Using Methanol Fuel in the MAN B&W ME-LGI Series

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MAN Diesel & Turbo

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Using Methanol Fuel in the MAN B&W ME-LGI Series

Background

Methanol as a ship fuel is interesting for ship operators because it does not contain sulphur and is liquid in ambient air conditions which makes it easy to store on board ships. So for ships operating in International Maritime Organization (IMO) emission control areas (ECA), methanol could be a feasible solution to meet sulphur requirements. When using methanol, the emission reductions are similar to the advantages obtained by using liquid natural gas (LNG), however installation costs on board is only a fraction of the costs for LNG. Furthermore, methanol can be produced from biomass.

Other issues also increase the interest for methanol and other new fuel types. To limit CO_2 emissions, IMO decided already in 2013 to adopt the Energy Efficiency Design Index (EEDI) as a mandatory instrument for ships built after January 2013. This influences the engine market and technical solutions faster than anticipated. Therefore, to lower the EEDI, alternative low carbon fuels, such as natural gas (NG), liquefied petroleum gas (LPG) and methanol will be serious candidates to fuel oil in the future.

By nature, NG, LPG and methanol generate less CO_2 emissions during combustion than fuel oils. Furthermore, methanol is interesting because bio-methanol can be made from a vast variety of biomasses and mixed with methanol made from fossil fuels.

Already today, the 7 x ME-LGI engine is on order. The first companies to order this engine type – designated 7S50ME-LGI and 6G50ME-LGI – are Mitsui O.S.K. Lines, Marinvest and Westfall Larsen.

MAN developed the ME-LGI engine in response to interest from the shipping world in operating on alternatives to heavy fuel oil. Methanol and LPG carriers have already operated at sea for many years and many more LPG tankers are currently being built as the global LPG infrastructure grows.

With a viable, convenient and economic fuel already on board, exploiting a fraction of the cargo to power the vessel makes sense with another important factor being the benefit to the environment. MAN Diesel & Turbo is working towards a Tier III compatible ME-LGI version, which can already be ordered today.

Further market feedback also tells us that there is an interest for methanol from ships operating in remote areas where it is difficult to establish LNG delivery and terminals. Large scale LNG is economically feasible, but small scale LNG becomes expensive due to the rather large investment costs.

Methanol can be stored in normal non-pressurised tanks, and are easy to transport. Train, truck and ship deliveries are already in place in many areas, so methanol infrastructure can easily be established and become feasible – also for a single ship in a remote area.

At the moment, the cost of methanol is higher than the cost of heavy fuel oil (HFO) so it only makes sense to use methanol in sulphur emission control area (SECA) zones, for river traffic, in remote areas with strict emission control (for example on lakes or in artic zones) and on inland waters.

In 2015, an approx. 30% reduction of fuel costs can be achieved when compared to marine gas oil (MGO) containing 0.1% sulphur. Therefore, it also make sense consider retrofit solutions for existing ships.

When all this is said, it is important to notice that methanol is toxic, corrosive and takes up twice as much space as marine diesel oil (MDO), see also fuel Table 1. Because of this, special considerations have to be taken – both in the design, during maintenance and in case of leakages.

Methanol as a Fuel

In 2012, MAN Diesel & Turbo decided to expand the engine portfolio by looking at low flashpoint fuels and, as a result, the ME-LGI engine series was introduced.

The MAN B&W ME-LGI engine is the dual fuel solution for low flashpoint liquid fuels contrary to the ME-GI engine where the fuel is injected in the gaseous state. Methanol is characterised by a low cetane number, see Table 1, and the self-ignition quality is therefore poor. In spite of this difference, the operation principle and safety concept of the ME-LGI engine are similar to the already accepted ME-GI concepts.

However, due to the difference in fuel properties, the ME-LGI components and auxiliary systems will be different from the ME-GI.

