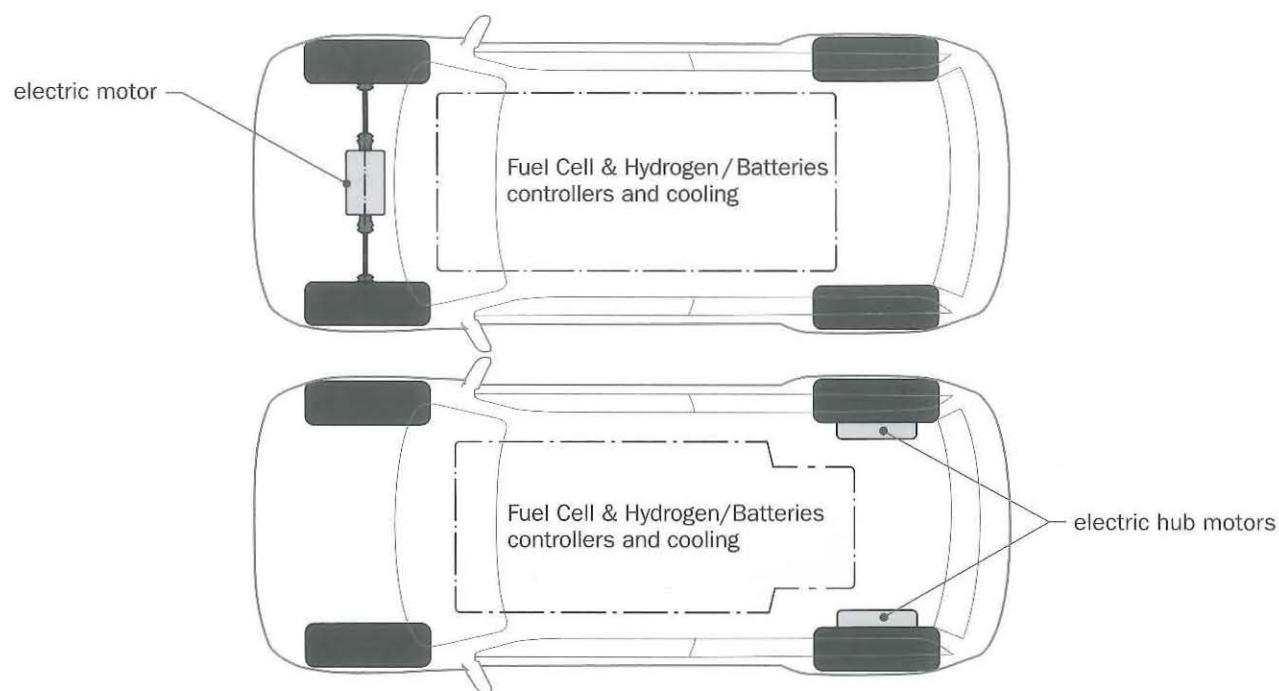
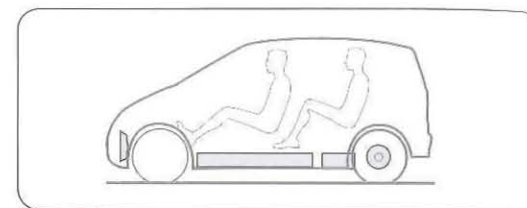
MID UNDER-FLOOR ENGINE - REAR-WHEEL DRIVE

This layout is used for space efficiency more than weight distribution and is usually applied to micro-utility vehicles. The engine is packaged under the passenger seat, which restricts its size and limits the weight of the vehicle. Access for maintenance can be an issue. AWD is possible through a transfer case.



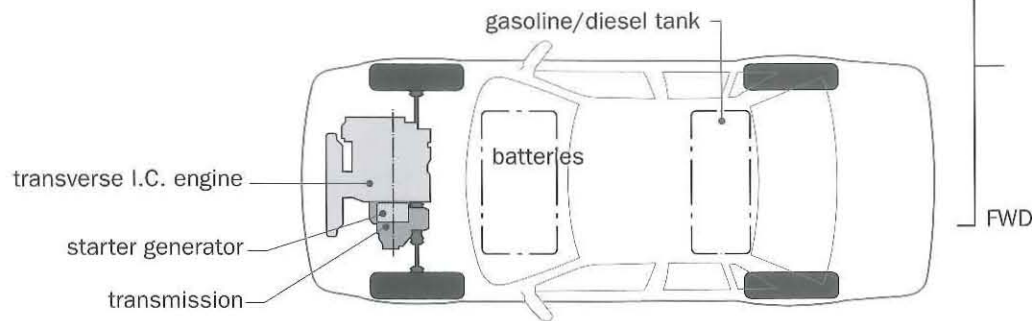
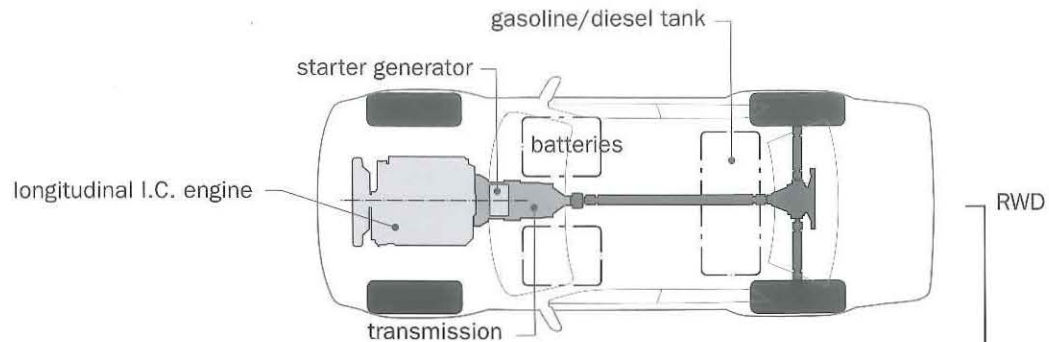
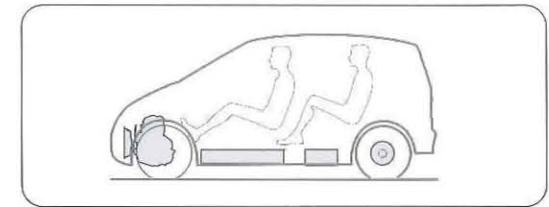
ELECTRIC DRIVE

