



electric power division

engaged • profitable • differentiated

one powerful future.

CATERPILLAR®

Diesel Fuel System

Diesel Engine Fuel System

The fuel system on a diesel engine is a highly specialized set of components which must deliver the correct amount of fuel to the cylinder at the precise moment it is needed. A well-designed fuel system enables the engine to produce maximum power at maximum efficiency with a minimum of exhaust emissions.

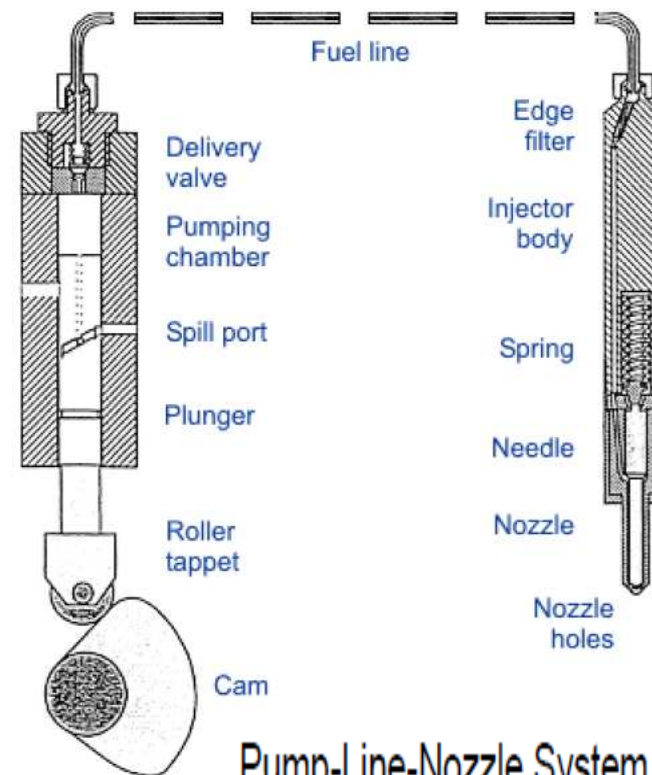
Caterpillar diesel engines are all furnished with a fuel system based on a conventional design, utilizing unit injectors, but with differing means of injector actuation and control.

The engine driven transfer pump delivers fuel to the unit injectors via the secondary fuel filter. The pump is equipped with a pump-mounted safety valve and the fuel flow at rated rpm is listed in the technical data and varies with engine speed

Types of Diesel Fuel Injection Systems

Diesel fuel injection systems can be classified into three categories, as follows:

1. Pump-Line-Nozzle
2. Unit Injector
3. Common Rail



Pump-Line-Nozzle System Principle

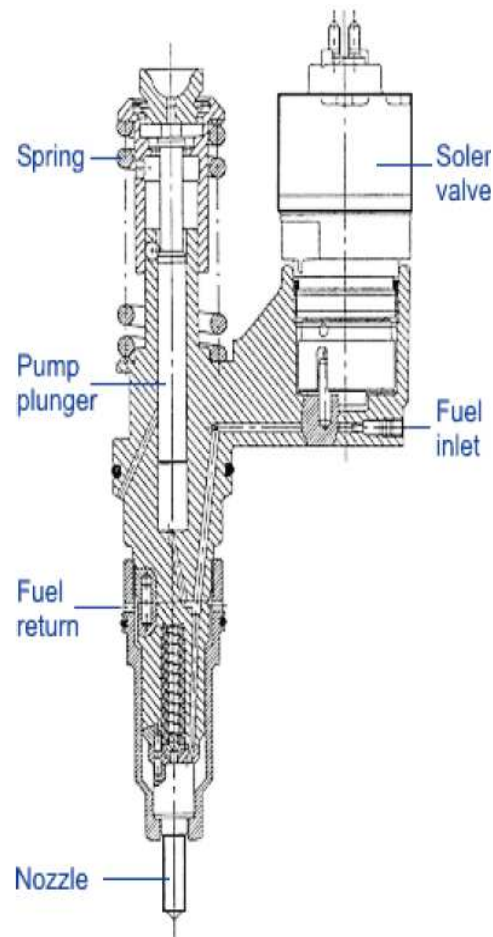
one powerful future.

engaged • profitable • differentiated

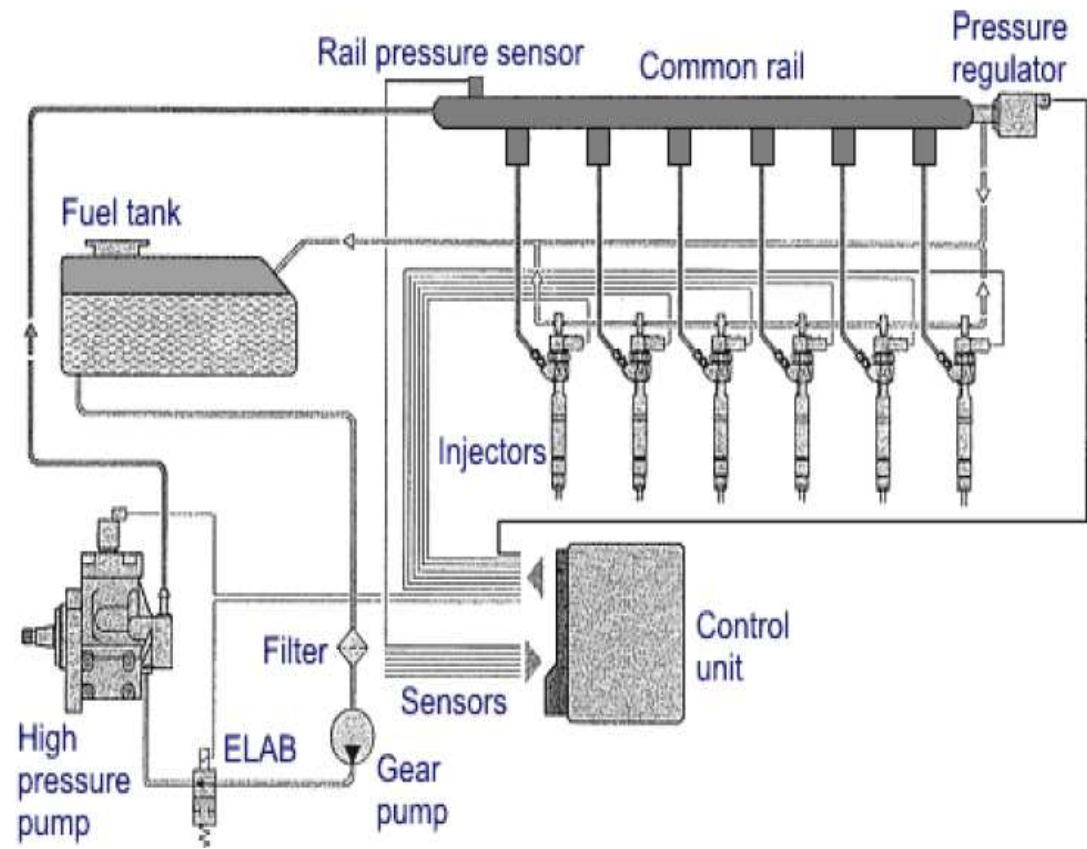
electric power division

CATERPILLAR®

Cross Section of Electronic Unit Injector



Common Rail Diesel Fuel Injection System



one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Diesel Engine Fuel System

Fuel System must ensure:

- The fuel is clean.
- There is no air or water in the fuel.
- The fuel is at the correct pressure.
- The fuel is at an acceptable temperature.

