Original Manuscript published in **Hydrocarbon Processing**,
Special Focus: Clean Fuels, February 2017 Issue *

DME as a diesel alternative in North America

By R.A. Sills, XTL & DME Institute[SM] , Houston, Texas

Major trends in the global hydrocarbon processing industry include the regulatory-driven demand for clean, low-emission fuels preferably produced from ample supplies of domestic natural gas, as in the US or coal as in China, or from renewable sources. Two decades of global efforts have shown that dimethyl ether (DME) can satisfy all these drivers.[1]

DME has been used for many years as an aerosol propellant in cosmetic and other personal and household products – but this is a small market. DME was first commercialized as a fuel in China as a liquefied petroleum gas (LPG) blendstock for the domestic home cooking/heating market. As a result, it now represents about 5% of methanol global demand.[2]

This article focuses on the challenges - and the significant progress that has been made - to commercialize DME as a diesel alternative in North America, particularly for heavy-duty trucks. Questions about supply, distribution infrastructure, vehicle modifications and market developments, will be discussed; as well as the "chicken or egg" challenges that face emerging alternative fuels.

What is DME? DME is a colorless gas at ambient temperature and pressure. It burns like natural gas in cooking applications, and handles like LPG, as it is a liquid at moderate pressure (75 psig and room temperature). DME is compared to other conventional fuels in **Table 1**. [3]

Table 1. Comparison of DME to other fuels

Characteristic	DME	Methane	Propane	n-Butane	Diesel Fuel
Chemical formula	CH_3OCH_3	CH_4	C_3H_8	C_4H_{10}	-
Boiling point [°C]	-25.1	-161.5	-42	-0.5	180-370
Liquid Density [g/cm^3, 20°C]	0.67	-	0.49	0.57	0.83
Relative gas density (air = 1)	1.6	0.55	1.52	2.07	-
Vapor Pressure [MPa, 25°C]	0.61	-	0.93	0.24	0.53
Max burning velocity [cm/s]	50	37	43	41	-
Explosion limit [%]	3.4~17	5~15	2.1~9.4	1.9~8.4	-
Ignition temp [°C]	235	650	470	365	250
Cetane number	55~60	0	5	10	40-55
Lower heating value [MJ/Nm^3]	59.3	35.9	91.0	118	-
Lower heating value [MJ/kg]	28.8	49.0	46.3	45.7	42.7

*In addition to the published text, this manuscript contains some text and photos that were not included in the published article due to space limitations.

DME's health and environmental effects have been evaluated extensively since its development and commercialization as an aerosol propellant for personal care products. DME is thermally stable, and does not form peroxides, deplete stratospheric ozone, nor contribute to global warming. It has minimal impact on land and water because of its volatility, has low order of inhalation toxicity, and presents no human hazard relative to systemic toxicity, carcinogenicity, mutagenicity or teratogenicity within occupational exposure limits (1000ppm in 8-hour Total weight average). [4]

DME as a diesel alternative. In the 1990s, DME in pure form ("neat") was recognized as having attractive combustion properties as a potential alternative to diesel. It has a high cetane number and can be used in conventional diesel engines with a modified fuel injection system. DME burns without soot (smoke or particulates) due to lack of carbon-carbon bond and oxygen incorporated in the molecule, and without SOx emissions as it is essentially sulfur-free. Engine noise is noticeably lower, as well.

An additional advantage of DME is that it can be produced from a variety of non-crude oil sources particularly from ample supplies of low-cost natural gas in North America, and biomass. Since DME has a very low viscosity and no natural lubricity, the fuel injection system must be designed to tolerate these fuel properties and a lubricity additive must be included to protect the fuel injector and fuel pump.

Over the past two decades, extensive global development work has been conducted in Europe, Asia and more recently in North America. A number of original equipment manufacturers (OEMs), including Volvo, Isuzu, Hino, Nissan, and Shanghai Automotive, Navistar and Ford, have tested DME as a diesel fuel in DME research, trials, and demonstrations.

In particular, the Volvo Group has been developing DME as a diesel alternative since the mid-1990s. These efforts include an extensive, large-scale fleet test in Sweden, from 2011 to 2016, that included 10 heavy-duty Class 8 trucks in commercial operation, accumulating 750,000 on-road miles. This program was part of a Bio-DME program that produced DME from paper mill residue, and included a DME distribution infrastructure with four filling stations

DME can be applicable to virtually all the demanding haul applications where fuel consumption is high enough to secure return on investment. Initially, Volvo is targeting Class 8 heavy-duty, regional haul trucks, as these return-to-base applications limit concerns for expanded fueling infrastructure during the early phases of this initiative.

The diesel fuel market for Class 8 trucks is significant – about 2 million bbl per day. Even 10,000 heavy-duty trucks using DME, which would be supplied from a world-scale 1 million metric ton per year DME plant (1 metric ton DME is equivalent to 395 gallons), would represent only a small fraction of the approximately 2 million class 8 active heavy-duty trucks in the U.S.

