Vulnerability and Opportunity of Methane Hydrates

14-15 March 2008
IIASA, Laxenburg, Austria

Workshop Participants

- Yuichi Abe (Japan Nus CO Ltd., Japan)
- Harald Andruleit (BGR, Germany)
- David Archer (University of Chicago, USA)
- John Bohannon (Science Magazine)
- Josep Canadell (GCP and CSIRO, Australia)
- Arnulf Grübler (IIASA, Austria and Yale University, USA)
- Neil Hamilton (WWF, Norway)
- Arthur Johnson (Hydrate Energy International, USA)
- Veselin Kostov (Rockefeller University, USA)
- Volker Krey (IIASA, Austria)
- Jean-Francois Lamarque (NCAR, USA)
- Nicholas Langhorne (US Office of Naval Research, UK)
- Gregg Marland (ORNL, USA)
- Nebojsa Nakicenovic (IIASA and TU Vienna, Austria)
- Euan Nisbet (University of London, UK)
- Brian O'Neill (IIASA, Austria and NCAR, USA)
- Walter Oechel (San Diego State University, USA)
- Keywan Riahi (IIASA and TU Graz, Austria)
- Michael Riedel (McGill University, Canada)
- Manfred Strubegger (IIASA, Austria)
- Weihua Wang (CAS, China)
- Vladimir Yakushev (VNIIGAZ/GAZPROM, Russia)
- Pacelli Zitha (Shell and Delft University of Technology, NL)

Workshop Agenda

- **Session 1:** Methane Hydrates Occurrences
  (Co-*Chairs: Nicholas Langhorne and Arthur Johnson)*
- **Session 2a:** Hydrates and Linkage to Carbon Cycle and Climate Change
  (Co-Chairs: Pep Canadell and David Archer)
- **Session 2b:** Methane Fluxes, the Carbon Cycle and Climate Change
  (Co-Chairs: Volker Krey and Walter Oechel)
- **Session 3:** Possible Implications for Energy Systems and Climate Mitigation
  (Co-Chairs: Nebojsa Nakicenovic and Pacelli Zitha)
- **Session 4:** Concluding Session
  Summaries by session chairs, General discussion of knowledge gaps, future research challenges and priorities

IIASA-GCP HYDRATES Workshop (2008)

“the question now is not whether industry will exploit hydrates but how soon.”

“200 billion industry in two decades (?)”

"More meetings like these are clearly needed."

Science [319(5871):1753](#)

ENERGY

Weighing the Climate Risks Of an Untapped Fossil Fuel

As the energy industry hungrily eyes methane hydrates, scientists ponder the fuel's impact on climate

VIENNA, AUSTRIA—A recent workshop* on methane hydrates felt like a powwow of 19th century California gold prospectors, looking ahead to both riches and peril. Sizing up the prize, Arthur Johnson, a veteran geologist of the oil industry who is now an energy consultant based in Kenner, Louisiana, predicted that "within a decade or two, hydrates will grow to 10% to 15% of natural gas production," becoming a more than $200 billion industry. And the peril? "The worst-case scenario is that global warming triggers a decade-long release of hundreds of gigatons of methane, the equivalent of 10 times the current amount of greenhouse gas in the atmosphere," said David Archer, a climate modeler at the University of Chicago in Illinois. Although no current model predicts such an event, said Archer, "we'd be talking about mass extinction."

When methane molecules become locked in atomic cages of water called clathrates, they form icy chunks that ignite when lit. These solids form wherever methane encounters water at high pressure and low temperature. The necessary conditions reign in permafrost and in some sea-floor sediments, forming a "ring around the bathtub" on continental slopes. This exotic fuel was discovered by the Soviet petroleum industry more than 3 decades ago, but even a few years ago many doubted its commercial potential (*Science*, 13 February 2004, p. 946). After several successful pilot drilling studies and heavy research investment over the past 4 years, says Johnson, "the question now is not whether industry will exploit hydrates but how soon."

Considering the skyrocketing price of oil, the answer seems to be soon, says one of the workshop organizers, Nebojša Nakićenović, an energy economist here at the International Institute for Applied Systems Analysis (IIASA) outside Vienna. "And yet hydrates are absent from most of the climate discussions," he says, "and virtually absent from the IPCC fourth assessment report," last year's 1000-page tome by the Intergovernmental Panel on Climate Change (*Science*, 11 May 2007, p. 812). The goal of the IIASA workshop was to bring together researchers from all the different fields that touch hydrates—from chemistry and economics to climate impact—to get an "interdisciplinary perspective" on the uncertainties.

"It's clear that one of our biggest knowledge gaps is figuring out the distribution," says Michael Riedel, a marine geophysicist at McGill University in Montreal, Canada. "We still don't know how much there is in the world, not even within an order of magnitude."

Another crucial gap is the flux of methane, which drives hydrate formation over time. The largest amounts of methane hydrates are thought to reside in sub–sea-floor sediments. In a newly built sea-floor–monitoring network called NEPTUNE off the western coast of Canada, Riedel is part of a team studying methane-spewing vents to get a handle on their flow rate and marine chemistry. Where the conditions are just right, methane hydrates form caps over pockets of such gas. These not only are sweet spots for those who want to tap hydrates for energy but also represent a major worry for climate modelers.

"If the sea floor warms up by a few degrees Celsius, the most vulnerable hydrates will melt, and then you're going to get a massive release of methane," says Euan Nisbet, a marine geologist at Royal Holloway, University of London. That warming and release is expected to take centuries or even millennia even in the most extreme climate scenarios. Riedel says the methane bubbles from sea-floor vents are sponged up by the ocean water. But if a methane release were large and shallow enough, it would reach the atmosphere, says Archer. What is unclear is whether the climate system has methane-driven positive feedback mechanisms that could lead to abrupt climate change.

Johnson threw cold water on the scenario of a massive release of submarine hydrate-trapped methane to the atmosphere. Most hydrate deposits found so far "are as deep as a kilometer below the sea floor," he says, "and they aren't going anywhere." Walter Oechel, an ecologist and carbon-cycle expert at San Diego State University in California, doesn't find the "doom-and-gloom scenarios" very likely either. "The real story for me is hydrates as yet another chronic contributor to greenhouse gas emissions," he says.

Others considered methane hydrates part of a greenhouse gas solution. A plan proposed by Vladimir Yakushev, a geologist at Gazprom, the world's largest natural gas corporation, based in Moscow, involves simultaneously extracting methane and methane hydrates while pumping liquefied carbon dioxide into the underground spaces left behind. Researchers also discussed the idea of using hydrates for electricity generation or even manufacturing on the spot. "We have to try to make it carbon-neutral if we're serious about climate change," says Nisbet.

The overarching question of whether methane hydrates should play a major role in climate change debate was up for grabs. Considering the workshop discussions, "the methane hydrate issue is one risk that shouldn't drive policy considerations at the moment," concludes Brian O'Neill, an IPCC author and climate modeler at the National Center for Atmospheric Research in Boulder, Colorado. "There are bigger fish to fry." But Neil Hamilton, director of the International Arctic Programme for the World Wildlife Fund, based in Oslo, Norway, says, "It's absolutely shocking that hydrates have gotten so little attention." The risk of a massive methane release, however unlikely, "is reason enough for very serious concern," he says. More meetings like these are clearly needed.

–JOHN BOHANNON

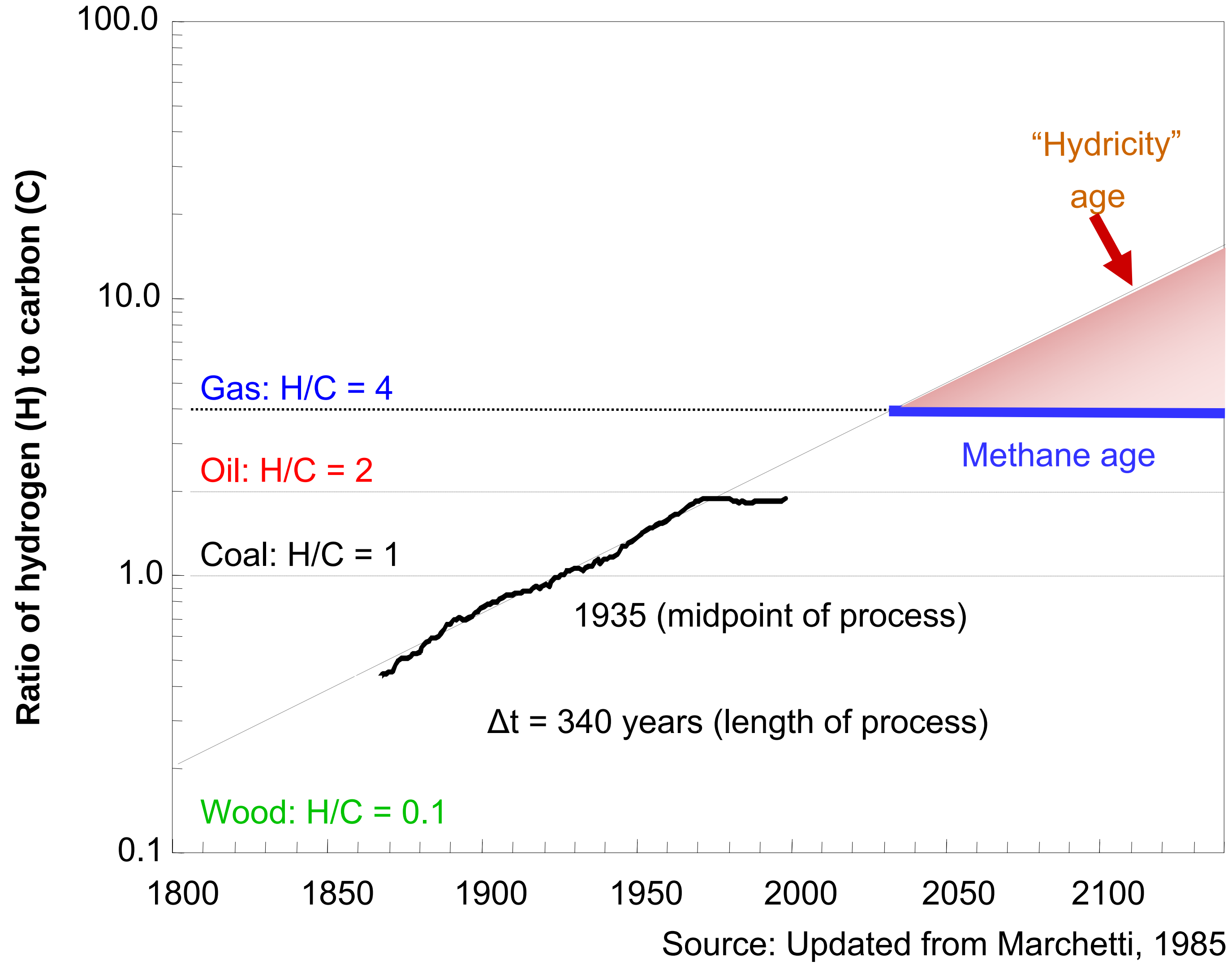
Great balls of fire! When methane meets water under high pressure and low temperature, it forms icy chunks that burn when lit.