Fuel System

- Fuel and Fuel System Publications
- Fuel Specifications
 - Fuel Specific Gravity (API number)
 - Fuel Cleanliness & Filtration
 - Fuel Cooling Requirements
- Fuel System Design Considerations
 - Fuel Tanks
 - Standpipes / Air Entrainment
 - Day Tanks
 - Fuel Return Lines
 - Fuel Heaters

Caterpillar Diesel Fuel Specifications

- Cetane Number or Index
 - Measure of Ignition Quality that affects starting and acceleration
 - Prechamber Engines - 35 Cetane Minimum
 - Direct Injection Engines - 40 Cetane Minimum
- API
 - Measure of Specific Gravity; an indication of fuel energy content
 - API range of 33 to 37
- Flash Point
 - The temperature at which fuel vapors can be ignited when exposed to flame
 - Minimum is about 38° C (100° F)
- Cloud Point
 - The temperature at which a cloud or haze appears in the fuel
 - Minimum is 6° C (10° F) below the lowest ambient temperature
- Pour Point
 - 3° C (5° F) above the temperature at which the fuel fails to flow (turns solid)
 - Minimum is 3° C (5° F) above the temperature at which the fuel just fails to flow
- For a complete set of fuel specifications, refer to the MASH Book (LEBV4830) or one of the Service Publication previously referenced.

EPA Mandate: Diesel Sulfur Timeline

Nonroad Diesel Fuel Standards										
Who	Covered Fuel	2006	2007	2008	2009	2010	2011	2012	2013	2014
Large Refiners & Importers	NON-ROAD	500+ ppm	500 ppm	500 ppm	500 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm
Large Refiners & Importers	LOCOMOTIVE & MARINE	500+ ppm	500 ppm	500 ppm	500 ppm	500 ppm	500 ppm	15 ppm	15 ppm	15 ppm
Small Refiners and other exceptions	NON-ROAD, LOCOMOTIVE AND MARINE	500+ ppm	500+ ppm	500+ ppm	500+ ppm	500 ppm	500 ppm	500 ppm	500 ppm	15 ppm

Except in California, compliance dates for Non-Road, Locomotive and Marine fuels are: June 1 for refiners and importers, August 1 downstream from refineries through fuel terminals, October 1 for retail outlets, and December 1 for in-use

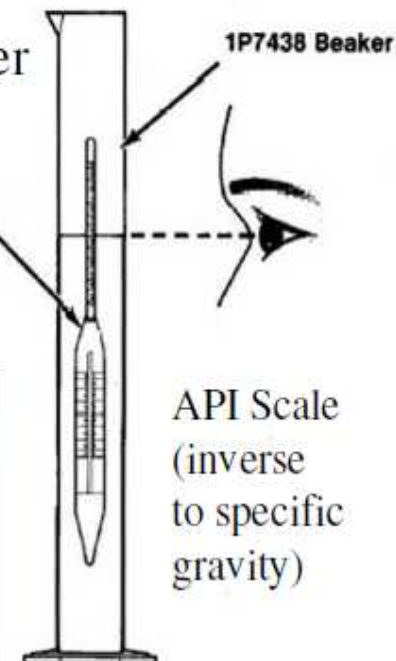
In California, all diesel fuel will transition in 2006. Compliance dates for Non-Road fuels are: June 1 for refiners and importers, July 15 downstream from refineries through fuel terminals, and September 1 for retail outlets. Locomotive and Marine diesel fuels must transition to 15 ppm ULSD by January 1, 2007

Specific Gravity and API Gravity Number

- The higher the specific gravity, the lower the API number and the heavier the fuel.
- Heavier fuels have more energy or power per volume.
- For most Cat diesel engines an API of 35 is optimum.
- Always check the API gravity of the fuel before an engine performance test.
- If the customer is complaining of low power, and the fuel has a high API gravity number, nothing can be done to the engine to correct this problem.

Fuel Hydrometer

1P7408 or 5P2712
Thermo-Hydrometer



Readings must be corrected to actual fuel temperature.

Duplex Fuel Filters

- Duplex fuel filters are an MCS requirement
 - Filters must have suitable redundancy to facilitate changing filters without interrupting flow of fuel to the engine
- There are two types:
 - Symmetrical type - two identical filter sets
 - Main-auxiliary type - a main filter set and a smaller capacity auxiliary filter set.
- A special valve connects the two sets of filters in each type.
 - The valve routes the fuel to be filtered through either or both sets of filters.
- Both filter sets can be used simultaneously to extend running time in an emergency

Diesel Fuels

1. Diesel fuel quality is an important factor in satisfactory engine life and performance.
2. Fuels must provide adequate combustion without producing excess contaminants that can harm the engine. Additionally, fuel selection involves economic and environmental considerations.
3. The availability of certain grades of diesel fuels may be cost prohibitive or inappropriate for various applications

Diesel Fuel Selection

The fuels recommended for use in Caterpillar diesel engine are normally No. 2-D diesel fuel and No. 2 fuel oil, although No. 1 grades are also acceptable. Table lists the worldwide fuel standards which meet Caterpillar requirements

Standard	Name	Description
American	ASTM D975	No. 1-D & No. 2-D Diesel Fuel Oils
	ASTM D396	No. 1 & No. 2 Fuel Oils
	ASTM D2880	No. 1-GT & No. 2-GT Gas Turbine Fuels
British	BS 2869	Classes A1, A2 & B2 Engine Fuels
	BS 2869	Classes C2 & D Burner Fuels

one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Diesel Fuel System

Fuel Options

- Generators do not necessarily have to run on diesel fuel.
- Fuels such as JP-5 and Jet-A may also fuel generator sets.
 - But have lower lubricating properties that require fuel additive package or equipment.
- Besides diesel, component life may be compromised
 - less generated horsepower.
- Because of the abundance of jet fuel, some installations may choose

Basic Fuel System

The basic fuel system common to all Caterpillar diesel engines, includes;

- A engine driven fuel transfer pump.
- A secondary fuel filter
- Unit fuel injectors
- A fuel pressure regulator.

Optional;

- Flexible hoses
- Manual fuel priming pump
- Duplex filter

one powerful future.

