The Future of Gas Hydrates as a Fuel

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Another version of this talk was presented as the 2014 CSPG University Outreach Lecture
Edward “Ted” Irving B.A., Sc.D.
May 27, 1927 - February 25, 2014

Mentor, Colleague and Friend: Geologist and Paleomagnetist.

The first to publish a convincing scientific argument for the relative and absolute displacements of the continents.


*PDF’s of these two papers will be with this Presentation on the CSPG website.*
1. Who is CMC Research Institutes Inc. (aka - Carbon Management Canada)? What is the Containment and Monitoring Institute? Why we are looking at Gas Hydrates as a source or storage and fuel and why should you care?


3. Global and Canadian GH Resources.

4. Mallik Gas Hydrate Drilling Programs and Results.

5. Future GH Fuel opportunities globally and in Canada.
Unlocking the Resource Pyramid:
If technology is the answer, what is the pathway to success?

Roger’s (1962, "Diffusion of Innovations") innovation characteristics that influence adoption:
• **Relative Advantage**: How improved an innovation is over the previous generation.
• **Compatibility**: Compatibility of an innovation for assimilation.
• **Simplicity**: Complexity and difficulty work against adoption.
• **Trialability**: Facile employment facilitates adoption.
• **Observability**: The extent that an innovation is visible to others creates reactions.

1. **SAGD**, A paradigm shift. Driven by **Relative Advantage** and **Resource Opportunity**. Conceived industrially, but abandoned until major public investment (AOSTRA) overcame **Complexity** and **Trialability** issues as global prices improved.
2. **MHSHWs**, Incremental improvements and hybridization. Driven by **Relative Advantage** and “**Price-Distortion**” in continental natural gas markets. “Shale Gas” technologies were first tried in oil plays (especially the Bakken) but were widely adopted for natural gas.
3. **Gas Hydrates**, Currently incremental with paradigm shift opportunities. Driven by **Relative Advantage** and **Strategic Energy Security** issues. Conceived and initiated in Canada, but momentum is passing to Asian companies. **Trialability and Visibility** (hostile operating environments and lack of transportation) are the major issues.
4. **Tertiary Recovery/Secure Carbon Storage**, Incremental with potential to double the WCSB conventional reserves lifetime, bedeviled by **Compatibility and Complexity** issues related to CO₂ capture, supply and transportation. Do regulators have a resource conservation responsibility?
Carbon Management Canada (1.0)
NSERC/Network of Centres of Excellence
44 research projects
155 researchers at 27 universities

Basic Scientific, Engineering and Social Science research to prepare Canadian Industry for future, sustainable carbon management.
CMC Research Institutes Inc. (2.0)
A not-for-profit Canadian Corp. translating and implementing Carbon Management into Competitive and Sustainable Business Practice.

"WE’RE ALL IN THIS TOGETHER"
Containment and Monitoring Institute (CaMI): Field Research Station

- FRS is a globally unique facility.
- Containment is critical for many subsurface applications including:
  - Secure Carbon Storage;
  - SAGD steam chambers;
  - induced hydraulic fracturing;
  - induced seismicity;
  - water and acid gas disposal;
  - enhanced petroleum recovery;
  - groundwater protection; etc.
- There is a need to better characterize containment risks.
- Learnings for many industries, as well as regulators and policymakers.
- Computational models need better earth images/models.

Fluid expulsion accident initiated from a nearby well, Innisfail AB

Web image from: “Fracking Canada”
FRS will provide industry, inventors and academics with a well characterized subsurface and surface technology test site, laboratory and classroom.

Dr. Don Lawton, Institute Director, 403 210 6671, don.lawton@cmcghg.com

CMC Website: http://cmcghg.com
• GH is an ice-like solid (clathrate) composed of gas (guest) molecules in a cage of water (host) molecules that forms at low temperature and moderate pressure.

• Like ice, GHs require energy input to dissociate, which also is the source of “self-preserving” characteristics.

• CH$_4$ and CO$_2$ are the common, but not the only guest molecules.