CREDIT: KAZUHIRO NOGI/AFP/GETTY IMAGES

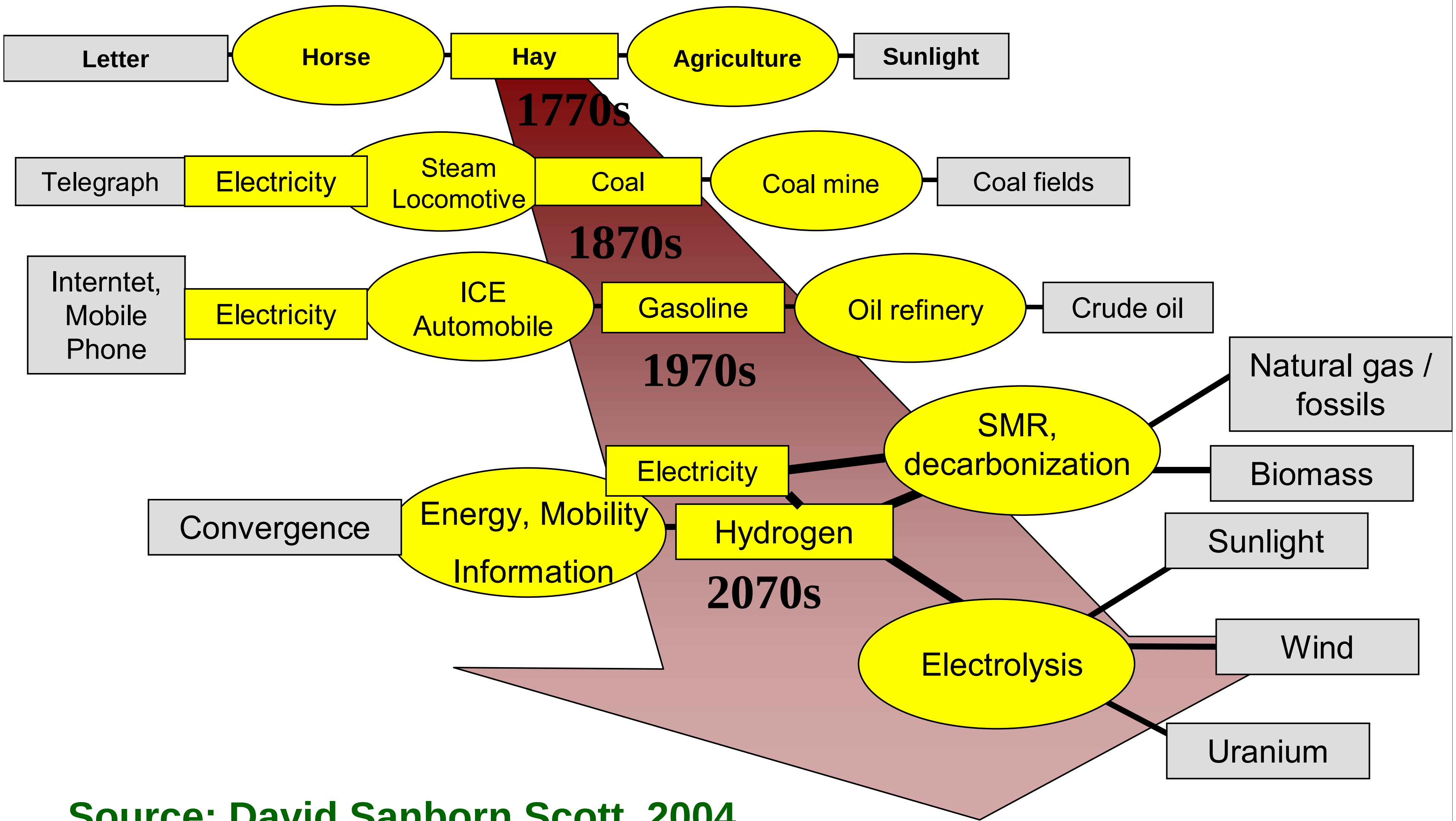
* "Vulnerability and Opportunity of Methane Hydrates Workshop," IIASA, 13–14 March 2008.

Published by AAAS

Hydrogen to Carbon Ratio of Primary Energy

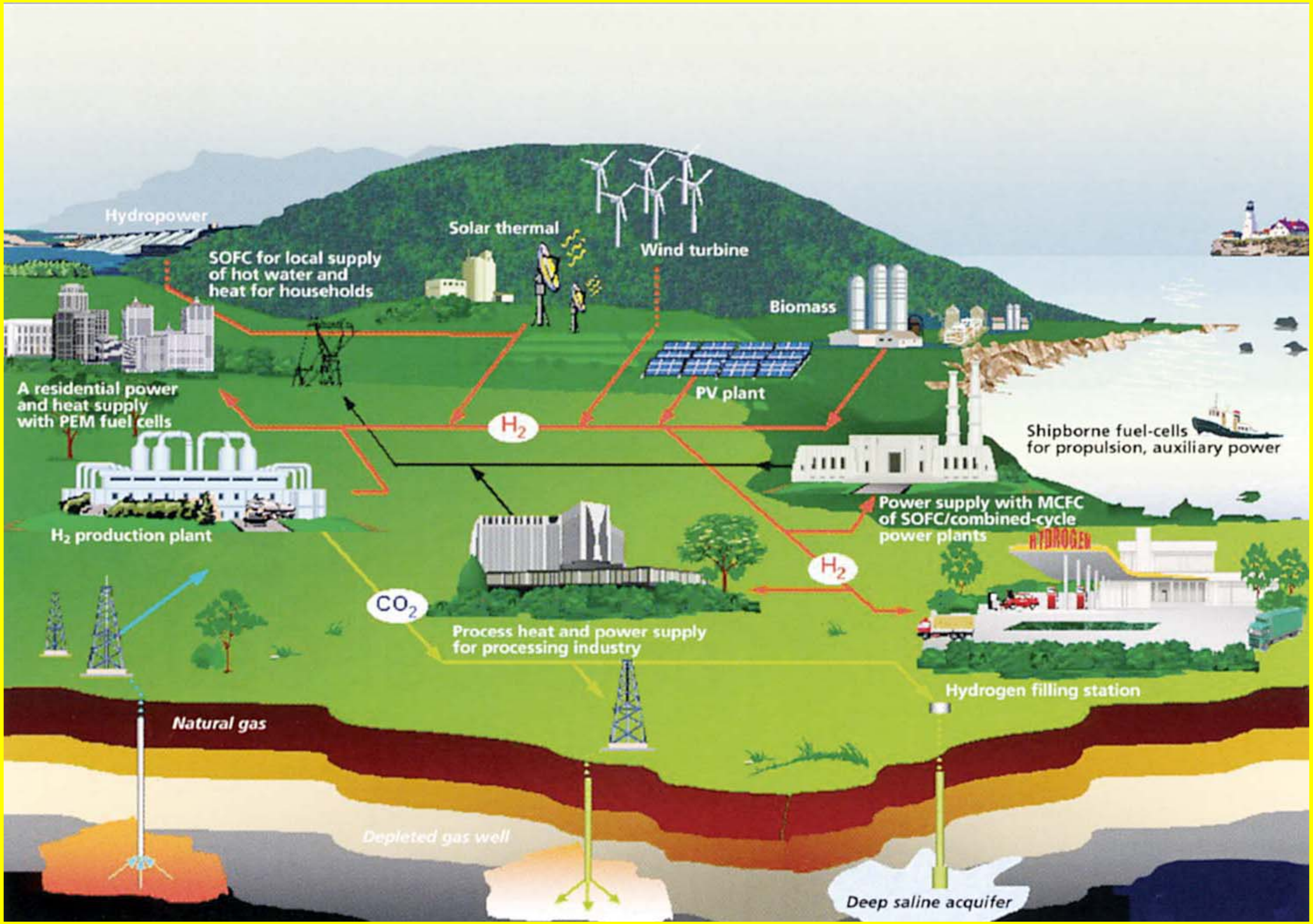


Mobility and Communication Through Time



Source: David Sanborn Scott, 2004

A Future Energy System



Summary of Global Fossil Resources
Energy equivalents in ZJ, carbon contents in GtC

	Consumption				Reserves		Additional Resources[a]		Resource Base[b]		Additional occurrences	
	1860-1998		1998									
	ZJ	Gt C	ZJ	Gt C	ZJ	Gt C	ZJ	Gt C	ZJ	Gt C	ZJ	Gt C
Oil												
Conventional	4.85	97	0.13	2.65	6	120	6	121	12	241		
Unconventional	0.29	6	0.01	0.18	5	102	15	305	20	407	45	914
Natural gas[c]												
Conventional	2.35	36	0.08	1.23	5	83	11	170	17	253		
Unconventional	0.03	1	0.00	0.06	9	144	24	364	33	508	930	14,176
Coal	5.99	155	0.09	2.40	21	533	179	4,618	200	5,151		
Total occurrences	13.51	295	0.32	6.53	47	982	235	5,578	282	6,560	975	15,090

ZJ = Zeta-joule or 10^{21} Joule or thousands of Exajoules
Gt C = Giga tonnes or 10^{15} grams of carbon

[a] Reserves to be discovered or resources to be developed as reserves
[b] Resources base is the sum of reserves and resources
[c] Includes natural gas liquids

