The Greenhouse Effect, a Comparison of Greenhouse Gas Contributions from Fossil Fueled and Geothermal Power Plants with Potential Solutions for Emission Reductions

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ABSTRACT

Fossil fueled power plants across the world emit greenhouse gases that contribute to global warming. Geothermal power is considered a "green" alternative to coal, oil and gas fired power production. But how green is it? Analysis of the non-condensable gases that come out of The Geysers' reservoir with the geothermal steam show varying amounts of carbon dioxide and methane. These constituents pass through the power production cycle; the CO_2 is emitted to the atmosphere, and so is the CH_4 unless it is burned as part of the hydrogen sulfide abatement process. This paper reviews a basic understanding of the greenhouse effect, and evaluates the relative contribution of greenhouse gas emissions from a geothermal power plant compared to other forms of power production, and proposes possible solutions to reduce these emissions.

1. Introduction

Climate change includes both global warming (the gradual increase in average surface temperature of the Earth) and its impact on Earth's weather patterns. During Earth's long history, there have been previous periods of climate change, however, most scientists agree that the current rapid rate of change is due to human-made emissions rather than due to natural phenomena. The so called "Greenhouse Effect" is caused by the emission of gases that trap radiant energy that normally would flow from the Earth's surface out into space.

Any warm mass radiates energy proportional to its temperature – the Sun at about 5,500 °C (9,930 °F) emits most of its energy as ultraviolet, visible and near infrared light. Approximately 75% of this energy arriving from our Sun passes through Earth's atmosphere, which does not absorb energy well at these wavelengths, and warms its surface. (25% of the sun's energy is reflected by Earth's atmosphere back into space). Earth's average surface temperature of about

15 °C (59 °F) is much cooler than the sun so it emits longer wavelength infrared radiant heat which is absorbed by natural “greenhouse gases” in our atmosphere. The atmosphere re-radiates energy both upwards and downwards; the part radiated downwards is absorbed again by the surface of Earth. This leads to a higher equilibrium temperature than if the atmosphere did not both absorb and radiate energy. Without the natural greenhouse effect, Earth's average temperature would be well below freezing. Current human-caused increases in greenhouse gases cause greater amounts of energy to be absorbed by the atmosphere and re-radiated by the atmosphere back to Earth, causing the Earth to grow warmer over time.[1]