• 1 m$^3$ of GH $\rightarrow$ 164 m$^3$ of methane gas, equivalent to a dry gas reservoir at 16 Mpa, or a gas pool at 1.6 km depth.

• Gas hydrate has an energy content comparable to bitumen and tar sands. Energy content in SCF/ft$^3$ of rock:
  - Gas Hydrate: 40 – 50
  - Coal Bed Methane: 8 – 10
  - Tight/Shale gas: 5 – 10
Modes of Gas Hydrate Occurrence

**Terrestrial Sub-Permafrost Accumulations**

- Common in Arctic regions and identified by drilling.
- Commonly part of a thermogenic petroleum system.
- Thickest, richest, most accessible, potentially associated or co-located with conventional natural gas in porous and permeable reservoirs.
- Preferred North American production target.

**Sub-sea Marine Accumulations**

- Common to continental shelves and slopes and detected using Bottom-Simulating-Reflections (BSR’s).
- Commonly part of a biogenic petroleum system.
- Typically hosted in silt and shale dominated lithofacies.
- Asian production target.

**Seafloor Accumulations**

- Discrete rich seafloor outcrop accumulations.
- Not well characterized.
- Not persistent due to concentration effects.
- Possible Korean alternate production target.
GH Stability Conditions

ARCTIC PERMAFROST

Metres

0

200

400

600

800

1000

1200

1400

1600

-20

-10

0

10

20

30

Temperature °C

BASE OF GAS HYDRATE

PHASE BOUNDARY

GEOTHERMAL GRADIENT

DEPTH OF PERMAFROST

SEDIMENT

METHANE HYDRATE

OFFSHORE CONTINENTAL MARGIN

Metres

0

200

400

600

800

1000

1200

1400

1600

-20

-10

0

10

20

30

Temperature °C

ZONE OF GAS HYDRATE

WATER

SEDIMENT

BASE OF GAS HYDRATE

GEOTHERMAL GRADIENT

METHANE HYDRATE
GH Research Themes:
How can you not love a geology topic that combines, ice cream, domestic heating and the 4 horsemen of the apocalypse?

- Flow-assurance issues for pipeline transportation.
- A potential seafloor and permafrost hazard.
- A potentially commercial or strategic petroleum resource with low emissions intensity.
- Secure Carbon Storage of natural or anthropogenic GHG’s (CH₄ and CO₂).
- A potential environmental change agent (e.g. the clathrate gun hypothesis).
- A natural gas transportation mechanism that is potentially cheaper than LNG (~21 shipping days).
- A new purification technology for CO₂ utilization (e.g. potable water from saline water).
- A model for “inclusion-based” materials science and technologies, more than just carbonated ice cream.
The Calthrate Gun: GHs & Apocalyptic Climate and Geological Changes

• Surface temperature forcing and conversion of a conventional gas pool to GH explains current observed GH and permafrost at the Mallik site (Case 1) and the observed gap between base IBP and top GH.

• In a GH trap permafrost grows downward through GH and the two are intermingled, but this is not observed and it does not predict the observed base of either IBP or GH (Case 2).

• The GH and IBP layers respond to surface temperature forcing. Permafrost buffers GH dissociation. The “clathrate gun” and the role of GH in climate cycles is complicated and delayed by enthalpies of melting and dissociation.

From (Majorowicz, Osadetz and Safanda, 2012)
Secure Carbon Storage In Porous Geological Media: 61-75 Gt WCSB
~10% as CO₂ GH in Alberta most near Oil Sands Operations

Unmineable coalbeds
~0.8 Gt

Depleted oil & gas reservoirs
~17-19 Gt

Deep saline Formations
~37-49 Gt

Storage as a CO₂ Hydrate;
~6 Gt AB

Enhanced oil recovery;
e.g. Weyburn,
Increased reserves with reduced emissions and footprint

Storage Volumes and CO₂ GH stability from from the 3rd ed. N.A. CCS Atlas and Cote and Wright, 2006
Why consider Gas Hydrate Fuel?

- Low Natural Gas prices are regional not global and Asian economies face supply security issues, e.g. Prior to Fukushima, Japan produced 3% of its petroleum domestically.