Hydrocarbon Reserves and Resources

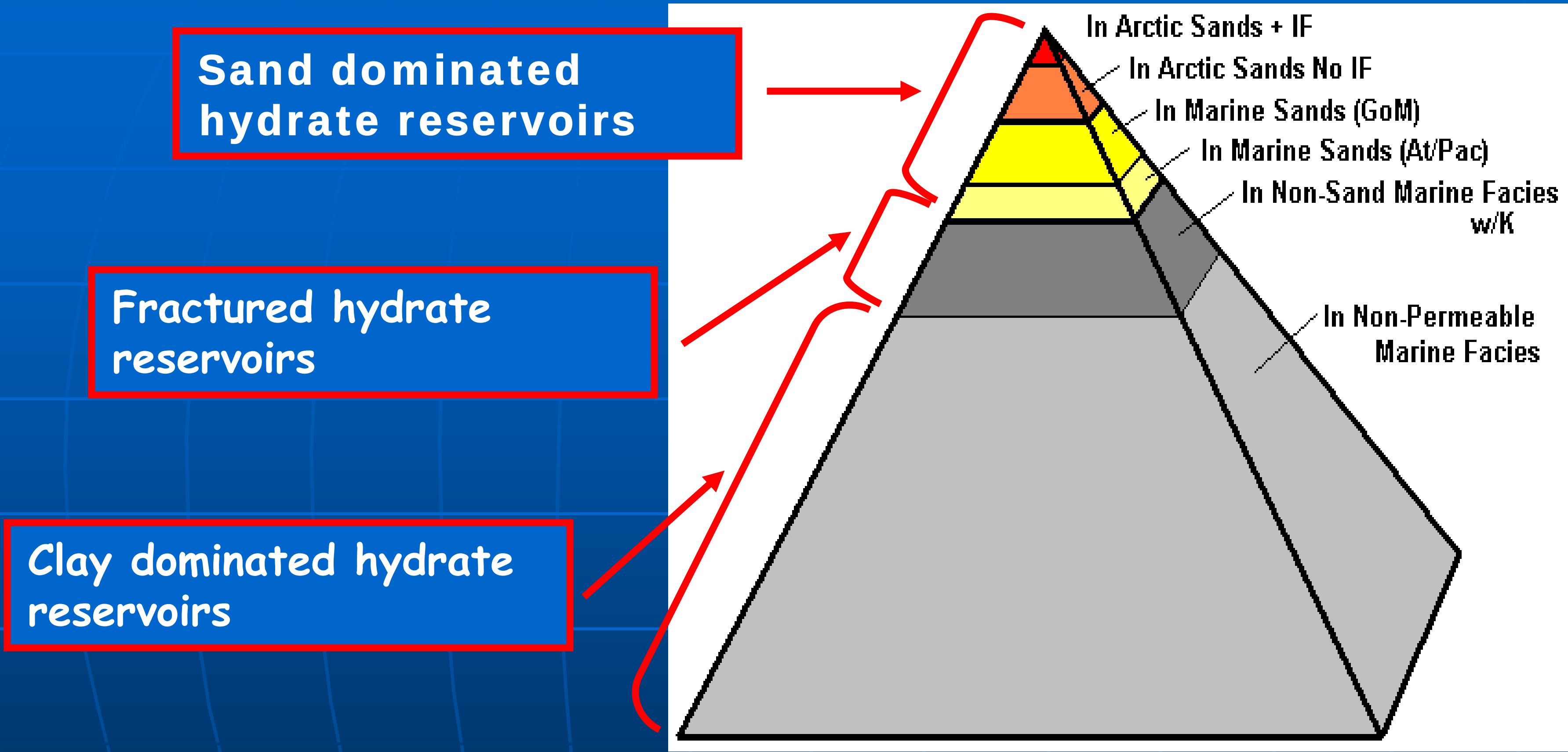
Scenario assumptions and utilization levels, in ZJ (10^{21}J)

	Conventional reserves and resources	Unconventional			Unconventional and additional occurrences			
		Enhanced recovery	Recoverable					Historical Consumption 1860-1998
Category	**I,II,III**	**IV**	**V**	**VI**	**VII**	**VIII**	**Total**	
Oil	12.4	5.8	1.9	14.1	24.6	35.2	94	5.1
Gas	16.5	2.3	5.8	10.8	16.2	800	852	2.4

Scenario/	Scenario assumptions						Consumption 1990-2100	
Category	**I,II,III**	**IV**	**V**	**VI**	**VII**	**VIII**	**Oil**	**Gas**
SRES								
A1B	gas/oil	gas/oil	gas/oil	gas/oil	gas	---	25.5	31.8
A1T	gas/oil	gas/oil	gas/oil	gas/oil	gas	---	20.8	24.9
A1O&G	gas/oil	gas/oil	gas/oil	gas/oil	gas/oil	gas	34.4	49.1
A1C	gas/oil	gas/oil	gas/oil	---	---	---	18.5	20.5
A2	gas/oil	gas/oil	gas/oil	gas	---	---	19.6	24.5
B1	gas/oil	gas/oil	gas	gas	---	---	17.2	23.9
B2	gas/oil	gas/oil	gas/oil	gas	---	---	19.4	26.9
WEC								
A1	gas/oil	gas/oil	gas/oil	gas/oil	gas/oil	gas/oil	34.0	28.9
A2	gas/oil	gas/oil	gas/oil	---	---	---	18.7	21.2
A3	gas/oil	gas/oil	gas	gas	gas	---	17.4	36.1
B	gas/oil	gas/oil	gas/oil	---	---	---	17.8	19.6
C1	gas/oil	---	---	---	---	---	12.4	14.9
C2	gas/oil	---	---	---	---	---	12.4	14.2

Table shows which of the categories are deployed in each scenario and compares cumulative use from 1990 to 2100 with historical consumption from 1860 to 1988

The new view of the world of gas hydrates

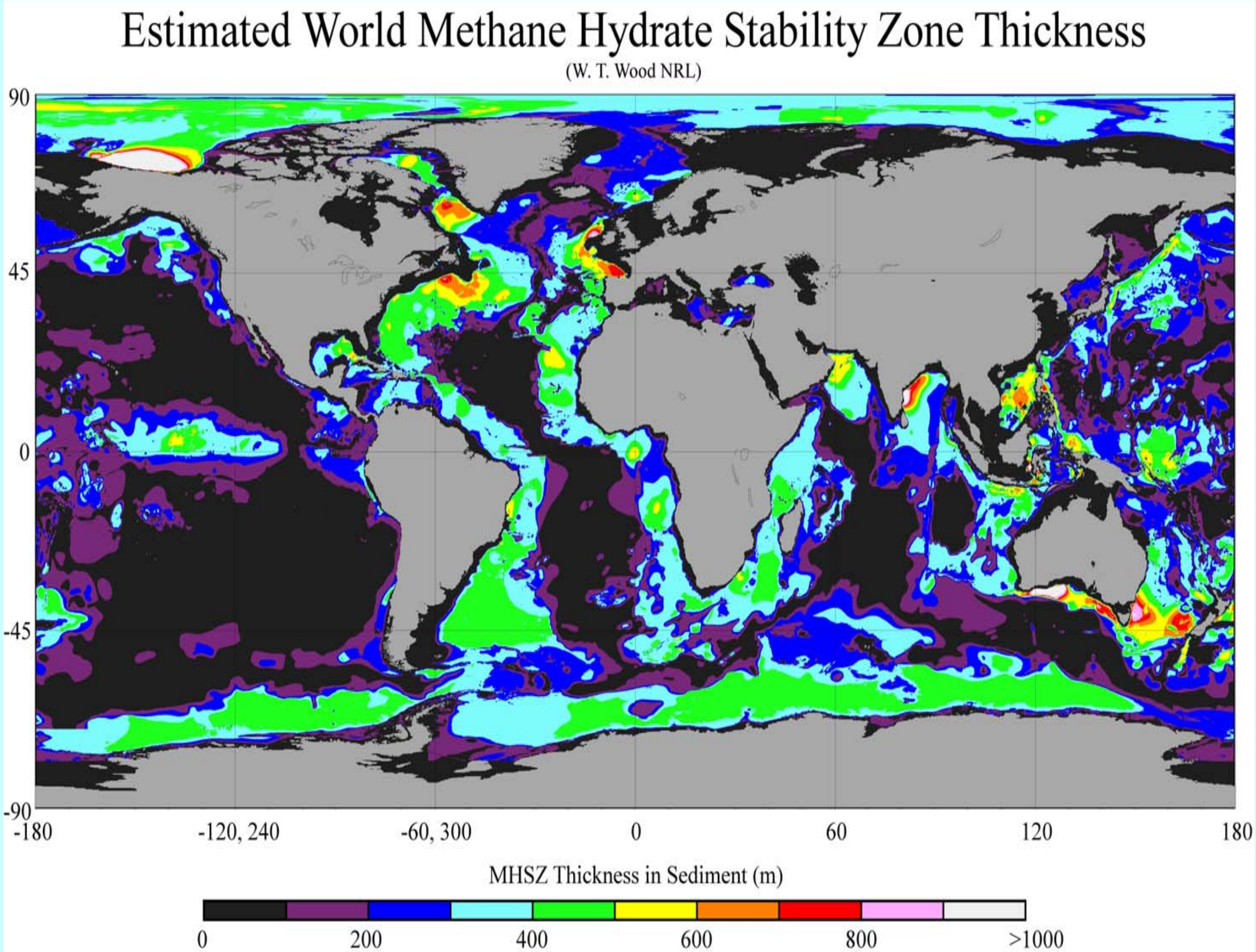


Resource Pyramid*

Gas hydrates occur in a variety of deep marine and onshore Arctic settings, with those in Arctic sandstone reservoirs, under infrastructure, being the most accessible portion of the gas hydrate resource.

* Concept developed by T.S. Collett and R. Boswell, NETL newsletter "Fire in the ice" Fall 2006.

