

### **Achieve a new decarbonized energy dimension.**

We contend the greater socioeconomic benefit and operational gain for SynergyGaz™ technology will be found in assisting the peat-bearing nations of the tropical zone. This is particularly true of countries that don't yet have well developed energy infrastructures. For instance, two Central African nations together have an estimated 467 billion tonnes of renewable fuel peat resources and nearly 117 million in population, but only minimal modern power generation capacity and little pipeline gas utility service. To address this situation, a regional peat-to-energy program could provide sufficient zero-emission power and clean-burning decarbonized pipeline gas for centuries to come, while **mitigating over time the area's massive deforestation** caused by tree-taking from priceless ancient rain forests for charcoal production. This is also the case for another Central African nation (27 billion tonnes of fuel peat resources) and a large Indian Ocean island (61 billion tonnes of peat), each with about 26 million in population but no low-cost national pipeline gas utility service. For these two nations SynergyGaz™ would provide each with 10 gigawatts of power and 12 billion cubic meters/year (bcmy) of decarbonized dimethyl ether (DME) pipeline gas, for centuries, with the greater portion of new energy going to expanded farming, mining and industry.

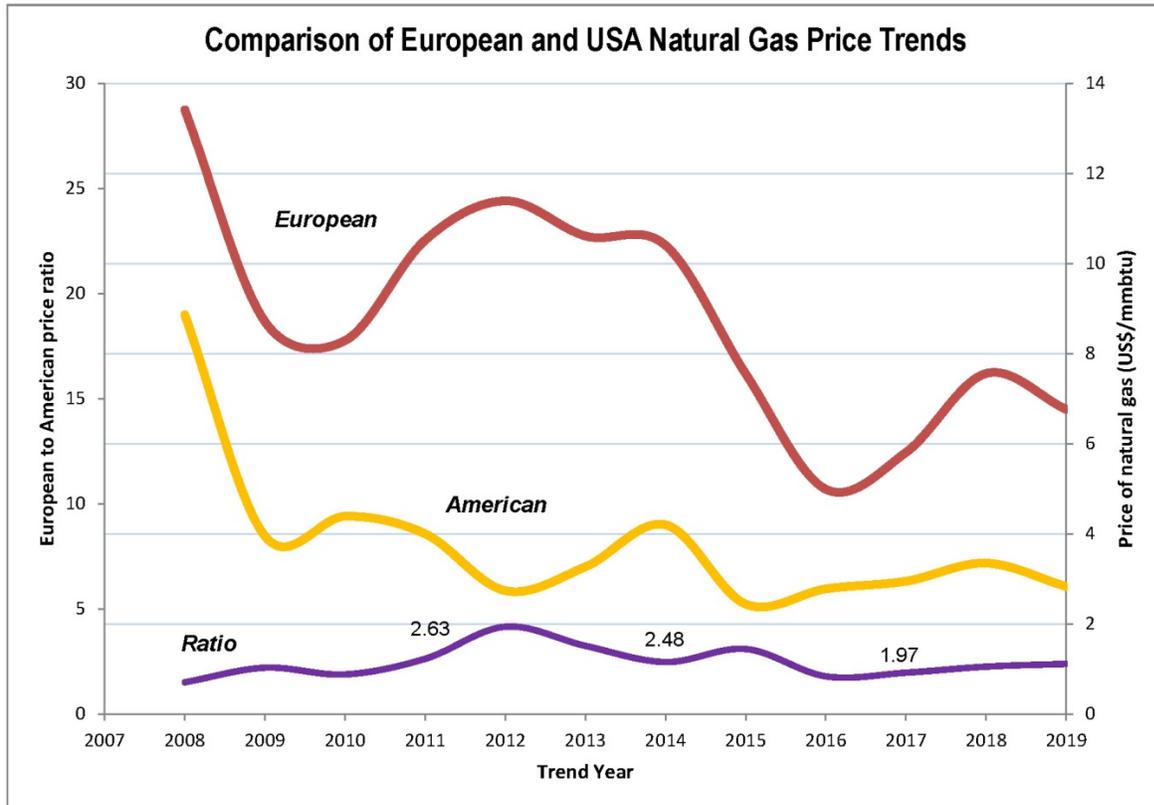
Bringing a fresh approach to this most crucial of developmental issues, SynergyGaz™ creatively *packages* new soft-currency revenue, domestic power and decarbonized pipeline gas utility capacity *together* with hard-currency revenue, export-oriented industrial units in petrochemicals/fertilizers, synthetic fuels, and mega-farming. This is done in a balanced manner, to achieve *high-ROI/net hard-currency outcomes* while meeting fundamental domestic needs in a region or a particular LDC. This unique mix of utilities and industrial units folds clean energy into the LDC's development mechanism while facilitating routine private sector foreign direct investment. This is achieved through strong project ROI, concrete provisions for hard-currency payout, risk mitigation, north-south carbon trading, and investor-preferred clean energy technologies.

