DME: The Best Fuel, Period

Dimethyl Ether: The Future of Electricity, Heat and Transportation

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About ChemBioPower Ltd.

Antonio Anselmo, an energy expert, founded the company with Mr. Stanton Hooper, a construction executive in late 2013. The company has a strong, long-term view on optimal energy use, producing the best fuel and additives for transportation and heating using a very efficient process. ChemBioPower has developed a “better way” to maximize fuel and power production from North America’s abundant natural gas reserves. The ChemBioPower process is also environmentally friendly, with a very low carbon footprint.

Combining “off the shelf” technology and proprietary patent pending system designs, ChemBioPower will deploy a network of modular polygeneration plants that will convert either natural gas or methanol into both electric power and a clean compression engine fuel, dimethyl ether (“DME”). ChemBioPower will also become a key developer of dimethyl ether enabling technology. This includes the development of fuel injection systems, burner heads, storage systems, protein extraction systems and cooling systems. ChemBioPower will also deploy a portfolio of generator sets on lease-only basis, providing fuel support exclusively. In addition, the company’s polygeneration plants will later possess the additional capability of producing dimethyl carbonate (“DMC”). DMC is a chemical reagent that serves as the backbone of the growing field of green chemistry and is an excellent octane enhancer.

Prolog: Vancouver, British Columbia 2020

Sheila McDonald steps into her new 13 Liter DME powered truck and leaves the fueling depot at the Fraser Surrey docks, gearing up slowly, using the computer-controlled gearshift. Fueling was clean and quick from the distribution rack, where the only thing to remember is which way to turn the fuel connector and pushing the "Start Fuel" button. The older drivers and mechanics still joke about "Getting diesel in your blood". Luckily, she doesn't fill up on the diesel side and only smells the flowers in barrier planters around the dimethyl ether fuel tanks.

As she heads through metropolitan Vancouver, she takes the faster "Green Truck" route, since she drives an emission-reduced rig. As she gears up and passes an older CNG powered truck, she's thankful that her trucking company only uses the more powerful and reliable DME trucks with compression ignition engines. Spark ignition, natural gas engines make more noise, are limited to local use and last half the miles. The company head mechanic made a tough call two years ago, but the trucking firm has benefitted greatly from the reduced infrastructure and maintenance costs of the Propane/DME complex. In addition, the fleet owner has a long-term fuel contract from the DME producer in Alberta, controlling the biggest expense facing her company.

As she heads towards Merritt and up the Coquihalla Highway, she remembers the earlier forecast on the Weather Channel warning about snow near the Great Bear shed. She is a cautious driver on the "The Coq", the so-called "Highway Thru Hell". At the same time, she is relaxed because she knows there is no better truck on the Coquihalla than a DME powered truck. On the return leg, she thinks of the 6 hour, 500 km trip as another comfortable run, without incident. As she heads down the hill into Hope, she sees the older trucks billowing smoke as they gear down for the climb. Admiring the mountains, she knows her children won't see diesel soot coming from her truck on this road. Moreover, her truck has a reduced greenhouse gas footprint, 20% lower CO2 (Carbon Dioxide) emissions, produces little NOx (Nitrous Oxides) and does not vent methane (a gas 20 times worse for the environment than CO2).

Dateline Today: Longueuil, Quebec 2015

{From the Montreal Gazette] On Wednesday, January 14th, about 28,000 liters of diesel fuel spilled at the city's water filtration plant, but it took several hours for the provincial environment department to be notified. Most the diesel went into the St-Lawrence River, but some of it ended up in water at the water treatment plant because of a crack in a sewer line. The water advisory affected about 300,000 people in Vieux Longueuil, St-Hubert, Boucherville and St-Bruno-de-Montarville.

According to the Montreal Gazette (Jan 15, 2015), South Shore residents who are dissatisfied with how the city of Longueuil handled a diesel spill in its water supply are seeking compensation through a class-action suit. A lawyer for several residents filed papers on Monday requesting permission to launch a suit against the city for about $29 million, $100 for the 288,100 residents affected by the water contamination last week.

Lawyer Jacky-Éric Salvant said the city waited too long before notifying residents of the leak, which was noticed by municipal officials about 4 a.m. last Wednesday. The city didn't put out a no-drinking advisory until about 10 a.m. on Thursday. The lawsuit could also extend to Environment Canada and the private company that owns the Longueuil pumping station, he said.

