

## Applications – Power train – Fuel system

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## 5 Fuel System

### 5.1 Introduction

The function of the fuel system is to store and supply fuel to the cylinder chamber where it can be mixed with air, vaporized, and burned to produce energy. The fuel, which can be either gasoline or diesel is stored in a fuel tank. A fuel pump draws the fuel from the fuel tank through fuel lines and delivers it through a fuel filter to either a carburetor or fuel injector and finally to the cylinder chamber for combustion.

Tank location and design (shape, volume) always depend on the available space. Most automobiles have a single tank located in the rear of the vehicle. Today's fuel tanks have internal baffles to prevent the fuel from sloshing back and forth. All tanks have a fuel filler pipe, a fuel outlet line to the engine and a vent system.

Two types of fuel pumps are used in automobiles; mechanical and electric. As engines moved away from carburetors and towards fuel injection, mechanical fuel pumps were replaced with electric fuel pumps, because fuel injection systems operate more efficiently at higher fuel pressures than mechanical pumps can generate. Electric fuel pumps are generally located within the fuel tank, in order to use the fuel in the tank to cool the pump and to ensure a steady supply of fuel.

The fuel filter is the key to a properly functioning fuel delivery system, in particular with fuel injection systems which are more susceptible to damage from dirt because of their close dimensional tolerances. Most cars use two filters. One filter is located inside the fuel tank and one is integrated into the line to the fuel injectors or the carburettor.

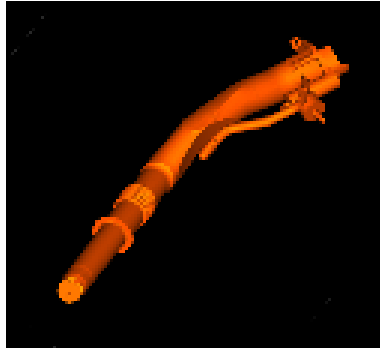
Due to its excellent corrosion resistance against gasoline, diesel and also biofuels at room temperature, aluminium is a suitable construction material for the different components of the fuel system. Care must be taken in high temperature applications (> 70 °C), in particular when biofuels are used. Corrosion effects have been observed sporadically in the sump of aluminium fuel tanks, specifically at welded joints. The reasons for the corrosion attack are in this case contaminations of the fuel (water, chlorides, etc.).

The application of aluminium in the fuel system offers significant weight savings compared to steel (50 – 70 %). Most interesting compared to plastics would be the tightness for HC emissions as well as the high electrical conductivity, which is important to avoid static electricity and thus sparking. Nevertheless, aluminium has found up to now very little applications in the fuel system of passenger cars.

This is in contrast to commercial (heavy trucks and busses) and special vehicles where aluminium tanks gained wide application and have reached a large market share. Lightweight aluminium solutions have been developed for fuel, hydraulic and urea tanks including support and special attachment elements for the truck body. The reliability of aluminium tanks has been proven over long terms. Furthermore the lack of corrosion results in less service and maintenance requirements, which means lower lifetime costs.

An additional aluminium application in the fuel system is covered in the chapter "Heat exchangers" (see 7.4.6 Diesel fuel cooling). With the growing application of high-speed diesel engines and the increasingly stringent emissions standards, this application will get more and more attention.

## 5.2 Fuel filler pipe



**Fuel Filler Pipe**

**Source: Kronert**

Aluminium fuel filler tubes are manufactured from an extruded tube which is then bent and formed in order to increase their ability to flex and bend without leakage in case of car crash. The standard alloy used in this application is EN-AW 6063, an AlMgSi alloy which is highly formable and can be extruded with thin walls.

### Typical Dimensions

Diameter: 36...70 mm  
Wall thickness: 1.5 mm

Examples of aluminium fuel filler pipes are described below, other applications in European cars included the Audi A8 and Mercedes A-class models.

Another solution for aluminium fuel filler tubes is offered by the application of Permeaflex tubes, a flexible aluminium tube concept developed by Hydro Aluminium Precision Tubing, which is vibration absorbent and permeation tight for low pressure liquid and gas lines. The advantages include:

- ▲ Permeation tight
- ▲ Flexible assembly
- ▲ One material throughout the entire tube
- ▲ Elimination of connections
- ▲ Increased crash integrity
- ▲ Vibration absorbent
- ▲ Cooling properties
- ▲ Recycling friendly



In addition, Hydro's flexible aluminium tube concept facilitates the assembly of components especially in tight spaces.

