Environmental Fossil Fuels Sciences & Technology Group

In cooperation with Envirotech Consulting Inc.

A) DME-based Bitumen Recovery and CO_2 Elimination

CO_2 Emission Sources:

1. **DME (Dimethyl Ether: CH_3OCH_3) Synthesis,**
2. **DME-Based In-Situ Bitumen Recovery**
3. **Transportation of Bitumen/DME Dilbit**

<u>Ad. 1.</u> DME Synthesis,

The GHG footprint for DME production is based on GREET and EcoInvent data.

a) <u>GREET</u>: 0.7411 kg CO_2e/kg DME synthetized (equivalent to 0.078 tonnes-CO_2/bb DME synthesized)

b) <u>EcoInvent</u>: 1.403 kg CO_2e/kg DME synthesized (equivalent to 0.148 tonnes-CO_2/bb DME synthesized).

DME is produced by either direct or indirect synthesis from syngas. The main by-products emitted are CO_2 and H_2O. Indirect DME synthesis generates H_2O as the main by-product. During direct DME synthesis, CO_2 - the main by-product - is either removed, utilized or recycled into the process or emitted. The direct DME synthesis generates relatively pure CO_2 ($3CO + 3H_2 \rightarrow CH_3OCH_3 + CO_2$).

Northern Alberta is well endowed with geothermal heat resources. Application of CO_2 for carbon-free electric power generation by injecting CO_2 for recovery of geothermal heat is being tested. Some of the injected CO_2 is captured by the earth and stored (CCS). CCS development has reached the commercialization stage. There are other promising options for CO_2 utilization including tri-reforming followed by synthesis of DME from generated syngas. Catalytic photosynthesis or hydrogenation of CO_2 are the most promising options for utilization of CO_2 for DME production (see synopsis B").

<u>Ad. 2.</u> DME-Based In-Situ Bitumen Recovery

The CO_2 footprint associated with bitumen recovery by a "DME-based extraction" technology originates from consumption of electric energy for liquids pumping and heating the reservoir to increase the temperature from around 10^0 to $50\text{-}70^0$C. The estimates indicate that bitumen recovery by the "DME-based extraction" is expected to produce 0.021 tonnes-CO_2 per barrel bitumen while SAGD produces 0.132 tonnes-CO_2 per barrel bitumen (see synopsis B and synopsis C: Tables 1 & 2). "DME-based extraction" technology for bitumen recovery reduces CO_2 emissions by around 84%, as compared to SAGD (Table 2). The remaining 16% is nearly pure CO_2 collected at the Integrated Central Facility (ICF); see next paragraph. The CO_2 produced by SAGD's natural gas fired boiler contains around 80% nitrogen and is emitted to atmosphere.

DME-oxy-fired co-generation is most effective for electric power production. In addition, it produces steam and quantitatively collects 97-98% pure CO_2. Such CO_2 can be utilized for a variety of applications including production of electricity via geothermal heat recovery, EOR and on-site urea synthesis using the NH_3 produced by the gasification system; the last two applications are commercially proven.

The co-gasification of blends composed of surface mined coal and the residue from bitumen distillation produces two main products namely, distillable partially upgraded bitumen and raw syngas that after clean-up is synthesized into DME. By feeding the municipal waste water to a co-gasification reactor the production of hydrogen can be increased above the level required to generate syngas (H_2/CO 1:1 molecular ratio) that is required to synthesize the DME via the direct low-cost technology. In addition to producing an environmentally ideal fuel (H_2) the cost of treating the municipal waste water is eliminated.

The "DME-based extraction" plant eliminates combustion of natural gas, potable water consumption, steam generation, process water treatment and it does not generate CO_2. The ICF supplies the "DME-based extraction" plants with electric power and DME.

Separating the DME from produced bitumen/DME dilbit followed by recycling the DME for bitumen extraction will reduce the CO_2 footprint (from DME synthesis & bitumen recovery) by approximately 10 times. That means that instead of the ICF producing about 16% CO_2 (100%-84%=16%) for utilization/recycling, it would generate around 1.6% CO_2 only (16%/10=1.6%) of that emitted by SAGD plant.

The "DME-based extraction" plants produce bitumen containing around 15-17wt% DME. The loss of DME during bitumen recovery was assumed to be about 10 wt% (Shell report nearly full recovery). A barrel of dilbit contains, at 25^{O}C and 0.45MPa pressure, approximately 35.8 L liquid DME and 123.2 L bitumen (volume contraction resulting from dissolving the DME in bitumen is disregarded).