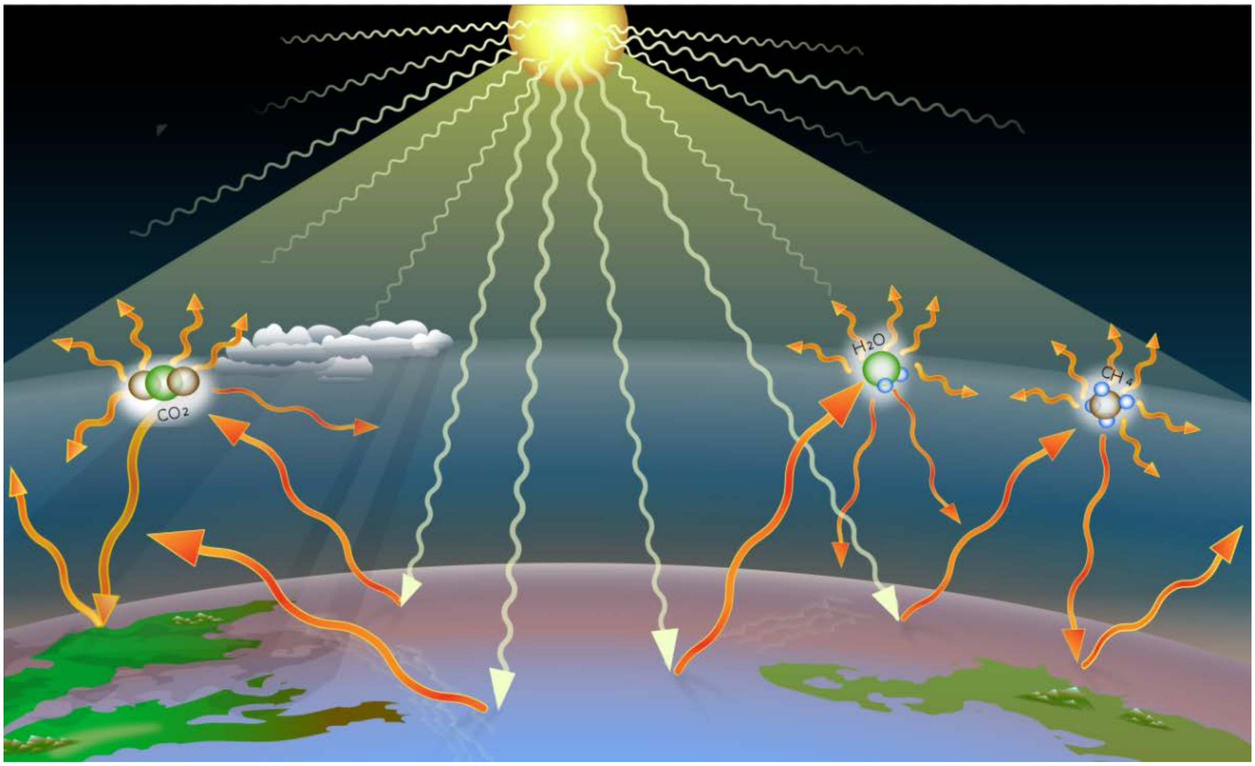


Figure 1: Diagram of radiant energy flow between the Sun, Earth, Earth’s Atmosphere, and Space.[2]

Greenhouse gases are specific airborne compounds that can absorb energy in the infrared radiation wavelength. The gases are ranked based on their global warming potential (GWP) which is the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass as the reference gas, carbon dioxide (CO_2). Thus it provides a common scale for measuring the climate effects of different gases. GWP is 1 for CO_2.

The GWP depends on the following factors:

- The absorption capacity of infrared radiation (dependent on chemical structure and bonds). A gas has the most effect if it absorbs in a "window" of wavelengths where the absorption by the natural atmospheric components is fairly transparent.
- The time horizon of interest (most regulators use 100 years).
- The atmospheric lifetime of the gas (how quickly the gas species is removed from the atmosphere)[3].

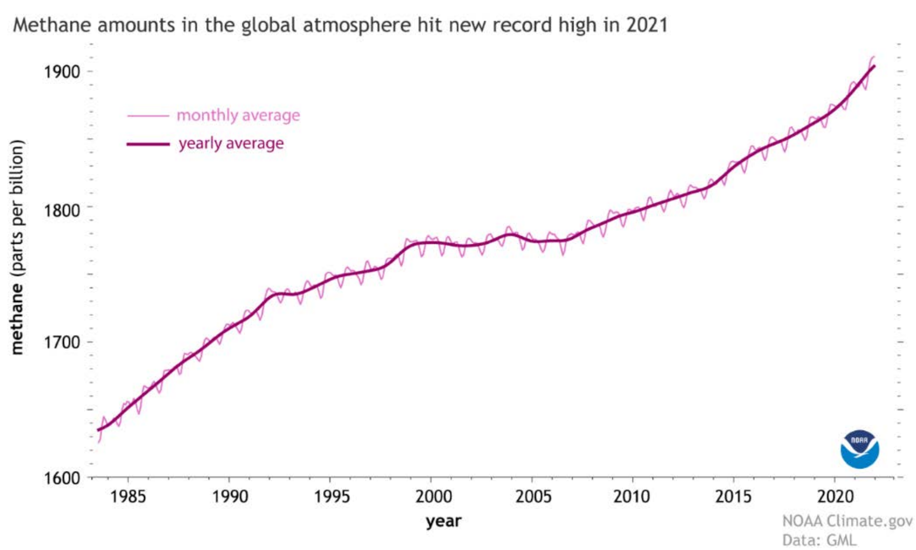
Table 1: Global Warming Potential values for CO_2 and CH_4. Table amended to show only the two most predominant greenhouse gases emitted from geothermal and fossil fueled power plants[4]

Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second Assessment Report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
Carbon dioxide	CO_2	1	1	1
Methane	CH_4	21	25	28

Water is actually the strongest greenhouse gas, because it has a profound infrared absorption spectrum with more and broader absorption bands than CO_2. However, it is removed via precipitation within weeks, so its GWP is negligible.[5]

The major constituents of Earth's atmosphere, nitrogen (N_2 at 78% by volume), oxygen (O_2 at 21%) and argon (Ar at 0.9%), are not greenhouse gases because molecules containing two atoms of the same element, such as N_2 and O_2, have no net change in the distribution of their electrical charges when they vibrate. Monatomic gases, such as Ar, do not have vibrational modes. Therefore, none of these major constituents can absorb the infrared radiation emitted by the Earth.

In 2020, methane (CH_4) accounted for about 11% of all U.S. greenhouse gas emissions from human activities. Human activities emitting methane include leaks from natural gas systems and livestock. Methane is also emitted by natural sources such as wetlands. However, natural processes in soil and chemical reactions in the atmosphere help remove CH_4 from the atmosphere. Methane's lifetime in the atmosphere is much shorter than carbon dioxide (CO_2), but CH_4 is more efficient at trapping radiation than CO_2. Pound for pound, the comparative impact of CH_4 is 25 times greater than CO_2 over a 100-year period.[6]



Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. In 2020, CO_2 accounted for about 79% of all U.S. greenhouse gas emissions from human activities. Carbon dioxide is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle–both by adding more CO_2 to the atmosphere and by reducing the ability of natural sinks, like forests and soils, to remove and store CO_2 from the atmosphere. While CO_2 emissions come from a variety of natural sources, human-related emissions are implicated for the increase that has occurred in the atmosphere since the industrial revolution. CO_2 emissions cause increases in atmospheric concentrations of CO_2 that will last thousands of years.[7]

