

Overview of Methane Emissions from Permafrost & Undersea Deposits.

A chat with ChatGPT on the critical methane tipping point. The following is a basis for discussion at the CCG meeting, the 15th Jan 2025. This is a background paper and those attending the meeting are requested to read beforehand. The documentary that will be shown at the meeting presents a good, balanced overview of the situation and clarifies what has been and is happening. MJC. 28.11.24

1. Overview

Question to Chat GPT: One of the most important climate change tipping points is the melting of the permafrost and the release of frozen methane from under the ocean and under the ground. The potential rapid growth in emissions will significantly increase the warming of the atmosphere. Please suggest an overview of this, looking at the past, present and projected future, the quantities involved, the heating potential and how we might address the situation. These emissions are of course in addition to the growth in methane emissions from human activities.

GPT wrote: The release of methane (CH₄) from thawing permafrost and undersea deposits is a significant **climate change tipping point** with substantial implications for global warming. Methane is a potent greenhouse gas, with a **Global Warming Potential (GWP)** approximately **28–34 times that of CO₂ over 100 years**, and its release could trigger a dangerous **positive feedback loop**.

1. Historical Context

- **Past Methane Reservoir Formation:**
 - During the last Ice Age, vast amounts of organic matter were buried under ice and soil, forming **permafrost** on land and **methane hydrates** beneath the ocean floor.
 - These deposits have remained frozen for millennia, trapping ancient carbon and methane.
- **Natural Methane Emissions:**
 - Historically, methane emissions from natural sources (wetlands, wildfires) have been balanced by methane sinks (oxidation in the atmosphere). Pre-industrial atmospheric methane levels were stable at ~700 parts per billion (ppb).

2. Present Situation

- **Current Methane Levels:**

- Atmospheric methane has increased to ~1,900–2,000 ppb, more than double pre-industrial levels. The rise is driven by both human activities (agriculture, fossil fuel extraction) and increasing natural emissions due to warming
- **Permafrost Thaw:**
 - Arctic permafrost covers **23 million square kilometers** and holds an estimated **1,500 gigatons (Gt) of organic carbon**.
 - As permafrost thaws due to rising global temperatures, anaerobic decomposition of organic matter releases methane and CO₂. Methane release has been observed in Siberia, Alaska, Canada and other regions
- **Methane Hydrates:**
 - Methane hydrates (frozen methane and water) beneath the seafloor contain an estimated **500–2,500 Gt of methane** globally.
 - Warming ocean temperatures and destabilization of hydrates have been observed in the East Siberian Arctic Shelf, where undersea methane release is accelerating.

3. Projected Future

- **Tipping Point Risks:**
 - **Runaway Warming:** Warming leads to permafrost thaw and methane release, which further warms the atmosphere, causing more thaw—a self-reinforcing feedback loop.
 - If large-scale permafrost thaw occurs, an estimated **200–300 Gt of carbon** could be released by 2100, primarily as methane and CO₂.
- **Potential Methane "Belches":**
 - Sudden, large releases of methane, such as those observed from Arctic craters, could result in catastrophic climate impacts. *A 50 Gt release from hydrates has been described as a possible, albeit debated, "methane bomb."*
- **Global Warming Impact:**
 - Methane released from thawing permafrost could contribute an additional **0.2–0.3°C** to global warming by 2100 under current emissions trajectories.

4. Addressing the Situation

- **Mitigation of Warming:**
 - **Reduce CO₂ Emissions:** Slowing global warming through aggressive reductions in CO₂ emissions is the most effective way to limit permafrost thaw and methane release.
 - **Methane Capture:** Research into methane-capture technologies, particularly from shallow waters or localized permafrost sites, could help mitigate emissions.
- **Adaptation Strategies:**
 - **Reforestation:** Planting vegetation in thawing permafrost regions could enhance carbon sequestration and slow soil erosion.

- **Cooling Technologies:** Experimental methods, like insulating permafrost or reflecting sunlight using reflective surfaces, are being explored to stabilize key areas.
- **International Cooperation:**
 - Initiatives like the **Global Methane Pledge**, aiming to cut methane emissions by 30% by 2030, must be strengthened to include natural emissions management.

5. Conclusion

The release of methane from thawing permafrost and undersea hydrates represents a critical tipping point with far-reaching implications. While the process cannot be entirely stopped, reducing global emissions and managing permafrost areas can slow the feedback loop. Immediate, coordinated action is essential to mitigate this threat and ensure a stable climate for future generations.

There seems to be a rather amazing omission in this very plausible 2-page overview.

2. The Improbable Methane Bomb

Question to ChatGPT: Where did the **50Gt methane belch** figure come from, which references, what sort of consensus that this is possible or probable?