Source: M. Riedel



Source: N. Langhorne

A Final Note about Seafloor Hydrate Mounds

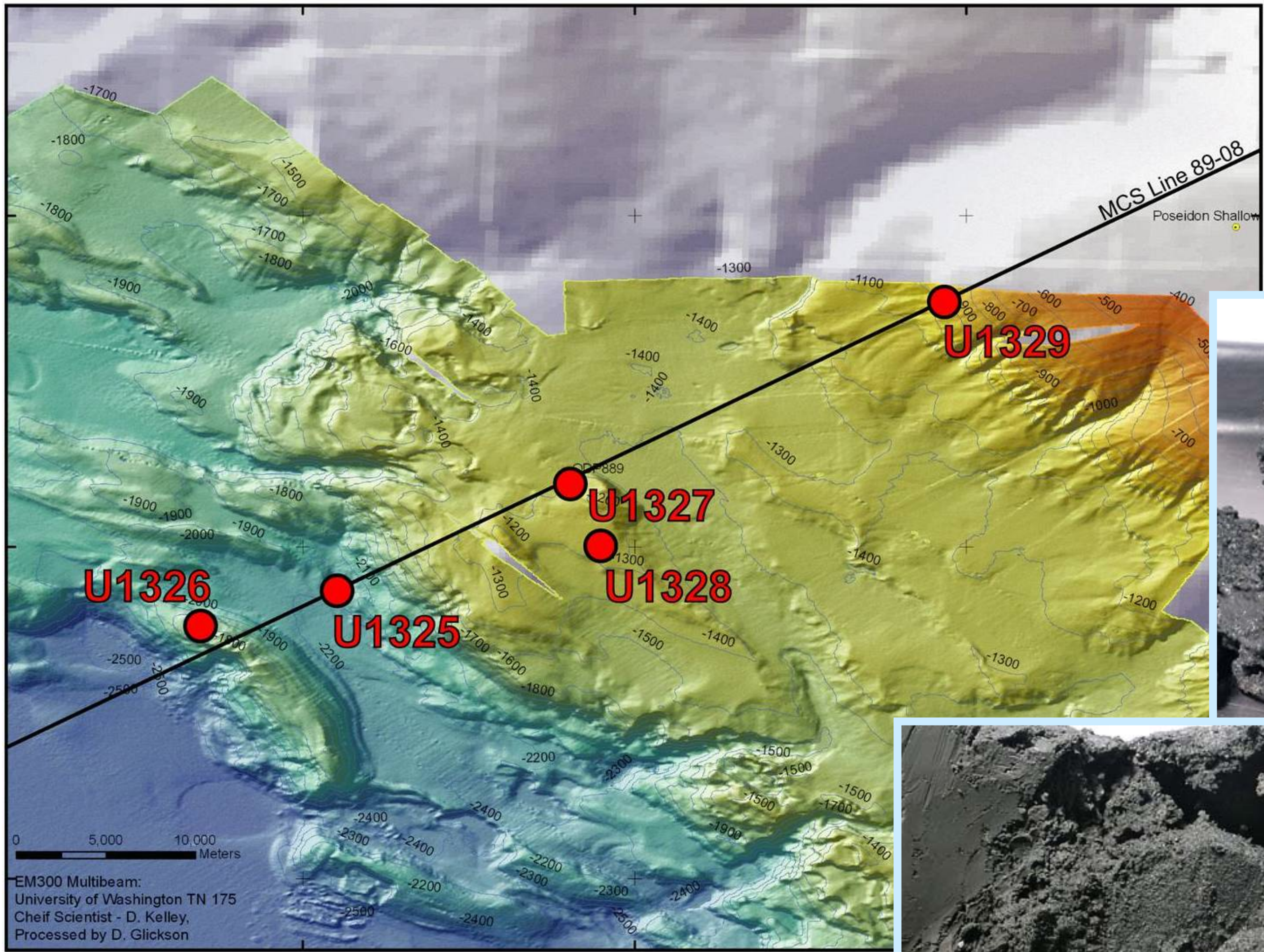
- Several approaches for recovering natural gas from hydrate mounds have been considered. Recent concepts may be commercially viable and environmentally acceptable.

The gas would have dissolved into seawater anyway – this might be considered as a renewable resource.

HEI

Source: A. Johnson

IODP Expedition 311 (2005): Margin-wide transect concept



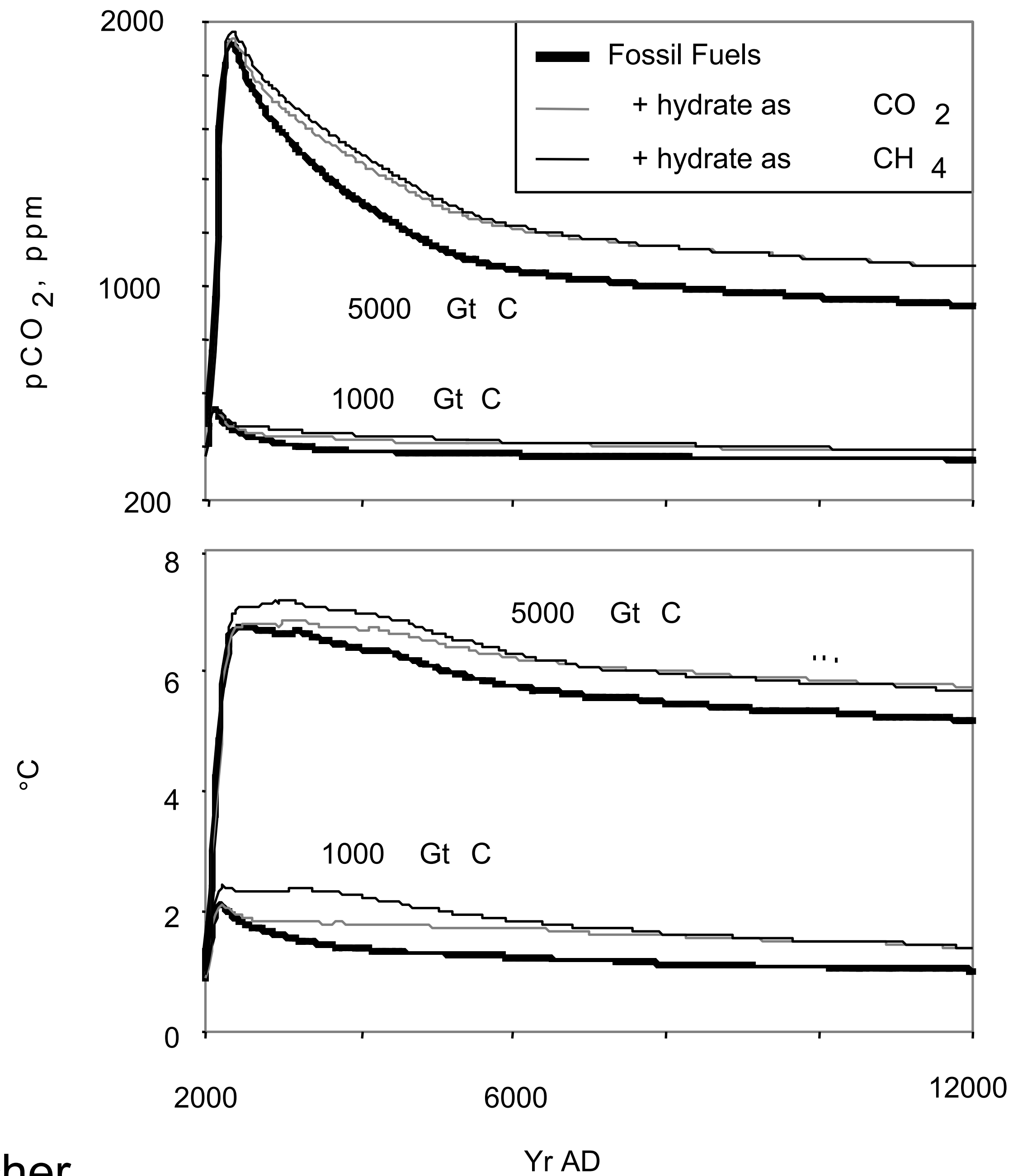
Hydrate in sands!

M. Riedel, T.S. Collett, M. Malone et al., 2006 (ER volume)

Web-links:

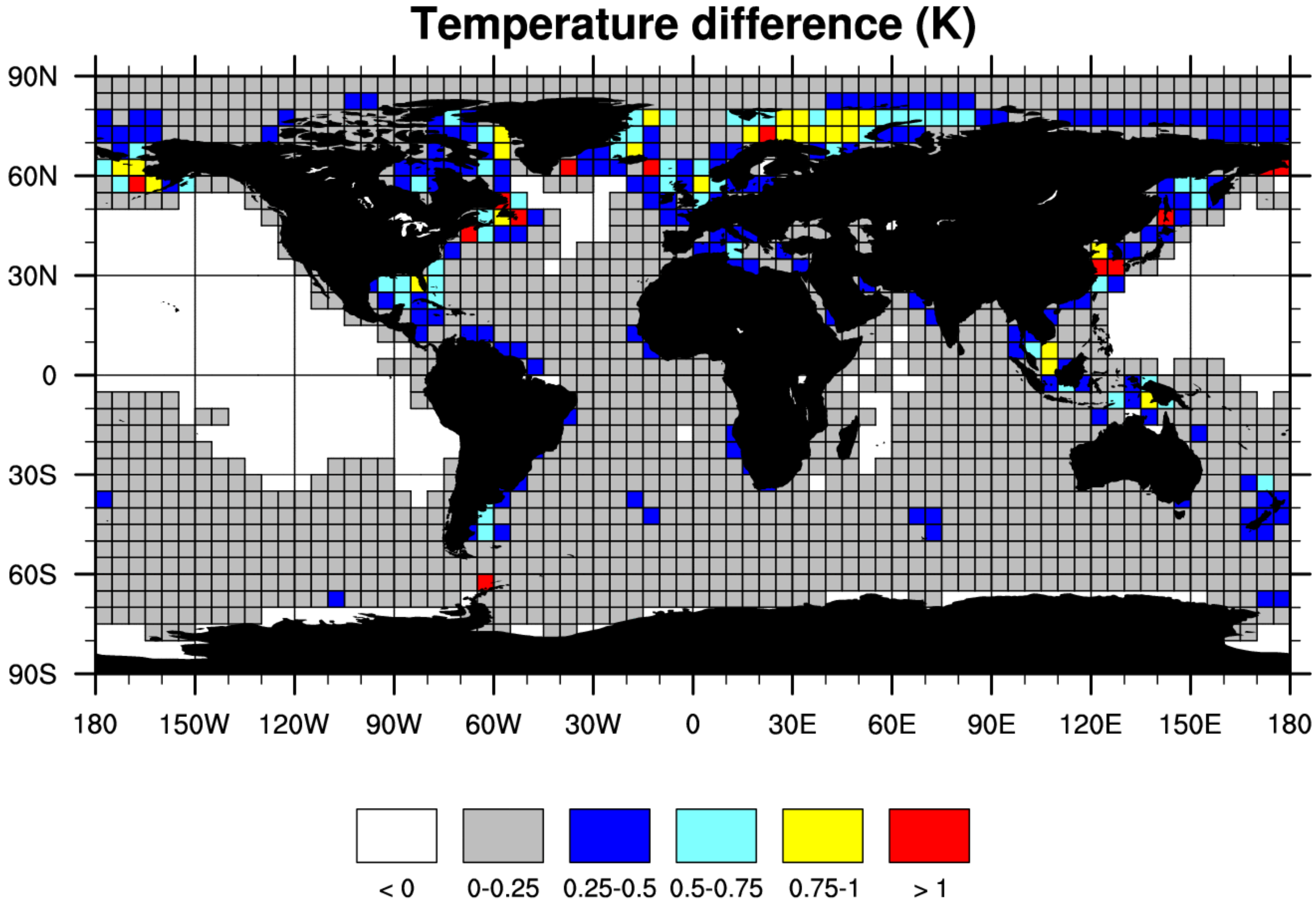
http://publications.iodp.org/proceedings/311/311title.htm

