SET ★ Foundation

vision and service – where the future begins

Achieve a new decarbonized energy dimension – LDME+LH2[1]

We contend the greater socioeconomic benefit and operational gain for SynergyGaz® technology will be found in assisting the major peat-bearing and oil & gas nations of the tropical zone. This is particularly true of countries that don't yet have well developed energy infrastructures. For instance, two contiguous Central African nations together have an estimated 467 billion tonnes of renewable fuel peat resources and 135 million in population, an estimated joint US$40 trillion in natural resources to be utilized, 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 each nation 25 gigawatts of zero-emission power plus clean-burning DME pipeline gas supply into the next century, 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 zero-emission power and 12 billion cubic meters/year (bcmy) of decarbonized dimethyl ether (DME) pipeline gas, into the next century, with the greater portion of new energy going to expanded mega-farms, mining and other industry.

Bringing a fresh approach to this most crucial of developmental issues, SynergyGaz® packages new soft-currency revenue, domestic power and decarbonized pipeline gas utility capacity *together* with hard-currency revenue from export-oriented industrial units in petrochemicals/fertilizers, synthetic fuels, and mega-farming, all to be led by the export of bulk liquefied hydrogen and DME. This is done in a manner to achieve *high-ROI/net hard-currency outcomes* while meeting domestic needs in a region or a particular host 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, internal debt security, risk mitigation, north-south carbon trading, and investor-preferred clean energy technologies.

Liquefied DME (LDME) + liquefied Hydrogen (LH2) supply clusters with large peat surpluses to export liquefied decarbonized fuel to Europe and Far East destinations for the long-term

Two liquefied DME+H2 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 with plentiful peat reserves 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 eight contiguous Central African nations have 860 billion tonnes - totaling 1.24 trillion tonnes in peat resources. As an alternative to the Asia-Africa cluster, the all-Africa cluster of eight nations, we estimate 860 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+LH2 to hard-currency metropolitan destinations in EU and the Far East. This pair of lower-cost (given the ***relatively shallow peat deposits*** and ease of recovery compared to many oil & gas deposits), clean-burning, decarbonized fuels bears strategic implications given the ***shutdown of nuclear power programs in Germany, Switzerland, Italy, and Japan*** and the possibly of closure in other nuclear power states like South

[1] Liquefied dimethyl ether (DME) plus liquefied hydrogen (H_2)

Korea. Even in France, for some time, grassroots organizations mounted protests against that nation's heavy reliance on nuclear power, and have voted for a shift to safer, cleaner power generation policy. Given France's new policy direction, SynergyGaz® LDME+LH2 may also have strong appeal there.

Decarbonized DME+H2 produced by SynergyGaz® (see *https://www.setvision.org/sg_petrochems.html*) can be marketed as attractive alternatives to less-than-clean NG [emitting 60% CO_2 of coal-fired power (see attached data sheet) or LNG despite promotionals that NG is a clean fuel] and the even more dangerous nuclear power. Additional SynergyGaz® hydrogen output is provided by SETF's proprietary Dissociation Water Carbon (DWC, *https://www.setvision.org/ec_recycler-feed.html*) method which is applied to carbon oxides (CO/CO_2) following *precombustion separation of syngas into H_2 and CO*. Another advantage of the SynergyGaz® is that it operates on the value-added carbon capture recycle (CCR) platform (an example is to convert captured CO/CO_2 to a range of value-added carbon fiber products for use in numerous infrastructure applications like bridge construction or repair), rather than the more broadly used and more costly carbon capture sequestration (CCS) which calls for high-pressure CO_2 liquefaction and conveyance to a point of geological sequestration.

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 available. Collectively, massive quantities of CO_2-emitting fuels are consumed in fuel rod production.

As an inducement to syndicate the substantial project financing 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 engaged, the designated firm would move to market and supply long-term, the competitive, decarbonized bulk LDME+LH2 gas to the European Union, China and Japan-South Korea consumer group (ECJK). The ECJK group has combined GDP of $30.2 trillion (37.8% of total global GDP at US$79.8 trillion) and population of 1,919.1 billion (25.6% of world population at 7.5 billion). For 2019, the ECJK consumer group GDP was 62% greater than that of the USA (with a GDP of US$18.62 trillion, source: *The Economist*).