### **Liquefied DME (LDME) supply clusters with large peat surpluses to export liquefied decarbonized fuel to Europe and Far East destinations for many centuries**

Two liquefied DME supply clusters of nations – both center on the same Central African nation – are envisioned: a) the Asia-Africa cluster consisting of a Southeastern Asian nation and the aforementioned Central African state, and b) an all-Africa cluster consisting of four contiguous, central African states. For the Asia-Africa cluster, we estimate that Southeastern Asian nation has 383 billion tonnes of fuel peat resources and the key Central African nation has 342 billion tonnes - totaling 725 billion tonnes in peat resources. As an alternative to the Asia-Africa cluster, the all-Africa cluster of four nations, we estimate 629 billion tonnes in renewable peat resources. Each of these supply clusters enjoy enormous surpluses in fuel peat beyond any possible scenario for domestic/industrial need that will support large-scale conversion and bulk export of LDME to numerous hard-currency metropolitan destinations in Europe and the Far East. This low-cost, clean-burning, decarbonized DME fuel bears strategic implications given the **shutdown in the nuclear power programs of Germany, Switzerland, Italy, and Japan** and possibly in other medium class nuclear power states like South Korea. Even in France, for some time, grassroots organizations mounted protests against that nation's heavy reliance on nuclear power, and have voted – in part – for a shift to safer, cleaner power generation policy. Given France's new policy direction, SynergyGaz™ LDME may also have strong appeal there. See DME to Turbine below.

With regards to the mid-term trend towards high and volatile prices for natural gas (NG) supplied mainly by Russia's Gazprom and Norway's Statoil, European utilities are understandably seeking relief. To quantify, the following chart shows that for year 2017 the cost of NG to Europe is 2-times the cost to the US (*Y-Chart.com*), and **the ratio has increased to a projected 2.4-times the cost to the US in 2019**. Lower-cost, clean-burning decarbonized DME produced by SynergyGaz™ can be marketed as an attractive alternative to expensive, less-than-clean NG [emitting 60% CO<sub>2</sub> of coal-fired power (see attached data sheet) despite promotionals that NG is a clean fuel] and dangerous nuclear power. *Public Citizen's* Winonah Hauter debunks the nuclear power industry's claim that nuclear energy is a "clean" alternative to fossil fuels. She points out that *the full nuclear fuel cycle* creates a vast amount of

greenhouse gases due to an *elaborate energy-intensive* process of uranium mining, milling and enrichment that must take place before the fuel rods are fabricated. Collectively, massive quantities of CO<sub>2</sub>-emitting fuels are consumed.



As an inducement to syndicate monolithic financing (\$106 billion: \$81 billion + \$25 billion for the cost of liquification apparatus and LDME bulk freighters) for the joint SynergyGaz™ Asia-Africa initiative, it is proposed that SETF and partners would offer a long-term energy marketing agreement to a broad-scope transnational leader in energy infrastructure development and major project financing. Once selected, the designated firm would move to supply low-cost, decarbonized bulk LDME gas to the European Union, China and Japan-South Korea consumer group (ECJK). The ECJK group has combined GDP of \$31.2 trillion (39% of global GDP) and population of 2.101 billion (27.6% of world). For 2017, the ECJK consumer group economy is 61% greater than that of the USA.