Source: M. Riedel



Source: D. Archer

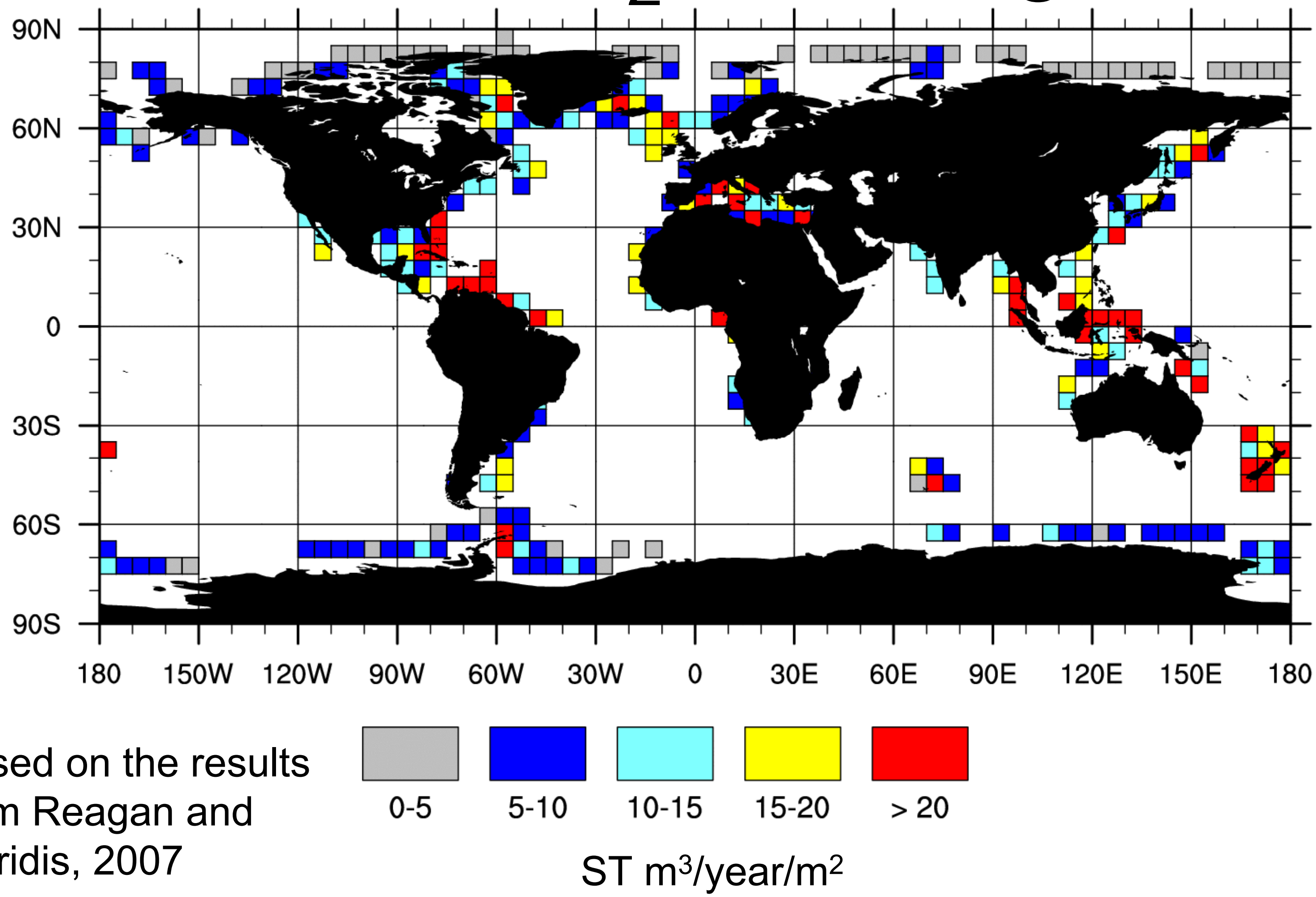
Mean ocean bottom temperature increase from doubling CO_2



Average of 16 models

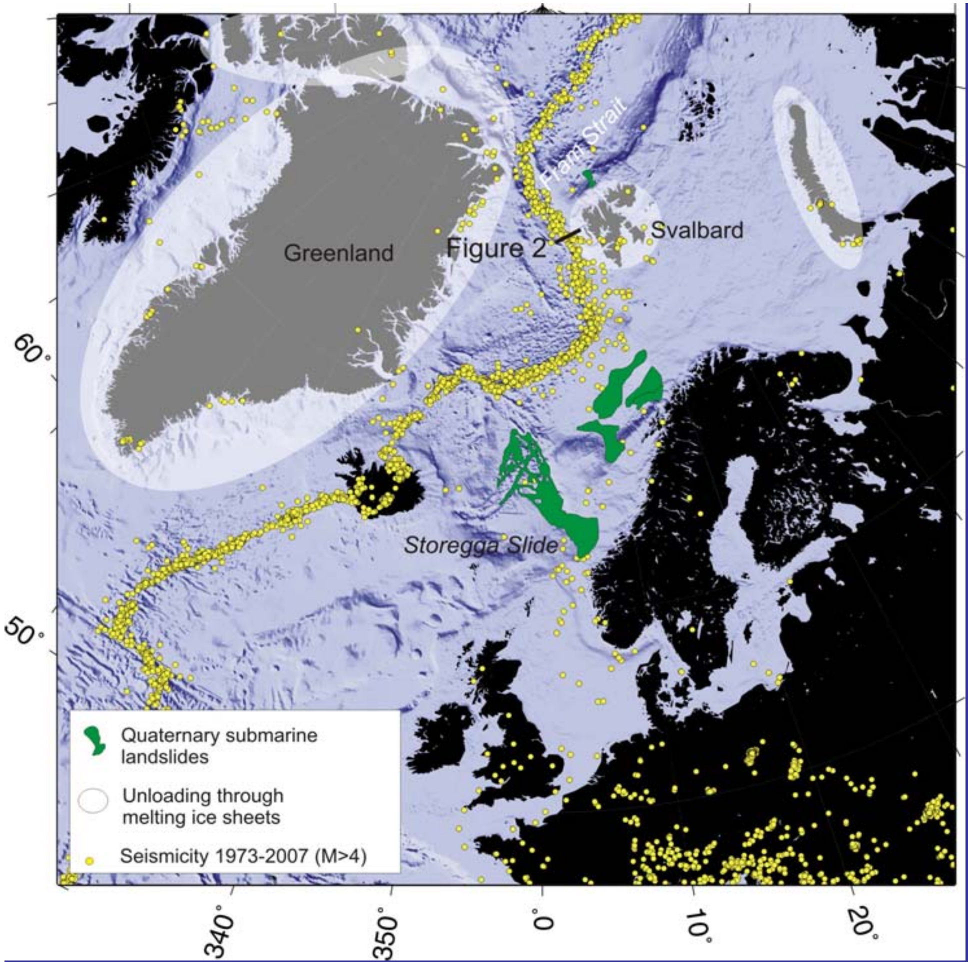
Source: J.-F. Lamarque

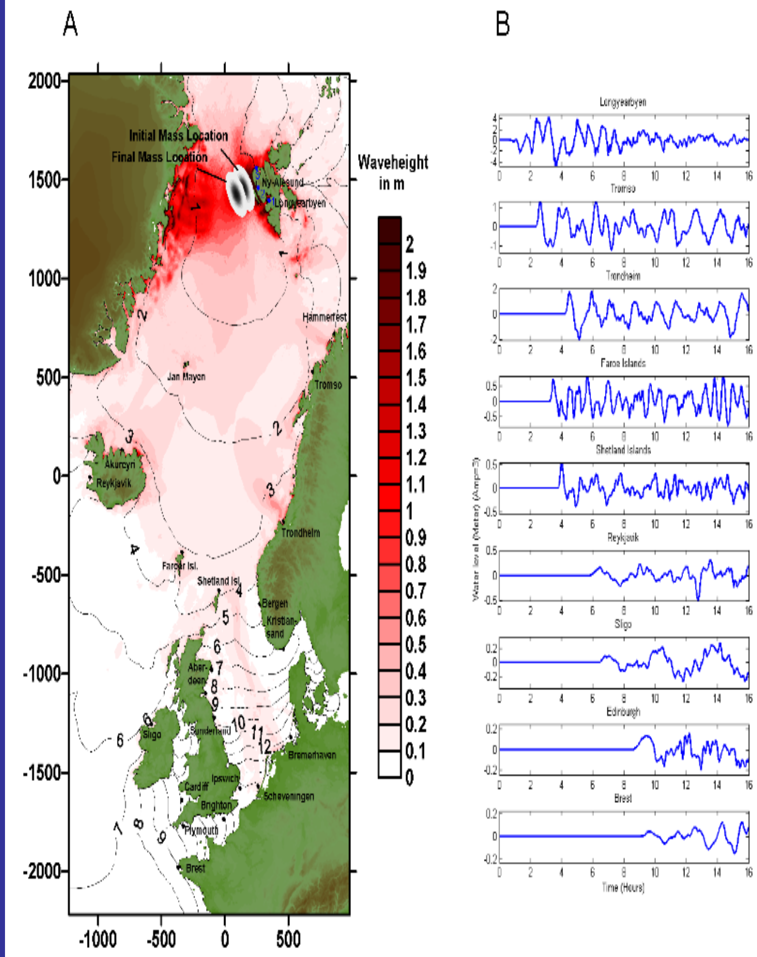
Estimated average methane flux from CO_2 doubling