Fleet tests in North America. Volvo, in partnership with Oberon Fuels, conducted a test program with Martin Transport in Beaumont, Texas, from 2013 to 2015 using three DME 13-Liter heavy-duty trucks. The three trucks were in daily service in East Texas hauling a range of liquid bulk cargoes and travelled a total of 60,000 miles.

Volvo's fleet tests and extensive engine development efforts have confirmed the attractive benefits of DME in heavy-duty trucks, showing that:

*In addition to the published text, this manuscript contains some text and photos that were not included in the published article due to space limitations.

- The DME engine is similar to the diesel counterpart. The diesel base engine remains unchanged, as DME ignites on compression. The main difference comes in the fuel injection system where specific pumps and injectors are required to deliver the fuel to the engine.
- The exhaust after-treatment system is similar to that used on modern diesel trucks with the notable exception that the diesel particulate filter (DPF), which weighs about 500 pounds, is unnecessary. The removal of the DPF eliminates the need for regeneration and eliminates DPF-cleaning maintenance requirements. NOx emissions are controlled by the existing Selective Catalytic Reduction (SCR). Raw engine exhaust NOx emissions are lower and compliant with U.S. GHG 2014 greenhouse gas emissions and fuel economy standards regulations.
- The fuel tanks resemble propane tanks, and require specific seals and material. The fuel tank is larger due to lower energy density, that is, 1.88 gallons of DME are energy equivalent to 1 gallon of diesel. Two saddle fuel tanks can achieve a range of 700 miles.
- The DME-fueled trucks achieve the approximate horsepower, torque and overall engine efficiency as a diesel truck. DME fuel economy is on par with diesel, as well.
- No truck chassis modifications are needed, and the weight penalty is less than 100 lbs.
- Early testing technical challenges overcome included fuel lubricity/additives package; temperature management and vapor lock; in-tank challenges due to iron oxides from supply chain and oil residues in fuel.

In July 2016, Mack Trucks , the sister company of Volvo Trucks N.A. , announced it is partnering with New York City's Department of Sanitation (DSNY) to explore the use of DME as an alternative fuel in the city's waste management fleet. The city, which runs the largest municipal sanitation department in the world, will begin assessing DME in a Mack Pinnacle Day Cab model equipped with a 13 liter engine.

DME Supply. DME can be manufacture by catalytic dehydration of methanol, followed by distillation, meaning that DME can be produced from a variety of feedstocks, such as natural gas, coal and biomass.[1] To produce 1 metric ton of DME, 1.4 metric tons of methanol is required.

DME production is a mature technology that is utilized in a number of countries including in Asia, Europe and North America. In North America, numerous plants have been built and are planned to produce methanol from ample supplies of low-cost natural gas. Methanol can also be produced from renewable feedstocks such as biogas from waste feedstocks, such as landfill solid waste, manure etc.; and black liquor from pulp mills. Methanex, the world's largest methanol producer and supplier, is a methanol supplier to the DME industry in China. Methanex supports the commercialization of DME in other regions, such as Korea, and in new markets, such as a solvent for bitumen recovery in the Canadian oil sands.

To supply its demonstration programs in North America, Volvo Trucks North America has partnered with Oberon Fuels, which is the first company to produce DME fuel in North America. Oberon Fuels operates a skid-mounted, small-scale production unit that converts methanol to DME. The company's first plant went on line in 2013 in the Imperial Valley region of southern California. The plant can produce 4,500 gallons of fuel-grade DME daily from methanol. The process converts methanol in an innovative catalytic distillation column, and purifies the product to meet fuel specifications.

Oberon Fuels' DME Plant

Distribution Logistics: Storage, Transport and Refueling. Multiple industries have ample experience storing and distributing DME, due to its use as a propellant. Diversified CPC International Inc, an authorized DME distributor of propellant-grade DME from Chemours™, has been storing and distributing DME since the mid-1980s.

Diversified CPC stated that DME can be safely transported, stored and handled and has an excellent safety record. [5] DME is transported in bulk containers- via truck and railroad tank cars- that are virtually identical to those used for propane, with consideration for the use of appropriate seals and elastomers.

For transfer hoses, Diversified CPC Inc. uses a convoluted stainless steel hose manufactured with double-reinforced stainless steel external braiding, meeting similar or higher-working pressure and burst pressure ratings as the LPG hose. Proper grounding and bonding is essential for safe handling of both DME and LPG when filling containers.

DME Truck Transport

DME Storage Tank

Parafour Innovations, LLC, which manufactures propane autogas refueling dispensers, has provided the DME refueling dispensers for the Volvo heavy-duty trucks program.

