Dual-Fuel Upgrade
As the availability of natural gas increases worldwide, gas powered engines are becoming more and more attractive for power generation in land-based and marine applications. Operators are looking for solutions that make use of gas in their existing diesel engines wherever possible.

Dual-fuel engines provide the ability to run on either gas or liquid fuels. Upgrade solutions for existing diesel engines to dual-fuel capability are a suitable way to benefit from the economical and environmental advantages of gas operation.

MAN Diesel & Turbo provides dual-fuel upgrade solutions based on the latest state-of-the-art technology, enabling engine operation with higher efficiency and lower emissions in combination with a lifetime extension.
MAN Diesel & Turbo currently offers two dual-fuel engine types in its four-stroke large bore program: 32/40DF for stationary application and 51/60DF for marine or stationary application. Both types are based on the existing and well-proven 32/40 and 48/60 engines with heavy fuel oil (HFO) capability. In addition, MAN Diesel & Turbo offers suitable dual-fuel upgrade solutions for both HFO diesel engines 32/40 and 48/60. They are designed and working according to the same principles, however, show differences in their technical details. In the near future more dual-fuel solutions for upgrading other engine types will be designed and introduced to the market.

Fuel flexibility
Dual-fuel engines combine the ability to run on either liquid or gaseous fuels. A variety of fuels can be used, such as natural gas in broad qualities and all kinds of liquid fuels including HFO. The 32/40DF is designed to run on DMB qualities (MDO) in liquid mode. The wide variety of applicable gaseous and liquid fuels generally secures a high level of plant availability. In a scenario of fluctuating fuel prices, operators can choose the most economic fuel depending on the current price differences.

Dual-fuel operation
Generally, the air-gas mixture in MAN dual-fuel engines is ignited by pilot injection of distillate fuel. For the combustion process at full load, about 1% of the required energy is represented by pilot fuel and 99% is gas or liquid fuel. The pilot injection is always activated: in gas mode for ignition purposes and in liquid mode to prevent clogging at the nozzle holes of the pilot injectors. The 51/60DF engine features an electronically controlled pilot injection system based on common rail technology with one pilot injector in each cylinder head. The common rail pump is electrically driven and provides up to 1,600 bars of injection pressure. The pilot fuel system of the 32/40DF consists of a mechanically cam-driven pump for each cylinder which feeds two pilot injectors in each cylinder head.

Dual-fuel engines, which are derived from diesel engines, have an adapted compression ratio and thus, in comparison to their pure diesel equivalent, a reduced mean effective pressure. This is necessary for gas combustion in order to prevent knocking. MAN Diesel & Turbo dual-fuel technology is based on low pressure gas application, which does not require a high pressure gas compressor for gas injection. Its absence is advantageous, resulting in a lower investment and no additional electrical losses for the operation of such plant equipment.

In liquid fuel mode, uninterrupted heavy fuel oil operation of the 51/60DF is possible in a power range from 100% to 20% and even, for limited periods, below 20%. In gas mode, newest MAN Diesel & Turbo technology allows operation of the 51/60DF on loads even below 15% MCR for a noticeable duration (“low-load” capability).

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**Fuel Flexibility**

**Dual-fuel operation mode**

**Liquid fuel mode**
- Main fuel nozzle: Diesel 99%
- HFO, MDO (DMA, DMB)
- Pilot fuel nozzle: Distillate < 1%
- MDO (DMA, DMB)

**Gas mode**
- Gas admission valve: Gas 99%
- Natural gas (vapourised LNG)
- Pilot fuel nozzle: Distillate < 1%
- MDO (DMA, DMB)

**Switching between fuels**

One of the major advantages of modern MAN Diesel & Turbo dual-fuel engines is the ability to switch over from gaseous fuel to liquid fuel at almost all load points during normal operation. The 51/60DF engine can seamlessly switch from gas to liquid fuel at any time and load. Even at full load no loss of engine output or speed is measurable and the engine will not trip. Therefore, operation on liquid fuel is a back-up mode for those operators who cannot rely on their gas supply. Switching over from liquid fuel to gas is a normal procedure during every engine start-up. Generally, a dual-fuel engine is started on liquid fuel and is switched to gas after a few minutes. The switch over is normally executed at loads higher than 15% and takes about two minutes. During the normal switch over the combustion residuals from the liquid start-up are burnt and do not result in hot spots which, in gas mode, would lead to knocking events. If the engine is scheduled to stop, it is switched to liquid fuel again and stopped in liquid mode.