The ME-LGI engine can be delivered in different versions, depending on

Fuel properties

Property	DME	Methanol	Ethanol	Diesel	HFO 45	Gasoline
Chemical formula	CH_3-O-CH_3	CH_3-OH	C_2H_5-OH	C8-C25	-	C4-C12
Fuel carbon (wt%)	52.2	38	52	85	-	86
Fuel hydrogen (wt%)	13	12	13	15	-	14
Fuel oxygen (wt%)	34.8	50	35	0	-	0
Molar mass (kg/kmol)	46	32	46	183	-	114
Liquid density (kg/m^3)	660	798	794	840	982	740
Lower heating value (MJ/kg)	22.8	20.1	27.0	42.7	40.9	-
Boiling temperature (°C at 1 bar)	-24.9	65	78	180-360	-	27-245
Vapour pressure (bar at 20°C)	5.3	0.13	0.059	«1	-	0.25-0.45
Critical pressure (bar)	53.7	81	63	30	-	-
Critical temperature (°C)	127	239.4	241	435	-	-
Kinematic viscosity (cSt at 20°C)	0.19-0.25	0.74	1.2	2.5-3.0	-	0.6
Surface tension (N/m at 20°C)	0.012	0.023	0.022	.027	-	-
Bulk modulus (N/mm^2 at 20°C 2MPa)	1,549	823	902	553	-	1,300
Cetane number	55	<5	8	38-53	-	-
Octane number	Low	109	109	15-25	-	90-100
Auto ignition temperature in air (°C)	350	470	362	250-450	-	250-460
Heat of vaporisation (kJ/kg at 1 bar)	467	1,089	841	250	-	375
Minimum ignition energy (mJ at ϕ=1)	0.33	0.21	0.65	0.23	-	0.8
Stoichiometric air/fuel ratio	9	6.5	9.1	14.6	13.5	14.7
Peak flame temperature (°C at 1 bar)	1,780	1,890	1,920	2,054	-	2,030
Flamability limits (vol%)	3.4-18.28	6-36	3-19	0.5-7.5	-	1.4-7.6
Flash point (°C)	-41	12	14	52	-	-45

Table 1: Fuel properties

the low flashpoint liquid (LFL) fuel type used. Fuels for the ME-LGI engine are categorised by their vapour pressure at 60°C. For fuel examples, see Table 2.

Fuel injection is accomplished by a Booster Fuel Injection Valve (BFIV), using 300 bar hydraulic power to raise the fuel pressure to injection pressure, illustrated in Fig. 1. The BFIV is an integration of our fuel oil booster design and our old slide injector design, which have been used for more than 10 years, now operating on more than 1,000 engines. Both designs are well-proven, and the combined solution has the advantage that it minimises the total weight and removes the HP pipes in-between. By using this design, the total inertia increases the response time of the valve, and tests in service have demonstrated better controlled injection profiles.

Vapour pressure at 60°C

<1 atm (Low)	>1 atm (Low) High)
Methanol, Ethanol,	LPG, DME,

Table 2: Categorisation of different fuels

Methanol has a flash point of 11°C, which is not Safety of Life at Sea (SOLAS) compliant. However, since we use a double wall design of all our methanol components, and all leakages are monitored and collected in the double barrier, there are no problems related to this. Indeed, it is far easier to handle methanol than LNG.

To be able to use methanol fuel on the ME-LGI, the cylinder covers will be equipped with the fuel booster injector valves designed specifically for methanol operation. For a 50 bore engine this means that each cylinder cover will be equipped with two additional methanol booster injectors. A liquid gas injection (LGI) block will be fitted on the cylinder cover.

