Environmental Fossil Fuels Sciences & Technology Group

In cooperation with Envirotech Consulting Inc. (ECI)

B) A Breakthrough Technology for In-Situ Bitumen Recovery

Summary: *In 2008 METI (the Japanese government) proposed to Alberta government to jointly demonstrate the DME (Dimethyl Ether) technology for in-situ recovery and upgrading of bitumen/extra heavy oils. Over the last decade additional effort has been placed into confirming the potential of the patented Canadian DME-based technology. The optimal version of the technology – the "Integrated DME-based extraction" - as compared to SAGD technology, eliminates water usage, steam generation, natural gas combustion and GHGs emissions. The technology is expected to recover from the reservoir 80-90% - instead of SAGD's 50% bitumen - at recovery rates 3-4 times higher [1], reduce the demand for energy by 10 times, reduce the mass flow for SAGD's recycled injection fluids (steam/water) by approximately 30 times and utilize the by-products generated. It converts the generated nearly pure residual* CO_2 *into value-added products. The effectiveness and simplicity of the "Integrated DME-based extraction" plant is reflected in reducing the capital cost by up to 80% and the bitumen recovery cost at plant gate (the breakeven cost) by expected 5-6 times, equivalent to US$7-8 per barrel as compared to SAGD's US$40 per barrel [2].*

The DME-based extraction technology is expected to convert this Province into economically and environmentally sustainable, diversified and versatile energy and petrochemicals hub.

1. SAGD's Replacement

The improvement of the economic and environmental performance of the in-situ bitumen recovery industry is essential to reverse the decline of this industry and curtail the free-fall of Alberta's economy. This synopsis outlines the principles of DME-based bitumen recovery. Alberta bitumen producers do acknowledge that SAGD should be replaced. SAGD's replacement will rejuvenate the bitumen industry and make it competitive with conventional crude oils.

1.1 DME-based bitumen recovery technologies

The improvement of SAGD can be achieved, at no risk, by admixing DME to SAGD's steam or replacing hydrocarbons with DME (CH_3-O-CH_3) in the "Hydrocarbons-assisted SAGD" process the industry is well acquainted with. The "DME-assisted SAGD" (*the basic technology*) will utilize the bitumen industry's huge multi-billion capital invested into existing SAGD plants. As compared to SAGD the "DME-assisted SAGD" plants are expected to increase overall bitumen recovery from 50% to around 65%, the rate of recovery by approximately a factor of 2 and lower the breakeven cost by up to 50%. The detrimental environmental impact of SAGD will be significantly reduced. The recovered bitumen containing around 15wt% DME spiked with methanol is expected to make the blend amenable to transportation thus eliminating the need for the condensate. The methanol plant, located in Alberta, Medicine Hat, could be readily converted to DME production. The conversion cost is minimal.

Table 1 summarizes the information on the three DME-based technologies for in-situ bitumen recovery. Each of them will outperform the SAGD technology.

Table 1: Summary of information on DME-based Technologies

DME-based Technologies	Key Features	Major changes in plant operation	Expected Performance
1. "DME-assisted SAGD" (DME-SA) The basic technology	Applies DME solvent in a SAGD plant	Admixes DME to SAGD's steam or replaces hydrocarbons with DME in hydrocarbon-assisted SAGD	Increases overall bitumen recoveries and recovery rates; no need for condensate to transport bitumen/DME dilbit
2. "DME-based extraction" (DME-E) The advanced technology	Bitumen recovery based on extraction with DME instead off steam assisted drainage	Eliminates natural ga combustion, CO_2 emissions, steam generation & process water treatment, applies electric in-reservoir heating of DME; reduces energy consumption by 10 times and recycling of injection liquids by 30 times	It is expected to reduce plant capital cost, as compared to SAGD, by up to 80% and breakeven costs by 65-80%, increases overall recovery of bitumen from 50% to 80-90% and extraction rates by 300-400%
3. "Integrated DME-based extraction" (I-DME-E) The optimal technology	The expansion of the ICF to produce value-added products by processing the by-products formed on ICF site; scales-up the conversion of $CO_2 \rightarrow$DME to maximally reduce the costs of DME and bitumen production	The expansion of the whole facility is limited to ICF; no changes to bitumen recovery plants; scaling up the $CO_2 \rightarrow$DME process will convert the whole facility (ICF and recovery plants) into sustainable & versatile energy system; significant reduction in DME production cost by scale-up of $CO_2 \rightarrow$DME conversion could enable handling and transporting the DME and its reforming to hydrogen (see synopsis D)	Among the 5 options identified for optimizing the performance of the ICF, scaling-up the process $CO_2 \rightarrow$DME followed by DME steam reforming is expected to provide optimal results; scaling-up the process $CO_2 \rightarrow$DME is expected to reduce bitumen recovery cost below that of conventional crude oils and bridge the transformation of bitumen recovery industry into a DME and hydrogen production hub