### 5.2.1 Example - Volvo V70/S80/S60/XC90 Fuel Filler Pipe

#### Specifications:

Fuel filler pipe with air pipe and pipe-integrated thread for the filler cap

Length: 700...800 mm

Diameter: 36...57 mm

Wall thickness: 1.5 mm

Alloy: EN AW-6063

#### Manufacturing process:

- ⤴ Extrusion of the main pipe and the air pipe,
- ⤴ Rotary draw bending,
- ⤴ End forming,
- ⤴ TIG welding of air venting pipe, epoxy-powder coating,
- ⤴ Leak testing (use of positive pressure or vacuum),
- ⤴ Restrictor mounting by electromagnetic forming



Fuel Filler Pipe, Volvo P2X

Source: Kronert

## 5.2.2 Example - Porsche 911/Boxster Fuel Filler Pipe

### Specifications:

Fuel filler pipe with thread for filler cap integrated in plastic restrictor

Length: 650 mm

Diameter: 36...70 mm

Wall thickness: 1.5 mm

Alloy: EN AW-6063

### Manufacturing process

- ⤴ Extrusion of main pipe and air pipe,
- ⤴ Rotary draw bending,
- ⤴ End forming,
- ⤴ Forming of bellows,
- ⤴ Mounting (Restrictor mechanically fixed),
- ⤴ Leak Testing



Fuel Filler Pipe, Porsche 9X6

Source: Kronert

### 5.3 Fuel tubing



**HYCOT™<sup>®</sup> precision drawn aluminium tubes coated with PA 12 for fuel lines**

**Source: Hydro Aluminium Precision Tubing**

Liquid lines, in particular fuel lines, can be produced from different products:

- ▲ Precision drawn tubes (bare)
- ▲ Permeaflex - flexible aluminium tube (see above, bare or coated with PA 12)
- ▲ Hycot™<sup>®</sup> tubes

Hycot™<sup>®</sup> tubes are porthole extruded and precision drawn aluminium tubes with a PA 12 coating characterized by the following properties:

- ▲ Low weight
- ▲ Easily bent and formed
- ▲ Excellent corrosion resistance
- ▲ High strength welding of plastic parts to coating
- ▲ Narrow tolerances
- ▲ High surface quality
- ▲ Stone impact resistance
- ▲ Internal cleanliness
- ▲ Full traceability

The Hycot™<sup>®</sup> tubes will not chip, peel or flake under the wide range of exposures and service conditions found in the modern automotive industry. The inner side of the Hycot™<sup>®</sup> tube is unique as well, since it is 100% free of particles. A unique feature of the coating is the easy welding to plastic parts, e.g. brackets, connectors or protection hoses. This allows for designing very cost effective systems based on simple and clean processes, without any need for further corrosion protection. Typical welding methods are ultrasonic, spin friction and induction welding.



Within this range there are certain limits depending on the alloy and the ratio between OD and WT.

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Alloy Designation			Surface Conditions	
Hydro Aluminium Internal designation	According to EN 573-3		Uncoated tubes	Hycot™/® PA-12 coated tubes
	Numerical	Chemical		
3103	EN AW-3103	AlMn 1	YES	YES
5049	EN AW-5049	AlMg2Mn0.8	YES	YES
HA 9048	Long life alloy		YES	YES

External Diameter	Wall thickness
8 - 40 mm	0.7 - 2 mm

## 5.4 Fuel rails



**Fuel distribution pipes for Volvo**

**Source: Sapa**

Common rail direct fuel injection is a modern variant of the direct fuel injection system for petrol and diesel engines. The common rail system takes its name from the shared high-pressure line which supplies all cylinders with fuel and serves as a pressure accumulator. By contrast with other injection systems, pressure generation and injection are separate from each other in common rail technology.

The primary pump supplies fuel to a high-pressure reservoir, the fuel rail, where the fuel is stored at the optimal pressure for the engine's instantaneous operating conditions in preparation for subsequent injection. Each of the engine's cylinders is equipped with an injector featuring an integral solenoid valve. This solenoid valve opens and closes to define the starting point and mass of the injection process. Today, for injection, newly-developed piezo injectors are more and more used instead of conventional solenoid valves.



