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AGU FALL MEETING
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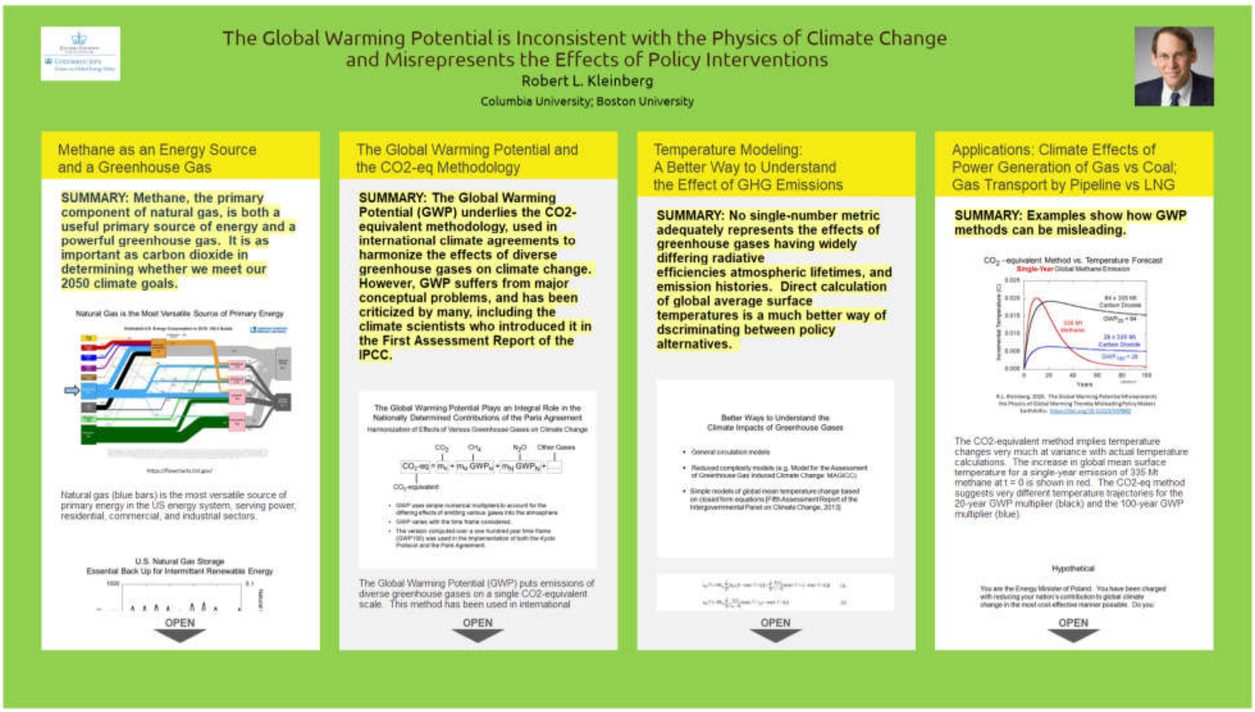
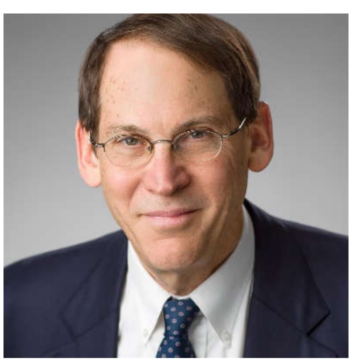
Poster SY012-0005

The Global Warming Potential is Inconsistent with the Physics of Climate Change and Misrepresents the Effects of Policy Interventions



Robert L. Kleinberg
Boston University Institute for Sustainable Energy



BU Institute for Sustainable Energy

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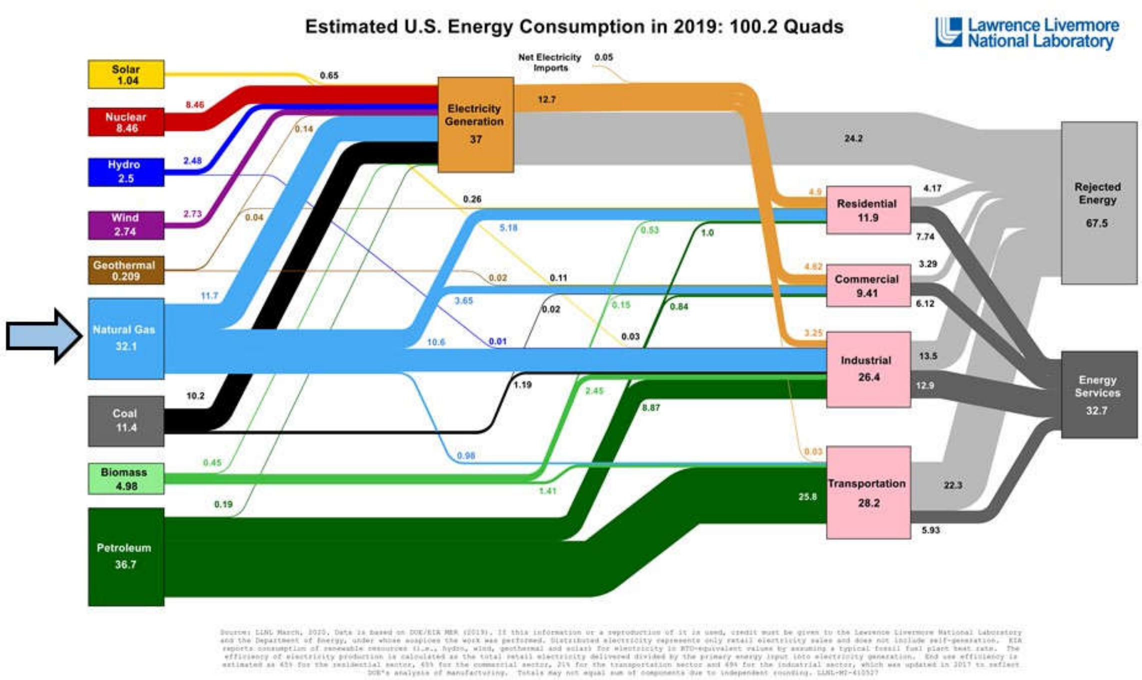
METHANE AS AN ENERGY SOURCE
AND A GREENHOUSE GAS

SUMMARY: Methane, the primary component of natural gas, is both a useful primary source of energy and a powerful greenhouse gas. It is as important as carbon dioxide in determining whether we meet our 2050 climate goals.

Natural Gas is the Most Versatile Source of Primary Energy



https://flowcharts.llnl.gov/

Natural gas (blue bars) is the most versatile source of primary energy in the US energy system, serving power, residential, commercial, and industrial sectors.