ChatGPT said: The **50 Gt methane release scenario** originates from studies exploring the potential for massive methane emissions from Arctic permafrost and methane hydrates. It represents an extreme "worst-case" tipping point scenario, not a prediction but a warning about the possible consequences of rapid warming. Here's what the research suggests:

Origins of the 50 Gt Methane Release Scenario

1. **Scientific Proposals:**
 - Research by Natalia Shakhova and colleagues highlighted the risk of large-scale methane releases from the **East Siberian Arctic Shelf**. They estimated that up to **50 Gt of methane** stored in subsea permafrost could be released rapidly if the seabed warms sufficiently. Such an event would have catastrophic warming implications **[214] [215]** .
 - This scenario is considered highly unlikely in the short term but is a useful "thought experiment" to understand potential impacts.
2. **Likelihood of Sudden Release:**
 - Most scientists agree that while permafrost and methane hydrates are releasing increasing amounts of methane, a sudden "methane bomb" release of this scale is **improbable**. Instead, emissions are expected to increase gradually over decades as warming continues **[214] [215]** .

Concerns and Implications

- **Gradual Methane Release:**
 - The Arctic is already releasing methane due to permafrost thaw and destabilization of methane hydrates. These processes are occurring faster than models predicted, with the Arctic warming at more than **four times the global average** [215] .
- **Potential Feedback Loops:**
 - As methane is released, it accelerates global warming, which in turn thaws more permafrost and destabilizes methane hydrates—a **positive feedback loop**. This has led to concerns about tipping points where these processes become self-reinforcing [215] .

Scientific Consensus

- While a rapid 50 Gt release is **unlikely**, the gradual increase in methane emissions is a serious concern. Current estimates indicate the Arctic could lose up to **89% of its permafrost by 2100**, significantly increasing emissions [215] .
- Immediate action to reduce global greenhouse gas emissions, especially CO₂, is critical to slowing permafrost thaw and mitigating methane emissions.

In summary, the 50 Gt methane scenario is a hypothetical extreme case to highlight risks. The focus should remain on reducing anthropogenic emissions to limit warming and prevent accelerating permafrost-related feedback loops. For detailed exploration, studies such as those by Shakhova and reports from the **Smithsonian** and **PNAS** are insightful [214] [215]

Here are the direct links to the sources referenced as **214** and **215** for information on methane release risks in the Arctic:

1. **Shakhova and East Siberian Arctic Shelf Research:** This article discusses the potential for significant methane release from subsea permafrost in the East Siberian Arctic Shelf, including studies by Natalia Shakhova. You can read the relevant information [here on ScienceDirect](#) or through other academic resources like PNAS, which house her foundational work.
2. **Smithsonian Article on Methane Time Bombs:** The Smithsonian article provides a comprehensive overview of methane emissions from Arctic permafrost and the risks posed by warming temperatures. The article, titled "Permafrost Thaw in Siberia Creates a Ticking 'Methane Bomb'," can be accessed here on the Smithsonian website.

3. Calculated Impact of a 50 Gt Methane Release

Question to Chat GPT: By my calculations, this would mean that a 50Gt belch of methane would raise the current annual CO₂e emissions of 50Gt in the year immediately following the belch, by a factor of 88. Have I made an error?

ChatGPT said: Your calculation assumes that the **Global Warming Potential (GWP)** of methane over 20 years is approximately **88** (often quoted as ~84–87, depending on the

source), and you are comparing the impact of a hypothetical **50 Gt methane "belch"** to the current **annual anthropogenic GHG emissions**, which are around **50 Gt CO₂e** per year. Let's verify your reasoning:

1. **Methane's Immediate CO₂e Impact:**

- Methane's GWP over 20 years = **88**.
- $50 \text{ Gt CH}_4 \times 88 = 4,400 \text{ Gt CO}_2\text{e}$
- This would indeed be an **88-fold increase** relative to the current annual emissions of 50 Gt CO₂e.

2. **Contextualizing the Impact:**

- This would mean that within the first year following the release, the Earth's atmosphere would experience a **total greenhouse gas burden equivalent to 4,450 Gt CO₂e** (4,400 Gt from the methane + 50 Gt from regular human activities).
- Such a sudden spike in GHG concentrations would cause a dramatic acceleration in warming, potentially overwhelming natural systems and triggering further tipping points.

Conclusion

Your calculation is accurate under the stated assumptions. A **50 Gt methane release** would indeed produce a warming effect equivalent to approximately **88 times the current annual GHG emissions** for the year following the event. This underscores the **severe risk** posed by methane release scenarios and their potential to radically alter the climate system in a very short timeframe.

