Sustainable Energy Science & Technology Group

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Transition from Alberta Bitumen to GHGs-Free Energy Economy

1. Introduction

It has been well demonstrated that DME (Dimethyl Ether: CH_3-O-CH_3), an amphoteric and low-cost solvent can eliminate the deleterious effect of SAGD on environment/human health and reduce the capital and operating costs of bitumen recovery by 80 and +80%, respectively (envirotechdme.com). The ultimate proof of DME effectiveness for bitumen recovery will be provided by field demonstration.

DME/water blends can be hydrolyzed/reformed under very mild conditions. The process generates large volumes of hydrogen that can be readily converted into other forms of energy. The DME capacity to significantly improve bitumen recovery and handling combined with the potential for generating hydrogen is expected to inject a new life into Canadian bitumen industry and enable for smooth transition from a carbon-based to a carbon-free energy economy. The potential of DME to innovate bitumen recovery and transform bitumen to a carbon-free energy generation industry in Canada is outlined below.

In the 1950s the United States government embarked on a project to evaluate the potential of hydrogen energy for replacing the combustion of fossil fuels. In the 1960s it was demonstrated that catalytic dehydrogenation of coal at near ambient temperatures enabled generation of a large volume of hydrogen at an acceptable cost. The second phase of the project was aimed at identifying the optimal solutions for hydrogen handling, storage and transportation including pipelining and shipping. No satisfactory solutions for hydrogen storage and shipping were identified.

In October 2004, the US Los Alamos National Laboratory issued a report [1] on hydrolysis/steam reforming of DME. DME can be readily handled, stored, transported and converted into hydrogen. Conversion of DME into hydrogen by hydrolysis/reforming, equation (17), can be carried out under very mild conditions. As opposed to natural gas (CH_4) reforming, equation (6), DME's hydrolysis/reforming is releasing, per volume of a gaseous-mole substrate, a large volume of hydrogen, equation (17).

$$(17)\quad CH_3OCH_3 + 3H_2O \rightarrow 6H_2 + 2CO_2 \qquad (6)\quad CH_4 + H_2O \rightarrow 3H_2 + CO$$

At 20^0C the conversion of CH_3OCH_3 (DME) into liquid can be readily accomplished under 0.45 MPa pressure only. Converting natural gas into liquid (LNG) followed by shipping, depressurizing and converting the LNG back into gas is an expensive and cumbersome process.

Our review of the scientific and technical information on the hydrogen economy indicates that so far no promising solutions have been identified for hydrogen storage and shipping.

The cost of DME production by direct synthesis [2] has been estimated by the Japanese technology developers at US$(60-90)/ton or US$(7-11)/barrel (2008 US$).

In addition to DME being identified and patented in Canada [3] & [4] as the most promising solvent for in-situ bitumen recovery, DME is definitely promising as a source of hydrogen. The production cost of DME has a significant effect on bitumen recovery and hydrogen generation costs.

DME's impact on human health and the environment has been tested extensively by the US EPA [5]. It has been confirmed that DME is nontoxic, non-carcinogenic, non-teratogenic and non- mutagenic [6]. Accidentally spilled DME readily evaporates from water or soil and decomposes in the atmosphere over 24-72 hours into H_2O and CO_2.

The suitability of DME for storage, transportation and utilization is of no concern. The DME production cost could be reduced by employing the CO_2/H_2O blend (2:4 molecular ratio) for methanol synthesis (1), which is followed by dewatering to DME (3).

$$(1)\quad 2CO_2 + 4H_2O \rightarrow 2CH_3OH + 3O_2 \qquad (3)\quad 2CH_3OH \rightarrow CH_3OCH_3 + H_2O$$

Reaction (1) takes place at ambient temperature and atmospheric pressure in presence of Cu_2O catalyst. Additional experimental work is required to confirm that reaction (1) can be scaled-up and its kinetics accelerated. Reaction (3) is a commercially applied dehydration of methanol to DME.

The reports [1] & [8] reveal that optimal conditions for DME steam hydrolysis/reforming as presented in reaction (17) are: a DME/steam mass ratio of 1/(1.2-1.5), an ambient (0.1 MPa) pressure, a temperature of $+200^0C$ and an alumina or zeolite based catalyst. The report [1] concludes that "thermodynamically, the DME processed with steam can produce hydrogen-rich fuel cell feeds with hydrogen concentrations exceeding 70%." Utilization of hydrogen for energy generation offers realistic and practical solutions for resolving the problems associated with climate change and the bitumen industry. DME could be exported to foreign markets by using proven LPG and LNG handling and transportation technologies. At the customer's site the DME would be converted into hydrogen by blending with water and subjecting the blend to hydrolysis/reforming at very mild conditions.