**Improvement of Emissions**

**Improvement of emissions**

Like pure gas engines, dual-fuel engines running in gas mode have a favorable emission profile in regard to nitrogen oxides and carbon dioxide. The NOx emissions of a 51/60DF engine in gas mode are up to 90% lower in comparison to liquid fuel operation. Emissions of the greenhouse gas CO₂ are likewise reduced by approximately 20%. Emissions of SOₓ are almost zero and mainly depend on the quality of the pilot fuel oil used. Thus, dual-fuel engines provide a considerably better emission footprint than diesel engines. The emission values of the 51/60DF engine are significantly below the current limits for land based and marine applications. In fact, in gas mode it already fulfills the strict IMO Tier III NOₓ limitations prescribed for maritime Emission Control Areas (ECAs).

**Comparison of emission in liquid fuel mode and gas mode of 51/60DF engine**
Gas and pilot fuel injection technology

The gas is supplied to the engine via a gas valve unit which regulates the gas pressure according to the current charge air pressure level. The gas injection timing and amount on each 51/60DF cylinder is controlled by solenoid valve.

The 51/60DF pilot fuel system, consisting of latest common rail technology, is fed by an electric powered high pressure pump mounted on-engine. Electronic controlled solenoid valves in the pilot fuel injectors allow for flexible settings of injection timing and duration for each 51/60DF cylinder. This offers the possibility to rapidly respond to potentially occurring combustion knocking or misfiring on a cylinder-by-cylinder basis.

The flexibility of gas and pilot fuel system is the key of optimizing efficiency and emissions of the 51/60DF at any point in its operating profile, even down to very low engine loads.

SaCoS\textsuperscript{one} control system

The 51/60DF engine is controlled by a special SaCoS\textsuperscript{one} electronic system. SaCoS\textsuperscript{one} is MAN Diesel & Turbo's advanced engine safety and control System. It houses the engine speed control, all micro-electronic controllers, safety functions and alarm pre-processing. The system integrates signals from the cylinder individual knocking sensors and controls the fuel injection timing for gas and pilot fuel, the lambda control flap for adjusting the air-fuel ratio and the off-engine placed gas valve unit. All controls communicate with SaCoS\textsuperscript{one} via CAN-bus connection.

Design Features 51/60DF

Engine design features

The 51/60DF engine is based on the design of the well-proven 48/60 engine - therefore the major engine components are the same. This is also a precondition for an upgrade solution. The main differences in engine design are the components of the combustion chamber, such as the cylinder liner, piston, cylinder head of the fuel supply systems for gas and pilot fuel, and special electronic control modules (including knocking detection). The following sections explain engine details.

Cylinder head

The cylinder head arrangement, one of the core components of a modern 51/60DF engine, features the most relevant dual-fuel components, such as the gas valve and pilot fuel injector. The on-engine gas pipe on top of the rocker arm casing has for safety reasons a double wall design. The inner pipe is for gas supply while the outer one is continuously ventilated. Potential gas leakages from the inner pipe are withdrawn from the engine and detected by special sensors.

The gas flows from the gas valve integrated in the air manifold via a gas flow control pipe to the inlet valve port, where it is mixed and swirled with the intake air. The geometry of the cylinder head and piston crown assures the optimum combustion process, resulting in low fuel consumption and emissions in both operating modes.
Dual-Fuel Upgrade

51/60DF engine upgrade

Because MAN Diesel & Turbo supports customers during the entire life cycle of their engines, upgrade solutions for engines in service in general and conversion packages from purely liquid fuel operated to dual-fuel engines are available. Even engines that have logged more than 100,000 operating hours can benefit from such conversion packages. Economically, the best approach for the operator is a combination of major overhaul work and DF upgrade at the respective interval.

A dual-fuel upgrade involves a limited number of components and assemblies necessary for gas operation to be added or replaced at the engine. Since the 51/60DF engine is derived from the 48/60 platform, the following major components remain after conversion: the engine frame, crankshaft, bearings, connecting rods, and main diesel injection equipment.

The upgrade centers on exchanging the original 48 cm bore cylinder liners and pistons for new 51 cm bore components. The enlarged cylinder displacement is the key to regain the initial power level of the engine for the most part. Together with the redesigned cylinder liner new support rings are installed. The larger liners fit into the existing bores of the 48/60 engine frame, thus no major machining of the engine frame is necessary. The dual-fuel piston crowns are specially designed to form an optimized combustion chamber for gaseous fuels.

The exchange of 48/60 cylinder heads for 51/60DF cylinder heads incorporates the fuel injection components for gas, pilot fuel, and diesel. Additionally the pilot fuel supply system consisting mainly of high pressure fuel pump and common rail piping is mounted on the engine and connected to the cylinder heads. New cam elements adjust the engine timing to Miller Cycle for emission reduction and optimized gas operation.

Depending on the gas quality and ambient running conditions of the engine, the turbocharger needs to be either “rematched” by fitting a new nozzle ring or modified by a different turbine or compressor geometry in order to be optimized for gas operation.