The water was declared safe for drinking on Friday evening, but the city continued to distribute bottled water throughout the weekend because the tap water in some sectors still smelled and tasted of diesel.

On Sunday, Longueuil Mayor Caroline St-Hilaire promised an investigation into the matter. Bernard Bigras, Longueuil's director of communications, said there will be at least two investigations into the spill and how it was handled. The city will conduct an investigation along with Environment Quebec. The federal environment ministry may also investigate, Bigras said, adding that he doesn't know when the reports will be completed.

Diesel Power at the Fork in the Road

The diesel engine is one the most important inventions in history, providing energy for small back-up power application to providing electricity to entire islands, across all continents and oceans, pole to pole. Diesel engines are used globally for trucking, shipping, rail, electricity generation and any other task requiring reliable power. No other power technology can cover so many diverse applications. The diesel engine also has the highest thermal efficiency

of any standard internal or external combustion power source. The engine's high compression ratio and inherent lean burn enables heat dissipation through excess air intake, making it an extraordinarily simple power source.

However, the continued use of conventional diesel fuel presents many challenges. Diesel fuel degrades the environment through the emission of greenhouse gases and particulate matter, while fostering dependence on volatile Middle East oil reserves. Diesel is poisonous, pollutes water and soil if leaked, requires layers of anti-pollution devices and uses 2 to 8 liters of purified, fresh water for every liter of diesel produced. Today, the compression engine is great power source with a problematic fuel.

New Tier 4 Diesel Standard

On January 1, 2015, the world moved to the Tier 4 diesel standard as a response to the increasing and widespread concern about the negative environmental impact of diesel fuel emissions. Truck, marine and off-road diesels under Tier 4 standards must reduce sulfur dioxide, nitrous oxide and particulate matter using anti-pollution devices that make diesel power more expensive and less reliable & efficient. Moreover, the additional particulate filters and selective catalytic reduction systems require increased monitoring and maintenance. Simply put, the new clean diesel engines are more expensive and less efficient.

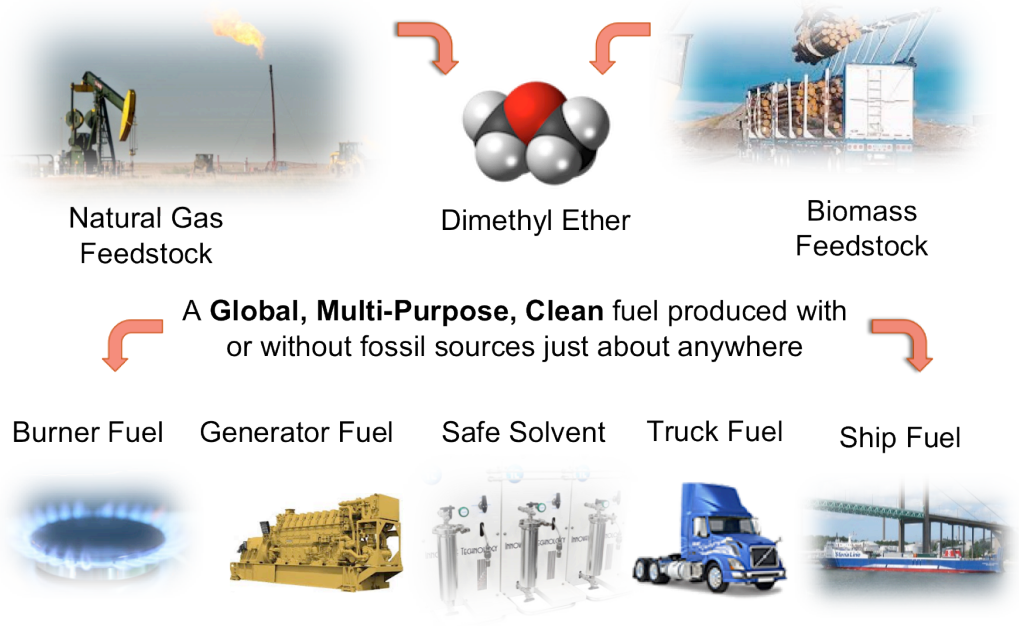

Figure 1: Dimethyl Ether is a multi-purpose fuel and solvent with 10 Million tonnes of global capacity.