Either the Asia-Africa or all-Africa LDME contemplated operations would ship from a new port facility in Southeastern Asia or from the mouth of the Congo River, to ECJK destinations. The successful establishment of long-term LDME bulk supply arrangements with ECJK power and gas utilities, supported by SynergyGaz™ operations, would result in the formation of a new world-class energy corporation.

## CO<sub>2</sub> Emission Factors by Fuel Type

Carbon	3 664 kg CO <sub>2</sub> /t	32 066 MJ/t	0.114 kg CO <sub>2</sub> /MJ
Coal	3 000 kg CO <sub>2</sub> /t	32 373 MJ/t	0.093 kg CO <sub>2</sub> /MJ
Coke	3 227 kg CO <sub>2</sub> /t	29 951 MJ/t	0.108 kg CO <sub>2</sub> /MJ
Coke Oven Gas	45 kg CO <sub>2</sub> /GJ	- kJ/Nm <sup>3</sup>	0.045 kg CO <sub>2</sub> /MJ
Blast Furnace Gas	280 kg CO <sub>2</sub> /GJ	- kJ/Nm <sup>3</sup>	0.280 kg CO <sub>2</sub> /MJ
Basic Oxygen Furnace Gas	185 kg CO <sub>2</sub> /GJ	- kJ/Nm <sup>3</sup>	0.185 kg CO <sub>2</sub> /MJ
Other Ironmaking Gas	- kg CO <sub>2</sub> /GJ	0 kJ/Nm <sup>3</sup>	- kg CO <sub>2</sub> /MJ
<b>Natural Gas</b>	<b>56 kg CO<sub>2</sub> /GJ</b>	<b>37 000 kJ/Nm<sup>3</sup></b>	<b>0.056 kg CO<sub>2</sub>/MJ</b>

<i>Natural Gas % of coal emissions</i>			$0.056/0.093 = 60.2\%$
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Liquefied Petroleum Gas	-	-	- kg CO <sub>2</sub> /MJ
Heavy Oil	3 170 kg CO <sub>2</sub> /t	40 569 MJ/t	0.078 kg CO <sub>2</sub> /MJ
Light Oil	3 170 kg CO <sub>2</sub> /t	- MJ/t	- kg CO <sub>2</sub> /MJ
High Pressure Steam	267 kg CO <sub>2</sub> /t	3 300 MJ/t	0.081 kg CO <sub>2</sub> /MJ
Medium Pressure Steam	240 kg CO <sub>2</sub> /t	3 200 MJ/t	0.075 kg CO <sub>2</sub> /MJ
Low Pressure Steam	224 kg CO <sub>2</sub> /t	3 100 MJ/t	0.072 kg CO <sub>2</sub> /MJ
Electricity	856 g CO <sub>2</sub> /kWh	9 200 kJ/kWh	0.093 kg CO <sub>2</sub> /MJ
Oxygen	556 g CO <sub>2</sub> /Nm <sup>3</sup>	650 Wh/Nm <sup>3</sup>	0.093 kg CO <sub>2</sub> /MJ
Nitrogen	171 g CO <sub>2</sub> /Nm <sup>3</sup>	200 Wh/Nm <sup>3</sup>	0.093 kg CO <sub>2</sub> /MJ
Compressed Air	103 g CO <sub>2</sub> /Nm <sup>3</sup>	120 Wh/Nm <sup>3</sup>	0.093 kg CO <sub>2</sub> /MJ
Industrial Water	86 g CO <sub>2</sub> /km <sup>3</sup>	100 Wh/m <sup>3</sup>	0.093 kg CO <sub>2</sub> /MJ

Electricity	856 kg/MWh	REFERENCE	Page 254, Section 7.8
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NOTE: Year average numbers for Ontario Hydro Energy range from 850 to 890 kg/MWh depending on coal, oil and natural gas mix.