Besides converting the engine, the adaption of plant equipment is necessary. Engine auxiliary modules for gas and pilot fuel supply and safety devices in the engine environment (i.e., gas sensors, alarm equipment, and sufficient ventilation) need to be installed. Ventilation units and rupture discs in the exhaust stack are essential for safety reasons as well. The new SaCoS engine control system is connected to the engine and plant control. After engine conversion and plant equipment adaptation, the recommissioning of the engine to gas operation is conducted.

MAN Diesel & Turbo offers a variety of services for a typical dual-fuel upgrade project:

- Site survey for evaluation of actual plant layout and check of engine conditions
- Determination of required plant adaptations
- Elaboration of a general conversion plan together with the customer and settlement of a division of work list
- Preparation of a conversion quotation
- Project management by experienced MAN Diesel & Turbo’s conversion experts
- Training of customer’s operating personnel in our PrimeServ Academys or direct onsite at the converted plant
- Continuous life cycle support after conversion with maintenance support and spare parts supply through our worldwide PrimeServ network
51/60DF upgrade, TMG
In 2008, MAN Diesel & Turbo’s after-sales organization MAN PrimeServ carried out the first conversion of an existing 12V48/60 diesel engine to a 12V51/60DF dual-fuel at an industrial cogeneration plant in Portugal. After logging approximately 88,000 operating hours in almost 12 years the owner, Têxtil Manuel Gonçalves, Sociedade de Producao de Electricidade e Calor S.A. (TMG SPE), decided to convert the 12V48/60 to 12V51/60DF. The fuel price advantage of gas and the reduced environmental impact of dual-fuel technology were key for this decision. Since the upgrade was combined with major overhaul work, the most economical approach was taken.

32/40 DF upgrade, Sanko Power Plant
The first dual-fuel conversion of an 18V32/40 to 18V32/40DF was at the SANKO Power Plant in Turkey. This genset, originally commissioned for HFO operation in 2001, was upgraded to dual-fuel capability in 2007. The major reason for this conversion was the availability and price advantage of gas.

Study: Gas-fuelled container feeder with integrated LNG-tanks in cargo holds
As a result of emission legislation and rising fuel prices, the market interest in converting marine engines to dual-fuel capability is strongly increasing. Vessel operators are looking for alternatives to HFO fuel. Together with leading partners from a classification society, a supplier of gas storage and supply systems, and a ship designer, MAN Diesel & Turbo conducted a feasibility study for a gas fueled 1200 TEU container feeder. The study showed that the LNG tanks and gas supply equipment could be accommodated on board without a significant loss of cargo space. A dual-fuel upgrade in marine application could therefore be carried out in the following steps:
- Conversion of existing main engine to dual-fuel operation
- Adaptation of engine room systems
- Safety installations
- Installation of bunkering equipment
- Installation of Fuel Gas Preparation Unit
- Adaptation of HFO and MGO tanks
- Installation of LNG-tanks in cargo holds

Study: Gas-fuelled RoPax ferry with exchangeable LNG-storage containers
A further study recently carried out by Flensburger Schiffbau-Gesellschaft (FSG), TGE Marine Gas Engineering and MAN Diesel & Turbo investigated the possibilities for incorporating exchangeable LNG storage tanks onboard of a RoPax ferry.

This study was based on applying standardized LNG containers for storage mounted on trailers and carried by tractor vehicles on board. They are placed at a designated place on the upper car deck and connected to the ship’s LNG handling system. The containers, filled before the port call with LNG at a land based terminal, would be waiting in standby at the wharf. A comparable solution could be applied to other cargo vessels where LNG containers are placed on board by crane.

Advantages of this solution are:
- Standardized, exchangeable LNG containers
- Cost advantages for short distance traffic as the investment cost would be considerably lower compared to a fixed mounted tank system
- Good upgrade possibility
- Bunkering procedure independent of port stay and not interfering with normal handling operations of commercial load
- High grade of flexibility
- Easy expandable LNG infrastructure

Gas as realistic option to fulfill future emission requirements (IMO TIER III, EU ships on berth)
Feasibility study:
Gas-fuelled container feeder for ECA operation
Partners: Germanischer Lloyd, TGE, Neptun Stahlkonstruktion / WIG
Realised between 05-11/2009

References
Characteristics and advantages of dual-fuel upgrades

- Dual-fuel upgrades offer the opportunity to use gaseous fuels in existing diesel engines
- Upgrade solutions for several MAN Diesel & Turbo medium speed engine types available
- High reduction of fuel cost by use of natural gas
- Attractive pay-back time
- Best economics if conversion is combined with major overhaul
- Lifetime extension of existing engine and plant
- Environmental advantages by reduction of NO\textsubscript{x}, SO\textsubscript{x}, and CO\textsubscript{2} emissions
- Fuel flexibility and switch over at almost all engine loads