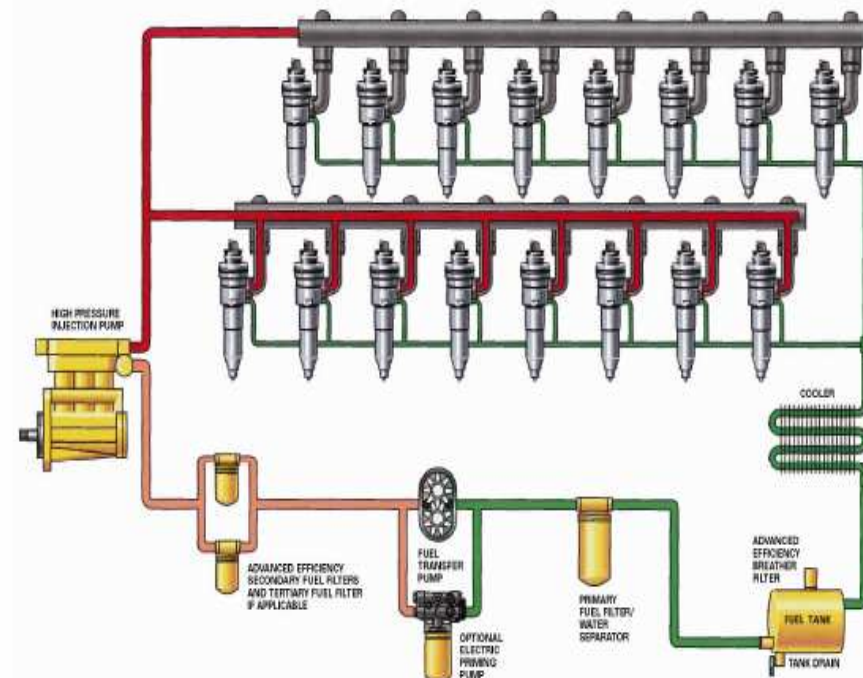
engaged • profitable • differentiated

electric power division

CATERPILLAR®

Diesel Engine Fuel System

1. MUI Fuel System
2. EUI Fuel System
3. HEUI Fuel System
4. Common Rail Fuel System
5. ACERT Fuel Technology



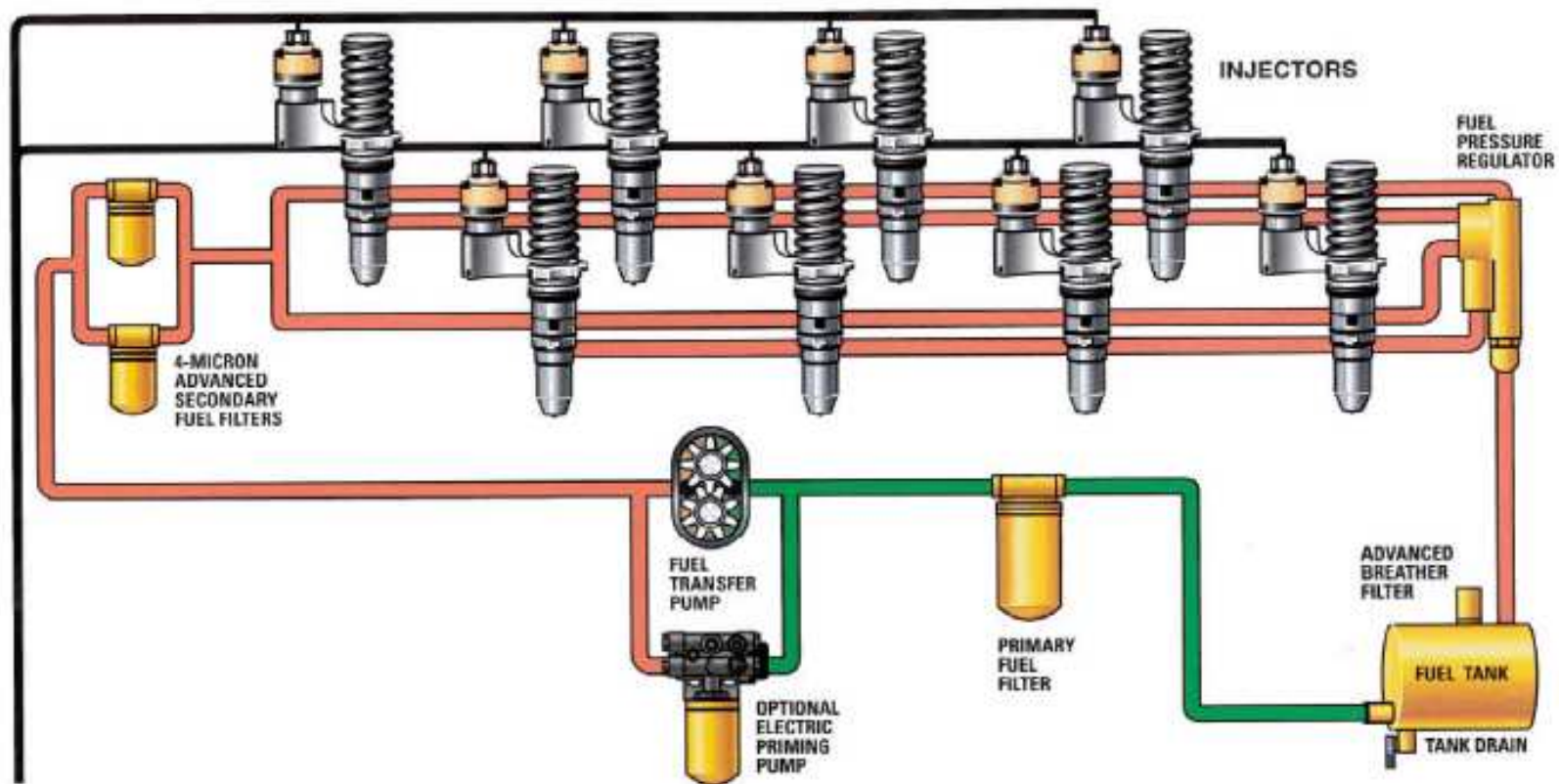
one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Basic Fuel System



Cat Engine Diesel Fuel System

- **MUI Fuel System**

- The mechanically actuated and controlled unit injectors use the camshaft and push rods to fuel injection pressure, and a mechanical linkage system to control the amount of fuel injected.

- **MEUI Fuel System**

- The Mechanically actuated Electronically controlled Unit Injectors(MEUI), also use camshaft and push rod to generate fuel injection pressure, but use Electronic Control Module (ECM) to control the amount of fuel injected into the cylinders.

Cat Engine Diesel Fuel System

- **HEUI Fuel System**

- The Hydraulically actuated Electronically controlled Unit Injectors (HEUI) use hydraulic pump and engine oil to generate fuel injection, and ECM to control the pressure and amount of fuel injected into the cylinder.

- **Common Rail Fuel System**

- In this system fuel pressure is created external to the injectors in a high –pressure fuel pump which is driven by engine. High pressure manifold that runs both sides of engine feeding high pressure fuel to the injectors. The electronic fuel injectors at each cylinder control the delivery and timing of the fuel injection(s).

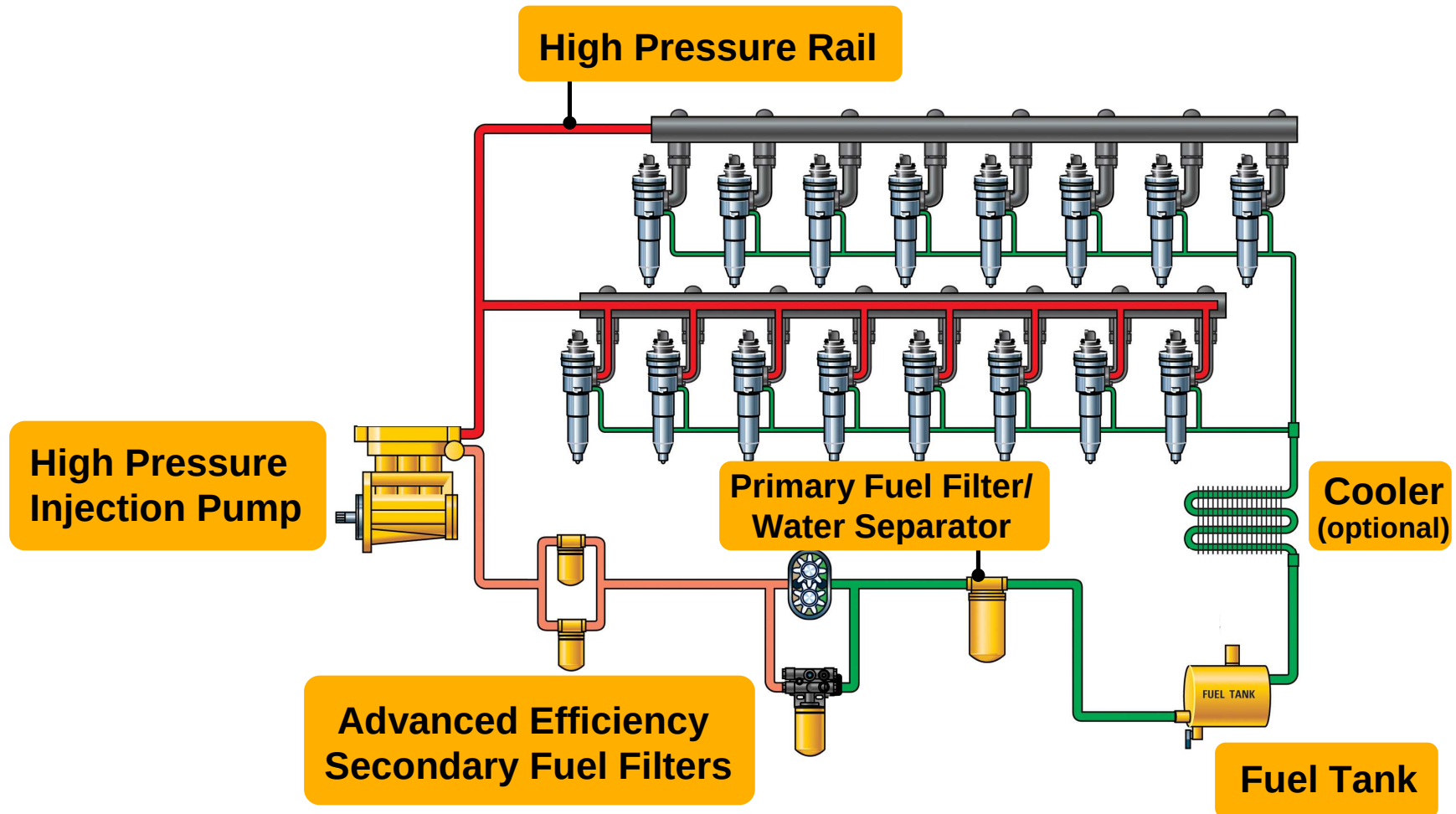
one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Diesel Fuel System



one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Diesel Fuel System Design Considerations