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The common rail system helps reduce exhaust emissions, makes fuel cleaner and more efficient, lessens engine noise, and is more powerful than the injector systems they replace.

The common rail injector system is used in gasoline direct injection for modern two and four-stroke gasoline-run engines, but is more popularly used in diesel engines. In the manufacturing of common rails, aluminium is used for its light weight, its mechanical stability, corrosion resistance and the easy machinability.

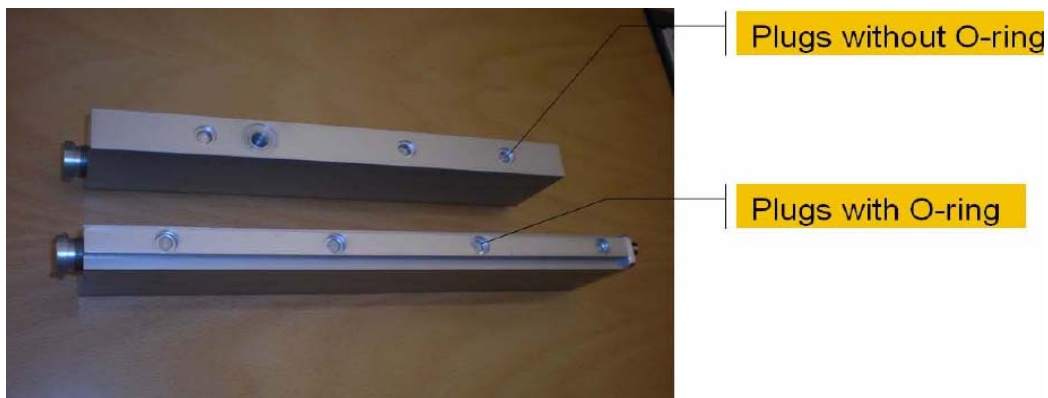
The common rail injector system must fulfil some challenging market requirements regarding:

### ➤ **Evaporative emissions**

The fuel rail application shall fulfil the PZEV requirements. The allowed evaporative emissions due to permeation and micro leakage are max 0.005 g HC / HS+D (Hot Soak + Diurnal tests) for the engine mounted parts of the fuel system. The big challenge is to find a system with a low number of sealings using materials like rubber or plastic and to find methods to decrease the evaporative emission in the sealings.

### ➤ **High pressure**

Fuel rails work at ever increasing high pressures. However, a combination of proper product design and intensive testing enables to meet these demands with both O-ring seals and without O-ring seals. For the moment, aluminium fuel rails systems are able to withstand 700 bar pressure without leakages or any damages on the tested rails.



Source: Sapa

### ➤ **Aggressive fuels**

Biofuels like for example E85, an alcohol fuel mixture of fuel ethanol and gasoline, can corrode metal and rubber parts in engines which are designed for use with gasoline. The hydroxyl group on the ethanol molecule is an extremely weak acid, but it still can enhance corrosion. To avoid such effects, a protective coating must be applied that can withstand these aggressive fuels. Corrosion tests with different types of surface treatments were carried out in special test chambers with temperatures up to 120°C for up to 1050 h. These tests showed that properly surface treated aluminium components may be used in fuel injection systems also in combination with E85 if there are not any couplings with cast iron or stainless steel.

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### ➤ **Confined spaces and additional functions**

The space in the engine compartment becomes tighter and tighter. Thus, the integration of several additional functions into a component such as channels, flanges forming, anchor points, heat sinks etc. provides an advantage, which can easily be done with an aluminium extrusion.