There are many economic and environmental benefits resulting from such an approach to hydrogen generation: DME transportation is of no concern, costs are limited to DME transportation only, there is no need for developing new infrastructure for hydrogen handling and transportation, water available on the hydrolysis/reforming site is blended with DME, over 50% hydrogen is generated from water, either the delivered DME or the DME recovered from bitumen/DME blends can be mixed with water and turned into hydrogen at a minimal energy input.

The Alberta bitumen industry has acknowledged that SAGD has to be replaced in order for the industry to meet economic and environmental requirements [9]. We propose that the best option is to replace SAGD's steaming with DME extraction. Lowering the production cost of DME will enable a reduction in the cost of bitumen extraction and transportation; DME can be employed as a solvent for bitumen extraction and an inexpensive diluent for bitumen transportation.

Though the reaction presented by equation (1) has not been demonstrated in a large scale yet, it has the potential to significantly reduce DME production cost. Further work on this reaction, equation (1), is required to fully explore its potential for DME production in the future.

At this time, a more advanced for commercial scale application option is based on CH_4 (natural gas) reforming using CO_2, equation (5).

(5) $CO_2 + CH_4 \rightarrow 2CO + 2H_2$

CO_2 is the main by-product of direct DME synthesis [2}. Recycling and converting the on-site generated CO_2 into equimolecular syngas (CO/H_2=1/1 vol. ratio) required for DME direct synthesis will reduce the demand for natural gas and the cost of DME synthesis.

An alternative route is based on reacting an equimolar blend of CO_2/CH_4 over TiO_2 catalyst supported on Al_2O_3 with the active phase modified by Ra and WO_3. The route provides 97% conversion of CO_2 into methanol and small amounts of formic acid, acetic acid and ether (16). The methanol can be readily dehydrated to DME generating H_2O as the main by-product, equation (3). This route has not been proven in a commercial scale.

Auto-thermal reforming that involves reacting natural gas (CH_4) with CO_2 and oxygen, reaction (18), has been developed to a commercial scale. The reaction is driven by generated heat and substitutes a portion of natural gas with CO_2.

(18) $2CH_4 + O_2 + CO_2 \rightarrow 3H_2 + 3CO + H_2O$ + heat

The auto-thermal reforming can be carried out in a compact, limited footprint plant. It requires low investment, its economy increases with scale-up, the operation is soot-free and flexible (short start up periods and fast load changes). Auto-thermal reforming combined with the Japanese direct synthesis of DME has the capacity to utilize CO_2, reduce natural gas consumption and eliminate CO_2 emissions thus releasing producers of large volumes of CO_2 from paying the Canadian carbon tax.

A low DME production cost will rejuvenate the Alberta in-situ bitumen recovery industry, play a significant role in reducing hydrogen production cost and the transition from bitumen to a hydrogen-based energy economy.

A different approach to developing the hydrogen economy has been conceived in Germany and has become the basis for the "Helios" project reportedly to be developed in Saudi Arabia. The "Helios" project is expected to play a major role in production of green hydrogen for export to Europe. It is based on electrolysis of water using green electricity generated by solar panels and wind mills. The generated hydrogen is to be synthesized into ammonia (NH_3). Liquid ammonia will be exported, delivered to a selected site and decomposed into nitrogen (N_2) and about 60vol.% H_2. The hydrogen will likely require clean-up in order to be fed into fuel cells for electric power generation. The cost of "green ammonia" synthesis (solar panels and wind mills as sources of energy) to be carried out in Saudi Arabia has been estimated at about US$250/tonne-$NH_3$. The cost of NH_3 decomposition and clean-up to generate green hydrogen has not been released at the time of preparation of this report.

Liquid DME can be readily pipelined and shipped and has been shown to be an effective corrosion preventer [10]. Either LPG tankers, tankers equipped with pressurized containers or with vapors recirculating systems can be employed for DME shipping. DME delivered to overseas markets can be utilized for a variety of applications. Apart from being a source of hydrogen, DME is a replacement for Diesel or cooking fuel or LPG diluent to effectively reduce its price. Under optimum processing conditions the DME/water blend will generate +70vol.%H_2, 20-25vol.%CO_2 and less than 1vol.%CO [1]. The generated gaseous product can be freed, if required, from CO_2 and CO using commercially available technologies thus yielding a gas containing +99 vol.% H_2.