Either the Asia-Africa or all-Africa LDME+LH2 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+LH2 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_2 Emission Factors by Fuel Type

Carbon	3 664 kg CO_2 /t	32 066 MJ/t	0.114 kg CO_2/MJ
Coal	3 000 kg CO_2 /t	32 373 MJ/t	0.093 kg CO_2/MJ
Coke	3 227 kg CO_2 /t	29 951 MJ/t	0.108 kg CO_2/MJ
Coke Oven Gas	45 kg CO_2 /GJ	- kJ/Nm^3	0.045 kg CO_2/MJ
Blast Furnace Gas	280 kg CO_2 /GJ	- kJ/Nm^3	0.280 kg CO_2/MJ
Basic Oxygen Furnace Gas	185 kg CO_2 /GJ	- kJ/Nm^3	0.185 kg CO_2/MJ
Other Ironmaking Gas	- kg CO_2 /GJ	0 kJ/Nm^3	- kg CO_2/MJ
Natural Gas	**56 kg CO_2 /GJ**	**37 000 kJ/Nm^3**	**0.056 kg CO_2/MJ**
Natural Gas % of coal emissions			*0.056/0.093=* ***60.2%***
Liquefied Petroleum Gas	-	-	- kg CO_2/MJ
Heavy Oil	3 170 kg CO_2 /t	40 569 MJ/t	0.078 kg CO_2/MJ
Light Oil	3 170 kg CO_2 /t	- MJ/t	- kg CO_2/MJ
High Pressure Steam	267 kg CO_2 /t	3 300 MJ/t	0.081 kg CO_2/MJ
Medium Pressure Steam	240 kg CO_2 /t	3 200 MJ/t	0.075 kg CO_2/MJ
Low Pressure Steam	224 kg CO_2 /t	3 100 MJ/t	0.072 kg CO_2/MJ
Electricity	856 g CO_2 /kWh	9 200 kJ/kWh	0.093 kg CO_2/MJ
Oxygen	556 g CO_2 /Nm^3	650 Wh/Nm^3	0.093 kg CO_2/MJ
Nitrogen	171 g CO_2 /Nm^3	200 Wh/Nm^3	0.093 kg CO_2/MJ
Compressed Air	103 g CO_2 /Nm^3	120 Wh/Nm^3	0.093 kg CO_2/MJ
Industrial Water	86 g CO_2 /km^3	100 Wh/m^3	0.093 kg CO_2/MJ

Electricity	856 kg/MWh	REFERENCE	Page 254, Section 7.8

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

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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 : CH3-O-CH3) 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, ^{o}C @ 1 atm	-24.9	-42.1	-0.5
Vapor Pressure @ 20 ^{o}C, bar	5.1	8.4	3.1
Liquid Density @ 20 ^{o}C, kg/m3	668	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%

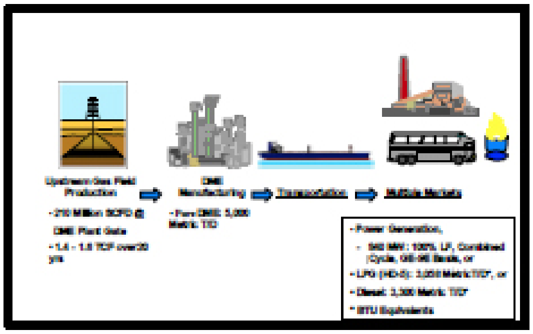
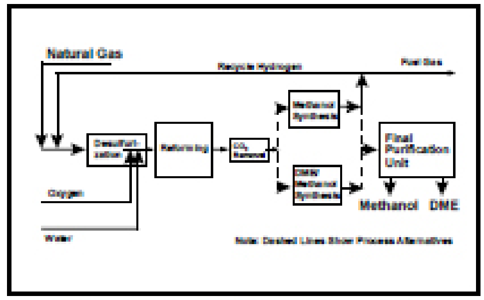


Fig 1: An Integrated DME Full Value Chain Project



DME and Methanol Manufacturing Process Steps are Very Similar

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 (SO2 and SO3) 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.

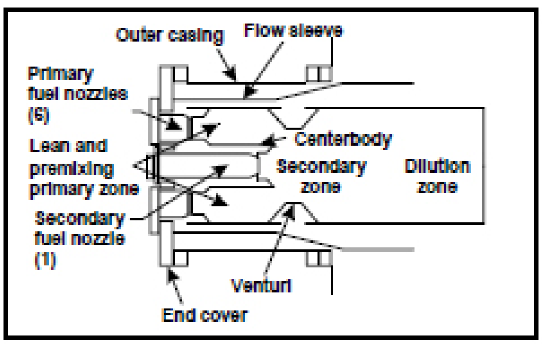


Fig. 3: DLN-1 combustor schematic

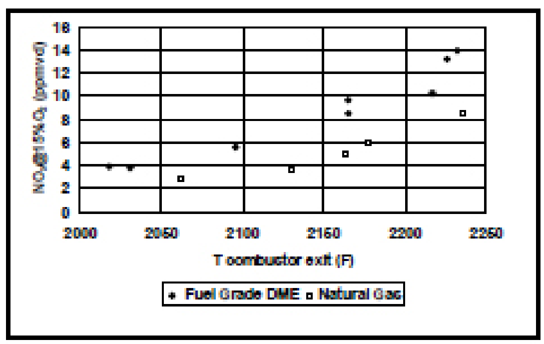


Fig. 4: MS9001E DLN-1 - Premix Emissions

- *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.