### **5.5 Fuel tank**

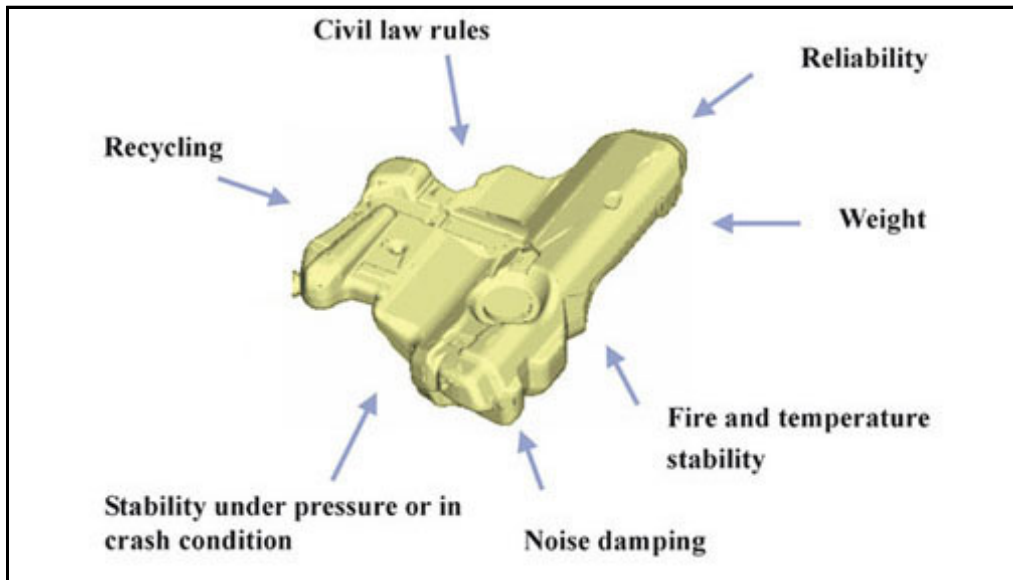
For each new vehicle a specific fuel system is developed in order to optimize the use of the available space. Moreover, for one car model, different fuel system architectures are developed, depending on the type of the car, the type of fuel (gasoline or diesel), nozzle models and region.

Two technologies are used to make fuel tanks for automobiles:

- ✦ High Density Polyethylene (HDPE) plastic fuel tanks made by blow moulding. This technology is increasingly used as it now shows its capacity to obtain very low emissions of fuel. HDPE can also take complex shapes, allowing the tank to be mounted directly over the rear axle, saving space and improving crash safety. Initially there were concerns over the low fracture toughness of HDPE, when compared to steel or aluminium. Such concern for safety and long term ability to function must be considered and monitored, but presented no major problems up to now.
- ✦ Metallic fuel tanks welded from stamped sheets. Although this technology is very good in limiting fuel emissions, it tends to be less competitive and thus it has not been able to enter the market for series production. Steel and in particular the significantly lighter aluminium fuel tanks are only used for specialty cars (niche vehicles).

### 5.5.1 Technical requirements

As listed in the figure below, the tank shell has to meet several technical requirements beyond the fuel emission limits, which drastically limit the choice of materials. The specific characteristics of aluminium promise to meet all the requirements for application in passenger car fuel tanks. As a matter of fact, aluminium offers big potential as a lightweight future zero emission fuel tank material.



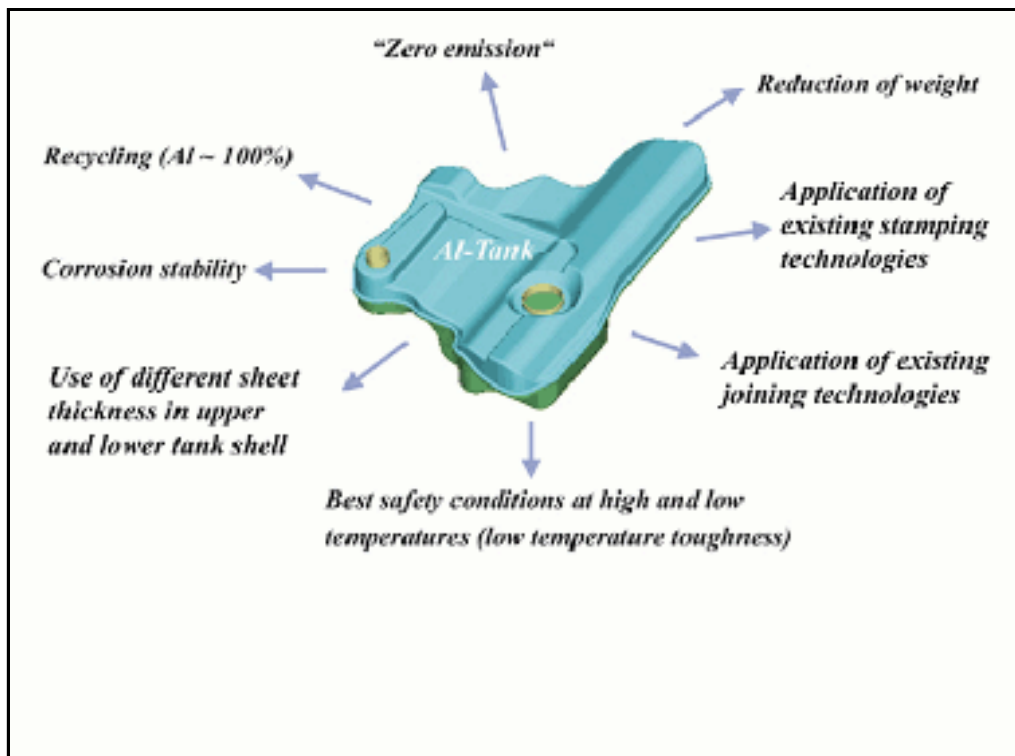
Source: Hydro Aluminium (former VAW)