## Use of DME as a Gas Turbine Fuel

Arun Basu, Mike Gradassi, and Ron Sills: *Upstream Technology Group, BP Exploration*  
Theo Fleisch, and Raj Puri: *Gas & Power, BP Exploration*

Presented at the ASME Turbo-Expo, New Orleans, June 2001

**Abstract:** A new, ultra-clean fuel for gas turbines - a blend consisting primarily of dimethyl ether (DME) with lesser amounts of methanol and water - has been identified by BP. This fuel, containing no metals, sulfur and aromatics, burns like natural gas and it can be handled like LPG. The turbine-grade DME fuel can be manufactured from natural gas, coal and other hydrocarbon or biomass feedstocks. High-purity DME, manufactured from methanol, is currently used as an aerosol propellant due to its environmentally benign characteristics. Fuel-grade DME is used commercially as a LPG-substitute in China.

BP initiated key programs to test various fuel mixtures containing DME in General Electric test combustors with equivalent electricity production of nearly 16 MW. Later, BP collaborated with EPDC (Electric Power Development Corporation, Japan) to conduct additional follow-up tests. These tests show that DME is an excellent gas turbine fuel with emissions properties comparable to natural gas. Based on the results of the BP/GE combustion test programs, GE is prepared to pursue commercial offers of DME-fired E class and F class heavy duty gas turbines. BP is currently working with the Indian Oil Corporation (IOCL), the Gas Authority of India Limited (GAIL) and the Indian Institute of Petroleum to evaluate the potential of DME as a multi-purpose fuel for India. In June 2000, the India Ministry of Power issued a notification permitting the use of DME as a fuel for power generation subject to its meeting all the environmental and pollution regulations. This paper presents key gas turbine combustor test results and discusses how DME can be used as a fuel in gas turbines.

**Introduction :** DME, or Dimethyl Ether (chemical formula :  $\text{CH}_3\text{-O-CH}_3$ ) is a clear colorless environmentally benign and nontoxic compound that is currently used commercially as a propellant for various aerosols products including perfumes, and other health products (1,2). Yunnan Methanol Fuel Company in China has been selling methanol-derived fuel-grade DME (referred to as "fine" grade) as a LPG substitute; five other companies in China have also built DME plants for this purpose.(3) DME is also not a carcinogen/teratogen/mutagen, and does not form peroxides even after prolonged exposure to air. It is not harmful to the ozone layer (unlike the previously used CFC gases) and is easily degraded to water and carbon dioxide in the troposphere (4,5). Importantly, it is physically similar to liquefied petroleum gas (LPG) which primarily contains propane and butane. Thus, DME can be handled like LPG, a proven commercial product traded and shipped globally. The key properties of pure DME are compared below with those of propane and butane:

Property	DME (pure)	Propane	Butane
Boiling Point, °C @ 1 atm	-24.9	-42.1	-0.5
Vapor Pressure @ 20 °C, bar	5.1	8.4	3.1
Liquid Density @ 20 °C, kg/m <sup>3</sup>	688	501	610
Lower Heating Value, KJ/Kg Liquid	28,360	45,990	45,367
Lower/Upper Flammability Limit in Air, vol.%	3.4 - 17	2.1 - 9.4	1.9 - 8.5

The total world production capacity for aerosol-grade DME is about 150,000 ton/year, and is today exclusively made by several manufacturers from methanol by a dehydration process. Although the current production of DME is limited, it is an important intermediate for the manufacture of synthetic gasoline (in New Zealand; ref. 6), and for the production of acetic acid (7). DME is currently attracting world-wide attention due to its potential as an ultra-clean diesel

fuel alternative.(8,9) Initial diesel engine tests indicate that DME would lead to ultra-low emissions that would surpass California's ULEV (Ultra Low Emission Vehicles) regulations.(8)

Recent publications from BP (10,11), EPDC (12), Chiyoda Corp. (13 ) and Haldor Topsoe & Snamprogetti/ENI S.p.A. (14) indicate the growing interest on the potential of DME as a gas turbine fuel for niche markets that can not be easily reached by natural gas supplies. As shown in Figure 1, BP's vision is to commercialize DME as an integrated gas project.