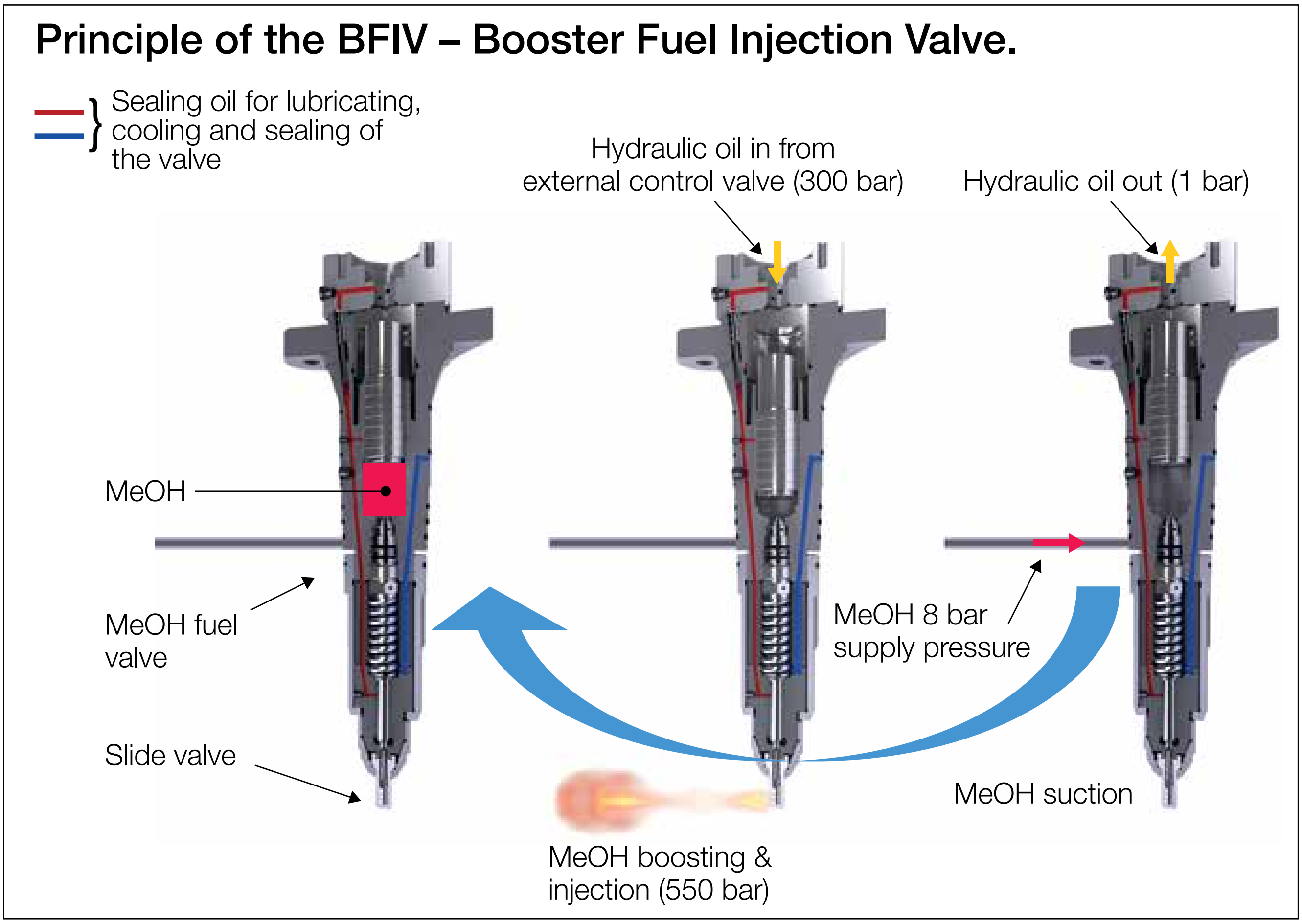

Fig. 1: Working principle in the Booster Fuel Injector Valve (BFIV) for methanol

Fig. 2: Cylinder cover equipped with fuel booster injectors and an LGI control block. All fuel pressure pipes are double-walled

This block contains a control valve for methanol fuel injection, a sealing booster activation valve, a forced suction activation valve, an LGI purge valve and methanol fuel inlet/outlet valves. All pipes for hydraulic oil and fuel are double-walled. Furthermore, the double-walled pipes for methanol fuel are vented with ventilation air, see Fig. 2.

The methanol booster injector valve must be cooled, and running surfaces must be lubricated. For this purpose, a combined sealing and cooling oil system delivering a 50 bar system oil pressure has been integrated on the engine, and the system both lubricates all running surfaces and controls that the temperature in the booster valve is lower than max. 60°C. The actual design is shown in Fig. 3.

The sealing oil pressure is generated internally in the booster valve in order to avoid contamination of the hydraulic oil operating the valve. The sealing oil has other advantages. It avoids methanol from going into the umbrella system and further down into the drain oil system. The cooling oil and sealing oil system are fully integrated in the engine design, including equipment for continuous monitoring of methanol contamination in the oil system. If methanol is