Diesel fuel supply systems must ensure continuous and clean supply of fuel to the engine's fuel system.

The diesel fuel supply system typically has three major components: a fuel storage system, a fuel transfer system and a fuel filtration system.

Fuel Tank Design consideration

- The fuel tank **MUST** be designed using materials that do not corrode and suitable for fuel oils.
- Tank should be sized sufficient for normal daily operation and heat dissipation from recirculated fuel.
- Position of tanks should consider radiated heat from other systems, e.g exhaust, turbocharger, hydraulics and the environment.

Fuel Tank design consideration

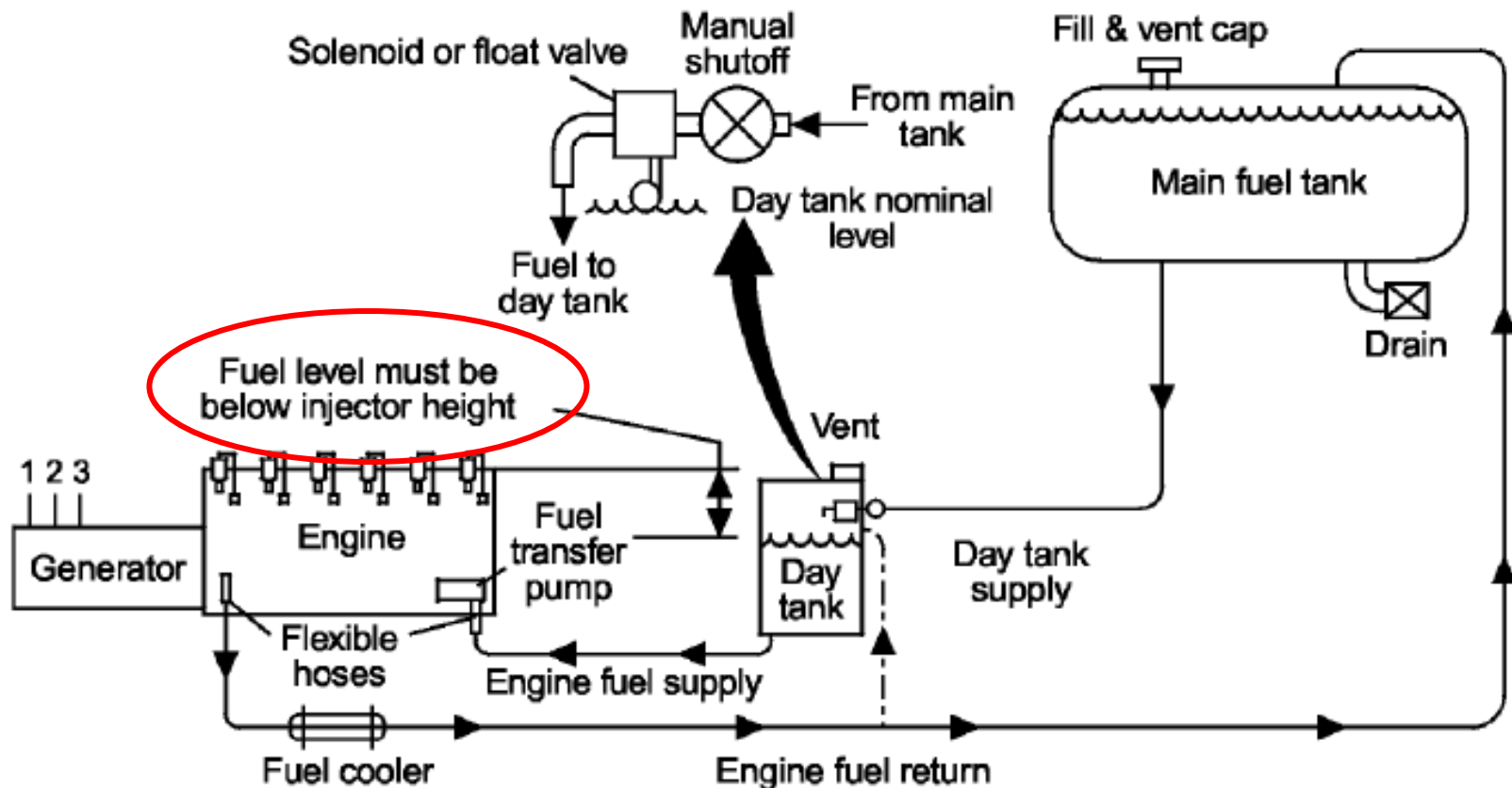
- Fuel tanks should have breather with integral filter to prevent dust or water ingress.
- Fuel tank must include provision for sediment collection & removal with a water drain at the base.
- To prevent excessive depression at lift pump inlet, there should be no gauze fitted on the fuel feed pipe from the tank.
- A serviceable coarse filter is recommended on the tank filler.

Fuel Line consideration

1. Fuel feed and return pipes should be at least 300mm (12") apart to prevent immediate recirculation and be clear of the base.
2. Return pipes should be positioned below the fuel level.

Design Considerations

- **Fuel Storage System;**



Design Considerations

- **Auxiliary, Day Tank are required in the following conditions;**
 - The main fuel tank is located on the same level but more than 15m (50ft) away.
 - The main fuel tank is located 3.7m (12ft) or more below the engine.
 - The main fuel tank is located above fuel injectors.
- **Fuel Tank Material;**
 - Low carbon rolled steel are best.
 - Zinc, either in the form of plating or as a major alloying component should not be used with diesel fuels.

Design Considerations

- **Fuel Supply Piping;**
 - Fuel pressure measured in the fuel return line should be kept below 27kPa (4psi) for all models except 3300 (3psi) and 3600 (51psi) series.
 - Black iron pipe is best suited for diesel fuel, copper may substituted.
 - Valves and fittings may be cast iron or bronze. Do not use brass components; they may contain zinc.
- **Fuel Filtration System;**
 - Primary fuel filter
 - Water separator – Water in diesel fuel is absolutely unwanted. It is extremely important to maintain the water & sediments level at or below 0.1%.

Design Considerations

- **Fuel Temperature;**

- Fuel temperature supplied to engine can affect unit injector life and maximum power capability.
- The minimum allowable viscosity at the injectors is 1.4 cSt.
- Maximum fuel temperature limit of 66°C regardless of viscosity.
- Maximum allowable inlet fuel temperature to transfer pump:
 - C7, C9, C15, C18, C27, C32 is 80°C (176°F)
 - C175 is 70°C (158°F)

one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Additional Considerations

- **Fuel Coolers**
- **Fuel Heaters**
- **Additional information can be found in Diesel Fuels & Diesel Fuel System Application & Installation Guide (LEBW4976)**

Common Rail System

- Most flexible fuel system injection strategy
 - Similar to HEUI system, injection quantity and pressure not tied to engine speed/load.
- Allows for noise reduction and less fuel consumption
- More flexible system for future engine rating expansion
- Supports increased injection pressure
- Current version easier to package in the engine head on HD engines

one powerful future.