Dimethyl Ether – Keep the Engine, Change the Fuel

The challenge is to find a fuel for compression engines that is environmentally friendly, stores easily and transported simply. DME is a clean burning, high-density liquid fuel that can be used as a direct replacement for diesel fuel in power generation, transportation, heating, marine and a wide variety of other applications. DME can be readily synthesized from abundant natural gas and biomass feedstock using a number of well-established chemical processes. DME is benign, evaporates after a spill, burns smoke free with no sulfur and reduced nitrous oxide and generates 1 to 2 liters of water for each liter of fuel produced. Unlike compressed natural gas (CNG) or liquid natural gas (LNG), most importantly, DME can also be used in compression engines, which substantially impacts the potential applications of this fuel.

The price of DME versus diesel is structurally lower in most global markets. In the future, diesel prices will likely remain significantly higher than shale produced natural gas prices on an energy equivalent basis. This divergence is a clear opportunity for methane derived synthetic fuels to gain market traction. DME production from biomass also

represents a compelling economic opportunity, especially in markets such as Latin America, Africa and Southeast Asia that possess abundant natural gas and/or biomass, but little or no local sources of petroleum.

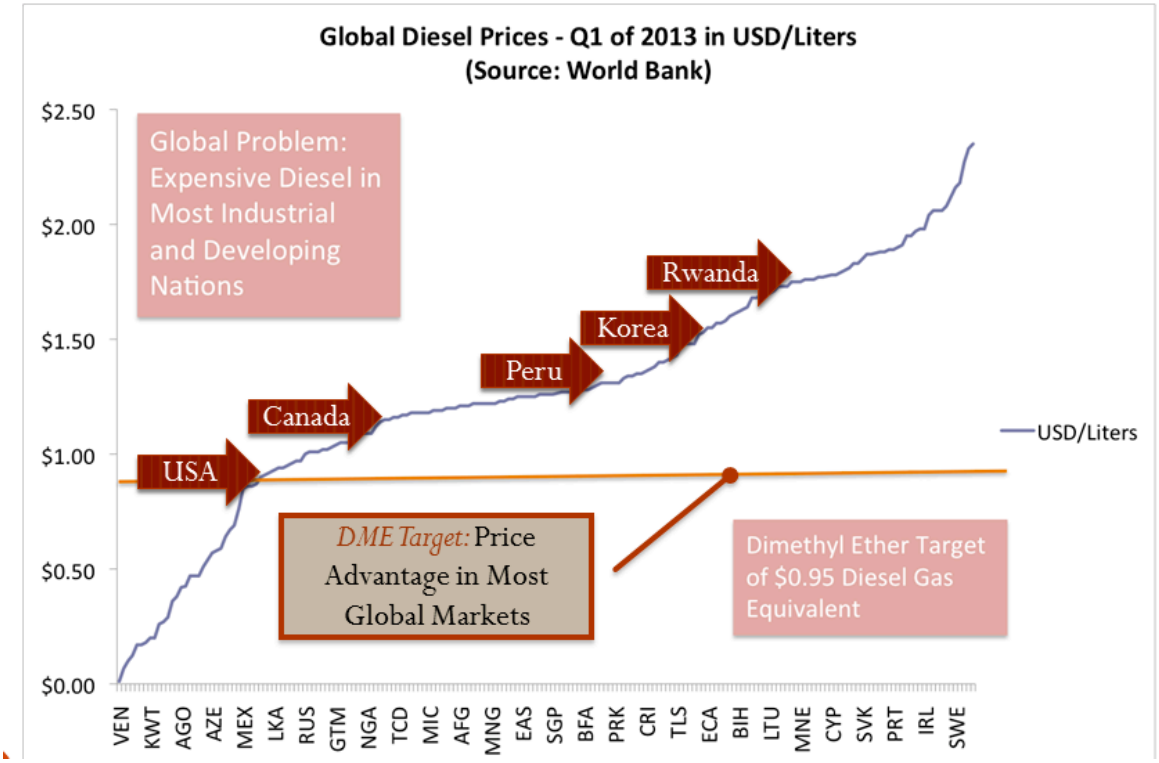

Figure 2: Dimethyl Ether can be produced at or below cost in most nations, in particularly countries without oil.