Shipping the DME in tankers offers another opportunity for DME utilization. The tankers can be equipped with a propulsion system powered by electricity generated by oxy-combustion of DME in a low-speed 2-stroke Diesel engine equipped with a re-burning boiler and cryogenic CO_2 condensation/storage system. The engine converts nearly 50% of the generated heat directly into electric power. Japan and two European countries have been involved, for a number of years, into developing and testing such systems. The low-speed 2-stroke Diesel engine is capable of eliminating any CO_2, SO_x and NO_x and reducing carbon micro-particulates emissions by 95%. An alternative approach is to develop a portable system for converting the DME into hydrogen, separate and store - if required - the condensed carbon oxides, feed the clean hydrogen into fuel cells and employ the electricity generated to power the tanker.

DME and natural gas net calorific values are 4,620 and 5,040 Kcal/L or 14,200 and 8600 Kcal/Nm^3, respectively. The conversion of natural gas destined for overseas export into LNG requires temperatures of -162^oC. The cost of conversion is high and the LNG generated has to be shipped by employing specialty tankers. Reforming natural gas requires pressures of 0.3-2.5 MPa, temperatures in the range of 700-1000^oC and typically a Ni-based catalyst.

DME is a near perfect Diesel fuel - Cetane # 55-60; natural gas has Cetane # of 0. In terms of explosion limits both DME and natural gas are comparable. The export of DME from Canada to the Pacific Rim makes more economic and environmental sense compared to generating and exporting LNG.

By being involved into developing the technology for producing the lowest cost DME, the bitumen industry could not only produce bitumen at a rock-bottom cost and meet or exceed all environmental requirements but would also emerge as a major supplier of DME. Generation of nearly pure hydrogen via hydrolysis/reforming of DME appears to be technically and economically a promising approach to producing green hydrogen for applications in fuel cell stacks. Preliminary estimates indicate that, as compared to “Helios”, DME/water-based hydrogen production shall be more acceptable. Production of DME-derived hydrogen in Canada opens an opportunity for a smooth conversion of the Canadian carbon-based bitumen recovery technology into a versatile and sustainable carbon-free hydrogen-based energy industry of the future.

2. Production of Hydrogen via a DME-Based Process versus Other Options

In addition to employing DME as a source of hydrogen, three other options are considered at this time for a large scale hydrogen production. They include: conventional natural gas reforming and two proposed and researched approaches of which one is to be based on water electrolysis using low cost electrical power generated by wind mills and/or solar panels; the second one is based on lignite gasification. The first one known as the “Helios” project, has been referred to in chapter 1. The second one to be commercialized in Australia is presently operated in a commercial scale. In the future it will be based on two-stage gasification of Victoria’s lignite. The generated gas composed mainly of H_2 and CO_2 will be freed of CO_2. The collected CO_2 is to be disposed offshore by CCS. The generated hydrogen will be liquefied and shipped to overseas customers. The technology cannot be classified as sustainable. The

shipping is being demonstrated by usage of a small capacity tanker specifically designed and constructed for this purpose.
The criteria for estimation of the value of generated hydrogen products are: cost, purity and the range of possible applications; application of hydrogen as a feed for fuel cells is most desirable. Hydrogen to be utilized for combustion does not require very high purity. Hydrogen to be fed into fuel cells (green hydrogen) has to meet high purity criteria and its production has to be based on the principles of sustainability. High purity is required to avoid fuel cells poisoning. The poisoning is typically caused by carbon containing impurities present in the feed material (e.g. natural gas).
Fuel cells have the capacity to convert the energy contained in the feed material into electricity. Hydrogen is the most desirable material for conversion into electric power; thermal efficiency of converting nearly pure hydrogen into electricity by application of fuel cells is about 90% and water is the only product of green hydrogen oxidation.
The cost of blue hydrogen to be converted into electric power shall not exceed US$2/kg. The cost of the renewable green hydrogen to be fed into fuel cells shall be less than approximately US$4/kg or per gallon gasoline equivalent.
The green hydrogen produced by “Helios” might be unsuitable for fuel cells operation. It is uncertain what will be the impact of trace amounts of ammonia (NH_3) in clean hydrogen on fuel cells performance. Ammonia is a hazardous product, its handling and transportation exposes humans to serious health hazards including death.
Though the hydrogen generated by water electrolysis meets the purity criteria, the costs of its liquefaction in Australia, handling and shipping from Australia in specialty tankers to overseas destinations may appear to be an obstacle in meeting economic requirements.
Production of hydrogen by hydrolysis/reforming of DME (CH_3OCH_3) has been demonstrated in a laboratory [1] and confirmed in a commercial scale.