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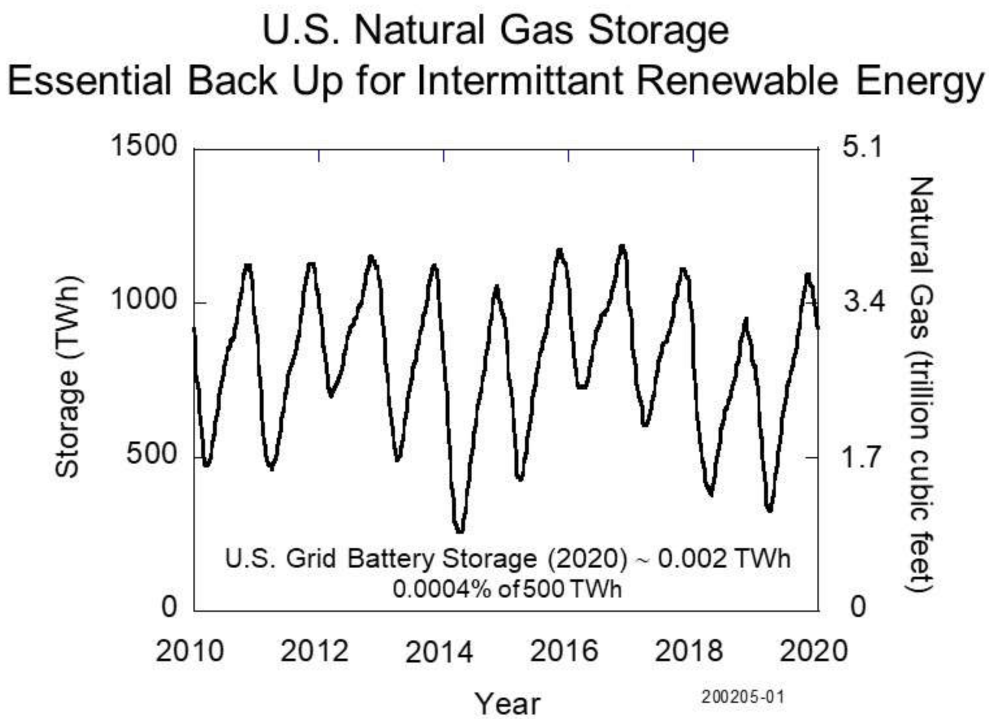

Data: US Energy Information Administration
Weekly Lower 48 States Natural Gas Working Underground Storage

Natural gas plays a unique role in energy storage. Every winter it feeds about 500 terawatt-hours of energy into power and heating systems. There is no other energy storage system that has anywhere near this capability, in overall capacity and ability to store energy for seasonal use.

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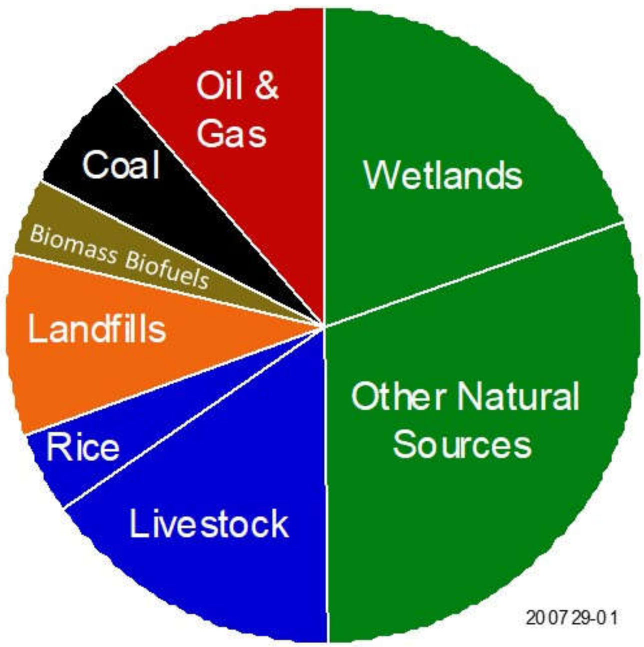
Natural & Anthropogenic Methane



Source	Methane Mt/y	%
Wetlands	145	19
Other Natural	222	30
Livestock	115	15
Rice	30	4
Landfills	68	9
Biomass & Biofuels	29	4
Coal	44	6
Oil & Gas	84	11
Other	7	1
Total	747	100

Data: Jackson, Environmental Research Letters (2020)
Methane, 2017, Bottom-Up Estimates

The primary constituent (90-95%) of pipeline grade natural gas is methane, which when emitted directly to the atmosphere is a powerful greenhouse gas. Globally, about half of methane emissions are from natural sources (green segments) and the other half are anthropogenic (other colors).

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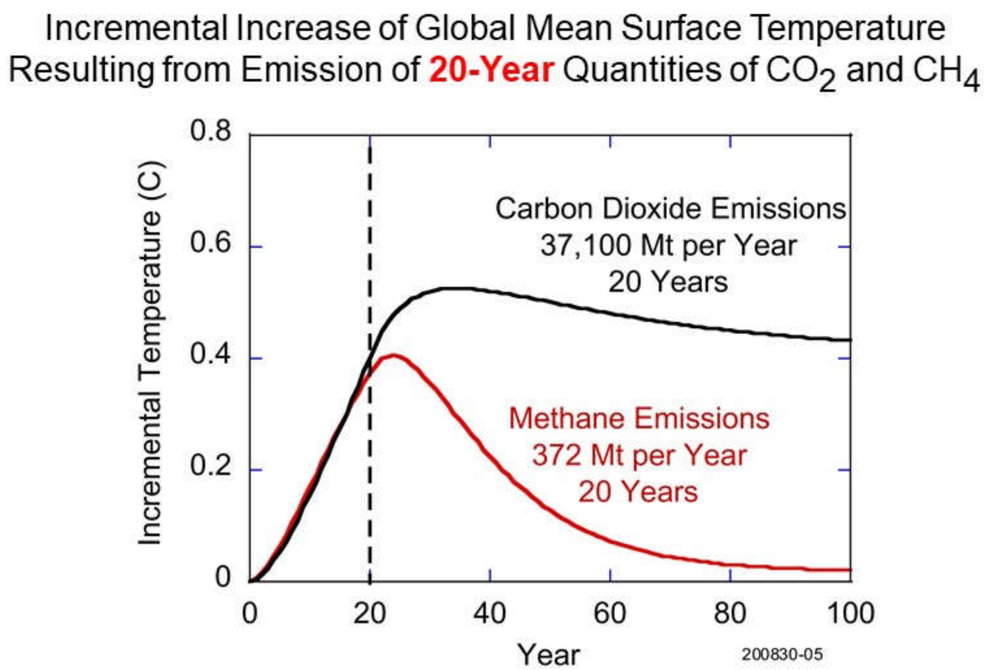

R.L. Kleinberg, 2020. The Global Warming Potential Misrepresents the Physics of Global Warming Thereby Misleading Policy Makers EarthArXiv: https://doi.org/10.31223/X5P88D