DME has the added environmental advantage of being non-toxic and environmentally low risk. Accidental spills cannot poison water, DME will not sink to the water table and DME is not absorbed by the soil. Unlike diesel or marine fuels, DME cannot poison aquatic life. DME as a marine fuel would have eliminated the disastrous 2014 Galveston Bay spill and the poisonous 2015 Longueuil spill.

Clean Tech Competition

In addition to DME, several natural gas alternative fuels have been introduced to the North American market including compressed natural gas (CNG), liquid natural gas (LNG), methanol, synthetic diesel and hydrogen. Recently, Volvo Trucks completed an extensive analysis of alternative fuels and, based on seven criteria, DME emerged as the preferred advanced truck fuel.

Dimethyl ether (DME) and its high cetane number makes DME a suitable candidate fuel for compression ignition engine vehicles, which are more energy efficient and powerful than spark-ignition engine vehicles. Like DME, CNG and LNG in heavy-duty natural gas engines achieve significantly lower NOx and particulate emission levels than diesel.

Neither liquid natural gas (LNG) nor compressed natural gas (CNG) can be used in a compression engine, whereas DME can be used in compression engines, along with spark ignition, diesel, turbine or fuel cell engines. Most natural gas fueling stations dispense compressed natural gas (CNG), which is compressed on site. The availability of liquefied natural gas (LNG) stations is more limited. Most LNG users are fleets that have the LNG infrastructure dedicated to their vehicles. Only a few large-scale liquefaction facilities provide LNG fuel for transportation nationwide. LNG must be delivered to stations via truck in specialized tankers.

In general, compression ignition engines would be more widely used if the difficulties producing low levels of emissions of both NOx and simultaneously lower particulate matter (PM) could be resolved. These standards are being sought in tightening air pollutant emission regulations throughout the world, driven by public health concerns.

The tradeoffs that make simultaneous NOx and PM control difficult for low sulfur diesel fuel do not exist for DME. In fact, DME and propane can fuel all engine sizes, from lawn mowers to the largest container ships.

Fuel Test Criteria	*X*	*Fuel Names*	*Ignition System*	*Rating*
Scores are a sum of the criteria:				
Climate Impact		**DME**	**Compression**	**28.5**
Energy Efficiency		Methanol	Spark	27.5
Land Use Efficiency		Syn Diesel	Compression	26.5
Fuel Potential		LNG	Pilot Injection	23
Vehicle Adoption		CNG	Spark	22.5
Fuel Cost		Hydrogen + Biogas	Spark	21
Fuel Infrastructure		Biodiesel 100	Compression	19
		Ethanol	Spark	17.5

Table 1: Fuel Comparison (Sourced from Volvo).

"DME engines run cleaner and produce low levels of NOx Emissions and Particulate Matter."

Particulate free fuels do not form soot after combustion. Dimethyl ether combustion generates essentially no PM because of the absence of C-C bonds and sulfur compounds. This category of fuels also includes hydrogen, methanol and some carbonates.

Moreover, low NOx emissions can be realized with much less complicated or no tailpipe emission control technologies. These pollution control advantages can facilitate a transition to fuel-efficient vehicles such as compression ignition engine/hybrid electric vehicles. The wholesale and retail issue can be simultaneously solved because DME is a gas that is stored in mildly pressurized canisters such as those required for propane above -25 C°. In other words, DME and propane can use the same storage, transportation and transfer technology globally.

Dimethyl Ether for Transportation

Volvo has invested in DME engine technology for decades and will introduce this technology to North America in selected markets during early 2018. The modified 13 Liter Volvo/Mack (VNL 300 DME) diesel engines run on DME at higher compression ratios and produce less noise than conventional units. The use of dimethyl ether in trucks eliminates particulate matter, reduces vibration and minimizes nitrous oxides generated by conventional diesel engines. These engines can achieve higher efficiencies, better well-to-wheel costs and emissions reductions over conventional diesels. The cost of DME fuel will also be lower than diesel fuel, since DME is not derived from oil, but from natural gas, coal or biomass via a constantly improving process.