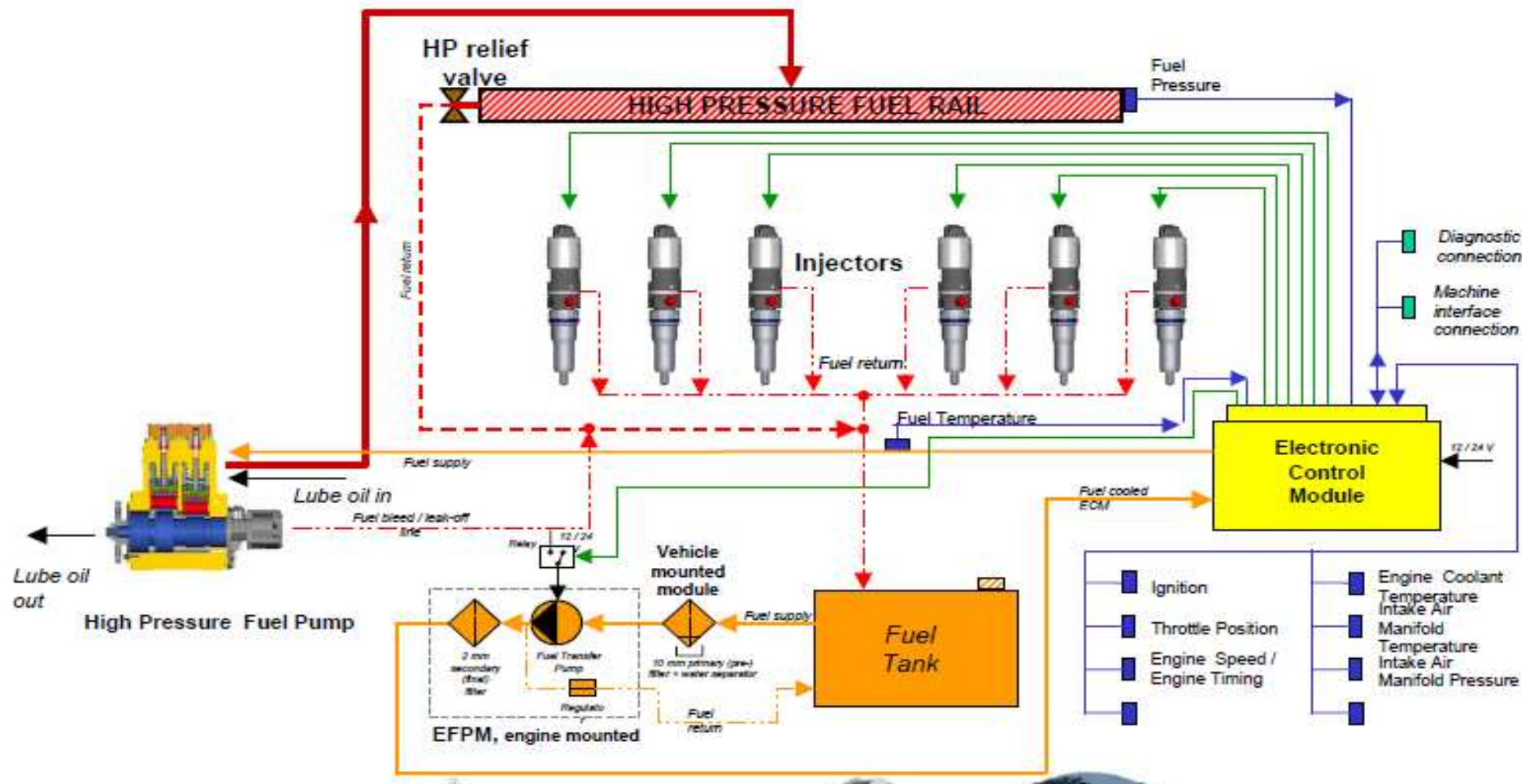
engaged • profitable • differentiated

electric power division

CATERPILLAR®

Common Rail System

Distributed High Pressure Fuel

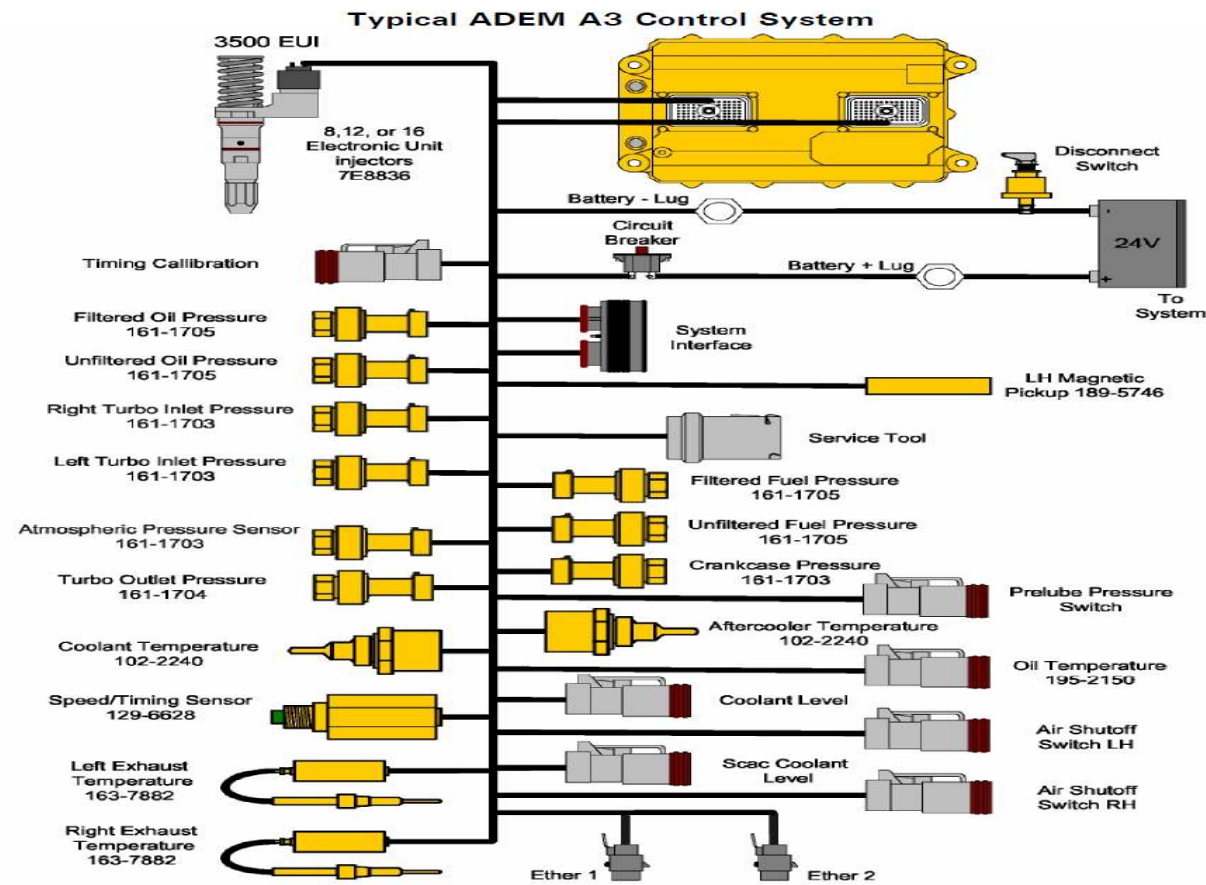


one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®



Fuel Filter

- All ACERT engines MUST use only CAT supplied secondary fuel filters. These are designed with the needs of the system in mind.
- Pre-Filters/Primary Filters must meet Caterpillar engine design requirements.
- No modifications are permitted between secondary filter and engine fuel return connection.