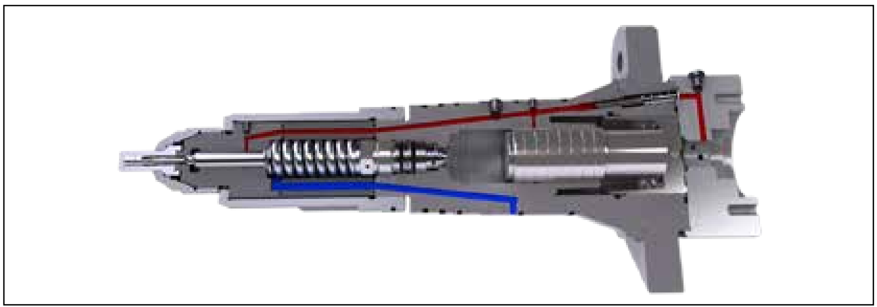

Fig. 3: The methanol booster injector with cooling oil (blue) and sealing oil (red) supply fully integrated

detected in the system, the engine will switch to fuel oil mode, and the methanol will be purged from the engine.

At the same time, the cooling oil pump supply side will be switched to clean system oil, and the oil circuit will be flushed with clean oil. Then, the clean oil will be collected together with the contaminated oil in the cooling oil tank, and the system will only be able to continue operation when no methanol is detected in the tank.

To ensure the correct temperature of the BFIV, the oil is cooled in a heat exchanger, which is connected to e.g. the low temperature cooling system. When the fuel is injected, the combustion condition is monitored with pressure mean indicator (PMI) sensors located in each of the cylinder covers. The injection pressure is approx. 500 bar. Three combustion conditions are monitored. The compression pressures, combustion pressures and expansion pressures.

The 8 bar pressurised methanol is delivered to the engine via double-walled pipes, ventilated with dry air taken from the starting air system. To suck in air, a ventilation system is fitted at the outlet. All methanol fuel equipment is made in a double-walled design, and any methanol leakage will develop into methanol vapour.

This is monitored by HC sensors located close to the outlet of the double-walled piping system. In case of a too high methanol vapour content in the ventilation, the safety system will shut down operation on methanol and return to operate on sole fuel oil. This switch is done smoothly and without any power loss.

A methanol control and safety system is integrated on the engine. The main operating panel (MOP) is equipped with a user-friendly interface for methanol operation. At this panel, the LGI system monitors and indicates the relevant pressure, temperatures and position of the different valves.

Corrosion and Formaldehyde – Not an Issue

Even though methanol is particularly corrosive, no changes to the corrosive level in the combustion chamber are expected when using it as fuel in standard engines. Already today, we have quite a corrosive environment and the combustion chamber is designed to cope with this. However, for the first engines in operation on methanol, tests of different lube oil types are needed to find the best suitable types.

We do not foresee problems with the formaldehyde generation from the combustion. Methanol will burn with a temperature of up to 1,300°C and consequently, all methanol molecules will be burned. Formaldehyde is generated at a temperature of approx. 400–600°C, and since our engines do not have any fuel slip, no formaldehyde is generated in the exhaust gas system.

For engines wuth a high fuel slip and methane slip – such as two-stroke and four-stroke engines using the Otto cycle – it is much more likely that they will experience problems with the formaldehyde generation in combustion or in the exhaust gas system.

ME-LGI Auxiliary Systems

This section describes the auxiliary systems specific for the ME-LGI engine. In addition to the systems described here, the normal ME auxiliary systems are also required – and since the ME-LGI is a dual fuel concept, a standard supply system for operation on fuel oil is also needed. See Fig. 4 for an overview of the LGI system only. In the ME-LGI system overview diagram, the fuel service tank is shown as a ventilated tank.

Methanol Supply System

The engine uses temperature-conditioned methanol at a fixed supply pressure and varying flow depending on the engine load. The methanol low flashpoint fuel supply system (LFSS) will have to supply this fuel to the engine while complying with the requirements described regarding temperature, flow, pressure and ramp-up capabilities. A different system layout could be chosen for this task. In the following, a