Methane is 120 times more powerful as a greenhouse gas than carbon dioxide, on a per-kilogram basis. However, the global annual mass of fossil carbon dioxide emissions is 100 times greater than the global annual mass of anthropogenic methane emissions. Therefore, the prompt warming effect of the two gases are comparable. The graph shows the temperature effect of 20 years emissions of fossil carbon dioxide at the current global rate (black) compared to the effect of 20 years of emissions of anthropogenic methane at the current global rate (red).

https://www.bu.edu/ise/files/2020/11/the-global-warming-potential-misrepresents-the-physics-of-global-warming-thereby-misleading-policy-makers-final.pdf

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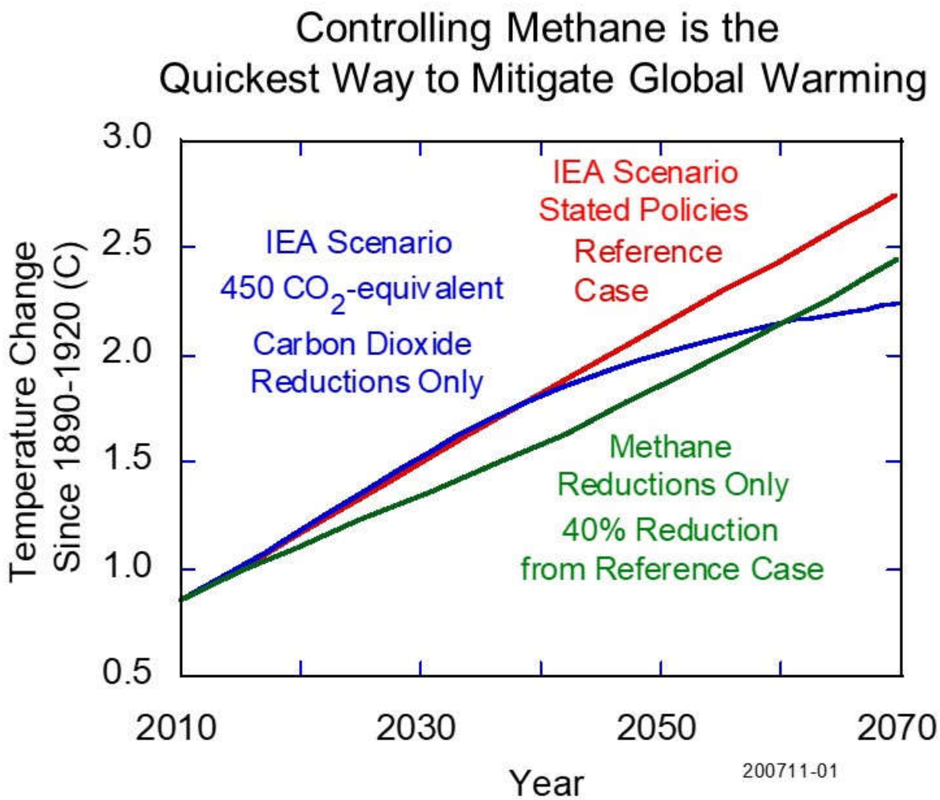

Shindell et al., Science 335, 183-189 (2012)

Methane emission reductions are the quickest way to slow global warming. Methane breaks down in the atmosphere with a time constant of about 12 years, whereas carbon dioxide has an atmospheric lifetime of centuries. Therefore, once methane is reduced, temperature effects are prompt. This plot shows the effect of reducing carbon dioxide emissions (blue) or methane emissions (red), starting in 2012.

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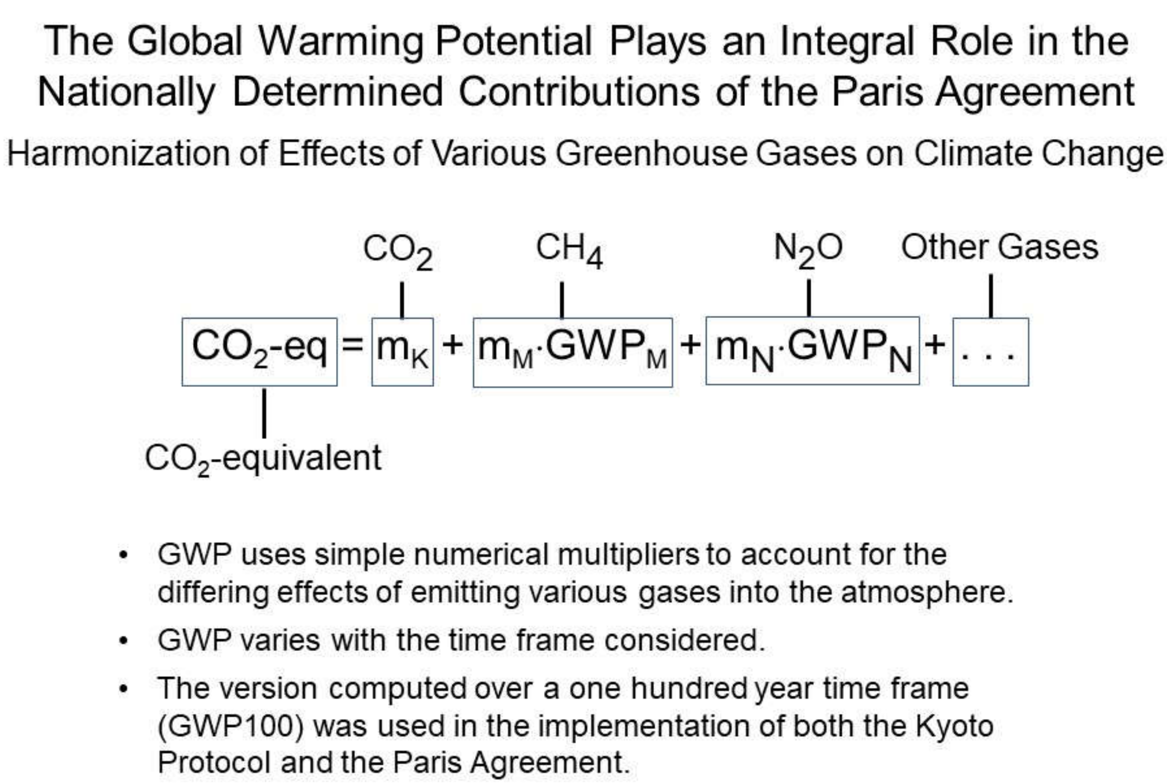
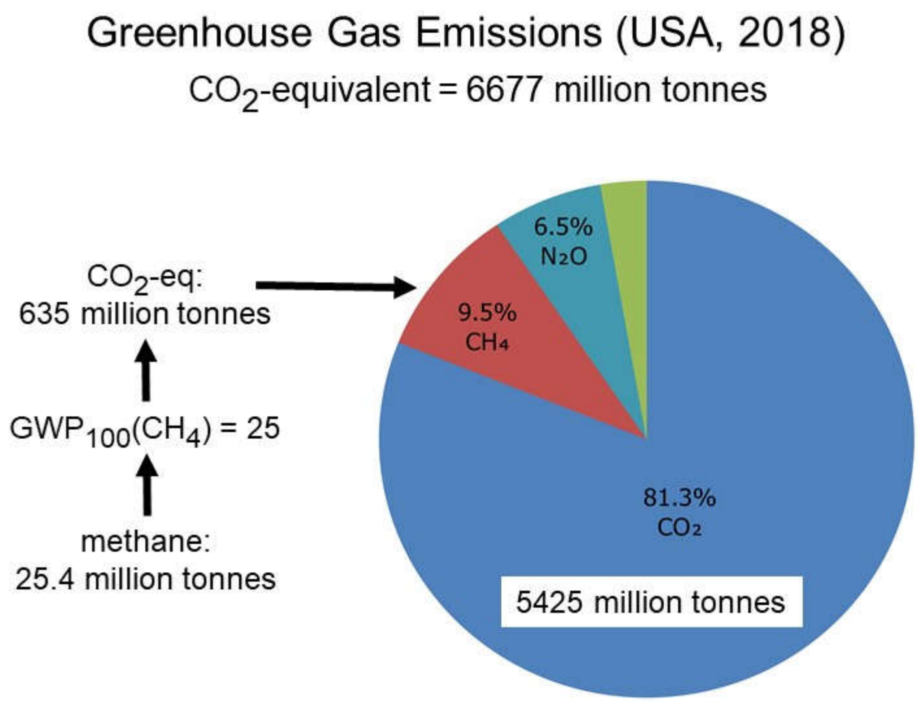
THE GLOBAL WARMING POTENTIAL AND THE CO_2-EQ METHODOLOGY