- Marine gas hydrates impact national boundaries and territorial disputes. How does dependence on Russian gas affect European diplomacy and security?

- Some countries and corporations consider longer timelines where technological “game-changers” are possible (e.g. SAGD; HD+IHF).

- Japan’s “commercial” gas hydrate production accelerated Asian (China, S. Korea/Statoil, India) R&D programs. GHs provide a “technology transfer” business opportunity model.

- Where will long-term supply for BC LNG come from?

- GH offer a unique combined cycle Arctic petroleum production + secure carbon storage opportunity.

GANS Project Areas, 2006-2010; Norwegian Continental Margin, Barents Sea, Western Svalbard Margin (Statoil Website).
1. Possibly the largest global carbon reservoir (~50% by weight), most GH resources are marine and inferred from geophysical data (Bottom Simulating Reflectors). Sub-permafrost GHs are less well constrained.

2. The resource is unevenly distributed and inferred resource volume distributions become smaller and more skewed as characterization improves.

3. Marine resources remain enormous: ~1- 5 X10^{15} m^3. (Milkov, 2004; ESR), compared to ~10.2 - 8.8 X 10^{12} m^3 (Osadetz and Chen, 2010, BCPG) for the Beaufort Mackenzie sub-permafrost resource.

4. Specific knowledge of large accumulations in good reservoirs is more important than global resource estimates.
Total in-situ amount of methane in gas hydrates is estimated to be 1,553 to 28,593 TCF (0.44 to 8.1 x 10^{14} m^3), compared to a conventional gas potential of ~953 TCF (0.27 x 10^{14} m^3).
Gas Hydrate S&T

GH Production Strategies

- Adaptation of available methods rather than entirely new technologies.

- General consensus to destabilize GH in situ and produce natural gas, although some still propose mining sea floor accumulations.

- Pressure reduction and dissociation using ambient heat transfer is the easiest and cheapest. Only borehole pressure drops have been employed, but gas or water production are potential enhancements.

- Thermal, hot water, or Chemical “freezing point-depression” stimulation could work, and may enlarge the area of pressure reduction effects.

- Guest gas displacement, CO2 will displace CH4 from the lattice.
Carbon Neutral GH Power Generation?

- The Ikhil conventional pool that supplies Inuvik is declining. GHs in Mackenzie Delta and Lancaster Sound could fuel northern military bases, communities and mines.

- GH formation that excludes heavier hydrocarbons producing “gas drying” effect during clathration.

- Nearly pure methane is a feedstock for $\text{H}_2$ generation to make fuel cell reactant for power and heat generation.

- High temperature fuel cells like Solid Oxide or Molten Carbonate also produce much heat, a potentially useful commodity in the Arctic.

- Effluent $\text{CO}_2$ is captured and injected into the GH reservoir to enhanced gas production.

Proof concept Torino SOFC schematic
Beaufort-Mackenzie Basin GH Occurrences and Characteristics
(Osadetz and Chen, BCPG, 2010)

- GH occurs rarely within the Ice Bonded Permafrost (except at Taglu).

- There is commonly a gap between the base IBP and top GH.

- Rich GH usually occurs below a geological ‘seal’.

- GH occurrences are strongly associated with tectonic and conventional thermogenic petroleum system features.

The BMB GH resource occurs predominantly in a few wells (i.e. it is unevenly distributed like the conventional resource).
Why work at Mallik?

1. Reduced Costs: A reasonably accessible onshore location compared to deep water Norwegian and Asian offshore occurrences.

2. Reduced Risk: 37 years of baseline engineering, geological and geophysical data and reduced project risks.

3. High Quality Occurrence: Mallik GH occurrences are thick >150 m and highly concentrated gross hydrate thickness pore space hydrate concentrations 50-85%.

4. Good Analogue: Reservoir environmental conditions are similar to those of offshore Norwegian and Asian GH occurrences.

5. Good Landowner/License holder Relationships: Positive history with NEB and OGD’s and the SDL holder (Imperial Oil).
The goal at Mallik has not been production rate, but rather to characterize the GH reservoir and its production response to provide high quality data for reservoir simulation, validation and history match.