DME Fueling Dispenser

Standards and Regulations. While DME is a relatively safe product that is environmentally benign, it requires that appropriate standards and regulations are in place and that safe handling procedures are followed. Over the past decade, the DME community has been working with international and regional standards/regulatory organizations to provide DME producers, engine manufacturers, infrastructure developers and others with the references and guidance.[6]

Since 2009, the International Organization for Standardization (ISO) has published numerous new DME specifications, establishing characteristics and testing methods for DME fuel, and providing important benchmarks. The ISO is continuing efforts to establish additional standards in the near future.

In 2014, the American Society for Testing and Materials (ASTM) International issued ASTM D7901, which covers DME for use as a fuel in engines specifically designed or modified for DME, and for blending with LPG.[7] DME can be legally sold as a fuel in all U.S. states. In addition, biogas-based DME is eligible under the U.S. Environmental Protection Agency's Renewable Fuel Standard for Renewable Identification Number credits. Washington State has already qualified DME-powered trucks for tax incentives.

Regional developments. Two noteworthy developments in other parts of the world are:

- In Trinidad & Tobago, state-owned National Gas Co. and Massy Holdings, in conjunction with a consortium comprised of Japanese companies, including technology provider Mitsubishi Gas Chemical, with the, is building a large-scale 1 million MTPA methanol plant and a 20,000 to 100,000 MTPA DME production plant. Target DME markets include diesel alternative, LPG blendstock and aerosol propellant.
- Ford European Research & Innovation Center is leading a 3.5 million euro project to develop the first passenger cars to run on DME and oxymethylene ether, a liquid used as a solvent in the chemical industry. This 3 year program started in 2015. Oberon Fuels is providing the DME fuel.
- In 2017, a major multinational automaker is expected to announce a new, multi-year project to develop a DME medium-duty truck for North America.

Path Forward. In North America, the opportunity to use ample supplies of low-cost natural gas, combined with government policy-driven policies to use renewable resources and consume clean fuels, has created an opportunity for DME to play a role in North America's fuels pool. This adoption is not without challenges, but the fuel supply, infrastructure and vehicle logistical challenges faced by many emerging alternative fuels can be addressed by developments such as mentioned in this article.

Prospects for market growth would be enhanced with more providers for trucks/engines, infrastructure, and fuel production. The International DME Association (IDA) has adopted a near-term goal of 20 DME engines, including the NYC test, engaged in commercial demonstrations in North America by 2018.

Remaining challenges include:

- Customer acceptance by fleet owners depends on DME meeting their criteria for vehicle performance, reliability, durability, economical operations including life cycle costs, maintenance capability, as well as fuel costs and availability, and
- Low crude oil and diesel prices, which are a challenge for all alternative fuels.

As express by Rebecca Boudreaux, IDA Chair and president of Oberon Fuels, DME as a diesel alternative can move from the demonstration phase to commercialization by harnessing the power of collaboration and contribution. The DME community has its sights beyond heavy-duty trucks and across multiple industries including locomotive, marine transportation, and as a fuel for power generation. To achieve these purposes and build the DME ecosystem, the DME community must continue working together, to recruit new members to become active members.[8]

ACKNOWLEDGEMENTS

The author gratefully acknowledge the contributions by the members of the International DME Association, particularly Volvo AB, Oberon Fuels, Methanex and Parafour Innovations; and Diversified CPC Int'l.

LITERATURE CITED

[1] Fleisch, T.H.; A. Basu and R.A. Sills, R.A.,"Introduction and advancement of a new clean global fuel: DME developments in China and beyond", *Journal of Natural Gas Science and Engineering*. 2012.

[2] Methanex Investors Presentation, October 2016.

[3] California Environmental Protection Agency, California DME Multimedia Evaluation, February, 2015.

[4] Creazzo, J., US dimethyl ether markets, manufacture, storage and transfer", 2005.

[5] Frauenheim, W.A.; 7th International DME Conference (DME7), Houston, Texas, September 2016.

[6] Zilioli, M.; "ISO Standardization of DME Components", 7th International DME Conference (DME7), Houston, Texas, September 2016.

[7] ASTM International, ASTM D7901-14b, "Standard specification for dimethyl ether for fuel purposes", 2014.

[8] Boudreau, R., 7th International DME Conference (DME7), Houston, Texas, September 2016.

RONALD SILLS is the co-founding director of the XTL&DME Institute, an educational and consulting service formed in 2010. Dr. Sills is an internationally recognized expert on the value chains for methanol and its derivatives, particularly those involving DME and methanol-to-gasoline (MTG). At BP in the 2000s, he was a member of BP's India DME Project team. In the 1980s and 1990s he held various R&D positions at Mobil, including Manager, Research Planning, and had hands-on experience in the production of DME from methanol as principle investigator for Mobil's four barrel per day MTG demonstration plant. He has been actively involved with the International DME Association since its inception, and is an honorary member of the organization. In the 2010s, Ron was a member of the Board of Directors and Technical Advisory Board for Cool Planet Energy Systems. He has a PhD in Chemical Engineering from M.I.T.

www.XTLInstitute.com rasills@alum.mit.edu