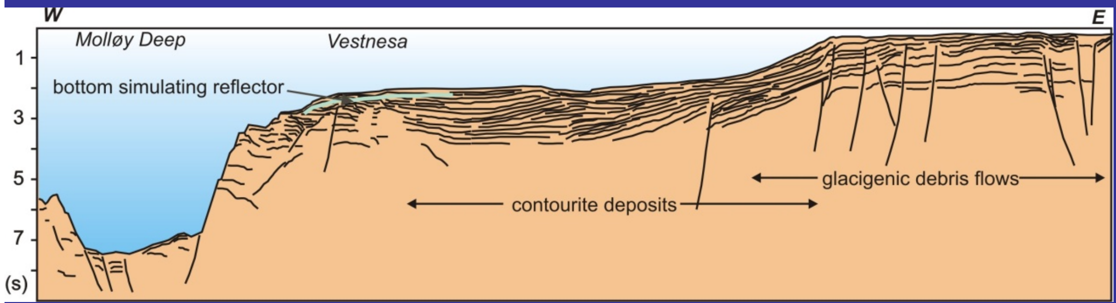


Based on the results from Reagan and Moridis, 2007

Source: J.-F. Lamarque







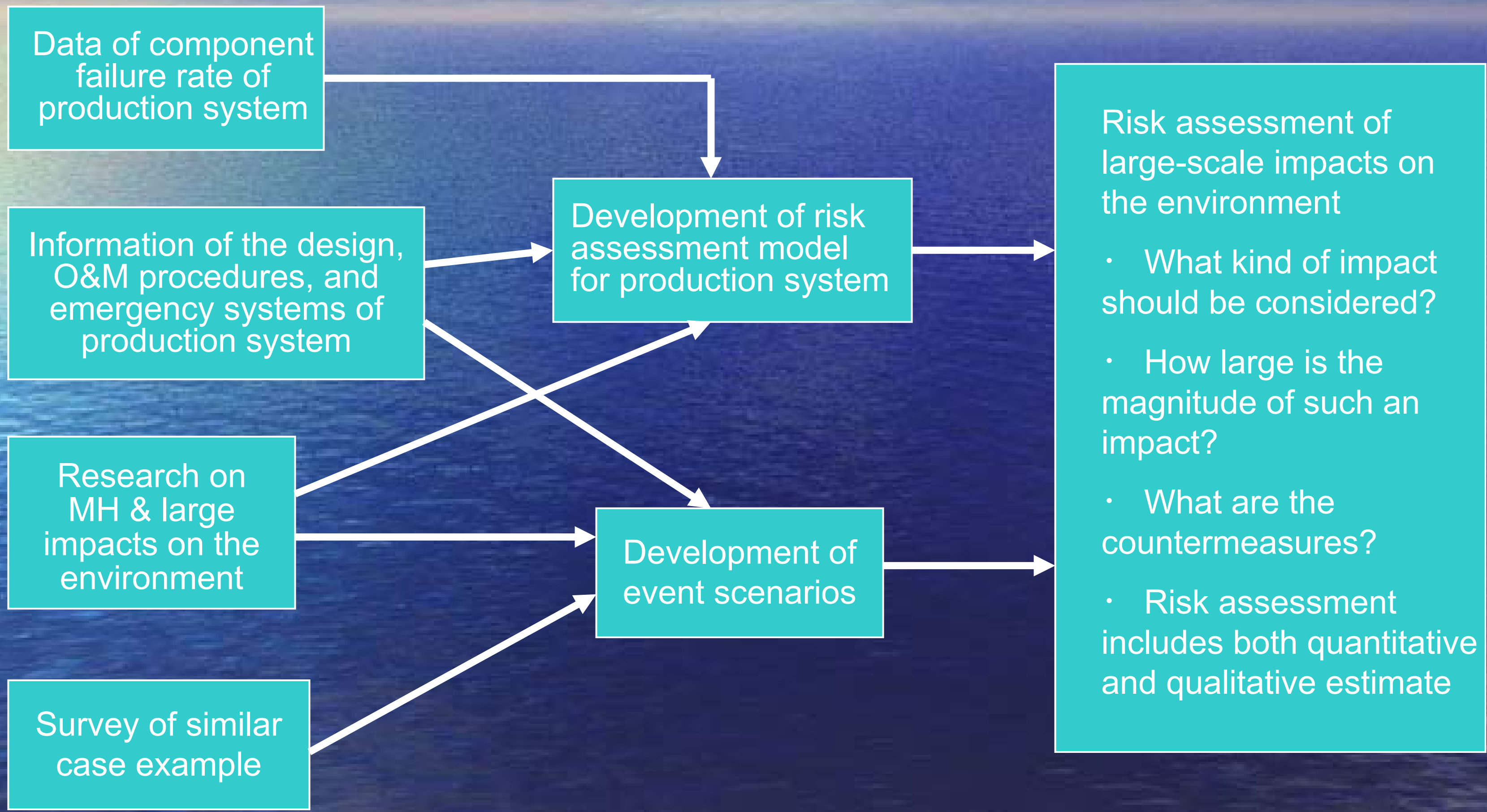
Line-drawing of a transect from the Svalbard shelf through the gas hydrate province into the Molløy Deep (after Eiken et al., 1994)(C. Berndt)

Tsunami Model (S. Brune, S.Sobolev)

Potential N. Atlantic tsunami risk: (Berndt, Brune, Nisbet, Sobolev models).

Source: E. Nisbet

Framework of Risk Assessment of Large-Scale Impacts on the Environment



Source: Y. Abe

Exploration and production

Studies to be completed:

1. Exploration of Sweet Spots
2. Reservoir stimulation

} Many studies, good progress

3. Gas dehydration and separation
4. Gas compression and transport

} Few studies, new technologic approach is required

Gas industry expectations in exploration and production of gas hydrates:

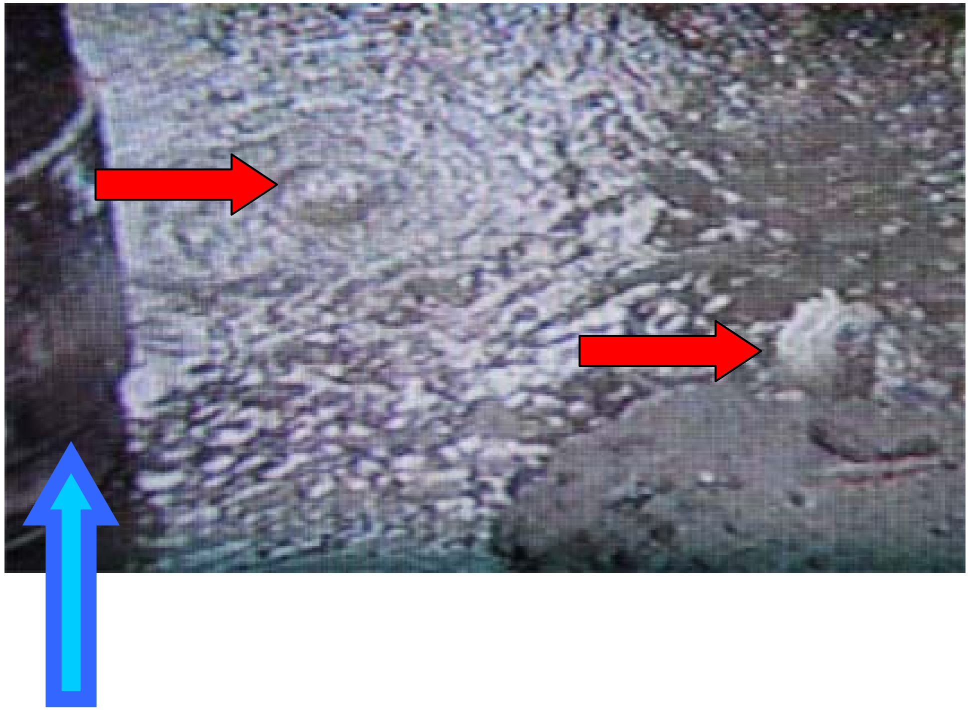
- Commercial production from gas hydrates onshore in USA (Alaska) and Russia (West Siberia) by 2020.
- Pilot development of few gas hydrate deposits offshore Japan and USA by 2020
- Commercial production of gas from offshore after 2030.

Geohazards when drilling and operation

Gas blowouts from permafrost in West Siberia

Fire when drilling monitoring well

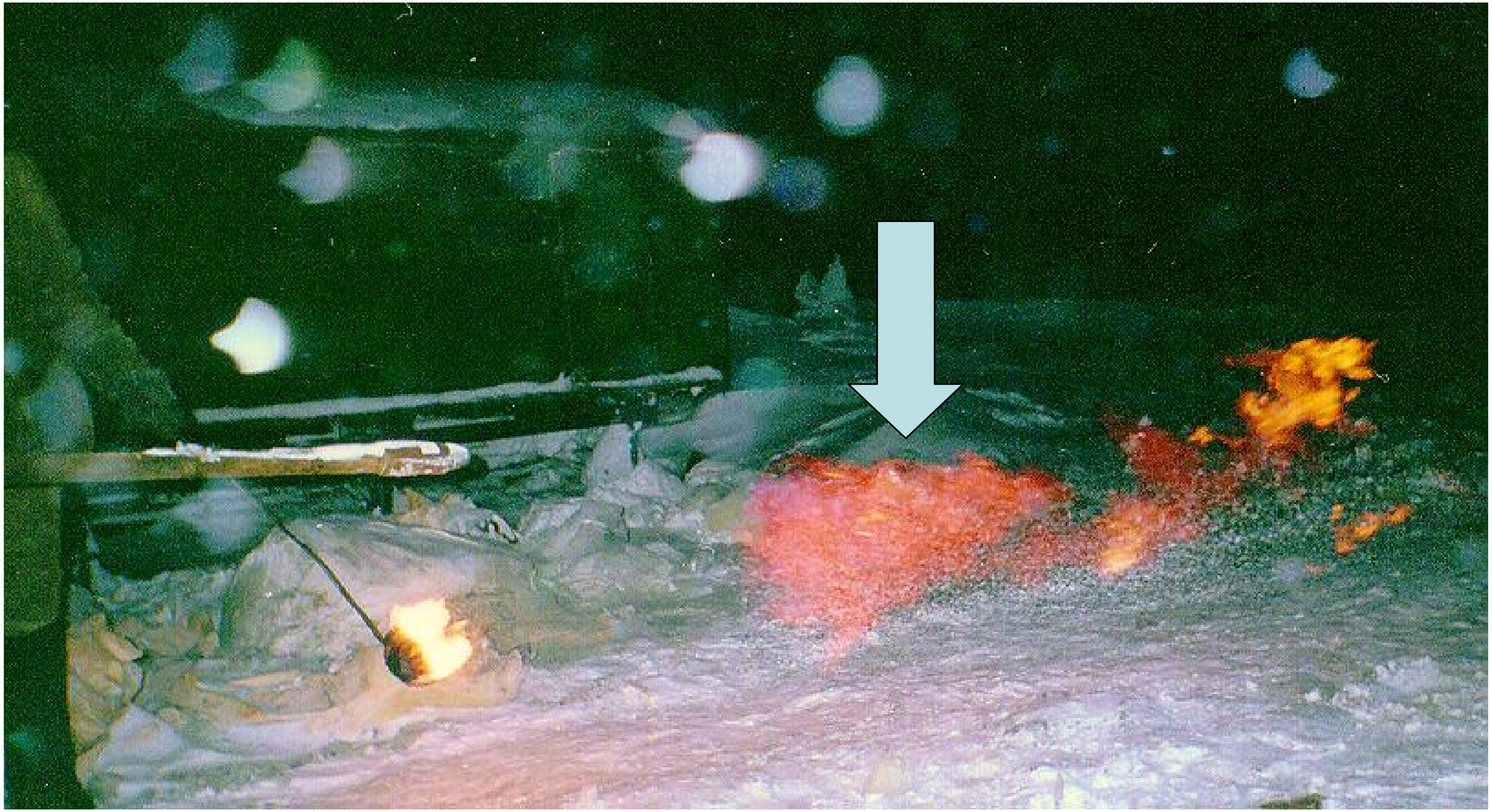
Permafrost gas bubbling around production well