Primary Fuel Filter Element Specification

The primary fuel filters elements should have the following properties:

- Mesh Size: 32 x 28 strands per cm (70 x 80 strands per in.)
- Element: Monel wire cloth material or equivalent
- Element Area: 645 cm² (100 in.²) or greater
- Opening Size: 0.1778 mm x 0.2235 mm (0.007 in. X 0.0088 in.)

Fuel Oil System Considerations

- **Fuel Storage**
 - Fuel Tank Size and Location
 - Sufficient Capacity for Normal Consumption
 - Ability to Dissipate Heat
 - Location Relative to Fuel Injectors
 - Drainability and Cleanability of Fuel Tanks
- **Fuel Cleanliness**
 - Primary Fuel Filtration
 - Duplex Filter with Differential Pressure Gauge
 - Sized for Engine's Fuel Consumption Rate
 - Both Filtration and Water Separation
 - Fuel Purification

Fuel Transfer Pumps

Caterpillar engine-mounted transfer pumps are positive displacement gear-type or piston-type pumps, with a limited prime and lift capability.

Caterpillar fuel pumps' prime and lift capability is 3.7 m (12 ft), but pipe size, routing, and ambient temperature will impact this capability.

Fuel Tank Sizing

Rule of thumb for tank size is to find the fuel consumption rate at 100% load factor (depending on application: Prime, stand-by etc.) and multiply it with the number of hours between refills.

Fuel consumption rates are shown on the Engine Technical Data Sheets for the specific engine.

Additionally, 10% should be added to the result; 5% for expansion at the top of the tank, and 5% for sediment settlements at the bottom.

Fuel Tank installation

- **Fuel Tank material make by low carbon rolled steel are the best.**
- **Zinc either in the form of plating or major alloying components should not be use with diesel fuels**
- **Tanks may be below or above ground Level. Generally above ground fuel tank should not exceeded the injector's height.**
- **Tanks need to grounded**

Fuel system Installation

Fill line - Located above the high fuel level, with outlet baffled to prevent agitation of sediment in the tank.

Delivery line - Located near the bottom but not so low as to pick up collected sediment or condensation.

- Return line - To carry excess fuel back to the auxiliary tank. Should have its outlet baffled for the reason described above.**
- Overflow line - Allows excess fuel to return to the main tank in event of overfilling of the auxiliary tank.**

.

Fuel System installation

Vent line - Allows air pressure to equalize as tank is drained or filled (vent cap should be located away from open flame or sparks).

- **Drain valve - Allows removal of condensate and sediment.**
- **Sight glass or float-type gauge provides a positive check on fuel level.**
- **To prevent damage to the filter, Not valve should add on fuel return line**

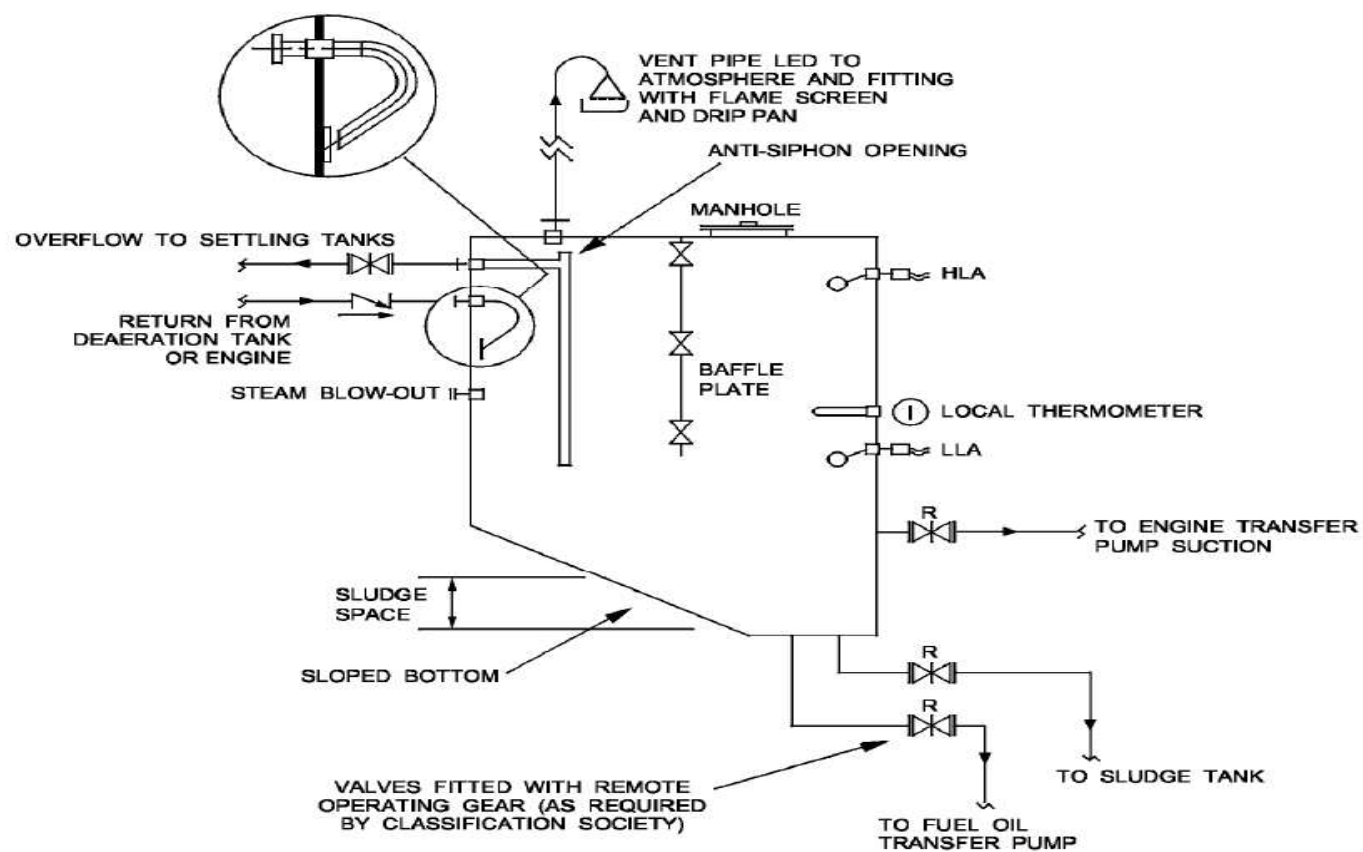
one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Typical Auxiliary Fuel Tank