DME can be inexpensively and safely delivered to any destination. At a selected site DME will be diluted with water and the blend subjected to hydrolysis/reforming. Over 50vol.% of generated hydrogen is derived from water and the balance from DME. The hydrolysis replaces the electrolysis. Hydrolysis of DME/water blend is the primary reaction leading to hydrogen formation. Hydrolysis makes it possible to drive the reaction at very mild conditions and prevents generation of carbon containing contaminants ($+C_1$) that are present in products of high temperature reforming of natural gas. No C-C bonds are present in DME; water does not contain carbon atoms. Cleavage of C-C bonds requires a lot of energy and high temperature; it is typically accompanied by formation of radicals resulting in generation of volatile $+C_1$ by-products. Natural gas contains 5-15% of C_2-C_5 carbon compounds; their reforming generates difficult to separate contaminants. The +99vol.% hydrogen fed into fuel cells is expected to be satisfactorily converted into electric power at high thermal efficiency.

The Japanese government (METI) had funded a large scale (100 tons/day) direct DME synthesis piloting facility. The Mitsubishi Corporation acquired all rights to the technology and maintains that it is ready for commercial application. The cost of syngas preparation is included into the cost of DME synthesis. Reaction (4) summarizes the catalytic DME synthesis.

(4) $3CO + 3H_2 \rightarrow CH_3OCH_3 + CO_2$

DME (CH_3OCH_3) production cost can be further reduced by on-site recycling and utilizing the CO_2 - the main by-product of the reaction (4). Auto-thermal reforming is commercialized and suitable for this purpose. It results in reducing natural gas consumption, provides the heat required for driving the process, reaction (18), and generates the syngas for DME synthesis.

(18) $2CH_4 + O_2 + CO_2 \rightarrow 3H_2 + 3CO + H_2O + \text{heat}$

The route to DME synthesis, reaction (1), via methanol dehydration, reaction (3) is the most promising future route to DME synthesis. Developing this route, reaction (1), to a commercial stage shall be of utmost importance to Canada and Japan.

(1) $2CO_2 + 4H_2O \rightarrow 2CH_3OH + 3O_2$ (3) $2CH_3OH \rightarrow CH_3OCH_3 + H_2O$

Reaction (1) delivers oxygen required for the application of a low speed DME oxy-fired Diesel engine that, in addition to other functions, enables quantitative collection of generated liquid CO_2. Reactions (1) & (3) open an opportunity to eliminate the demand for natural gas reforming and formation of equimolar syngas to produce DME. Reaction (1) has the potential to reduce the DME, bitumen and hydrogen production costs to a rock-bottom level. It would also provide additional profits for DME producer(s) by utilizing CO_2 supplied by large emitters who are facing huge carbon tax payments unless they identify a solution to sequestrate their CO_2 emissions at an acceptably low cost.

3. Economics of DME-Based Hydrogen Production

The DME-based hydrogen production includes generation of DME, hydrolysis/reforming of a DME/water blend to form hydrogen rich gas, removing carbon oxides from the gas (if required) thus leading to +99vol.% hydrogen product. The cost of generation of equimolar syngas $CO/H_2=1/1$ (vol. ratio) followed by the Japanese direct synthesis to DME has been assumed, based on METI's estimates, to be approximately US$10/barrel of DME. The cost of DME hydrolysis/reforming including the removal of carbon oxides from the hydrogen has been tentatively accepted as US$0.70/kg hydrogen. This cost is equivalent to the cost of conventional steam reforming of natural gas at its source. The cost of conventional reforming of natural gas supplied from off-site sources does increase the reforming cost by US$(1-2)/kg-hydrogen.

DME hydrolysis/reforming proceeds at very mild conditions. Conventional natural gas reforming produces a blue non-sustainable product. The literature [11] and commercial experience show that carbon oxides present in hydrogen can be separated by allotrope membranes. Other methods recommended for removal of these two compounds (CO_2 & CO) from hydrogen include: pressure swing adsorption, a cryogenic distillation method at a low temperature, amine gas sweetening solutions, and absorption of CO_2 with other absorbents.

By advancing the Nazimek/Yimin concept [12] of reacting CO_2 and H_2O to form methanol/DME a large portion or a total cost of methanol synthesis would be paid off by major CO_2 emitters based upon pre-negotiated long term service agreements for CO_2 sequestration.