DME is the safest solvent available (US EPA), it has amphoteric properties (soluble in water and organic compounds) that makes it most effective for bitumen recovery, can be produced commercially at low cost (METI & China), serves as a valuable additive to LPG and a super-clean transportation Diesel fuel (China). Oxy-combustion of DME in a low-speed two-stroke Diesel engine equipped with a re-burning

boiler and cryogenic CO_2 separator (Germany, Denmark & Japan) is most efficient for electric power production combined with recovery of geothermal heat by application of the generated 97-98% CO_2.
The demonstration of the "DME-assisted SAGD" technology can be carried out right away. Replacing the "DME-assisted SAGD" with the "DME-based extraction" (*the advanced technology*) will elevate the performance of the DME technology by replacing the steam/bitumen gravity drainage with the highly effective bitumen extraction carried out with the solvent that displays exceptional affinity to bitumen. As compared to SAGD, the capital and breakeven costs of the "DME-based extraction" plant is expected to be reduced by up to 80% and 65%, respectively. The latter plant eliminates natural gas combustion, GHG emissions, usage of potable water and steam. The "DME-based extraction" plants are supplied with electric power and DME by the off-site Integrated Central Facility (ICF). As compared to SAGD, the "DME-based extraction" reduces the energy consumption by around 10 times, mass flow of recycling liquid (DME) by about 30 times, increases nearly twice bitumen overall recovery and the recovery rates by up to 4 times. The advanced "DME-based extraction" shall be demonstrated when the operation of the "DME-assisted SAGD" plant confirms the performance criteria previously outlined for this plant.

1.2 Bitumen recovery mechanism: SAGD versus DME

SAGD employs steam preheated to 200-230^{0}C for heating the reservoir to at least 80^{0}C to reduce the viscosity of bitumen so it can be pumped to the surface. Steam is dispersed within the reservoir primarily via channels and fissures that display the least resistance to flow. Reservoirs containing excessive water are not suitable for bitumen recovery by SAGD – huge volumes of steam are wasted to heat water. Steam is typically unable to penetrate through those areas of the reservoir that are filled with wet fines and clays bound by bitumen. Bitumen recovery from those areas will be impeded and any bitumen recovered will have increased content of clays. Bitumen's heterogeneity changes from reservoir to reservoir and can be significant. High molecular weight components of bitumen require more heat for viscosity reduction. It has been demonstrated during the more than two decades of commercial application that SAGD can recover from "the best of the best reservoirs" approximately 50wt% bitumen only. Despite the efforts placed into SAGD's improvement the overall recovery and other parameters of SAGD's performance remain essentially unchanged. That confirms that SAGD's recovery mechanism based on application of steam fails to either effectively transfer its heat to the reservoir's bitumen or ensure proper drainage or both. Steam generation and usage are the main causes of SAGD's economic and environmental underperformance. Replacing the source of heating (combustion of natural gas) is not expected to significantly improve the recovery of bitumen as long as steam is employed for transfer of heat to, and distribution within, the reservoir.

Though the concept of using solvents for bitumen extraction is an old one the bitumen industry preference to work with hydrocarbons has delayed application of non-hydrocarbons for this purpose. Hydrocarbons are insoluble or only slightly (some aromatic hydrocarbons) soluble in water; their density is significantly below that of water and their affinities to bitumen, as determined by specific physical and chemical properties [3] (are incompatible. These three factors are the main reason why the extensively tested “Hydrocarbons-assisted SAGD” technology has marginal impact on SAGD’s improvement. Replacing hydrocarbons with DME leads to the “DME-assisted SAGD” technology that is expected to significantly outperform “Hydrocarbons-assisted SAGD” or SAGD.