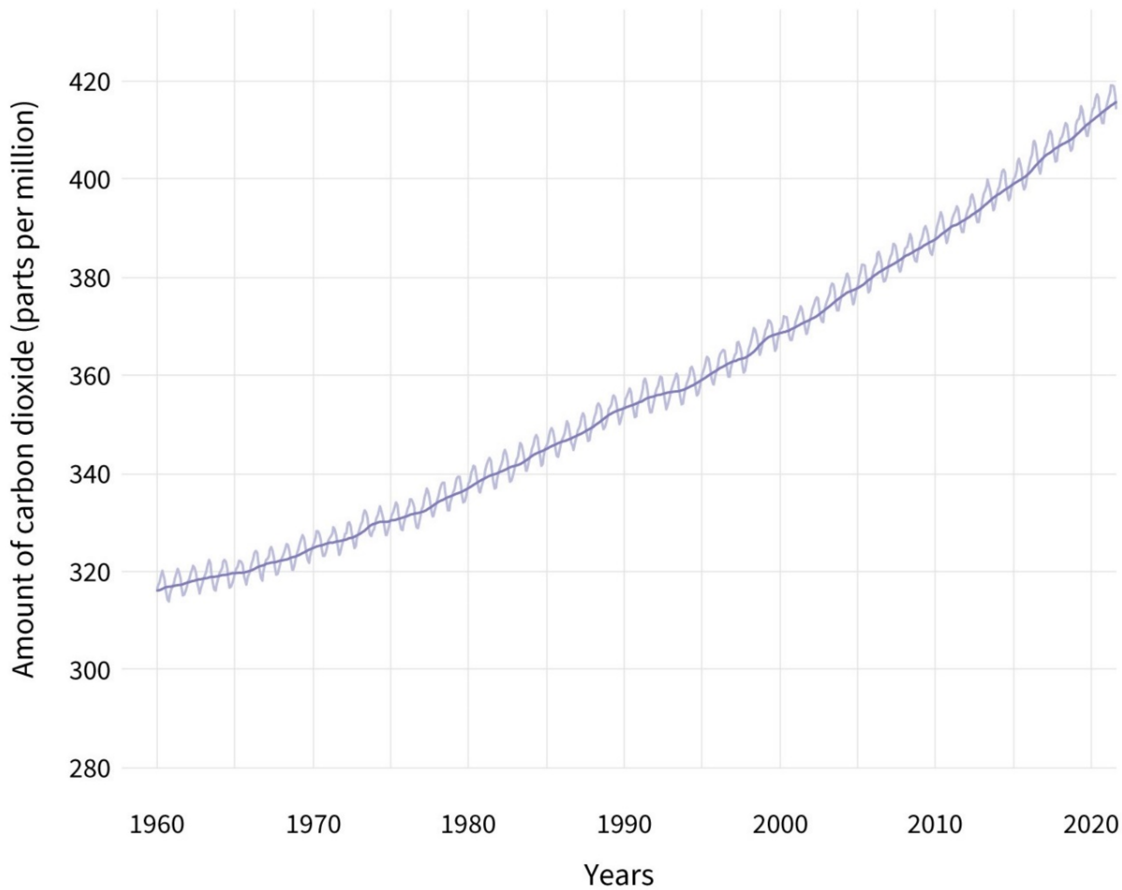


Figure 2: Atmospheric Carbon Dioxide (1960-2021)[7]

Carbon dioxide equivalent (CO_2e or CO_2eq or CO_2-e) is calculated from GWP. For any gas, it is the mass of CO_2 that would warm the earth as much as 1 kg of that gas. Thus, it provides a common scale for measuring the climate effects of different gases. It is calculated as GWP times mass of the other gas. For example, if a gas has GWP of 100, two tonnes of the gas have CO_2e of 200 tonnes.

2. Greenhouse Gas Emissions from Fossil Fueled Power Plants

In 2020, power plants that burned coal, natural gas, and petroleum, accounted for 62% of all U.S. electricity generation, but they account for 99% of U.S. electricity related CO_2 emissions. And even though fossil fueled power plants are being shut down all over the country in preference for cleaner sources of energy such as wind and solar, there is still a need for electricity generation that is not limited by nighttime darkness and calm, windless days.

Table 2: U.S. Electric Power Generation and CO_2 Emissions by Fuel 2020[8]

	Electric Generation (MWh)	CO_2 GWP Emissions (Metric Tons)	kg GWP/MWh
Coal	757,763,000	767,000,000	1,012
Natural Gas	1,402,438,000	576,000,000	411
Petroleum	13,665,000	13,000,000	951

(GWP =global warming potential)
Combined cycle plants are excluded because some of their CO_2 emissions are from fuel consumption for heating purposes.
*US Energy Information Administration, 2020[8]

3. Greenhouse Gas Emissions at The Geysers

Geothermal power is a reliable energy source that is available 24 hours a day, all year round. However, it is not 100% carbon free when it comes to greenhouse gas emissions and global warming potential. But the greenhouse gas emissions from geothermal power are more than an order of magnitude lower than those emitted from fossil fuel fired power plants.

Table 3: Summary of 2021 Green House Gas Emissions from Calpine Geysers Power Plants[9]

Net Generation MWh **5,519,164**

	Metric Tons		Metric Tons	kg GWP/MWh
	CO_2	CH_4	GWP	
Global Warming Potential (GWP) (CO_2 equivalent)	**1**	**25**	**CO_2 Equivalent**	
Power plants	126,788	3,021	202,314	37

The steam emanating from The Geysers' deep underground geothermal reservoir contains less than 1%wt non-condensable gases, including some CO_2, CH_4 and Hydrogen Sulfide (H_2S). The exact amounts of these three constituents varies over the geographical area of the known geothermal resource. It is believed that the CO_2, CH_4, and H_2S are natural remnants from volcanic activity in this region over 1.1 million years ago. (which, by the way, is also the source of the heat for the hot, dry steam that makes geothermal power in this area possible.)