Within a wide range of DME production costs (US$0.00-100/barrel) the hydrogen product cost might be reduced to US$0.70-4.31/kg hydrogen.

1. at US$0.00/barrel DME→ US$0.00/kg hydrogen + US$0.70/kg hydrogen → US$0.70/kg hydrogen
2. at US$50/barrel DME → US$ 1.80/kg hydrogen + US$0.70/kg hydrogen →US$ 2.50/kg hydrogen
3. at US$100/barrel DME → US$ 3.61/kg hydrogen + US$0.70/kg hydrogen →US$4.31/kg hydrogen

Comments reg.: 1. 2. & 3:

- Reg.1.: The cost (US$0.70/kg-hydrogen) of DME synthesis, hydrolysis/reforming of the DME/water blend and CO_2/CO removal might be underestimated by up to US$2.00/kg hydrogen;
- Reg.1.: The cost of DME synthesis can be reduced from US$10.00 to US$0.00/barrel-DME due to recycling and converting the on-site generated CO_2 into DME;
- Reg. 2. & 3.: The costs of DME synthesis (US$50/barrel DME and US$100/barrel DME) can be significantly reduced depending on volumes of CO_2 supplied by off-site emitters for sequestration;
- Green hydrogen production cost from DME/water blend via hydrolysis/reforming is expected to be competitive as compared to other proposed green hydrogen generation technologies;
- Production of low-cost hydrogen from DME/water can be carried out at any site that can be supplied with low-cost DME or alternatively bitumen/DME blends originating from Canada;
- The application of DME for bitumen recovery and generation of hydrogen/electric power has the potential to convert Canada and Japan into a major sustainable energy hub.

The estimates for energy consumption by the gasoline and hydrogen powered automobiles are

1. The gasoline powered automobile:
   - Typically consumes 70 L (52.5 kg) gasoline per 700km;
   - Gasoline heat combustion and specific gravity are about 45MJ/kg and 0.75kg/L, respectively;
   - The energy contained in 70L of gasoline is about 2,363MJ, equivalent to 338MJ/100km;
   - Reportedly the average consumption of energy by a small automobile is 248MJ/100km;
2. The hydrogen powered automobile:
   - A 97.5L high pressure (690 atm.) fiber-composite tank contains approximately 6.0kg hydrogen;
   - Hydrogen's combustion heat is 141.6MJ/kg; the energy contained in 6kg hydrogen is 850MJ;
   - Hydrogen powered automobile engine reportedly requires 115.2MJ/100km;
   - The range of the automobile powered with 6.0kg hydrogen is about 738km.

In terms of range (distance driven) the gasoline and green hydrogen driven automobiles are comparable. The +99vol/% hydrogen powered automobile will not generate GHG emissions. The cost of green hydrogen (US$4/kg hydrogen - based on US DOE estimate) to fill the 97.5L tank pressurized to 690 atm. amounts to about US$24. The market price of gasoline to fill the 70L tank amounts to about US$55 (2021 US$). Reportedly the energy consumption by a hydrogen automobile (115MJ/100km) is about 30% of that of gasoline automobile (338MJ/100km). Hydrogen powered automobiles offer an ultimate solution to preventing climate change and have the capacity to reduce the demand for energy. The costs of hydrogen distribution/marketing, developing and constructing the infrastructure required for hydrogen are unavailable. These costs will be huge and the-to-be developed hydrogen infrastructure may fail to meet some economic expectations.

Green hydrogen, as opposed to DME/water blends, does not have the capacity to contribute much to lowering the cost of powering the automobile. An automobile equipped with approximately 124L tank containing DME/water blend (about 1/1.2 mass ratio) at a pressure of about 4.5 atm. shall outperform the hydrogen powered vehicle. The DME/water blend powered vehicle will be equipped with a portable system capable of hydrolysis/reforming the blend, separating carbon oxides (if required), passing the hydrogen through fuel cells stack, converting electric into mechanical energy plus a battery/alternator-based starter. Such system will generate 12kg hydrogen - twice as much as the 6kg of hydrogen pressurized to 690 atm. and contained in a 97.5L tank. The DME/water blend tank contains approximately 69L (46Kg) liquid DME and 55L (55Kg) water. At US$10/barrel-DME the production cost of DME contained in the tank will amount to about US$4.30. By recycling and utilizing the generated CO_2 to synthesize the DME, the cost of DME production will be reduced significantly. The cost of 69L of liquid DME blended with water and deposited in the tank will, therefore, be significantly below the US$4.30.