SUMMARY: The Global Warming Potential (GWP) underlies the CO_2-equivalent methodology, used in international climate agreements to harmonize the effects of diverse greenhouse gases on climate change. However, GWP suffers from major conceptual problems, and has been criticized by many, including the climate scientists who introduced it in the First Assessment Report of the IPCC.



The Global Warming Potential (GWP) puts emissions of diverse greenhouse gases on a single CO_2-equivalent scale. This method has been used in international agreements to harmonize the nationally determined contributions of nations which promise to limit emissions of greenhouse gases other than carbon dioxide. There is no intention here to suggest this system be changed. However, in selecting policy instruments to actually mitigate global climate change, the CO_2-eq method and the global warming potentials on which it is based can be deceptive.



Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2018
U.S. Environmental Protection Agency, 2020, EPA 430-R-20-002
https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

The US Greenhouse Gas Inventory published by the Environmental Protection Agency uses GWP to compare the contributions of the various greenhouse gases to climate change. This chart suggests that carbon dioxide is the dominant contributor. This is deceptively over-simplified. See page 8, where it is shown that methane is an equal contributor to prompt temperature increases.

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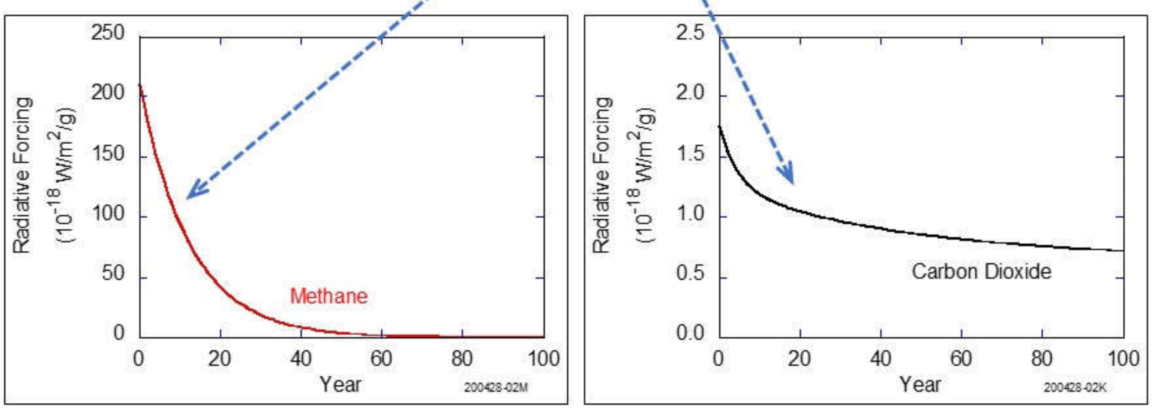
Global Warming Potential

RF = radiative forcing (W/m^2/g)

$$GWP_{CH_4}(T) = \frac{\int_0^T RF_{CH_4}(t)\,dt}{\int_0^T RF_{CO_2}(t)\,dt}$$



The Global Warming Potential of methane is the ratio of two integrals. The numerator is the integral over time of the radiative forcing due to a unit mass of methane emitted to the atmosphere at t=0. The integrand is shown at the lower left. Dimensions are incident power per square meter per gram. Methane is oxidized and removed from the atmosphere with a time constant of 12.4 years. The denominator is the analgous quantity for carbon dioxide, the integrand being shown on the lower right. Atmospheric carbon dioxide is characterized by a multiexponential decay, with the longest time constants on the order of centuries. The upper bound of both integrals, T, is a relevant horizon time. T is often selected to be 20 years or 100 years.

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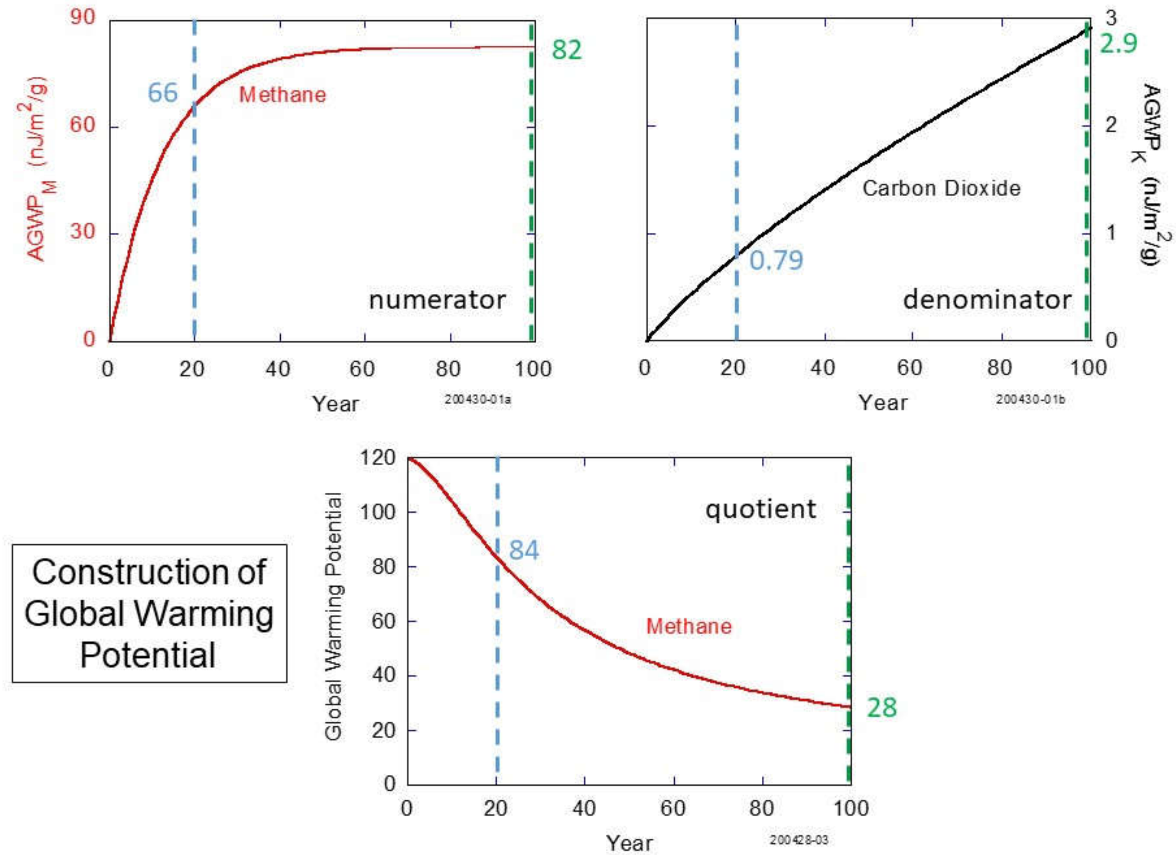