As opposed to hydrocarbons the DME is well soluble in water and very well in a variety of organic compounds - bitumen and extra heavy crude oils in particular. Some DME introduced with SAGD’s steam to the reservoir will readily dissolve in cold reservoir’s water and penetrate in this form, via the water phase, through the ore. The remaining DME will be dispersed within the reservoir, depending on temperature and pressure, as liquid and gas. Because of the exceptional affinities between the bitumen and DME, the DME will quickly diffuse into bitumen. The kinetics of DME removal from water and diffusion into bitumen will accelerate with an increase in temperature. By the time the temperature is elevated from 10^0C to about 50^0C (in-reservoir electric heating) the bitumen/DME solution can be delivered to the surface. Low boiling hydrocarbons (C_3 & C_4) have the capacity to rapidly precipitate, even at very low concentrations, the heavy components of bitumen thus making product recovery from the reservoir more difficult. DME content in the bitumen/DME dilbit would have to amount to about 80-90% to reach the onset of precipitation. DME shall be successfully employed for bitumen recovery from very heterogeneous as well as shallow reservoirs due to low vapor pressures at temperatures below 50^0C. Compared to DME, application of heavier hydrocarbons ($+C_5$ aliphatic or aromatic) will be costly, require high pressures and temperatures and their insolubility or very low solubility in water will prevent them from extracting the bitumen efficiently.

1.3 GHG emissions: SAGD versus “DME-based extraction”

Tables 1 and 2 (see synopsis C) relate to GHG emissions from two bitumen recovery facilities of which each is composed of either SAGD or “DME-based extraction” plants. The number of bitumen recovery plants in each facility is the same and it has been assumed that each facility annual output amounts to 109.5 million barrels of bitumen. Based on the assumptions presented in Table 1, Table 2 presents the CO_2 emissions estimates for both facilities. The results indicate that whilst the SAGD facility will generate 14.5 million tonnes CO_2/year (0.132 tonnes CO_2/barrel bitumen), the “DME-based extraction” facility is expected to produce 2.4 million tonnes CO_2/year (0.021 tonnes CO_2/barrel bitumen) which is 84% less compared to SAGD’s facility. Furthermore, the 16% CO_2 generated at the ICF will be quantitatively collected. Resultantly, the “DME-based extraction” plants will not generate any CO_2. The CO_2 collected at the ICF site can be recycled/utilized as required.

The estimates in Table 2 are based on assumption that the bitumen recovery rates for SAGD and the “DME-only extraction” technologies will be comparable and the plants will be operational for 12 (twelve) years. Bench scale testing completed by Alberta Innovates of which the results have been presented in a 2017 report [1] has confirmed that the “DME-based extraction” rates are up to 4 times higher compared to light (C_3 & C_4) hydrocarbons. The application of light hydrocarbons for bitumen extraction at 50^0C results in recoveries comparable to those of a typical SAGD plant [4].

By assuming that the recovery rates of the “DME-based extraction” are four times those of SAGD, the annual production of bitumen from one “DME-only extraction” plant would amount to around 400% of that of the SAGD plant.

The estimates have confirmed that SAGD consumes a lot of energy and generates massive volumes of CO_2 mainly for water/steam recycling and heating the reservoir to 80^0C or more. On the other hand SAGD’s plant recovers small volumes of bitumen. The “DME-based extraction” delivers to the surface very small volumes of reservoir’s water (Intro, compare Fig. 1 & 2) that meets the criteria for surface disposal, and a large volume of bitumen/DME solution containing relatively small volume of DME. Liquid DME for bitumen dissolution will be pumped from the surface to the reservoir. The energy used by the “DME-based extraction” has been estimated to be 10% or less of that required by SAGD. SAGD plant’s energy demand for heating and pumping is exorbitant but results in recovering of approximately 25% only of the bitumen that can be recovered by the “DME-based extraction” plant. The mass flow of recycled steam/water is for SAGD plant approximately 30 times higher compared to that associated with liquid DME recycled through the recovery plant. Furthermore, it is expected that unlike the bitumen produced by SAGD, the bitumen/DME dilbit shall be amenable to pipelining directly to the harbor for shipping.