For gas turbine applications, a fuel-grade DME (with about 7-8 wt% methanol and 2.9-3.5 wt%

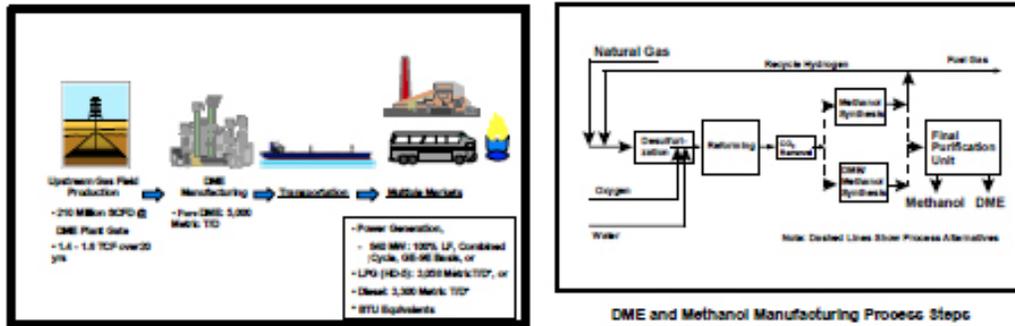


Fig 1: An Integrated DME Full Value Chain Project

water) has been formulated to reduce manufacturing costs, and to enhance shipping as well as gas turbine operations.

**Large-Scale Manufacture of DME :** For effective commercial uses of DME as a low-cost multi-purpose fuel, DME should be produced in very large quantities. Haldor Topsoe A/S (HTAS) of Denmark has developed and demonstrated, in a 50 kg/day pilot plant, an integrated process for the direct production of DME from synthesis gas (mixture of hydrogen plus carbon monoxide) made from natural gas.(15) As shown in Figure 2, the process is very similar to commercial methanol manufacturing processes. Other companies, such as Air Products(16) and NKK Corp.(17) are also developing DME synthesis technologies. Haldor Topsoe and Snamprogetti have claimed that very large scale DME plants (e.g., : about 7,500 metric tons/day of pure DME which is equivalent to about 10,435 metric tons of methanol/day) with single-train DME synthesis reactors can be built using the current HTAS AutoThermal Reforming and DME synthesis technologies.(14)

**Performance in Gas Turbines ; DME Infrastructure and safety Requirements :** Since DME can be handled like LPG, ocean transport of DME can use conventional LPG tankers. It can be offloaded and stored at a receiving power plant site using equipment that is similar to conventional LPG-type unloading and storage equipment. We at BP are also evaluating alternative designs for unloading DME and supplying nearby power plants, including : *Single Point Mooring System (SPM) design that uses a cantenary anchor mooring system for DME off-loading.*(11)

As DME can be totally vaporized quite effectively at inlet conditions (e.g., at 150-250 psig) of gas turbine combustors, it can be used in modern efficient Dry-Low-NOx (DLN) type gas turbines and meet NOx emissions at limits of 25 ppmvd (at 15% oxygen level). Liquid DME, stored as either refrigerated liquid (about minus 25 C, 1 atm) or under pressure (at ambient temperature), can be first pumped to a higher pressure (say 350-450 psig) and then vaporized by the utilization of hot water/steam produced as a part of the combined cycle power plant.(10) As discussed in page 5, this type of process integration for a DME terminal and a power plant would allow improved power generation efficiency through heat recovery from the flue gas leaving a combined

cycle power plant. For DME, specific industrially proven materials for gaskets/seals will be used. The environmental, health and safety aspects of pure DME are very acceptable as demonstrated by its use as a CFC aerosol-propellant replacement. However, similar to LPG and other combustible fuels, DME needs to be handled with care. The LPG and the DME-as-aerosol industries have an outstanding safety record. Fuel-grade DME would contain some methanol (typically about 8 wt%) which is toxic; however, due to LPG-like closed vessel handling, it can be handled safely with appropriate procedures.