Consequently, significant development efforts have been spent on the various tasks necessary to exploit the advantages of aluminium fuel tanks for passenger cars:

- ✦ Selection of an adequate alloy
  - Corrosion resistance
  - Formability
  -
- ✦ Forming technology
  - Meeting package constraints
  -
- ✦ Joining technology
  - Tightness
  - Automatic operation
  - Reliability

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All the development goals could be reached:



Source: Hydro Aluminium (former VAW)

## 5.5.2 Technical feasibility

### Corrosion resistance:

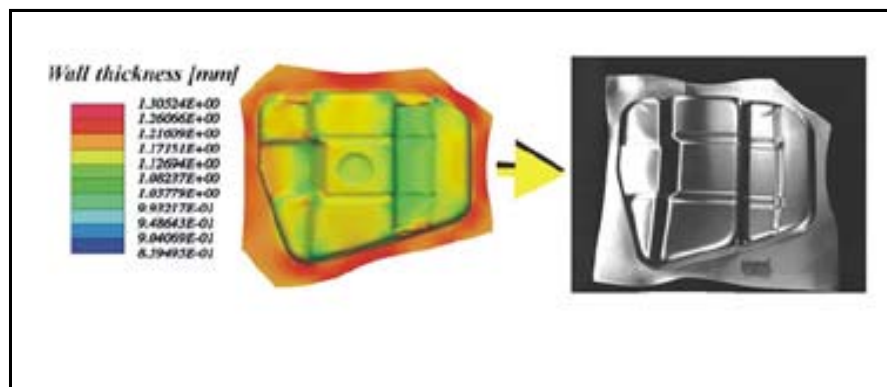
Using the aluminium sheet alloy AlMg3 in the soft temper (EN-AW 5754-0), the required corrosion resistance could be demonstrated:

- ✦ Corrosion tests with water contamination:
  - Eurosuper + 3 % water
  - Biodiesel + 0.3 % water
  - E22 + 3 % water
  -
- ✦ Test condition: liquid phase, half wetted and gas phase
- ✦ Test temperatures: -5°C, 25°C, 50°C
- ✦ Test results after 80 days:
  - Layer degradation products of the fuel
  - No corrosion visible.

### Fabrication concept:

A two shell concept, where the two shells were joined after forming, was evaluated:

- ✦ Application of conventional deep drawing or other sheet metal forming processes.
- ✦ Possibility of mounting of system assemblies, slosh baffles, tubes and system assemblies before joining.
- ✦ Possibility of three-dimensional shaped flange



Source: Allgair, IFU Stuttgart, Hydro Aluminium (former VAW)

Forming by conventional deep drawing:

- ✦ Application of a series production tool for a steel fuel tank
- ✦ Adaptation of deep drawing parameters to aluminium by simulation
- ✦ Prototyping of tank shells with AlMg3 (EN-AW 5754-O), thickness 1.2 mm

MIG – welding of flange:

- ✦ Joint configuration: edge weld
- ✦ One side of fusion flange bent, other side of flange flat

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- ⤴ Welding wire: AlMg4.5Mn, 1.2 mm
- ⤴ Use of Argon as (low cost) shielding gas
- ⤴ Welding speed up to 3 m/min
- ⤴ Bridging of 0.8 mm gaps possible without adapting welding parameters
- ⤴ Stable welding process

### Prototype production



**Prototype of shell concept fuel tank**



**Pressure test with modified tank of a series production car (burst pressure 2.5 bar)**