The integrations of GWP numerator and denominator are shown on the upper left and upper right. The vertical axis dimensions are cumulative energy per square meter per gram. The horizontal axis is the upper limit of integration, T. GWP, at the bottom, is computed by dividing numerator and denominator at each time point T. Note that although the methane integral stops changing after about 40 years (by which time 95% of the methane emitted at t=0 has disappeared from the atmosphere), GWP continues to change because the denominator continues to grow.

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Global Warming Potential is Widely Used and Widely Criticized

GWP is

- poorly grounded in physics
- arbitrarily designed
- ignores the time dependence of emission sources
- difficult to understand intuitively
- overly naïve as a policy driver
- in some cases potentially misleading

The same doubts have been expressed by the convening lead author of the relevant chapter in the First Assessment Report of the Intergovernmental Panel on Climate Change, in which GWP was introduced [Shine et al., 1990; Shine et al., 2009; Collins et al., 2020], and have been echoed by others over the years [O'Neill, 2000; Myhre et al., 2013a, page 711 and references therein].

Economists have also recognized the shortcomings of GWP, which has been rejected as a method to relate the social cost of methane to the social cost of carbon dioxide [IWG, 2016].

Problems of the Global Warming Potential

Unphysical

The earth is not a simple integrator of radiative forcing. It is in dynamic equilibrium with a low temperature reservoir and has multiple thermal lags.

Arbitrary

The choice of an upper limit of integration has no clear connection to temperature trajectories.

Unintuitive

The climate scientists who invented it can't explain it.

> "It must be stressed that there is no universally accepted methodology for combining all the relevant factors into a single [metric] . . . A simple approach [i.e. the GWP] has been adopted here to illustrate the difficulties inherent in the concept." [Shine, 2009, quoting from the First Assessment Report]

For detailed discussions of these points see: R.L. Kleinberg, 2020. The Global Warming Potential Misrepresents the Physics of Global Warming Thereby Misleading Policy Makers, EarthArXiv: https://doi.org/10.31223/X5P88D

https://www.bu.edu/ise/files/2020/11/the-global-warming-potential-misrepresents-the-physics-of-global-warming-thereby-misleading-policy-makers-final.pdf

https://www.essoar.org/doi/10.1002/essoar.10504991.1

TEMPERATURE MODELING:

A BETTER WAY TO UNDERSTAND THE EFFECT OF GHG EMISSIONS

SUMMARY: No single-number metric adequately represents the effects of greenhouse gases having widely differing radiative efficiencies atmospheric lifetimes, and emission histories. Direct calculation of global average surface temperatures is a much better way of dscriminating between policy alternatives.

Better Ways to Understand the Climate Impacts of Greenhouse Gases

- General circulation models
- Reduced complexity models (e.g. Model for the Assessment of Greenhouse Gas Induced Climate Change: MAGICC)
- Simple models of global mean temperature change based on closed form equations [Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2013]

$$\Delta_K(T) = RE_K \sum_{j=1}^{2} \{a_0 c_j [1 - \exp(-T/d_j)] + \sum_{i=1}^{3} \frac{a_i \tau_i c_j}{\tau_i - d_j} [\exp(-T/\tau_i) - \exp(-T/d_j)]\} \quad (1)$$

$$\Delta_M(T) = RE_M \sum_{j=1}^{2} \frac{\tau_M c_j}{\tau_M - d_j} [\exp(-T/\tau_M) - \exp(-T/d_j)] \quad (2)$$

$$\Delta_M(T) = A_M \sum_{t=0}^{T} m_M(t) \left\{ \sum_{j=1}^{2} \frac{\tau_M c_j}{\tau_M - d_j} \left[\exp(-(T-t)/\tau_M) - \exp(-(T-t)/d_j) \right] \right\} \quad (3)$$

Carbon Dioxide	a_0	0.2173		
	a_1	0.2240	τ_1	394.4 years
	a_2	0.2824	τ_2	36.54 years
	a_3	0.2763	τ_3	4.304 years
Methane			τ_M	12.4 years

Parameters for the atmospheric lifetimes of carbon dioxide and methane

c_1	0.631 °C/(W/m^2)	d_1	8.4 years
c_2	0.429 °C/(W/m^2)	d_2	409.5 years

Thermal time constants of the earth

R.L. Kleinberg, 2020. The Global Warming Potential Misrepresents
the Physics of Global Warming Thereby Misleading Policy Makers
EarthArXiv: https://doi.org/10.31223/X5P88D

These are equations for incremental changes of global mean surface temperature due to a unit mass increase of atmospheric carbon dioxide (Eqn 1) and methane (Eqn 2), as published in the Fifth Assessment Report of the IPCC. Also shown is a generalization of Eqn 2, taking into account time-varying emissions of methane (Eqn 3). There is an analogous equation accounting for time-varying emissions of carbon dioxide. These equations are simple enough to be coded on spreadsheets. They lack the sophistication of general circulation models and their reduced complexity offspring, but include enough physics to provide semi-quantitative estimates of the consequences of policy alternatives.