1.4 Converting the “DME-based extraction” into “Integrated DME-based extraction.”

Such conversion is limited to ICF only and will result in developing within the ICF some of the selected unit processes/options listed under 1-5, below. The conversion will further reduce the DME production and bitumen recovery costs. That could be attained by several means of which recycling and utilizing CO_2 by catalytic photosynthesis appears to hold a higher potential (item 1.) as compared to the remaining items (2-5) listed:

1. Generating methanol by catalytic photosynthesis of CO_2/H_2O or heterogeneous catalytic hydrogenation of CO_2 followed by methanol dehydration to DME,
2. Tri-reforming of blends composed of natural gas (CH_4), CO_2 and other oxygen containing gases to syngas followed by synthesis of methanol and its dehydration to DME,
3. Co-gasification of blends composed of coal and bitumen distillation residues to generate partially upgraded distillate, syngas for DME synthesis, hydrogen and by-products amenable to conversion into value-added products,
4. Sale of generated nearly pure CO_2 for enhanced oil recovery (EOR),
5. Recovering geothermal heat using CO_2.

The catalytic photosynthesis (item 1.) shall optimize the DME production and the in-situ DME-based bitumen recovery provided the technology is scaled-up and field demonstrated over the next decade. The process is based on generation of methanol and oxygen from CO_2/H_2O blends (1:2 molecular ratio) and has been developed a few years ago in the United States by Dr. Yimin Wu [5] in a bench scale. It is a reflection of the photosynthesis occurring in the nature (“Artificial Leaf”). Scaling-up and increasing the kinetics of this process could enable converting the in-situ bitumen recovery to an optimal and sustainable energy generation system. The need for natural gas and/or syngas to produce DME would be eliminated. The "Artificial Leaf" would enlarge hugely the opportunities for the Alberta bitumen recovery industry. The dehydration of methanol to DME is a low-cost simple and proven process. The cost of dehydration could be further reduced by producing DME containing some residual methanol. Generation of DME containing 1-3wt% methanol will lower distillation cost. Moreover, application of DME spiked with methanol for bitumen extraction will significantly reduce the viscosity of the generated bitumen/DME dilbit. Consequently, the mass of DME required for bitumen extraction and the rate of DME volatilization from the dilbit shall be reduced. That would enable to directly transport the bitumen/DME dilbit to customers thus eliminating the need for separating the DME from bitumen, and acquiring the condensate for blending with the DME-free bitumen. The DME and bitumen production costs would be further reduced by approximately C$24/barrel bitumen [6].

In addition to generating DME by methanol dehydration (equation 3), the process (equation 1) produces oxygen.

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

Oxygen is required for combusting DME in Diesel engine and producing nearly pure CO_2 for geothermal heat recovery. The supplied oxygen (equation 1) eliminates the need for constructing ASU (air separation unit), the tri-reforming facility and the whole DME synthesis technology hardware except for the methanol dehydration segment.

Municipal waste water to be supplied according to arrangements negotiated more than a decade ago between a private Canadian company and the Edmonton municipality shall be utilized for co-gasification of blends composed of residue from bitumen distillation and low rank surface mined coal. In addition to producing three products – partially upgraded relatively high octane distillate (Esso Petroleum Canada R 41412 Internal Report), hydrogen and syngas – the co-gasification by-product (CO_2) could be also converted into DME.

Apart from its effectiveness in bitumen extraction, DME is considered to be an environmentally safest solvent (US EPA). It is also a super-clean substitute for replacing the conventional Diesel fuel. Several years ago the State of California government classified conventional Diesel fuel as carcinogenic and banned its usage. The demand for DME for firing Diesel engines is expected to grow. Low speed DME-fired Diesel engines installed in large ocean going vessels could eliminate the acidification of the oceans. The engines do not generate SO_x and NO_x and enable collecting the liquefied CO_2 instead of emitting it to the atmosphere.

DME has been long known as corrosion inhibitor [7]. Its application as diluent during pipelining the bitumen is expected to prevent localized corrosion that frequently is the main cause of pipelines raptures.

The heterogeneous catalytic hydrogenation of CO_2 has been extensively researched. It produces methanol (equation 2) that can be readily dehydrated to DME (equation 3).

(2) $CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$ (3) $2CH_3OH \rightarrow CH_3OCH_3 + H_2O$

Though the hydrogenation of CO_2 has reached an advanced stage of development it still requires further work on improvement of catalyst performance.