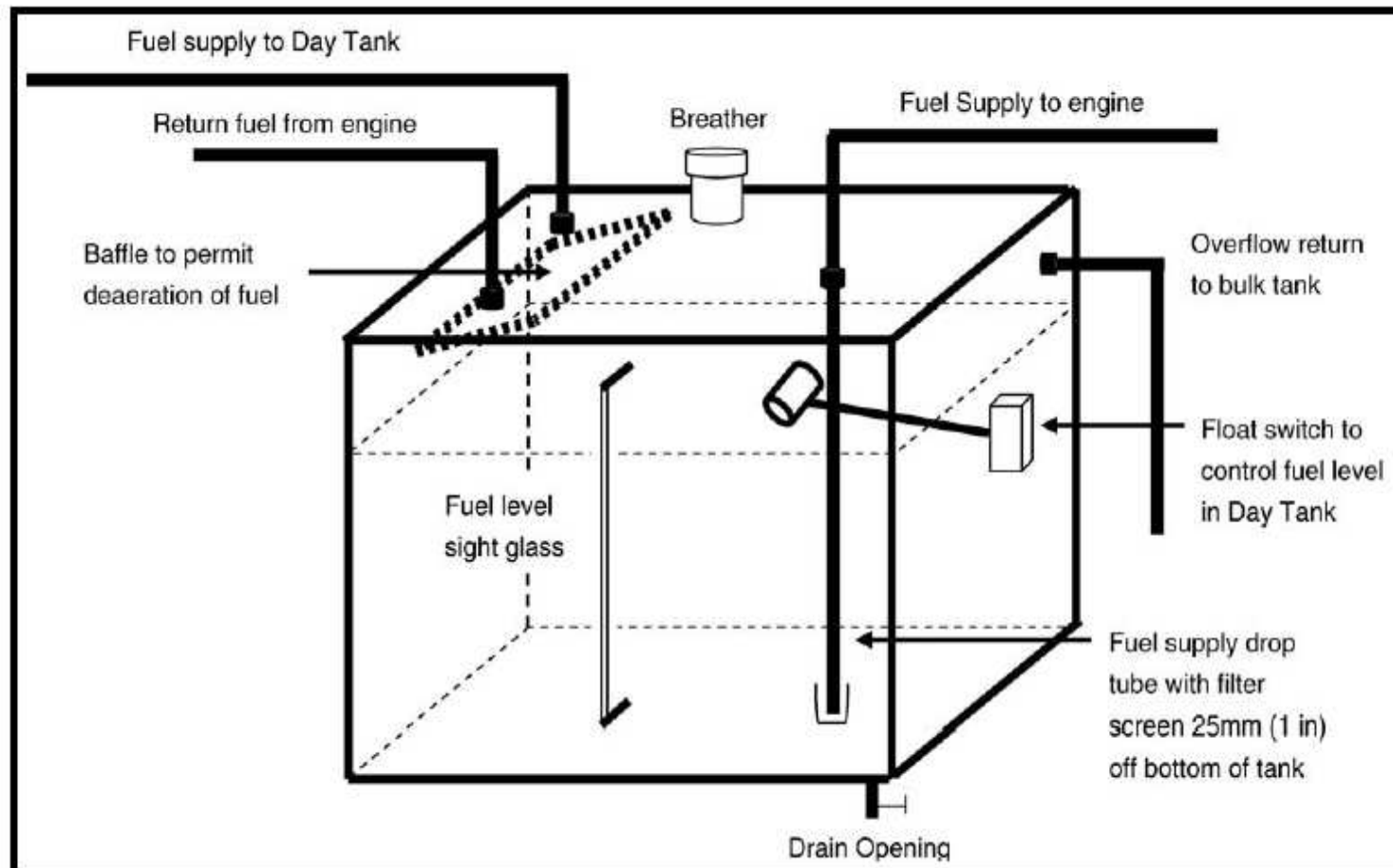
one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Fuel Tank Construction

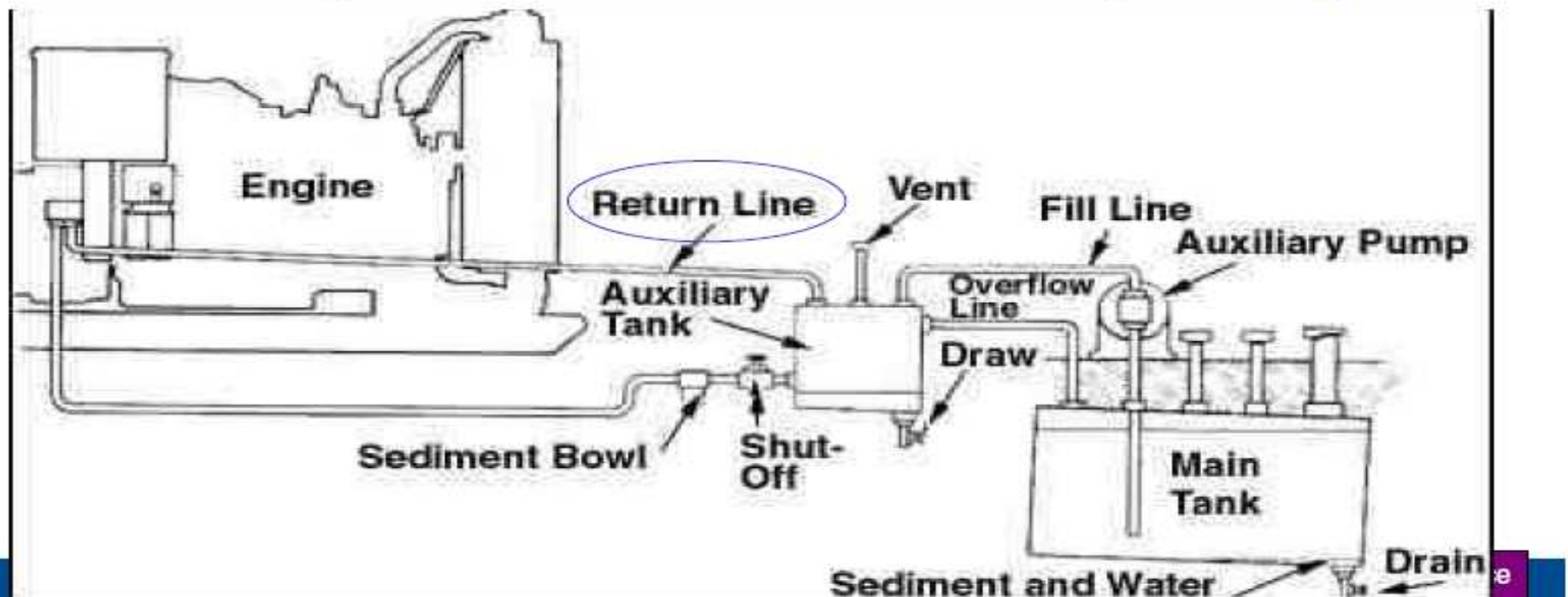


Fuel Lines

- Black iron pipe is the best suited material for diesel fuel lines.
- Valves and fittings should be Cast Iron or Bronze
 - Do Not use Brass valves (Brass is a combination of Copper and Zinc)
- Route fuel lines under machinery so any leakage is confined to the bilges.
 - Leaks from overhead fuel components may fall on hot machinery and created a fire hazard.
- Use the fuel flow data in TMI to properly size fuel supply and return lines.
 - Supply and return lines should be at least the size of the fittings on the engine.
 - The fuel return line must be at least the same size as the

Fuel Return Lines

- Engine return line fuel pressure should be kept below 27 kPa (4 psi) for all electronic engines.
 - This is to ensure adequate fuel flow through this line
 - Fuel flow through the engine is used to cool fuel components. Reducing this flow could result in reduced fuel system component life.