Figure 3: Volvo DME VNL 300 Truck at the Whitehouse

On the waterways, MAN Diesel & Turbine has developed DME engines for marine applications. The ME-LGI concept is an entirely new system that can be applied to all MAN Diesel & Turbo low-speed engines, either ordered as an original unit or through retrofitting. With two new injection concepts, the ME-LGI concept greatly expands the company's multi-fuel portfolio and enables the exploitation of more low-flash-point fuels such as DME and propane.

The ME-LGI came about due to interest from the shipping world in operating on alternatives to heavy fuel oil (HFO) and diesel. Propane carriers have already operated at sea for many years and many more propane tankers are currently being built as the global propane infrastructure grows. The same ship can carry propane and DME. With a

viable, convenient and comparatively cheap fuel already onboard, it makes sense to use a fraction of the cargo to power the vessel with an important, side-benefit being it's better for the environment. MAN Diesel & Turbo states that it is already working towards a Tier-III-compatible ME-LGI version, which can easily run on DME.

Projected North American DME Market by 2024		*Notes*
# Of Combination (Tractor Trailer) Trucks in U.S.	2,220,995	(1)
# Of Combination (Tractor Trailer) Trucks in Canada	396,432	(2)
Total U.S. and Canadian Combination (Tractor Trailer) Trucks	2,617,427	
Average Annual U.S. Diesel Fuel Consumption Per Truck (in Gallons)	12,839	(1)
Average Annual Canadian Diesel Fuel Consumption Per Truck (in Gallons)	11,887	
Total Annual U.S. Diesel Fuel Consumption (in Gallons)	28,515,354,805	(1)
Total Annual Canadian Diesel Fuel Consumption (in Liters)	17,435,813,000	(2)
Total Annual Canadian Diesel Fuel Consumption (in Gallons)	4,712,381,892	
Avg. U.S. Diesel Retail Price Per Gallon (including all taxes) as of 3/3/14	$4.016	(3)
Avg. Canadian Diesel Retail Price Per Liter (including all taxes) as of 3/4/14 in US$	$1.325	(4)
Estimated Annual Retail Cost of Diesel Consumed by Combination Trucks in the U.S.	$114,517,664,897	
Estimated Annual Retail Cost of Diesel Consumed by Combination Trucks in Canada	$23,104,834,167	
Estimated Annual Retail Cost of Diesel Consumed by Combination Trucks by Both	$137,622,499,064	
Green Trucks in 2024 with fleet growth of 0.5% CAGR with 20% of the fleet Green	550,257	NTI
DGE Consumed per Truck (gallons/year by each truck using 20% efficiency gain)	10,156	
DGE Price per Gallon (USD/gal.)	$4.01	
Green Fleet Fuel Market	$22,409,168,037	
DME Market for Class 8 Trucks in 2024 at 40% the Green Fleet	$8,963,667,215	

Table 2: Fuel Sales and Market Size

Sources:

(1) U.S. Bureau of Transportation Statistics (2007 Data)
(2) Statistics Canada - Road Transportation (2012 Data)
(3) U.S. Energy Information Administration Database
(4) Natural Resources Canada Website

Alternative Markets for DME as a Propane Substitute

Moreover, dimethyl ether can be blended into the propane supply on a 20/80 basis with no effect on end users. The Eastern Seaboard currently has the highest prices for propane, at well above 4.30 $/gallon. In particular, propane distributors can use their infrastructure to move and store dimethyl ether for delivery to "behind the fence" fueling stations at each truck fleet. Unlike CNG and LNG, the global propane infrastructure is robust, inexpensive and extensive. Propane has 1.22 times the energy density than DME on a volume basis, so 3.52 $/gallon of DME is energy equivalent to 4.30 $/gallon of propane.

China Leads the Way

The DME markets in other countries are growing year over year and are expected to accelerate significantly in the future. Nations like South Korea, Japan, Indonesia, Sweden, Egypt and Trinidad & Tobago have their own respective focus to develop the DME by producing it domestically or by sourcing it from other countries. Currently, the production facilities are concentrated in China, with smaller capacity in Japan, Korea and Germany. The Netherlands, the U.S.A. and Canada have no major DME facilities, although production may come from recent methanol re-starts.