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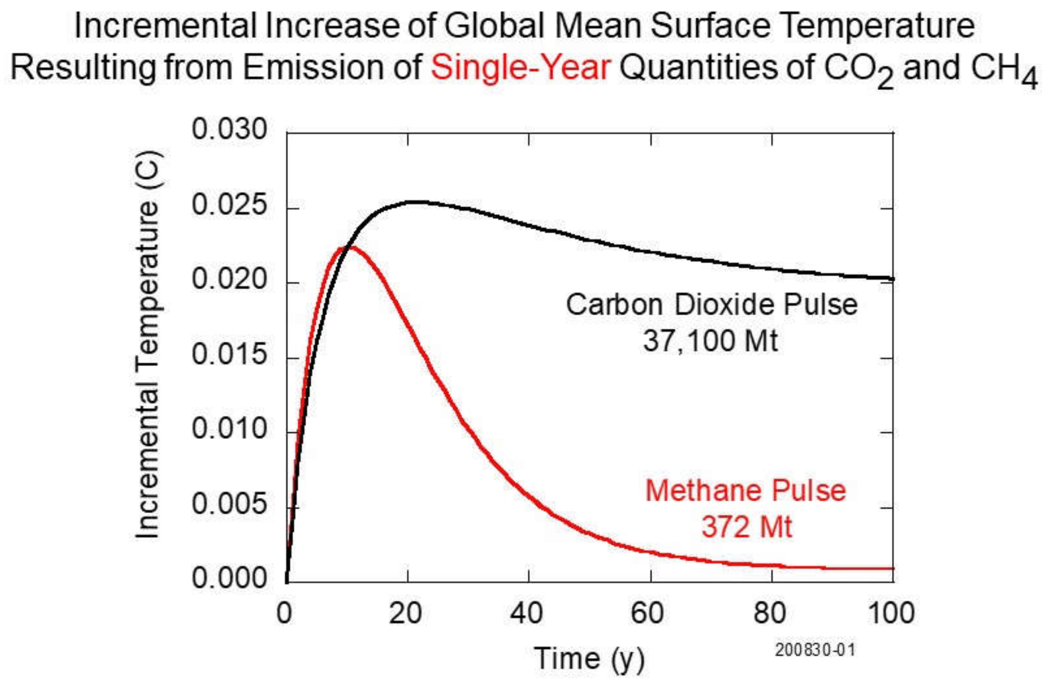

R.L. Kleinberg, 2020. The Global Warming Potential Misrepresents the Physics of Global Warming Thereby Misleading Policy Makers
EarthArXiv: https://doi.org/10.31223/X5P88D

The IPCC equations show that single-year emissions of carbon dioxide (black) and methane (red) at their current global rates have comparable effects on global mean surface temperature for the ten years following emission. This despite the fact that 100 times more carbon dioxide is emitted per year.

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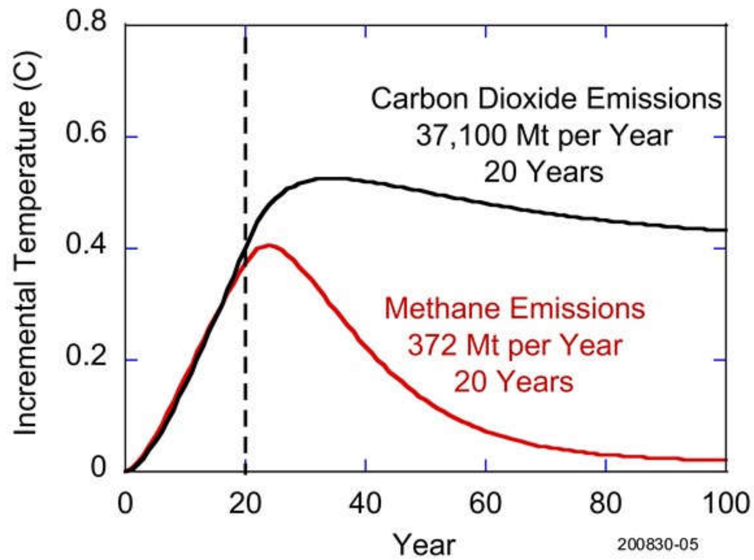
Incremental Increase of Global Mean Surface Temperature
Resulting from Emission of **20-Year** Quantities of CO_2 and CH_4



R.L. Kleinberg, 2020. The Global Warming Potential Misrepresents
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The multiyear extensions of the IPCC equations [Kleinberg, 2020] show that carbon dioxide (black) and methane (red) have comparable effects on global mean surface temperature as long as they are both emitted at current rates.

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APPLICATIONS: CLIMATE EFFECTS OF POWER GENERATION OF GAS VS COAL; GAS TRANSPORT BY PIPELINE VS LNG

SUMMARY: Examples show how GWP methods can be misleading. (1) GWP is a poor method for computing greenhouse gas offsets. (2) CO_2-equivalent methodology provides poor support for selecting real world climate mitigation options.

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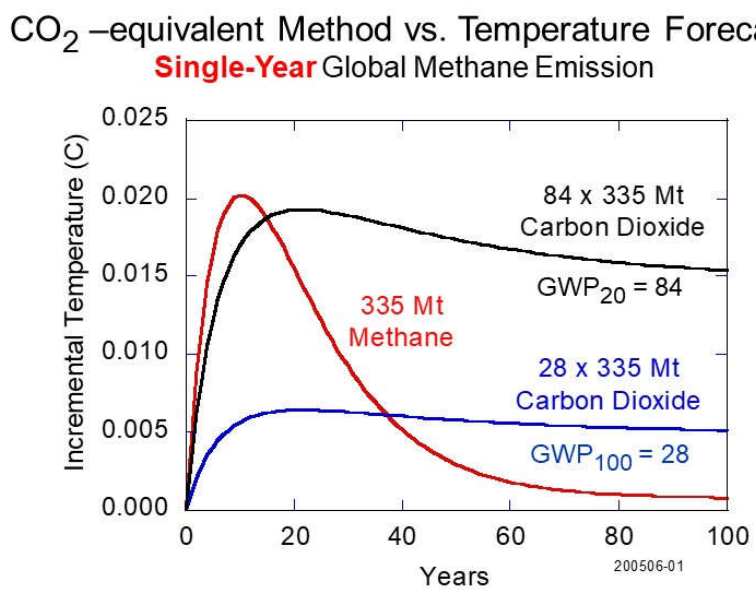
(1) GWP is a poor method for computing greenhouse gas offsets.*

* E.D. Sherwin suggested this example.



R.L. Kleinberg, 2020. The Global Warming Potential Misrepresents the Physics of Global Warming Thereby Misleading Policy Makers EarthArXiv: https://doi.org/10.31223/X5P88D

The CO_2-equivalent method implies temperature changes very much at variance with actual temperature calculations. The increase in global mean surface temperature for a single-year emission of 335 Mt methane at t = 0 is shown in red. The CO_2-eq method suggests very different temperature trajectories for the 20-year GWP multiplier (black) and the 100-year GWP multiplier (blue).

As a practical example, consider a refinery seeking an offset for the carbon dioxide it emits as an inescapable by-product of petroleum processing. It proposes to reduce its methane

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emissions by use of engineering controls. There is no GWP mutiplier it can apply to its methane reduction that will compensate for its carbon dioxide emissions.

(2) CO_2-equivalent methodology provides poor support for selecting real world climate mitigation options.