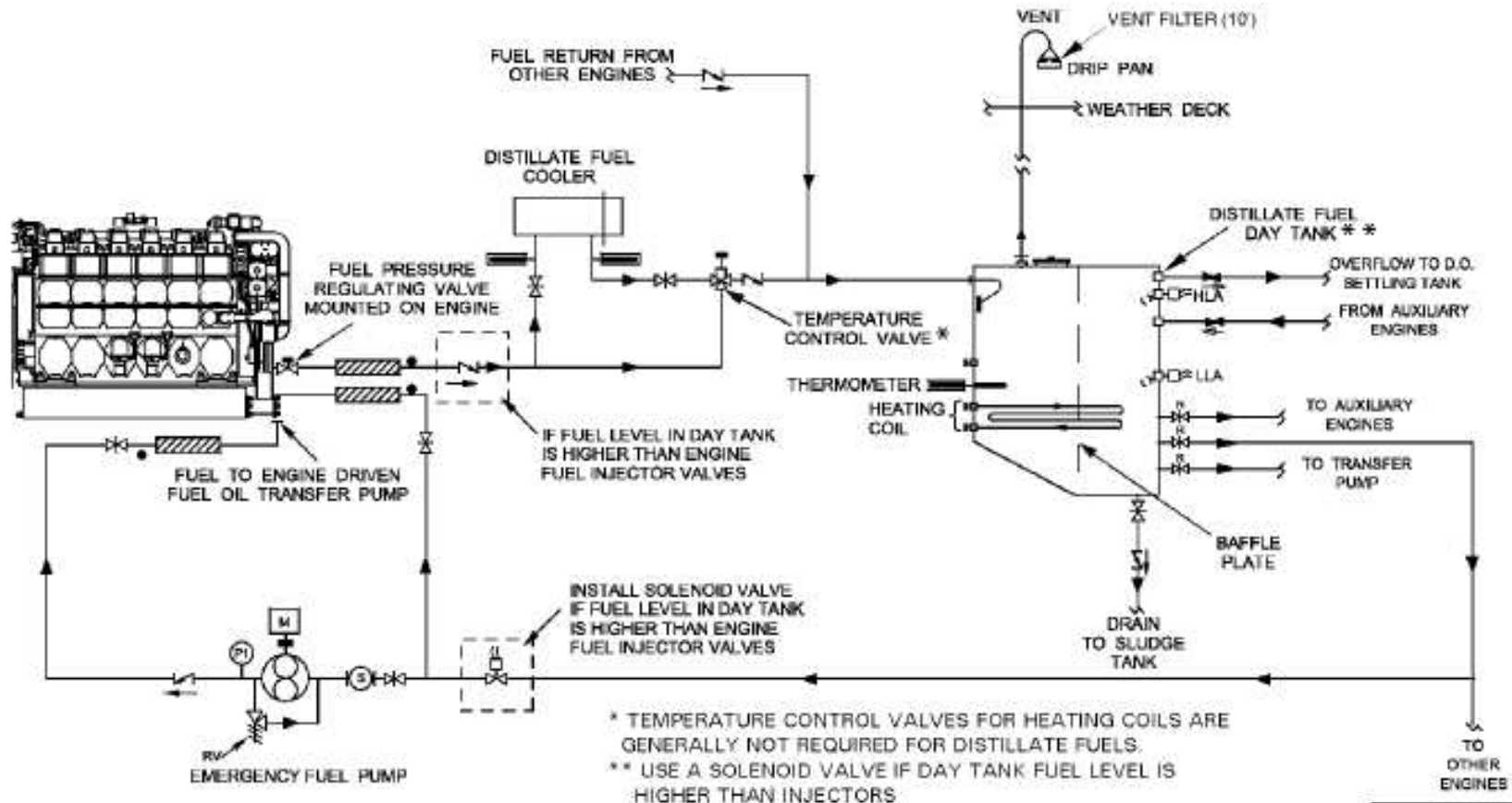
one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Fuel transfer System



Fuel System Installation

- All connecting lines, valves, and tanks should be thoroughly cleaned before making final connections to the engine.
- The entire fuel supply system should be flushed prior to engine start-up.

Fuel Heaters

- Fuel Heaters are effective when the minimum expected ambient temperature is
 - Below the Cloud Point and
 - Above the Pour Point
- Heat the fuel before it flows through the filters.
- When the ambient temperature is below the Pour Point, fuel heating must be applied to the entire fuel storage volume.

Use Fuel Heater to Increase Fuel Temp Above Cloud Point

Fuel Temp to First Filter	Fuel will flow through lines, pump, and filters
Cloud Point	Haze (wax) appears in fuel. Fuel will flow through lines and pump, but not filters
Pour Point	Fuel will not flow in lines or pump. Do not use a fuel with a Pour Point above the expected ambient temperature.

Fuel Heaters

- Heaters must be sized for handling the maximum fuel flow of the engine.
- The restriction created by a fuel heater must not exceed published allowable restriction limits
- Fuel heaters must be turned off when the ambient temperature exceeds 15°C (60°F).

Water in the Fuel

- Water appears in the fuel because of
 - condensation, handling and environmental conditions (humidity)
- Water in the fuel will be more prevalent in humid climates
- Water in the diesel fuel will cause damage to the engine and its components.
 - Water reduces fuel lubrication properties
 - Water will oxidize iron, introduce iron oxide in fuel
 - Water and fuel offer a medium for bacterial growth which will build up sludge.
 - Will affect
 - Injector Performance
 - Accelerate Injector Wear
 - Plug or Wear Fuel Filters
- Maintain water and sediment levels at or below 0.1%.

Water Separators

- A water and sediment separator can be installed in the supply line ahead of the transfer pump.
- The separator must be sized to handle the fuel being consumed by the engine as well as fuel being returned to the tank.
- Design Considerations
 - Include Pressure Drop in Restriction calculations
 - Do not location the Drain over Electrical Items



Injector life

Water separator/primary filter–Prevent injector water damage•100% free water•90% emulsified water–Extend secondary filter life

Fuel Water Separator Options-Standard (20 microns and up)-Advanced (10 to 20 microns)



Plunger
scuffing due
to excess
water

Fuel Cooling

- Excess fuel is delivered to engine and returned to the fuel tanks
 - Provides cooling and lubricating of the pumps and injection systems
 - Picks up engine heat and can raise the temperature of the fuel in the tanks.
- Elevated fuel temperature increases fuel system component wear
 - Fuel expansion reduces viscosity
 - Low viscosity reduces lubrication properties
 - May result in damage to injection components
- Elevated fuel temperature reduces engine power
 - Heat increase the specific volume of the fuel
 - 1% power loss for each 6 °C (10 °F) above 38 °C (100 °F)
- For optimum performance and increased injector life, maintain fuel at room temperature: 15-40 °C (59-104 °F)
- Maximum fuel temperature limit: 66 °C (150 °F) to the unit injectors.
 - See TMI Engine System Data for Model Specific Limits

Factors Affecting the Need for Fuel Cooler

Proper fuel tank location and size will help temperature control.

Factors that affect the need for fuel cooling

- Length of periods of continuous operation
 - If operating periods are short, the amount of heat returned to the fuel tanks will be relatively small.
- Length of time between periods of operation
 - If the time between periods of operation is long, the heat will have an opportunity to dissipate.
- Volume of the fuel tank
 - If the volume of the fuel tank is large (>11 000 L [3,000 gal]), it will accept a great deal of heat before the temperature of the fuel leaving the tank increases significantly.
- Ability of the fuel tank to dissipate heat.

If the stabilized fuel tank temperature is high, the returning fuel should be cooled.

Application Of Fuel Cooler

- The need for a fuel cooler is application dependent, and can only be determined through testing the installation to ensure the fuel temperature into the high pressure pump does not exceed the limit for the specified engine.
- The following factors can significantly effect fuel temperature.
 - plastic fuel tank
 - fuel tank is next to a heat source, i.e. hydraulic system
 - High engine bay temperatures
 - Low or no air flow over engine or fuel ta

one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Fuel Tank Grounding

Fuel tanks, both bulk and auxiliary, need to be grounded. This is for personal safety and reduce the fire hazard of sparks discharge from static electricity build-up during refueling operations.

Fuel Tank Maintenance

Fuel has a storage life of approximately one year. This period may vary widely depending upon initial fuel quality, contaminant levels and storage conditions.

To remove water, scale and bacteria growth, periodic exchange of fuel and filtering/treating is recommended to extend fuel life.

one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Reference Material

- LEBV4830, Marine Analyst Service Handbook (MASH Book)
- LEBW4976, Diesel Fuels & Diesel Fuel Systems A&I Guide
- SEBD0717, Diesel Fuels and Your Engine
- SEBU6251, Caterpillar Commercial Diesel Engine Fluids Recommendations
- SEBU7003, 3600 Diesel Engine Fluids Recommendations for Lubricants, Fuels, and Coolants
- REHS0104, Guidelines for 3600 Heavy Fuel Oil (HFO) Engines
- SENR9620, Improving Component Durability: Fuel Systems
- WECAP Web Engineering Cataloging and Procuring website

one powerful future.

engaged • profitable • differentiated

electric power division

CATERPILLAR®

Questions?