Since 2006, the large Chinese investment program in methanol and dimethyl ether has created an installed capacity of 6,500,000 t/y (tonnes per year), or about 85% of worldwide production. Dehydration of methanol, produced

mainly from coal, is used for DME production. Interest in Methanol-to-Gasoline (MTG) has been observed in China, but with slower progress. Shortly, China will be capable of producing over 10 MM t/y.

Three integrated, coal-based methanol to olefin (MTO) projects in China have been commissioned recently. Also after some delays, one other non-integrated MTO project has been started up. This non-integrated plant is relatively small for MTO, while a significant number of future MTO plants are "still on the drawing board". For example, Shenhua Ningxia has a methanol capacity 1,670,000 t/y with a large fraction earmarked for DME production. Shenhua Baotou produces 1,800,000 t/y of methanol combined with ethylene/propylene production. The immense Chinese coal-to-chemicals sector remains industrial user focused, but support for "high value" applications, like DME production emphasizes Chinese fuel self- sufficiency objectives.

Shanghai will test the use of DME fuel in heavy trucks and gradually expand it to buses and taxis to help bring down 2.5 PM particulate pollution. The Shanghai Economic and Information Technology Commission stated that DME will be tested by 50 or so taxis in Minhang District and a few local bus lines. Chinese markets are quoting a price of 3,000 yuan (US $482.10) a short ton, currently cheaper than locally distributed diesel. The Chinese trucking industry will bypass particulate filters, selective catalytic reduction and complex exhaust gas recirculation, moving to simple DME engines for emissions reductions.

The Best Fuel, Period

Abstract From Report 10: Department of Shipping and Marine Technology, Chalmers University of Technology, Göteborg, Sweden by Selma Brynolf, Shweta Kuvalekar and Karin Andersson:

The combined effort of reducing the emissions of sulphur dioxide, nitrogen oxides and greenhouse gases to comply with future regulations and reduce impact on climate change will require a significant change in ship propulsion. One alternative is to change fuels. In this study the environmental performance of two potential future marine fuels, methanol and dimethyl ether (DME), are evaluated and compared to present and possible future marine fuels.

Methanol and DME produced from natural gas was shown to be associated with a larger energy use and slightly more emissions of greenhouse gases in the life cycle when compared to HFO, MGO and LNG. Use of methanol and **DME results in significantly lower impact when considering the impact categories particulate matter, photochemical ozone formation, acidification and eutrophication compared to HFO and MGO without any exhaust abatement technologies** and of the same order of magnitude as for LNG.

Methanol and DME produced from willow or forest residues have the lowest life cycle global warming potential (GWP) of all fuels compared in this study and could contribute to **reduce the emissions of greenhouse gases from shipping significantly.**

Post Script: Elizabeth, New Jersey 2021

Chip Taylor stops his DME powered tractor-trailer for a red light along North Fleet Street after leaving the New Jersey Turnpike at Exit 13. It's been a long trip from Cleveland, hauling construction equipment parts in a 40 ft. shipping container for export to Africa. As the light turns green, he gears up his powerful 15 Liter engine. Looking in rear mirror, he sees no smoke as he speeds up, remembering the clouds of soot from his early driving days in 2005.

As he enters the crane yard, he notices the tank farm on his right, holding different grades of DME for different modes of transportation. He sees the familiar blue tanks used for truck fuel, along with the new orange tanks used for marine applications. As he queues up in the offloading line, he notices a brand new tug heading out to guide the incoming container ship. It speeds up, smoke stack completely clear of soot, obviously powered by a new DME marine engine.

As he listens to his favorite talk show on the satellite radio, he remembers how he hated the stink of diesel and the clouds of smoke in the Port of Newark line-up. Now he can enjoy a nice day with window down and smell the salt water nearby.

Conclusion

North America currently holds tremendous natural gas reserves that could soon make United States and Canada completely independent of foreign oil. Furthermore, Canada holds 11% of world's biomass, another feedstock for the production of DME.

"*There's a way to do it better—find it!*"

Attributed to Thomas Edison

The natural resources are in place. What has been lacking is a solution using natural gas and biomass for the North American chemical industry and transportation infrastructure, thereby reducing the region's dependency on Middle East petroleum.