Hypothetical

You are the Energy Minister of Poland. You have been charged with reducing your nation's contribution to global climate change in the most cost-effective manner possible. Do you:

- Keep burning coal, by far the most economical solution.
- Continue using cheap domestic coal, but upgrade the power plants.
- Shut down your coal burning electric power plants and buy Russian gas for your new gas turbines.
- Shut down your coal burning electric power plants and buy American LNG for your new gas turbines.

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NATIONAL ENERGY TECHNOLOGY LABORATORY

LIFE CYCLE GREENHOUSE GAS PERSPECTIVE ON EXPORTING LIQUEFIED NATURAL GAS FROM THE UNITED STATES: 2019 UPDATE

SELINA ROMAN-WHITE, SRIJANA RAI, JAMES LITTLEFIELD, GREGORY COONEY, TIMOTHY J. SKONE, P.E.

September 12, 2019

DOE/NETL-2019/2041

The National Energy Technology Laboratory (NETL) released a lifecycle emission study of power generation in Europe for three cases: domestic coal burned in coal-fired power plants, Russian pipeline gas burned in gas-fired power plants, and US liquefied natural gas burned in those plants. I take their input assumptions at face value without necessarily endorsing them.

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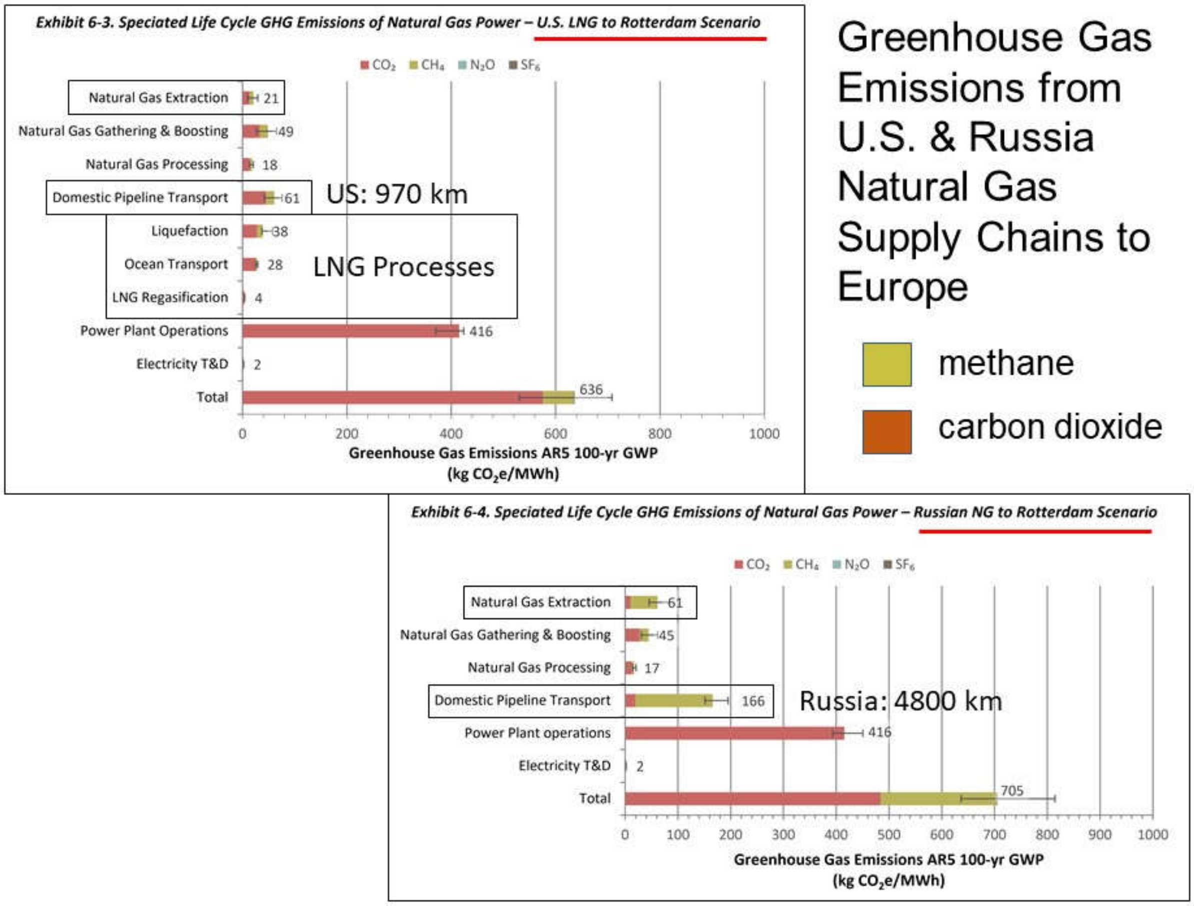

Two cases from the NETL study are shown here. At the upper left is an analysis of the GHG impact of US LNG fueling a gas-fired power plant. At the lower right is an analysis of the Russian pipeline case. Carbon dioxide emissions (brick color) and methane emissions (yellow/green color) are put on the same scale (CO_2-eq/MWh) using GWP=36 for methane.

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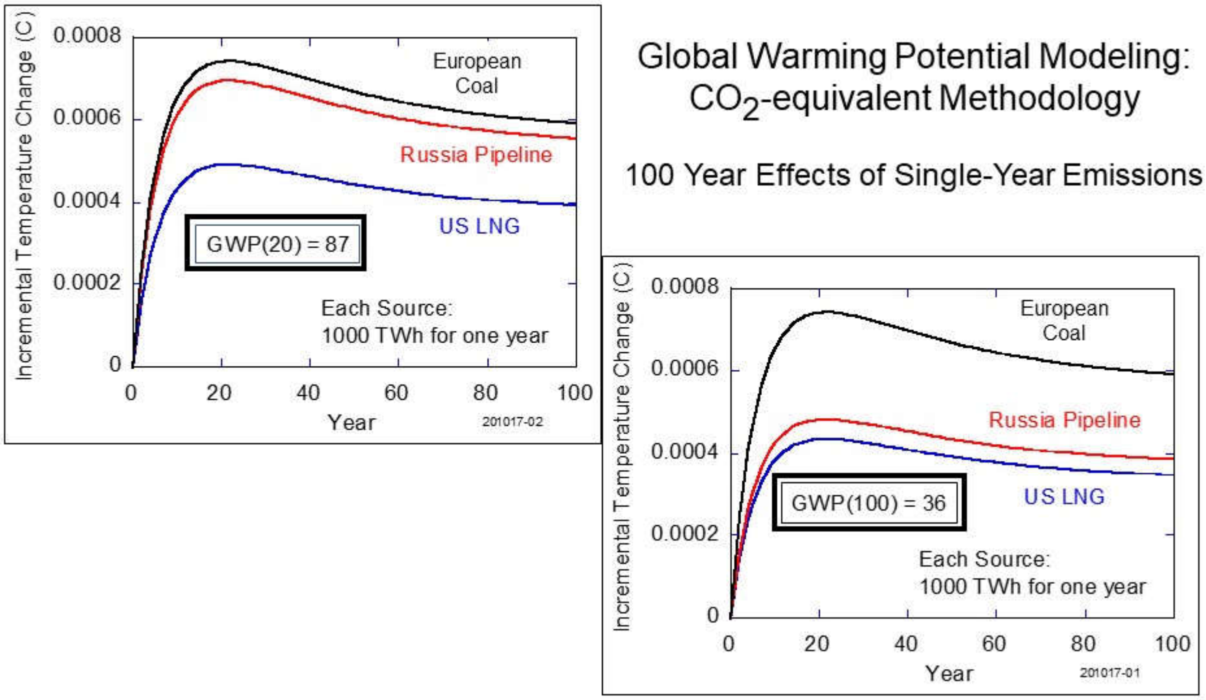