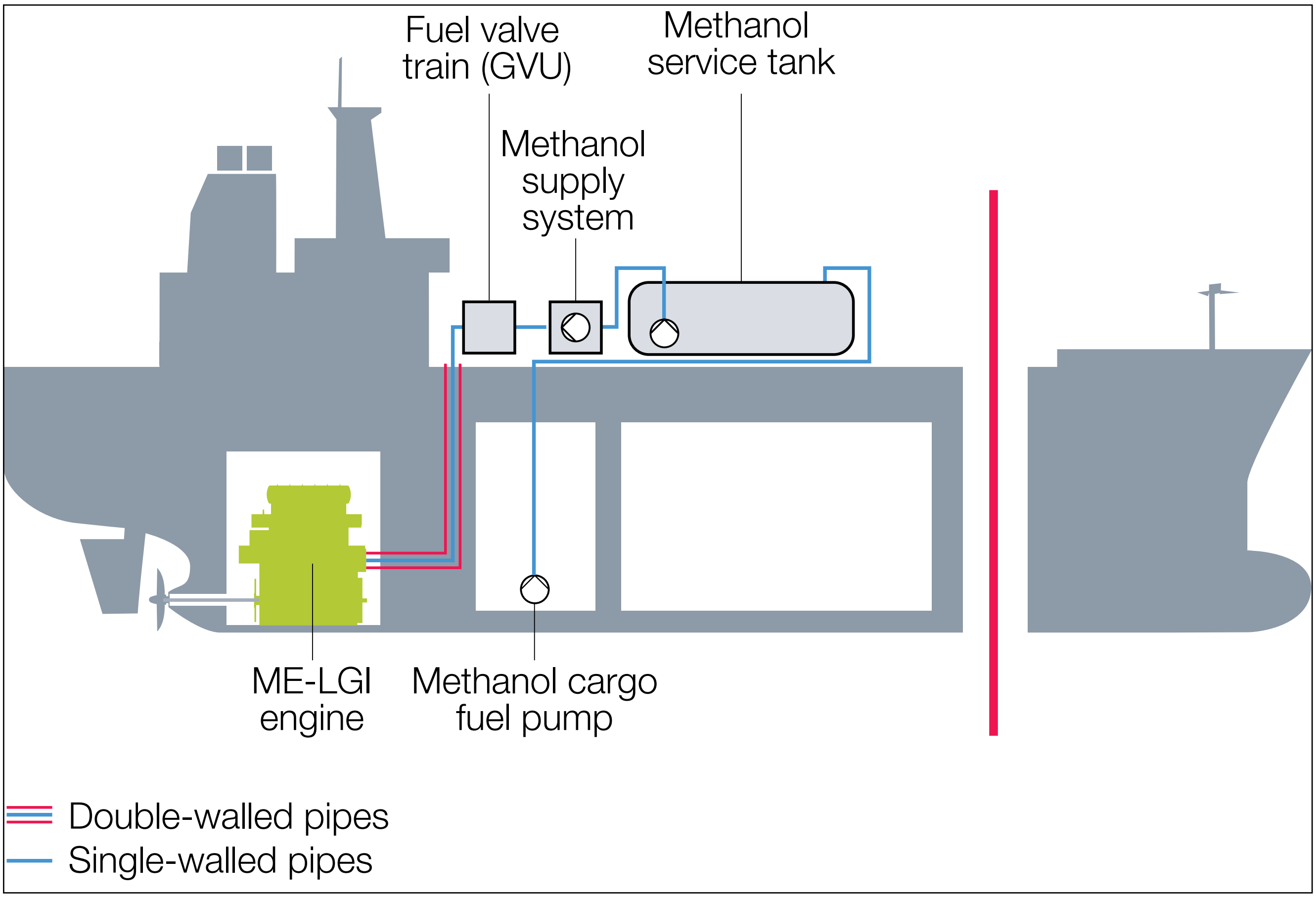

Fig. 4: ME-LGI system overview

circulation solution is described as an example.

The methanol LFSS follows the same concept as an ordinary fuel oil supply system. The fuel is taken from a service tank containing liquid fuel and boosted to a pressure close to the supply pressure, e.g. for methanol approximately 8 bar. The fuel is then circulated by the circulation pump, and the pressure is raised to the engine supply pressure, e.g. for methanol approximately 10 bar. The delivery pressure must ensure that the fuel will stay liquid, and no cavitation will be generated at the temperatures to which the fuel is exposed until injection in the BFIV. The flow of fuel in the circulation circuit should at all times be higher than the fuel consumption of the engine. A typical circulation factor is 2-3 times the fuel consumption.

To ensure the fuel delivery temperature, a heater/cooler is placed in the circulation circuit. It is recommended to connect this through a secondary cooling circuit to the LT cooling system.

Methanol Valve Train

The fuel valve train connects the LFSS with the engine through a master fuel valve (MFV) arranged in a double block and bleed configuration. For purging purposes, the valve train is also connected to a nitrogen source.