- **BP/EPDC/GE Combustor Tests ; Background**

The power generation efficiency (E) is usually expressed via a "heat rate" number that corresponds to the amount of thermal energy needed (LHV or HHV basis) to generate one unit of electrical energy (e.g., Btu/kwhr). A lower heat rate number reflects higher power generation efficiency. The significant products of combustion in gas turbine emissions are : (1) oxides of nitrogen (NOx), (2) carbon monoxide (CO), (3) Unburned hydrocarbons (UHC) that are formed due to incomplete combustion and (4) oxides of sulfur (SO<sub>2</sub> and SO<sub>3</sub>) particulates. Modern GE DLN (Dry Low NOx) Combustors are designed to improve E values and reduce NOx and other emissions.

Figure 3 shows the schematic of the GE DLN-1 combustion system that includes four major components: fuel injection, liner, venturi and cap/center body assembly.(13) As described by Davis (GE Power Systems; Ref. 18), the DLN-1 system operates in four distinct modes, namely : Primary, Lean-Lean, Secondary and Premix. The primary-only mode, used for start-up and low-load operation, is a "diffusion flame" mode. This mode was tested on DME to verify operations for GE "diffusion" machines. Intermediate loads are run in the lean-lean mode. The "premixed" mode of operation is utilized from mid- to full-load on the gas turbine. The key GE gas turbines with DLN technologies are, for example, (1) MS-3000, MS-5000, MS-7000B/E, MS-7001EA and MS-90001E machines with DLN-1 combustors, and (2) higher firing temperature machines including FA, EC and H class machines that use DLN-2 class combustors.

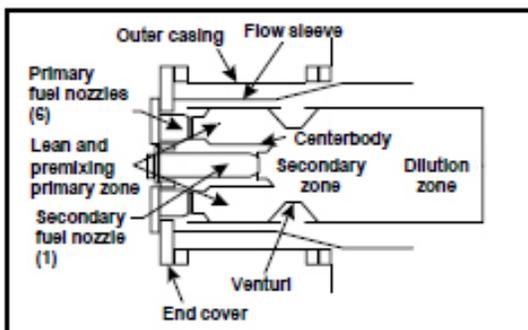


Fig. 3: DLN-1 combustor schematic

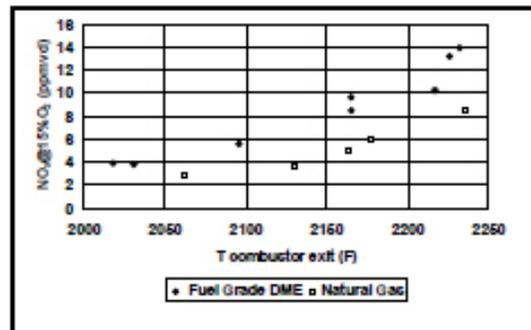


Fig. 4: MS9001E DLN-1 - Premix Emissions

- **Combustion Test Facilities :** The pressurized combustion tests with pure and fuel-grade DME were performed at the GE Power Generation Engineering Laboratory in Schenectady, NY.(10) This facility houses single combustor test stands designed to simulate the operating conditions of a turbine in the field. The test stand (1) tests a full-size combustor (each containing multiple DLN-1 or DLN-2 class burners) at machine rated flows, pressures, and temperatures, and (2) models a section of the gas turbine from the compressor discharge to the first-stage turbine inlet, matching the boundary conditions representative of those in the machine. The GE 9E machine has 14 such full-size combustion chambers. For the DME tests, an existing 30,000 gallon propane fuel storage, associated delivery system, and a fuel vaporizer/superheater were modified which included retrofit of all shut off, control and relief valves with gaskets and seals compatible to the DME fuel.