Gas production well column

Geohazards when drilling and operation

GAS TORCH FROM SHALLOW PERMAFROST AT WELL 62-P-2 (BOVANENKOVO FIELD,YAMAL PENINSULA) FROM DEPTH 64 M WHEN TESTING

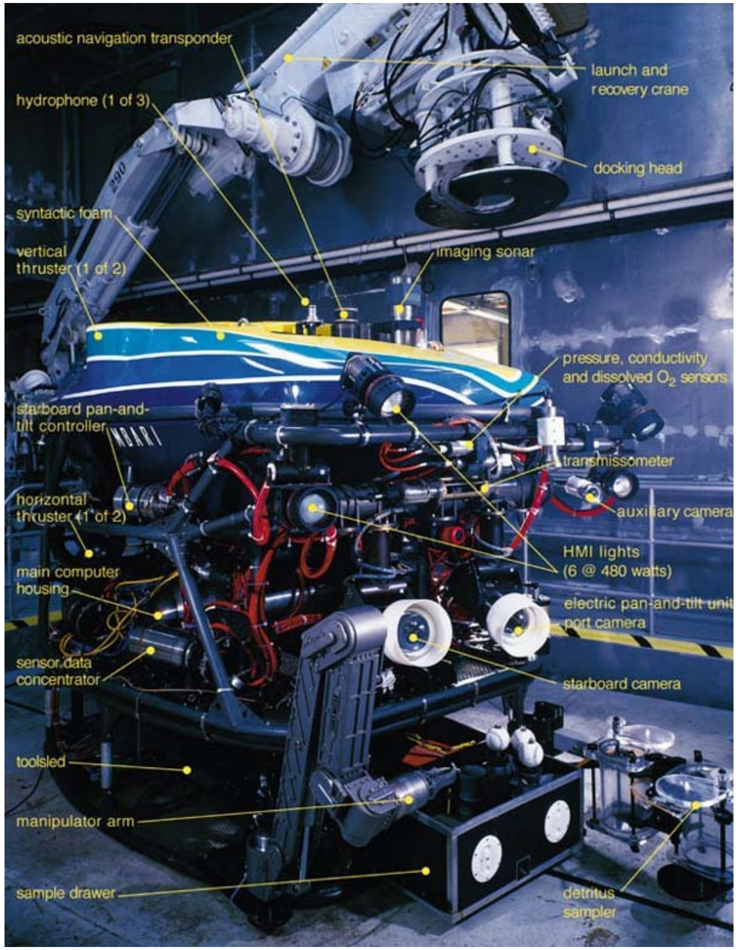


Intelligent ROV's

Remotely Operated Hydrate Appraisal (ROCA)

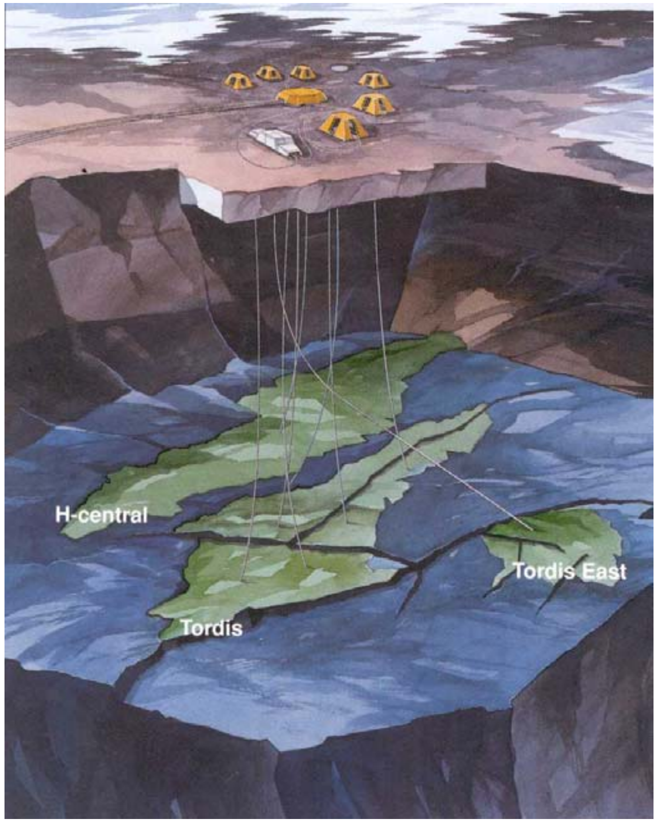
- geophysical tools
- drilling and production arms
- autonomy