The conversion of the energy contained in the DME/water blend to mechanical energy consumes about 25% of total energy of 1,700MJ generated by the portable system. The energy balance of 1,275MJ will enable the DME/water blend powered automobile to drive for at least 1,100km. Approximately half of this distance will be driven on nearly zero cost hydrogen generated from DME-activated hydrolysis of water.

The developed portable system shall provide a simple, safe and practical solution to power any transportation vehicles or stationary electric power generation systems. Powering the whole transportation industry with DME/water blends, including aviation, sea and land transportation, looks promising and does not require developing and constructing hydrogen infrastructure.

4. Benefits of DME-Based Heavy Crudes Recovery and Hydrogen Production

DME is the key to optimizing the performance of bitumen/heavy crudes recovery and a source of inexpensive either +70vol.% hydrogen containing CO_2 and -1vol.% CO or a nearly pure +99vol.% hydrogen – both generated from DME/water blends. It is expected that the +99vol.% hydrogen can be employed as feed for fuel cells to generate electric power at up to 90% energy efficiency. The DME can be produced and the hydrogen/electricity generated regardless of whether the wind is blowing and/or the sun is shining. DME can be stored, handled and transported using the existing infrastructure developed for gaseous/liquid fossil fuels. DME can be converted to hydrogen at a selected site by blending with water followed by hydrolysis/reforming.

The DME can be delivered to a selected site in the form of a liquid or as bitumen/DME dilbit. DME can be readily separated from bitumen. Bitumen can be utilized as required including production of asphalt for roadways construction, petrochemicals, carbon fibers, a feed for refining to transportation fuels and so on. DME can be employed as super-clean, low cost Diesel or cooking fuel, a substitute for LPG or as feedstock for conversion to +99vol.% hydrogen or electric or mechanical power.

The upgrading of bitumen separated from bitumen/DME dilbit for transportation fuels production will emit some CO_2. The CO_2 emissions can be offset by generation of large volumes of hydrogen from

DME/water blends. No other petroleum products/blends have the capacity to offset CO_2 emissions generated by their upgrading/processing. That increases the value of, and the demand for, bitumen/DME dilbit of which the usage is protected by patent applications. The bitumen/DME producers will profit by charging the importers for both the bitumen and the DME. The producers will also profit by replacing expensive condensate with DME for bitumen transportation. DME enables bitumen extraction, thinning and transportation. Eliminating the need for condensate reduces the bitumen producers' cost by up to US$20/barrel-bitumen.

Fuel cells powered with hydrogen have been of particular interest to the transportation sector. They were employed in electric vehicles including Hundai's Tucson (2014 year) and Toyota's Mirai FCEVs (2015 year). Steps are to be taken for planning and developing hydrogen infrastructure for powering electric vehicles equipped with fuel cells in the whole of the United States. As compared to generating, pipelining and shipping pure hydrogen the DME route offers a much less expensive but very practical solution to carbon-less economy.

Pure hydrogen in portable power generation CHP fuel cells eliminates CO_2 emissions, deposition of carbon and extends the life time of fuel cells operation [8]. CHP systems have been installed all over the world for a variety of applications including stores, hospitals, corporate facilities at any sites ranging from 200kW-1MW.They require highly pressurized, pure hydrogen.

DME shall improve transportation vehicles performance provided they are equipped with systems enabling DME/water conversion into mechanical energy as outlined in chapter 3. The cost of producing 46kg DME to be blended with water in 124L tank shall be less than 4.30US$. The blend will generate about 12kg of hydrogen and enable to drive the automobile over a distance of approximately 1,100 km. The market price for gasoline required to drive same automobile for a distance of 1100 km would amount to around US$110 (2021 US$).

The Japanese direct DME synthesis integrated with auto-thermal reforming provides a strong argument in favor of developing large scale and low cost DME production in Canada. The DME output shall be about 5,000 tons/day to bring maximal benefits from a large, commercial scale production. Initially, a singular 1,000 tons/day direct DME synthesis reactor shall be constructed. The construction of such a singular reactor must be preceded by a successful demonstration of the DME-assisted bitumen extraction plant. After confirming the high performance of the DME assisted bitumen extraction plant, an additional 1,000 short tons/day reactors would be constructed within the Integrated Central Facility (ICF) site. That would provide the basis for developing specifically Canadian/Japanese expertise in a large scale DME production and transition from carbon-based bitumen to a carbon-free, sustainable hydrogen/electric power economy.

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