4. Further clarification of GWP

Verifying Assumptions

- The **GWP of 88** is used for short-term effects over a **20-year timeframe**. If the focus is on **100 years**, the GWP drops to ~28–34. However, for immediate impacts, your use of **88 GWP** is valid.
- The assumption of **50 Gt methane release** aligns with some extreme hypothetical scenarios (e.g., destabilization of Arctic methane hydrates). While debated, such an event could theoretically occur under rapid warming conditions.

Methane's Atmospheric Lifetime and Decay

1. **Atmospheric Lifetime:**

- Methane has an average atmospheric lifetime of about **12 years** before it is broken down into water vapor (H₂O) and CO₂ through oxidation.
- After ~12 years, about 37% of the initial methane remains in the atmosphere; after ~50 years, its direct warming effect becomes negligible as most methane is removed or converted to CO₂.

2. **GWP Dynamics:**

- **Short-Term GWP (20 years):** ~84–87 times that of CO₂.
- **Long-Term GWP (50 years):** Declines as methane breaks down, approaching CO₂'s warming potential (1).

Calculation of Warming Impact Over Time

Year 1:

- Methane's GWP: ~87.
- **CO₂e:** 1 Gt CH₄ × 87 = 87 Gt CO₂e 1Gt CH₄ × 87 = 87Gt CO₂e.

Year 12 (approximate methane half-life):

- About **37%** of the methane remains: 1 Gt CH₄ × 0.37 = 0.37 Gt CH₄ 1Gt CH₄ × 0.37 = 0.37Gt CH₄.
- GWP begins to decline: Remaining methane contributes a lower CO₂e.

Year 50:

- Virtually all methane is oxidized, and its warming potential is now equivalent to the **1 Gt of CO₂** produced by its oxidation.

Cumulative CO₂e Impact

The overall warming effect of methane can be visualized as a **rapid spike** in the first few decades, followed by a gradual reduction:

1. **Initial Phase** (Years 0–12): Dominated by methane's high GWP (~84–87), contributing a strong, short-term warming pulse.
2. **Transition Phase** (Years 12–50): Methane levels decline as it oxidizes, and its contribution to CO₂e decreases.
3. **End State:** Methane is fully converted to CO₂, leaving behind a residual warming effect equivalent to 1 Gt of CO₂.

Graphical Representation

If represented graphically:

- **Years 0–12:** A steep peak, reflecting methane's high GWP and immediate warming impact.
- **Years 12–50:** A sharp decline as methane decays.
- **After 50 years:** A flat line at **1 Gt CO₂e**, representing the long-term residual impact.

Key Takeaways

- A **1 Gt methane release** results in approximately **87 Gt CO₂e** in Year 1.
- By Year 50, the residual warming impact is reduced to **1 Gt CO₂e** as methane is converted to CO₂.
- The initial warming pulse is a critical short-term driver of climate change, emphasizing the urgency of mitigating methane emissions.

GWP (Global Warming Potential) is a measure used to compare the ability of different greenhouse gases (GHGs) to trap heat in the atmosphere over a specific period, typically **20, 100, or 500 years**. It provides a way to express the impact of GHGs in terms of a standard reference gas—**carbon dioxide (CO₂)**—which has a GWP of **1**.

Key Points About GWP:

1. **Purpose:** GWP helps policymakers and scientists compare the relative climate impacts of emissions of various gases.
2. **Factors Determining GWP:**
 - **Absorption of infrared radiation:** The extent to which a gas absorbs and traps heat.
 - **Atmospheric lifetime:** How long the gas stays in the atmosphere before breaking down.
 - **Infrared radiation emitted:** The energy released by the gas back into the atmosphere.
3. **Time Horizons:**
 - **20-Year GWP:** Emphasizes short-term warming effects, particularly relevant for gases like methane.
 - **100-Year GWP:** The most commonly used metric in climate reporting (e.g., by the IPCC).
 - **500-Year GWP:** Provides a very long-term perspective.

Examples of GWP Values (100-Year Timeframe):

- **CO₂:** 1 (baseline).
- **Methane (CH₄):** ~28–34 (depending on source and conditions).
- **Nitrous Oxide (N₂O):** ~298.
- **CFCs and HFCs:** Ranges from hundreds to thousands due to their high heat-trapping potential and long lifetimes.

Why GWP Matters:

GWP allows aggregation of emissions from different GHGs into a single metric, **CO₂e (carbon dioxide equivalent)**. This simplifies climate modeling and target-setting under international agreements like the **Paris Agreement**.

For detailed and official values, refer to the **IPCC reports** or the **U.S. EPA** guidelines on GHG equivalency metrics. Let me know if you'd like references to specific resource