From a packaging perspective, electric drive offers a tremendous opportunity to design more space-efficient vehicles, mainly because the motors are so much smaller than internal combustion engines. The other components that make up the powertrain can be distributed throughout the package in remote locations, unlike conventional powertrain systems which are linked mechanically, creating a large, heavy assembly that has to be worked around. Another significant difference is the power source or fuel. Conventional cars have fuel tanks that are relatively small and can be molded to fit around other components, whereas the energy source for an electric system, either a battery or fuel cell, is quite large and in the case of batteries, very heavy. This can work as an advantage, lowering the center of gravity.



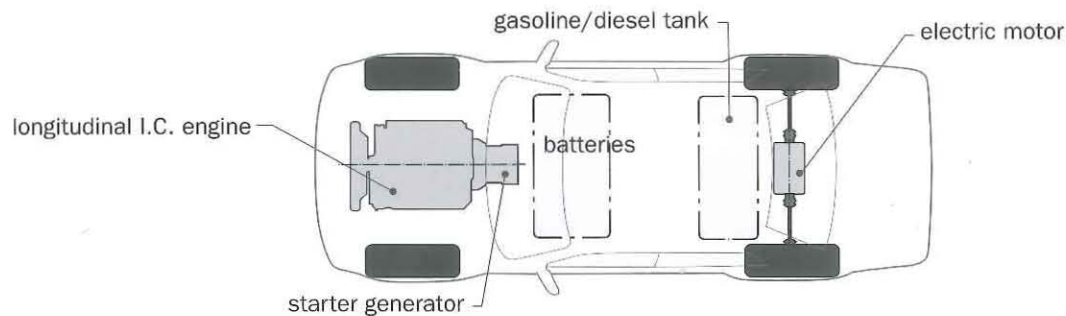
HYBRID DRIVE SYSTEMS

These systems are seen as a stepping-stone toward future all-electric powertrains. They mix the attributes of internal combustion engines and electric motors to provide a fuel-efficient powertrain with a long range. Although they have more components than conventional systems, the engines can be smaller because of the extra torque provided by the electric motor.



PARALLEL HYBRIDS

The internal combustion engine and electric motor (starter generator) are linked mechanically and the power is fed to the driven wheels through the transmission and final drive system.



SERIES HYBRIDS

The generator is turned by the internal combustion engine and the electricity is fed to the electric motor(s). This type of hybrid system offers packaging advantages by eliminating the need for a mechanical transmission and driveshafts as well as divorcing the internal combustion engine from the wheels.

FUEL AND ENERGY STORAGE

Traditionally, fuel tanks have been considered part of the “chassis” group of components, but with advanced alternative propulsion solutions, storing the energy or fuel is now often the responsibility of powertrain groups.

Whether the powertrain uses a traditional internal combustion engine or is driven by an alternative electric solution, the basic principles of storage remain similar.

Wherever possible, the fuel tank, batteries or fuel cell should not, in themselves, unduly influence the overall package of the vehicle. The fuel tank should be located wherever there is a natural open volume away from other key elements. For example, most passenger car fuel tanks are located under the rear seat in an open space created by the rear occupant's posture. Always look for a void space in the architecture and try to place the fuel there. Because the fuel storage usually takes up a significant volume, it should always be included in the initial package ideation sketches so that it does not become an afterthought.

Next, consider safety. This is actually the most important part of fuel packaging and should not be overlooked. Unlike other elements in the package, the fuel is combustible, so if the vehicle is in a high speed collision or rolls over, the fuel should remain inside the storage container and away from the occupants, on the other side of a firewall, such as a metal floor or bulkhead.