1972 – IOL L-38 DST pressure reduction test of GH dissociation.

1980s-90s – GSC Permafrost coring studies.

1998 - 1st Canada-Japan Mallik drilling program cored + logged the GH interval.

2002 - Canadian-led, 5-nation partnership conducts “state of the art” gas hydrate science program and production tests.

2007-08 – Canada-Japan R&D study with successful 6 day proof of concept depressurization test in March 2007.
2007-08 re-entered and recompleted Mallik 2L-38 (test) & 3L-38 (disposal)
Mallik GHs occupy conventional pore space

Base of GHSZ

Core

-9  -8  -7  -6  -5  -4  -3  -2  -1  0  +1  +2  +3  +4  +5

nm  µm  mm  m  km

10^x meter
Field Scale Impedance Inversion

Bellefleur et al., 2005

Mallik Reservoir

Field scale
Initial Reservoir Models: Evaluating the role of a free gas “leg”

**Case 1:**
- 50 m gas hydrate, over 10 m free gas.
- Gas hydrate: 1.07 TCF of GIP (5 sq mi).
- Free gas: GIP = ~ 232 BCF (5 sq mi).

**Case 2:**
- 50 m gas hydrate, over water.
- Gas hydrate: 1.07 TCF of GIP (5 sq mi).

**Cases 1 and 2:** *Mallik-like reservoir using pressure depletion only in adapted “CMG Stars” model.*

(Hancock, Okazawa and Osadetz, 2005 CSUG Meeting)
Simulations consider high and low relative permeability models for gas associated with gas hydrate (red) and gas hydrate alone (blue)

(Hancock, Okazawa and Osadetz, 2005 CSUG Meeting)
Case 1 gas associated with gas hydrate (red) behaves like a standard petroleum prospect; while Case 2 and gas hydrate alone (blue) behaves like a utility.

GH reservoir performance depends strongly on the presence or absence of underlying free gas.

GH gas should be commercial at prices comparable to that required for co-located conventional gas developments.

GH could augment frontier gas supplies, and reduce environmental (footprint) impacts of Arctic Gas developments.

The results remain valid, generally, but are augmented by new data and models from the 2007-08 experiments.

(Hancock, Okazawa and Osadetz, 2005 CSUG Meeting)
2008 Test Mallik 2L-38
Production interval 1093–1105m

- Continued pressure reduction testing employed improved methods to control sand and fines production.
- Identified that efforts to suspend the well had induced GH dissociation.
- 3 stage pump down to 4.5 Mpa resulting in sustained production for 6 days.
- Surface metering of produced gas and estimation of total produced gas (formation storage).
Stage 1: Unstable flow with fluctuation flow rate during the test. Dominated by near well bore effects. Low water production.

Stage 2: Steady but increasing flow rates interpreted as stable in situ gas hydrate dissociation. Low water production.

Stage 3: Step change in flow rate attending increased pressure reduction. Steady and increasing gas rates interpreted as stable in situ gas hydrate dissociation. Low water production.

- Total gas and water produced was about 13000 m$^3$ and 70 m$^3$, respectively.

- Production rates were between 1500-2500 m$^3$/day gas and 5-15 m$^3$/day water.

- Gas production rate continued to rise toward the end of the test.
“Successful” history matches were obtained by both Japanese and Canadian modellers using very different assumptions.

Japanese (Kurihara) models included formation and collapse of “wormholes” and adjustments to model permeability structure, some depending on borehole pressure dynamics.

Canadian (Uddin) models employed a pressure dependent gas evolution model similar to gas formation from heavy oil production to obtain a match.

Projected rates and volumes are encouraging, while differences in reservoir models need to be resolved – indicating the need for a protracted (~12 month) test.
Current and Future Global Opportunities

1. JOMEC and the Japanese program will continue with a focus on domestic marine resources, but with an interest to participate in another terrestrial long-term production test.