The direct Japanese synthesis of DME [8] generates purity DME product at a reasonably low production cost of US$60-90 per ton (2007 US$) provided it is carried out in a large scale and based on gasification of surface mined, non-exportable coal. The syngas is subjected to a clean-up and synthesized directly into DME and nearly pure CO_2 (equation 4). Utilization of CO_2 reduces the costs of DME synthesis and in-situ bitumen recovery.

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

The tri-reforming (TRM) technology - item 2. – enables improving the “DME-based extraction” technology. According to DOT:10.5772/intechopen.74605 [9], the TRM process enables to use oxygen containing gases to produce syngas which can be converted to methanol. Methanol can be readily dehydrated to DME.

The TRM operates based on the principles of commercial methane reforming. TRM replaces two frequently applied commercial processes namely, the dry (O_2) and the wet (H_2O) reforming. Instead of feeding the reformer with either $CH_4/O.5O_2$ or CH_4/H_2O, the TRM is fed with blends typically incorporating CH_4, CO_2, O_2 and H_2O. The feed containing several reactants makes the TRM reactions energetically more efficient and less hazardous compared to wet or dry reforming. The TRM offers additional advantages; it allows to change the ratios of feed components, does not require pure CO_2, either the flue gas or coke oven gas are acceptable, the catalyst life-time is significantly extended (no carbon deposition), the ratio of CO/H_2 in the syngas produced can be adjusted from 1-3.

The TRM is a synergistic combination of the endothermic CO_2 and steam reforming reactions (5 & 6) with the exothermic oxidation of CH_4/natural gas (reactions 7 & 8). The reactions occurring are presented below and they are carried out in a single reactor:

(5) $H_2O + CH_4 \rightarrow CO + 3H_2$ (206.3 KJ x mol^{-1})
(6) $CO_2 + CH_4 \rightarrow 2H_2 + 2CO$ (247.3 KJ x mol^{-1})
(7) $CH_4 + \frac{1}{2}O_2 \rightarrow CO + 2H_2$ (-35.6 KJ x mol^{-1})
(8) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ (-880 KJ x mol^{-1})

In addition, during the tri-reforming process, methane cracking (9), CO disproportionation (10), water-gas shift (11) and complete oxidation of carbon reactions occur simultaneously (12).

(9) $CH_4 \rightarrow C + 2H_2$ (75 KJ x mol^{-1})
(10) $2CO \rightarrow C + CO_2$ (-172 KJ x mol^{-1})
(11) $CO + H_2O \rightarrow CO_2 + H_2$ (-41 KJ x mol^{-1})
(12) $C + O_2 \rightarrow CO_2$ (-393.7 KJ x mol^{-1})

An example of composition of feed gases, including CO_2, that TRM can convert into a syngas (13) for methanol synthesis (14) followed by dehydration to DME (15) is outlined below. In this example no attention has been paid to energetically optimize the process. In a commercial plant generating syngas energy optimization would receive considerable attention (see reactions 5-12).

(13) $CO_2 + 4CH_4 + 2H_2O + 1/2O_2 \rightarrow 5CO + 10H_2$
(14) $CO + 2H_2 \rightarrow CH_3OH$
(15) $2CH_3OH \rightarrow CH_3OCH_3 + H_2O$

Incorporating the TRM into the ICF enables to utilize significant percentage of the generated CO_2 for producing the syngas required for DME synthesis.

Urea production – item 3. – requires nearly pure CO_2 (e.g. from oxy-combustion of DME in a low-speed Diesel engine) and ammonia. Ammonia is produced as a by-product of co-gasification of blends of coal and the residue from bitumen distillation. Urea production from CO_2 and NH_3 generated during coal gasification has been commercialized in the North Dakota Great Gasification Plant. The NH_3 and CO_2, the by-products of the co-gasification gas clean-up and separation can be converted into the urea fertilizer using the same technology as has been employed in North Dakota.

For a long time the North Dakota Great Gasification Plant had been selling CO_2 to Saskatchewan (item 4.) for recovery of conventional crude oils from depleted oil wells (EOR). The CO_2 applied for the recovery shall be of reasonably high purity. Oxy-combustion of DME in low speed Diesel engines generates CO_2 suitable for EOR.