The fuel source, whether liquid, gas or solid, is dense and often heavy. In the case of gasoline or diesel, the mass of the fuel tank will vary as the fuel is consumed. On sports cars, this may lead to a noticeable variation in handling if the fuel tank is located in the wrong place. Keeping the fuel as low as possible and toward the center of the vehicle is always the objective.

Considering these three objectives usually pushes the fuel to an inboard, under-floor location often under the rear occupants' seat. It is always good to look for the strongest areas of the body structure and locate the fuel inboard of these. The main frame rails and cross members will help to protect the fuel from impact.

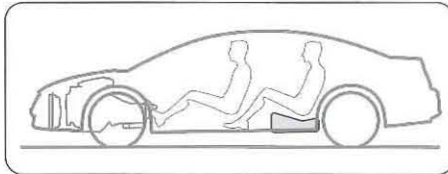
The amount of fuel required is going to depend on the functional objectives. Range and fuel consumption will be the two main factors, but packaging space may also limit fuel capacity. Benchmark existing vehicles for ideal fuel volumes.

Batteries generate heat as they provide energy and require cooling, so additional space should be allocated for cooling solutions. Hydrogen for fuel cells is stored under very high pressure (10,000 psi) and the tanks must be designed and located to avoid rupture on impact. Traditional fuel tanks will also require some space for the fuel pump and measurement systems.

The examples on the opposite page show some typical existing fuel/energy storage locations.

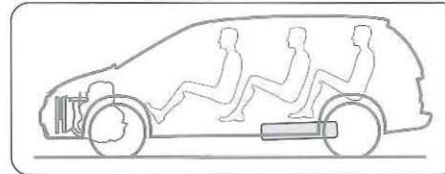
VARIOUS FUEL STORAGE LOCATIONS

PASSENGER CARS



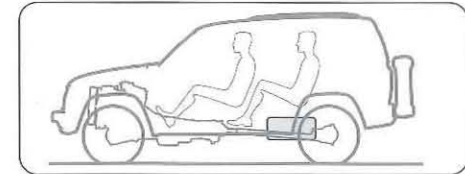
The most common location for passenger car fuel tanks is in the space under the rear occupants' seat. In rear-wheel drive cars, the tank has to straddle the prop shaft.

MINIVANS & TRUCKS



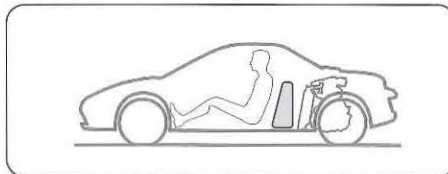
Minivan fuel tanks are quite large but usually package easily under the long high floor structure. Stowing seats can be an obstacle in some vans.

SUVs



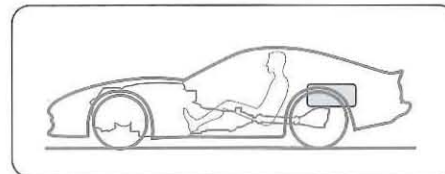
SUVs have been forced to move their fuel tanks from under the rear cargo floor to in front of the rear axle to comply with rear impact safety legislation.

SMALL SPORTS CARS



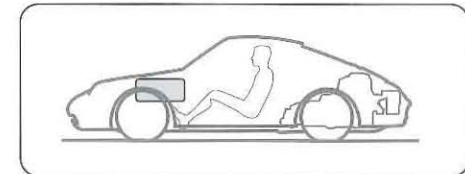
It is common to locate the fuel behind the driver in small front or mid-engine sports cars to help with good weight distribution.

LARGE SPORTS CARS



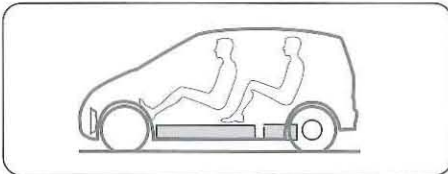
Larger sports cars may package the tank on top of the rear axle to help shorten the wheelbase.

REAR-ENGINE SPORTS CARS



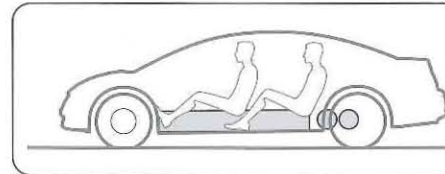
Packaging the fuel in front of the dash is uncommon but helps to distribute the masses in rear-engine sports cars.

ELECTRIC VEHICLES



Due to the large but low profile proportions of electric powertrains, it is common to package the whole system under the floor. This results in a high occupant package which may be desirable in some vehicles.

ELECTRIC SEDANS



With the reduction in the size of fuel cells and batteries, it is possible to package an electric propulsion energy system in the tunnel and various locations to allow for a low passenger compartment floor.

GENERAL INFORMATION

All of these fuel storage solutions will be molded to fit into as small a space as possible, and mounted symmetrically about the vehicle centerline (where possible) to improve weight distribution.

Benchmark existing vehicles to understand the typical range and fuel consumption versus the tank capacity or battery volumes.

One small design feature to consider is that the fuel filler will need to be close to the tank location.