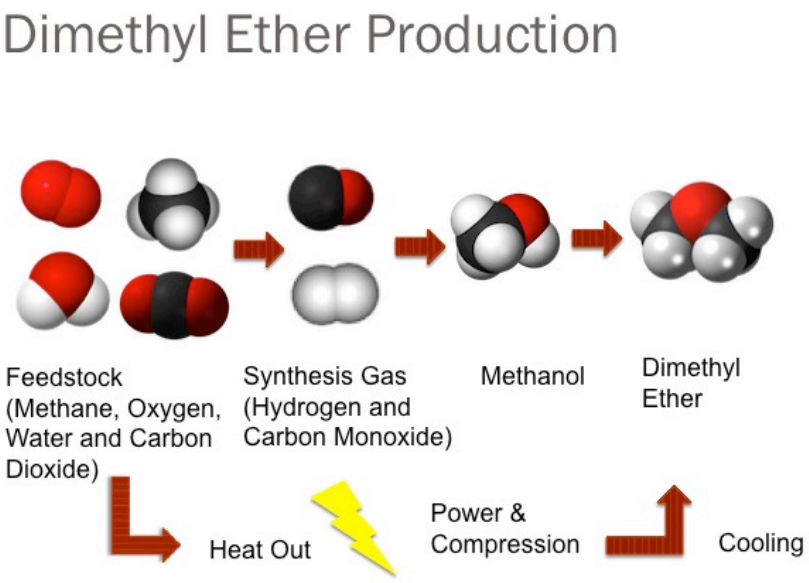

Figure 5: Simple Production of DME from Natural Gas or Methanol

About the Authors

Antonio Anselmo (Chief Executive Officer)

Dr. Anselmo is a principal at Altametric and a founder of The Allocated Materials Management Company. Dr. Anselmo is a recognized world-class expert in the fields of advanced particle accelerators, plasma physics, system engineering and financial engineering. He is an expert on the design and control of complex systems. Dr. Anselmo worked for 12 years at J.P. Morgan Chase in the Financial Engineering and Electronic Commerce groups in the Investment Bank. Prior to this, he was a Scientist at Varian Associates for 4 years designing accelerator and radar systems. He has written numerous scientific papers on nuclear fuel chain optimization, particle accelerators and complex systems.

He holds a B.Sc., M. Eng. and Ph.D. from Cornell University and an M.B.A. from the Amos Tuck School at Dartmouth College. He was a McMullen Honorary Scholar and a Teagle Graduate Fellow at Cornell and an Edward Tuck Scholar and Adams Entrepreneurial Award Winner at Dartmouth.

Jeremiah Sullivan (Chief Financial Officer)

Jeremiah has served as CFO and COO of three PE/VC owned companies and one private company. He increased shareholder value at all four companies by leading strategic growth and turnaround initiatives. He has extensive international experience and has negotiated transactions in Europe, Asia and Latin America. Most recently, Jeremiah served as the CFO of Cirqit.com, Inc., a technology firm that provides print procurement SaaS software and on-site technical services solutions to its clients. He helped the company's private equity owners engineer a turnaround of the company's operations culminating in two liquidity events involving the sale of Cirqit's operations in North and South America.

He holds a M.B.A. from the Amos Tuck School at Dartmouth College and B.S. in International Affairs from Georgetown University. He was an Adams Entrepreneurial Award Winner at Dartmouth.

Please visit the following web links for a quick primer on DME:

http://gasinvestingnews.com/8048-dimethyl-ether-the-most-promising-fuel-youve-never-heard-of.html

https://www.youtube.com/watch?v=QqY4euAix3M

http://www.thestreet.com/story/12288035/5/dimethyl-ether-the-most-promising-fuel-youve-never-heard-of.html

http://www.aboutdme.org/index.asp?sid=1

http://www.navigantresearch.com/blog/dimethyl-ether-the-next-big-truck-fuel

If you are interested in the detailed chemistry of DME, please visit:

http://www.ohio.edu/people/lees1/DME.html

Please visit the following web links to see Volvo trucks powered by DME in action:

https://www.youtube.com/watch?v=4XzcOkDZ0mM

https://www.youtube.com/watch?v=2r4AtWk8Pqk

https://www.youtube.com/watch?v=PxWGrqwQjRU

If you are interested in the use of DMC, please visit:

http://www2.epa.gov/green-chemistry

http://pubs.rsc.org/en/content/articlepdf/2012/GC/C2GC36226K