Geothermal heat recovery – item 5. - using CO_2 instead of steam, in order to reduce corrosion and erosion, is gaining momentum. Northern Alberta is blessed with a large geothermal power potential. Various versions of geothermal heat recovery are being field tested in different jurisdictions including Alberta and Saskatchewan. Generation of electric power by oxy-combustion of DME in Diesel engines looks particularly attractive due to their capability to convert 48-52% of the generated energy into electricity and around 40% into heat. Integration of this technique with utilization of generated CO_2 for geothermal heat recovery combined with partial capture of CO_2 in the reservoir shall be of interest to Alberta.

The ICF could produce DME and electric power by utilizing the CO_2 supplied by off-site emitters on terms defined by carbon tax and/or cap-and-trade regulations and agreements. Due to its capability to effectively recycle CO_2 for either methanol/DME generation or urea production or carbon-free electric power generation, the integration of the ICF with the “DME-based extraction” bitumen recovery plants has the capacity to convert Alberta bitumen industry into a uniquely Canadian, zero carbon emission fully sustainable and diversified energy conglomerate.

The co-gasification of a blend of coal and the residue from distillation of recovered bitumen enables formation of partially upgraded distillate (10). The yield of the distillate is equal to the mass of the residue present in the blend. The process is based on hydrogen donating properties of coal studied by I. Wender and co-workers (11). It can be carried out using Lurgi/BG moving bed gasification reactors for caking charges. The Lurgi/BG technology has been extensively tested in a large piloting scale, using caking coals and is available for commercial application. The co-gasification does not generate any non-salable by-products. The distillate from the co-gasification combined with the distillable portion of the bitumen recovered by the "DME-based extraction" will be amenable to pipelining without diluent.

The co-gasification of blends of coal and a bitumen distillation residue enables generation of raw syngas. China has perfected the raw syngas clean-up process.

About 15% of the DME produced for bitumen extraction would be oxy-fired in a low speed 2-stroke Diesel engine operated on ICF site to generate electricity for powering the bitumen recovery plants as well as for other processes converting the by-products of DME and bitumen production into value-added products.

The application of DME for the in-situ bitumen recovery has been patented in Canada [9]. It appears that DME has the potential to offer a simple solution for hydrogen generation, storage, transportation and utilization. The capacity of DME for bridging the fossil fuels with hydrogen economy is summarized in synopsis D.

2. Markets for Bitumen and Products of Its Processing

Application of DME-based technologies for recovery of bitumen shall convert this Province into a low-cost, sustainable and diversified energy hub.

Since 2007/8 the inadequate performance of the bitumen recovery technology has been magnified by:

- departure of major petroleum multinationals from Alberta,
- crude oils price wars,
- the precipitous drop in crude oil consumption caused by covid-19,
- blacklisting of the four largest Canadian bitumen producers by the world's largest Norwegian energy fund,
- the Canadian federal and Alberta governments' commitment to discontinue subsidies to the oil sands industry by 2025, and,
- United States Democratic Party presidential candidate announcement that the construction of the Keystone pipeline for delivery of bitumen to the States might be discontinued.

Since 2014 the performance of the Alberta oil sands industry has become of particular concern. It is clear that SAGD cannot now and will not be able in the future to compete with the low-cost high quality conventional crude oils flooding world's petroleum markets. Especially that the pressure for implementation of the hydrogen economy and the demand for electric cars is spreading. That will likely reduce the demand for petroleum-based transportation fuels.

The experts acknowledge that prognoses on crude oils markets volatility are unreliable. But the experts do agree that ultimately, over a long run, "the low-cost producers will win". DME enables the bitumen industry to become the lowest cost sustainable producer of bitumen, DME, partially upgraded bitumen, carbon-less electric power, hydrogen and other value added products and ensure the public at large that the industry will make a significant contribution to reverting the climate change.

Due to development of fracking technology the United States have become a net exporter of crude oil. Fracking is expensive, sensitive to geological conditions and any reduction in crude oil prices to less than US$50 per barrel might precipitate selective shut-down of fracking-based recovery wells, bankruptcies and a need for importing foreign petroleum instead. Political changes in the United States may well result in more attention directed to climate change issues thus limiting fracking-based crude generation. Elimination of fracking could reduce petroleum production in the United States by 30-40% and increase the demand for heavy oils either from Canada or Venezuela or both. The costs of Venezuelan bitumen recovery are lower compared to Canada's. But in addition to immense volumes of extra heavy crude available from Canada there are other factors that shall favor Alberta's bitumen for export to the United States.