One DME commercial size synthesis reactor (1,000 metric tonnes DME/day) located at the ICF can supply a sufficient amount of DME for the "DME-based extraction" plants to produce the bitumen in a DME recycle mode at the rate of around 420,000 bb bitumen/DME dilbit per day. Such volume of dilbit shall generate approximately 0.0021 tonnes CO_2 instead of 0.021 tonnes CO_2/bb bitumen/DME dilbit. The 420,000 bb of bitumen/DME dilbit would generate approximately 880 tonnes CO_2 instead of 55,400 tonnes CO_2 diluted with nitrogen and emitted to the atmosphere by equivalent SAGD plants every day. The 880 tonnes CO_2 generated and collected by the ICF will be recycled and utilized and not emitted to the atmosphere.

An alternative to DME recycling is transporting (pipelining followed by shipping) the bitumen/DME dilbit, directly from the recovery site to the overseas customer. If dilbit's shipping in commercially available tankers equipped with a system for vapors condensing and recycling is feasible, dilbit's handling and transportation cost could be reduced by approximately C$ 20 per barrel (GLJ Petroleum Consultants) as compared to present practice associated with condensate usage.

If CO_2 generated due to producing additional DME required for bitumen/DME dilbit transportation can be effectively utilized at the ICF site via conversion into DME or other value-added products (synopsis B, chapter 1.4) and an overseas customer is interested in both the bitumen and the DME (e. g. China), the producer would be paid for both the bitumen and the DME. The bitumen producer would avoid all costs related to DME recovery from dilbit, condensate purchase, purchasing and blending the condensate with the bitumen, pipelining and shipping the bitumen occupying 70% of the volume of pipeline or shipping containers, recovering the condensate from the bitumen at the final destination and recycling the condensate to the producer.

Partially upgraded bitumen does not require diluent for transportation. Pipelining the distillable portion of the bitumen blended with the partially upgraded and distillable product, generated by co-gasification, to the East Coast would ameliorate the Quebec government's concerns regarding dilbit spills remediation and enable the European conventional refineries to process Canadian crude. Eastern Canadian refineries could convert this crude into transportation fuels and petrochemicals and discontinue importation of expensive crude oils from unreliable, distant sources.

<u>Ad. 3.</u> Transportation of Bitumen/DME Dilbit

Transportation of crude oil and derived petroleum products by on-shore pipeline and shipping in conventional tankers are the least expensive transportation means. In terms of GHG emissions the data acquired indicate that both of these transportation means have approximately the same footprint:

- on-shore pipeline (24 in.) - 16 g CO_2/ton – km, (equivalent to 0.0000026 tonnes CO_2/bb
- sea water shipping - 22 g CO_2/ton – km, (equivalent to 0.0000035 tonnes CO_2/bb - km).

Conclusions:

- The GREET's CO_2 footprint for DME production is 0.078 tonnes CO_2/bb DME. The simplest way to reduce $C0_2$ footprint is to recover and recycle the DME from the bitumen/DME dilbit. That will reduce both the need for DME and the CO_2 emissions by approximately 10 times. The generated nearly pure CO_2 can be utilized for a variety of applications. Conversion of CO_2 to DME, by catalytic photosynthesis and dehydration of methanol, will eliminate emissions and reduce DME synthesis and bitumen recovery costs.
- The CO_2 footprint for "DME-based extraction" of bitumen in a recycle mode is 0.0021 tonnes CO_2/bb of dilbit. This footprint is approximately 63 times lower as compared to SAGD. Catalytic photosynthesis or hydrogenation of CO_2 followed by dehydration of methanol to DME will eliminate emissions and further reduce DME and bitumen production costs.
- The CO_2 footprints for bitumen/DME dilbit pipelining (Edmonton – Burnaby, BC) and tanker shipping (Burnaby –Tokyo) are 0.003 tonnes and 0.026 tonnes CO_2/bb dilbit, respectively. Elimination of CO_2 emissions and 95% reduction of carbon micro-particulates emissions is possible by replacing in large ocean going vessels the existing propulsion systems with electric propulsion based on oxy-combusting the DME in a low-speed 2-stroke Diesel engine, generating an electric power (48-52 thermal efficiency) and collecting liquid CO_2 for conversion to value-added product(s).