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Incremental temperature trajectories resulting from sinlge year GHG emissions are shown here. The methane contribution with the 20-year GWP multiplier of 87 is shown in the upper left. The methane contribution with the NETL 100-year GWP multiplier of 36 is shown in the lower right.The results are strikingly different. The GWP100 calculations suggest there is little difference between pipeline and LNG supply. The GWP20 calculation suggests a much larger, persistent difference between pipeline and LNG supply with the pipeline having consistently higher impact.

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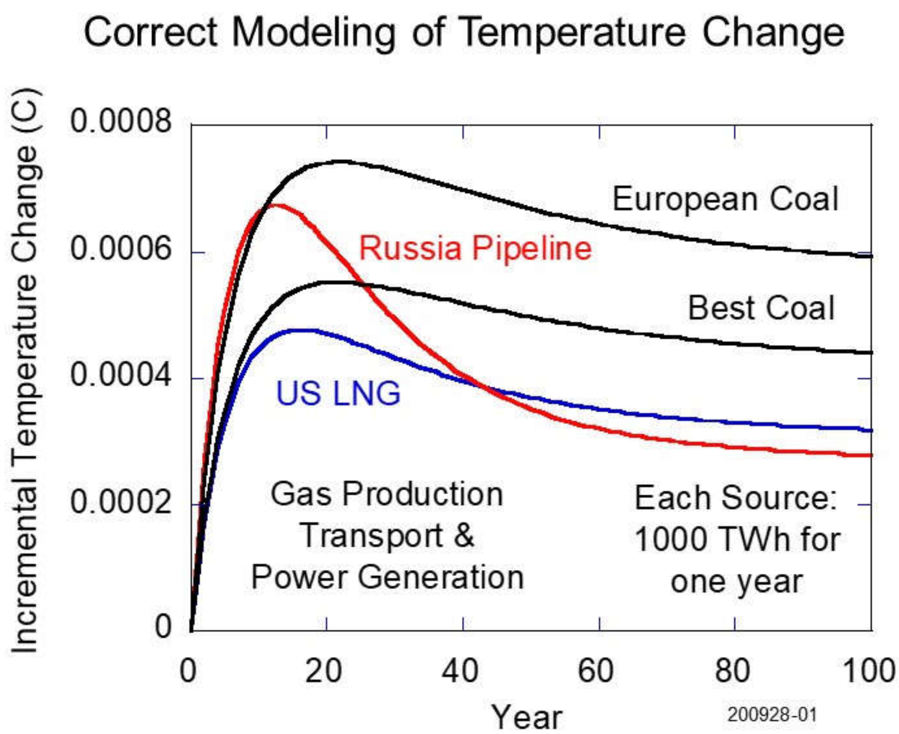

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The actual temperature calculations for the three cases are supplemented by a calculation for the lowest emitting coal-fired power plant ("Best Coal"). The results show that larger methane emissions associated with the pipeline have a significant impact in early years, but eventually become less significant than the higher carbon dioxide emissions associated with LNG. Considering the long service lifetimes of the infrastructure, the methane effect will continue to be important for many decades.

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AUTHOR INFORMATION

Robert L. Kleinberg, Ph.D.
Member of the National Academy of Engineering
Senior Fellow, Boston University Institute for Sustainable Energy
Senior Research Scholar, Columbia University Center on Global Energy Policy
robert@robertkleinberg.com
http://www.linkedin.com/pub/robert-kleinberg/19/177/131

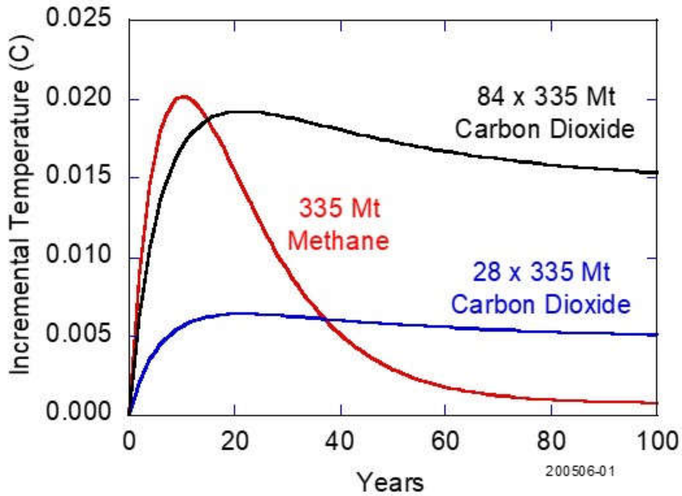
ABSTRACT

The Global Warming Potential (GWP) is a widely used single-number metric used to compare the climate change effects of various greenhouse gases. Although GWP has an established role in international climate agreements, it is unphysical, unintuitive, arbitrary, ignores the time dependence of emission sources, and is in some cases misleading. The same doubts have been expressed by the convening lead author of the relevant chapter in the First Assessment Report of the Intergovernmental Panel on Climate Change, in which GWP was introduced. GWP and the related CO_2-equivalent methodology have no place in describing the effects of climate change mitigation strategies beyond a 20 year horizon.

An important element of sound policy making is the quantitative analysis of policy interventions. This work argues for the broader use of temperature change trajectories in educating policymakers and the public about greenhouse gas control. Modeling tools include general circulation models, related reduced complexity models, and simpler models of global mean temperature change. Unfortunately these are underutilized in describing the leading physical principles of global warming to non-specialists and transparently illustrating the consequences of various climate policy interventions.

Examples are presented illustrating the misleading nature of GWP and the CO_2-equivalent methodology. These include the use of natural gas and coal in the electric power sector, and the pipeline and LNG transport of natural gas.

Responding to climate change is likely to require global investments measured in trillions of dollars. Clear and accurate communication among and between scientists, policymakers, and the general public is essential. GWP is a crude, inaccurate tool that played a constructive role in the formulation of international agreements. Using better modeling tools can help make climate policy discussions more scientifically rigorous while demystifying the criteria upon which policy choices are made.



Temperature trajectory of a 335 Mt pulse of methane at t = 0 (red) compared to temperature trajectories for corresponding CO_2-eq pulses for GWP_{20} = 84 (black) and GWP_{100} = 28 (blue).

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and 66 refererences therein