Typically, the valve train will be placed outside the engine room above the weather deck to avoid the need for double safety barriers. From the valve train, the fuel is fed to the engine in a double-walled ventilated pipe through the engine room.

Purge Return System

As mentioned, the ME-LGI concept involves methanol fuels on the engine. Because of the low flashpoint, there are a number of operation scenarios where the fuel piping will have to be emptied and inerted. For the ME-LGI, the fuel piping on the engine and in the engine room is arranged so that the liquid fuel can purge it and thereby return it to the fuel service tank.

After the methanol fuel has been returned to the service tank, full purging and inerting are conducted for the double-walled piping system.

Stop Gas Operation

If gas operation is expected to be stopped for a longer period, e.g. during short harbour stays, the procedure for switching to gas standby mode is used. However, the LFSS is switched off when the procedure finishes. Major servicing work involving lifting equipment over the supply lines is not recommended in this mode. The reason being that the supply lines in the engine room and on the engine are methanol filled.

Stop for Complete Shutdown of Liquid Gas System

In the event of a complete shutdown of the liquid gas system, all piping is emptied from methanol fuel and the LFSS and ventilation is turned off.

Facts – How is Methanol Made?

Methanol can be made from a wide array of feedstocks, making it one of the most flexible chemical commodities and energy sources available today. To make methanol, you first need to create synthesis gas, which has carbon monoxide and hydrogen gas as its main components.

While natural gas is most often used in the global economy, methanol has the distinct advantage of "polygeneration" – whereby methanol can be made from any resource that can be converted first into synthesis gas. Through gasification, synthesis gas can be produced from anything that is or ever was a plant. This includes biomass, agricultural and timber waste, solid municipal waste and a number of other feedstocks.

In a typical plant, methanol production is carried out in two steps. The first step is to convert the feedstock natural gas into a synthesis gas stream consisting of CO, CO_2, H_2O and hydrogen. This is usually accomplished by the catalytic reforming of feed gas and steam. Partial oxidation is another possible route. The second step is the catalytic synthesis of methanol from the synthesis gas. Each of these steps can be carried out in a number of ways and various technologies offer a spectrum of possibilities which may be most suitable for any desired application.

Conventional steam reforming is the simplest and most widely practiced route to synthesis gas production:

$$2\ CH_4 + 3\ H_2O \text{ -> } CO + CO_2 + 7\ H_2 \text{ (Synthesis Gas)}$$

$$CO + CO_2 + 7\ H_2 \text{ -> } 2\ CH_3OH + 2\ H_2 + H_2O$$

This process results in a considerable hydrogen surplus, as can be seen above.

If an external source of CO_2 is available, the excess hydrogen can be consumed and converted to additional methanol. The most favourable gasification processes are those in which the surplus hydrogen is "burnt" to water, during which steam reforming is accomplished through the following partial oxidation reaction:

$$CH_4 + ½O_2 \text{ -> } CO + 2\ H_2 \text{ -> } CH_3OH$$

$$CH_4 + O_2 \text{ -> } CO_2 + 2\ H_2w$$

The carbon dioxide and hydrogen produced in the last equation would then react with an additional hydrogen from the top set of reactions to produce additional methanol. This gives the highest efficiency, but may be at an additional capital cost.

Unlike the reforming process, the synthesis of methanol is highly exothermic, taking place over a catalyst bed at moderate temperatures. Most plant designs make use of this extra energy to generate electricity needed in the process.

Renewable Methanol

Renewable methanol (or biomethanol) is perhaps the oldest form of methanol production. Sometimes referred to as wood alcohol, methanol was originally created by the Egyptians for the embalming process through the destructive pyrolysis of timber and has since evolved to provide a number of essential materials and chemicals to society.

Though much of today's methanol comes from the methane in natural gas, one of the most remarkable aspects of methanol is the diversity of feedstocks that can be used in its production. Though often methanol comes largely as a by-product of the methane in natural gas, a great and growing amount of methanol is being made from renewable and sustainable resources.

As the most basic alcohol, methanol has the distinct advantage of "polygeneration" – whereby methanol can be made from any resource that can be converted first into synthesis gas. Through gasification, synthesis gas can be produced from anything that is or ever was a plant. This includes biomass, agricultural and timber waste, solid municipal waste, landfill gas, industrial waste and pollution and a number of other feedstocks.

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