Currently, The Geysers only has air pollution control regulatory limits for H_2S, SOx, NO_X, CO, HAPS>10 TPY and particulate emissions. Of these, only H_2S and SO_2 require special removal equipment to meet the emission limits. There are several methods used for removing H_2S from the non-condensable gases that are discharged from the power plant condenser. The thermal oxidation (burner) method at four of the power plants affects the greenhouse gas emissions by converting the CH_4 to CO_2 which is emitted to the atmosphere along with the rest of the CO_2. This reduces the global warming potential of the CH_4 portion of the NCG emissions by a ratio of 2.75:25. (remember that we need to take into account the fact that newly formed CO_2 (MW = 44) weighs more than CH_4 (MW = 16), so we don't get the full benefit of 1:25 reduction in global warming potential.)

However, eight of the power plants at The Geysers do not use burners for H_2S emission control. At these units the CH_4 along with most of the CO_2 passes through the power plants and are released to the atmosphere.

4. Case Study: Lake View-Unit 17

The steam that supplies Unit 17 comes from a relatively high non-condensable gas region of the geothermal reservoir. This unit uses a Stretford process for H_2S abatement rather than a burner. Consequently, since both the CO_2 and CH_4 will pass through a Stretford process, this power plant has the highest greenhouse gas emissions at the Geysers.

Table 4: 2021 Green House Gas Emissions from Calpine's Lake View-Unit 17[9]

Net Generation MWh	**471,638**			
	Metric Tons		**Metric Tons**	**Kg GWP/MWh**
	CO_2	**CH_4**	**GWP**	
Global Warming Potential (GWP) (CO_2 equivalent)	**1**	**25**	**CO_2 Equivalent**	
Unit 17	21,272	809	41,497	88

Although Lake View-Unit 17 emissions have a global warming potential far below the values created by fossil fuel power plants, the question arises, can we do better?

Listed below are several concepts that have been proposed for reducing CO_2 and CH_4 emissions. If the current level of GHG emissions from the geothermal industry are ever deemed unattractive for power purchase contracts, subsidies or tax credits, it may be prudent to evaluate the feasibility and economics of some of these proposals for future use in geothermal power plants.

1) Use a waste heat boiler (WHB)[10] to combust any non-CO_2 greenhouse gases (e.g., methane) to less GWP intensive CO_2. This may provide the extra benefit of generating some additional steam which could
    a) Supplement the geothermal steam and lower the GWP/MWh.
    b) Be used in a separate stand-alone power cycle to produce energy which could be classified and valued as “zero emission” power.
2) Use CO_2 in greenhouses (possibly after burning the NCG stream in a WHB and recovering heat?)
3) Direct injection of NCG underground into a suitable zone (assumes this is possible and does not cause other problems)
4) Purification of CO_2 (e.g., to ~90+%) and then injection into a suitable zone purely for sequestration
5) Purification of CO_2 to EOR grade and transport it to a location that can use it for enhanced oil recovery (EOR)
6) Purification of CO_2 to beverage grade (this CO_2 ends up emitted when the beverage is drunk, but it might displace other CO_2 and may reduce carbon footprint
7) Conversion of CO_2 to methanol, MeOH
8) Conversion of CO_2 to other hydrocarbons or chemicals (via syngas route)
9) Purification of CO_2 and use as a concrete additive (note, this is a sequestration measure and not a value-adder for concrete. This may have the benefit of qualifying for tax credits)

5. Conclusion

Although geothermal power may not be 100% carbon free, its greenhouse gas emissions are far below the amount emitted from conventional fossil fueled power plants on a per megawatt basis. This fact coupled with the potential to lower GHGs even more with enhanced technology, should make geothermal power a preferred choice within the electric industry. The even lower global warming potential could be a valuable selling point for geothermal power.

6. References

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[2]A loose necktie, July 12, 2019 File: Greenhouse-effect-t2.svg Wikimedia Commons, Licensed under the Creative Commons Attribution-Share Alike 4.0 International license

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