The completion of TMX pipeline construction shall enable China to import Alberta's bitumen. That as well as the unending social and political unrest plaguing Venezuela, Alberta's bitumen production cost reduction and, in parallel, making bitumen recovery sustainable, will strengthen the position of Alberta bitumen producers in negotiations with the operators of the extra heavy crude refineries in the United States.

Over the next three decades the key two factors that will benefit Canadian bitumen industry will be the differential between the breakeven cost of bitumen recovery and its market price and the financial and environmental benefits flowing from application of sustainable recovery technology. By application of the "Integrated DME-based Extraction" technology the breakeven cost of bitumen recovery will become competitive to that of conventional crude oils. The benefits flowing from bitumen production will change the hostile attitude of a significant percentage of the public at large towards bitumen industry, pipelining the bitumen and products of its processing and generate the required support from environmental circles in Canada and abroad for supporting bitumen industry operations for decades to come.

There is a strong indication that Alberta's bitumen diluted with DME will be of considerable interest to China provided both countries will be successful in resolving the animosities resulting from political events that were developed over the last two years. Chinese government places a lot of emphasis on expanding their highways/freeways infrastructure. Bitumen enables production of transportation fuels, asphalt for roads construction, petrochemicals, plastics and pharmaceuticals. Furthermore, China is interested in DME production and its application as super-clean Diesel fuel as well as cooking fuel compatible with LPG. Volvo Cars, now a subsidiary of a Chinese company, have accumulated extensive experience in producing world's renowned heavy duty tracks and applying DME as environmentally acceptable Diesel fuel for trucking and bussing. The demand for DME in China cannot be fully met by utilizing the syngas generated by large scale gasification of Chinese coals. Gasification of

Chinese coals presents serious processing difficulties resulting from their poor quality including high sulfur and mineral matter contents.

China shall likely emerge as a key and a desirable market for Canadian bitumen as well as other value-added products generated by the Alberta integrated energy industry. It is in the interest of Canada to strike a right balance in evaluating American and Chinese energy markets needs and progressively increase the efforts to understand the complex energy related issues between two Pacific Rim economic giants – China and Japan - versus the remaining countries in this region.

Today's Japanese advanced conventional petroleum refining capacity is approximately 3.5 million barrels per day; reportedly about 30% of this capacity remains underutilized. In 2007-8 Japan petitioned the Alberta government to jointly demonstrate the innovative DME technology for bitumen recovery and its partial upgrading. The upgraded bitumen was to be converted in Japan into transportation fuels and some of it sold to the Pacific Rim countries lacking refining capabilities. In 2009 the Japanese proposal was - based on Alberta Innovates (AIs) evaluation of the DME technology (Doc. 1, 2 & 3) - turned down by the Alberta government.

Private sector companies from Japan and Denmark in cooperation with other foreign and Canadian companies have advanced the concept of providing large ocean-going vessels with a low-speed DME oxy-firing 2-stroke Diesel engines equipped with re-burning boiler and cryogenic system for liquid CO_2 collection. Such system enables direct production of electric power with very high thermal efficiency. Based on the concept proposed the vessels would be equipped with electric propulsion systems that would eliminate GHGs and reduce by 95% carbon micro-particulate emissions. During 2011-19 this concept was proposed by private companies, on several occasions to AIs for more in-depth technical evaluation. Tankers equipped with electric propulsion systems and employed for shipping Canadian energy products (bitumen, DME, LNG and LPG) to Pacific Rim would benefit from implementation of this concept, contribute significantly to reducing the acidification of the North Pacific and potentially offer a solution to restoring environmentally healthy pH of the ocean.

It would be desirable for Canada to explore with China and Japan the options for cooperating in the area of sustainable diversified generation of energy and their interest in the role DME can potentially play in the development of the hydrogen economy. Though both countries have publically expressed interest in hydrogen as source of energy, the issues of handling, storage and transportation of this gas produced by electrolysis remain unresolved. The rejuvenation of the bitumen industry in Alberta precipitated by application of low-cost DME for bitumen recovery may create opportunities for this Country in the next 2-3 decades to play a significant role in developing environmentally friendly and economically promising DME-based hydrogen energy economy.

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