Seek, Find, Drill, Produced

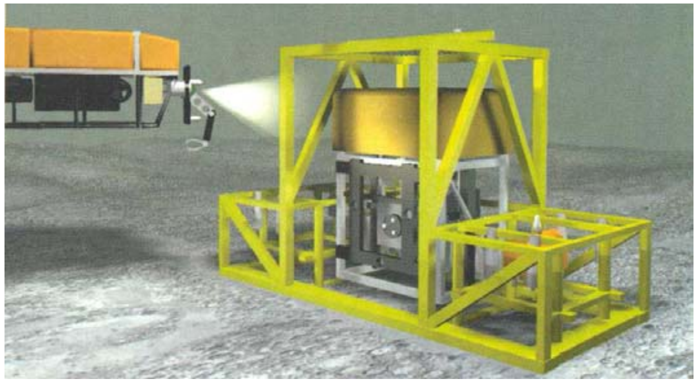


Source: P. Zitha

More mobility is needed



Move from fixed systems to mobile rapidly deployable and removable systems

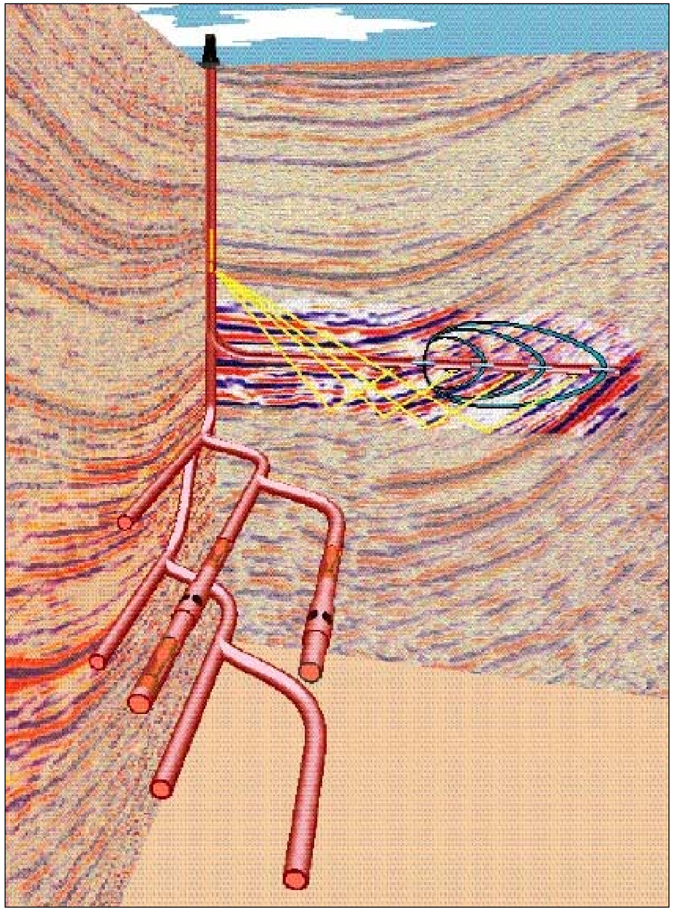


Source: P. Zitha

Multilateral intelligent systems

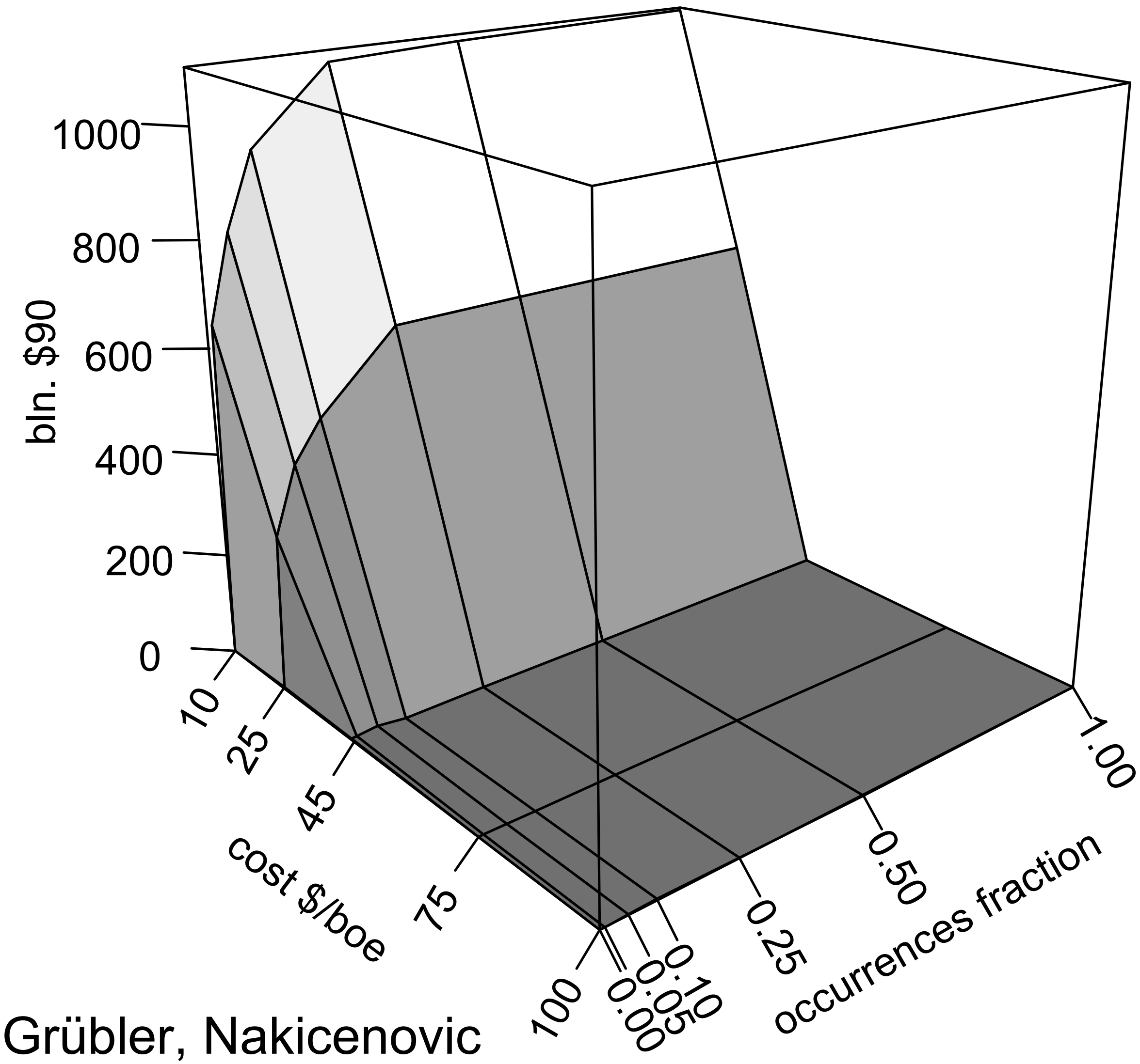
Greater accessibility of hydrate reserves:

- well equipped with downhole measurement & control instrumentation
- production and reservoir engineering
- advanced computational methods



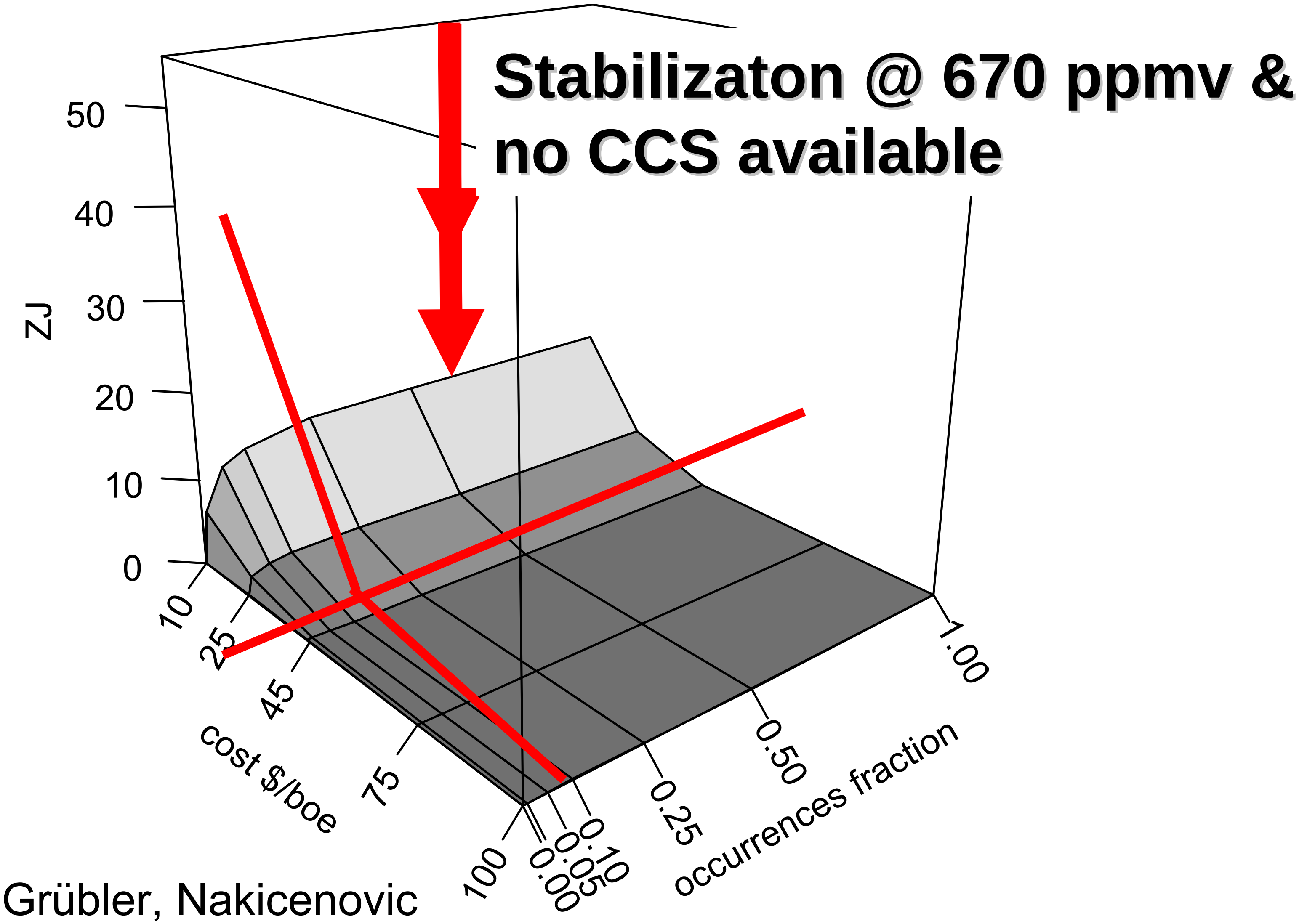
Source: P. Zitha

Market Size in 2050



Source: Krey, Grübler, Nakicenovic

Cumulative Hydrates Extraction



Source: Krey, Grübler, Nakicenovic

IPCC WG1 Treatment of Methane Hydrates

- **Synthesis Report: no mention**
- **WG1 Summary for Policy Makers: no mention**
- **WG1 Technical Summary: no mention**
- **Chapter 4: Observations (1 paragraph)**
  - Permafrost has warmed in the NH, changes to “subsea permafrost” cannot be assessed (Ch. 4.7.2.2 & 4)

NCAR Source: B. O’Neill

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IPCC WG1 Treatment of Methane Hydrates

- **Chapter 7: Climate System-Biogeochemistry Couplings (one paragraph)**
  - "Recent modelling suggests that today's seafloor CH4 inventory would be diminished by 85% with a warming of bottom water temperatures by 3°C (Buffett and Archer, 2004). Based on this inventory, … an anthropogenic release of 2,000 GtC to the atmosphere could cause an additional release of CH4 from gas hydrates of a similar magnitude (~2,000 Gt(CH4)) over a period of 1 to 100 kyr (Archer and Buffett, 2005)."
  - "Thus, gas hydrate decomposition represents an important positive CH4 feedback to be considered in global warming scenarios on longer time scales." (Ch. 7.4.1.1)

NCAR Source: B. O'Neill

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IPCC WG1 Treatment of Methane Hydrates

- **Chapter 8: Climate Models and Their Evaluation (two paragraphs)**
  - "The *likelihood* of methane release from methane hydrates found in the oceans or methane trapped in permafrost layers *is assessed in Chapter 7*. " (Ch. 8.7.2.4)
- **Chapter 10: Global Climate Projections (one sentence)**
  - "… some sources of future radiative forcing are yet to be accounted for in the ensemble projections, including those from land use change, variations in solar and volcanic activity, and CH4 release from permafrost or ocean hydrates (*see Section 8.7*)." (Ch. 10.5.1)

Source: B. O'Neill

IPCC WG2 Treatment of Methane Clathrates

- **Ch. 19: Assessing Key Vulnerabilities and the Risk From Climate Change ("key vulnerability" table entry + one paragraph)**
  - "AR4 temperature range (1.1-6.4°C) accounts for this [climate-carbon cycle] feedback from all scenarios and models but additional CO2 and CH4 releases are possible from permafrost, peat lands, wetlands, and large stores of marine hydrates at high latitudes *" (medium confidence)
  - "Permafrost already melting, and above feedbacks generally increase with climate change, but eustatic sea-level rise likely to increase stability of hydrates ***" (very high confidence)
  - "One study (Harvey and Huang, 1995) reports that methane releases may increase very long-term future temperature by 10-25% over a range of scenarios."

Source: B. O'Neill

IPCC Summary

- Little discussion of the issue
- Scant likelihood assessment (medium confidence that "additional releases are possible")
- No good idea of potential consequences
- No communication of extent of uncertainty, disagreement, etc.
- No prioritization or comparison of risks across different events (e.g., permafrost vs. methane hydrates)

NCAR Source: B. O'Neill

IIASA

Outline of Summary Article

- The **fraction of hydrates, vulnerable to climate change** (e.g. hydrates in shallow marine Arctic and hydrates disseminated in permafrost), and the **fraction of hydrates that might become available as an energy resource** need to be **further constrained**.
- Extended **drilling** and improved **inventory modeling** are required to constrain the total global methane hydrates inventory and its distribution (in particular with depth).
- The energy resource potential of hydrates is very high, where hydrates from onshore sub-permafrost can be exploited by use of semi-conventional technology. Extensions of current technologies can be used to exploit ocean hydrates, but extended exploitation will require a **paradigm shift in production technologies**. Such developments would require dedicated research and development efforts beyond the current exploration industry.
- If this large potential is realized, **carbon capture and storage (CCS) will be required** under any CO_2 stabilization regime given the gigantic potential hydrate occurrences. Therefore, development of CCS should accompany that of hydrate extraction technologies.
- Improved understanding of implications of methane hydrates for climate change is required for assessing the **role of hydrates in the global carbon cycle**, and the **sensitivity of the deep ocean temperature to surface climate change**.
- Better **monitoring of arctic and marine methane sources** is required to improve understanding of different sources and anthropogenic effects.
- Finally, the presence of methane hydrates and its potential implications for climate change as well as its role as a future source of energy **is not included in most large assessments**.