2. China is determined to become a leader in GH S&T.

3. Statoil is keenly interested to begin a program, perhaps onshore in Canada.

4. US Government Agencies and CONOCO/Phillips appear interested in Alaska, but BP operational issues are an impediment.

5. India-USGS are moving toward an offshore test (~$80 Million) with JOIDES Resolution soon.

6. Korea with Statoil have strong interest to conduct a domestic offshore test soon.

7. A number of other countries, especially Germany, have a scientific interest and are looking for opportunities to participate under the leadership of others.

8. There is a climate friendly, commercial, collaborative technology transfer opportunity for Canadian Industry that can maintain our S&T leadership.
Site(s) of future test(s)

Return to Mallik (onshore).
- Minimized geological and engineering risks.
- Imperial/Exxon must be a partner (access).
- Well understood cost structure (~$50-80 Million).
- Apparent lack of a free gas column to test a gas production depressurization method.

Arctic Islands Prospect (onshore).
- Higher geological and engineering risks.
- No legacy partners or back-ins.
- Inferred free gas column to test a gas production methods.
- Higher costs and contingencies (~80-100 Million?).

Participation in another project (Asian offshore/Alaska).
- Asian offshore settings are not suited to long tests and are more expensive.
- Competition with corporate goals makes operations in Alaska difficult.
Sverdrup Basin (Arctic Archipelago): GH occurrences

1. Well logs suggest that hydrates occur within at least 57 and possible 93 of 150 wells.

2. The GHSZ is discontinuous, extending up to 2 km underneath the Islands and 1 km below sea level in deep inter-island channels.

3. GHSZ occurs in many formations including both well indurated sandstones.

4. Top of GHs occur commonly 300 to 700 m above the base of the GHSZ.

5. Gas hydrate/free gas contacts are inferred in 14 wells.

6. 23 inferred hydrate occurrences overlie conventional pools and other occurrences are on ‘dry’ structures, some exhibiting oil staining, where the top seal is inferred to have failed.
Ellef Ringnes Is. Gas Hydrate/Free Gas Prospect

1. Level of the base of ice-bonded permafrost (blue) as interpreted at top of porous Hassel Formation (orange). Note: very fine-grained overlying Kanguk Formation shows no evidence of the lateral continuation of ice-bonded permafrost.

2. Level of the base of gas hydrate in an intra-Hassel Formation sandstone (yellow) interpreted at amplitude decrease caused by water replacing gas hydrate downdip.

3. Level of gas/water contact in sandstone near base of Hassel Formation. Interpreted at amplitude decrease and polarity reversal from water replacing free gas downdip. Note: very-fine grained Christopher Formation underlies Hassel Formation.

4. Level of base free gas/gas-hydrate within a lower Hassel Formation sandstone. Interpreted as polarity reversal of reflector caused by shale on gas sand (negative) changing to shale on gas hydrate sand (positive).
• Seismic attributes of the Svedrup Basin onshore prospect are consistent with the inferred depth of GH stability.

• The hosting formation is well indurated and sand production problems should be minimized.

• The site is “greenfields” and there would be no “back-in” from an SDL lease-holder.

• Additional costs related to seismic characterization and infrastructure would be incurred.

• Initial staging to Ellef Ringnes Island could be done by reliable sea lift.

• Activities occur in Nunavut. Consultation will be required, but the area has less landuse competition and there could be leverage or public support for economic development.
Conclusions

1. The GH resource is a very large, potentially commercial resource, but it is diverse and unevenly distributed.

2. GH research proceeds internationally, especially with Asian and Norwegian interest.

3. Currently onshore sub-permafrost GH accumulations, like we have in Canada, represent the most efficient S&T development and demonstration opportunities.

4. The Mallik projects successfully demonstrates “proof of concept” for the depressurization production, especially if there is an associated free gas “leg”. A return to Mallik represents the “easiest” opportunity to advance GH production technology, but a new prospect on Sverdrup Basin represents an alternative opportunity to advance commercial production, including production with a free gas “leg”.

5. A collaborative consortium approach presents a pre-competitive business opportunity for technological leadership with reduced risks and costs.

6. CMC Research Institutes Inc. is potential altruistic partner available to facilitate Canadian opportunities for Industrial Carbon Management, Subsurface Containment and Conformance and GH formation and production testing.