Water Vapor from Thermoelectric Power Plants, Does it Impact Climate?

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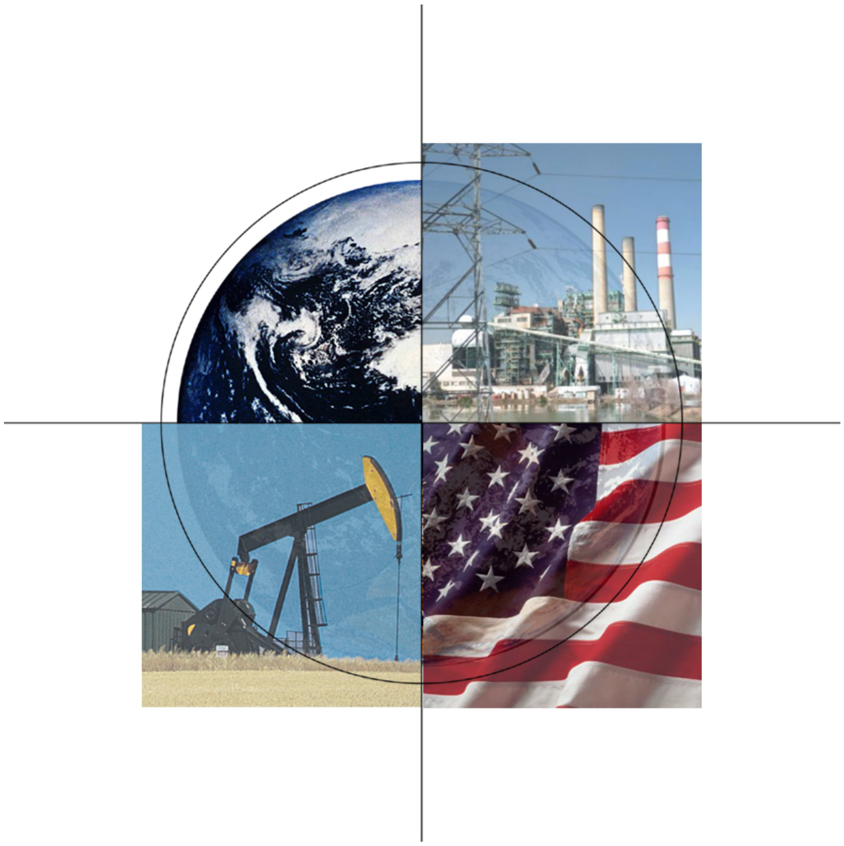

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It is difficult to experimentally parse the radiative forcing effects of different gases in the atmosphere, but most scientists agree that water vapor accounts for 90-95% of the total greenhouse gas effect.

This leads to the question, “Do the clouds of steam billowing from power plant chimneys exert a global climate change impact, in addition to the impact from CO_2?”

The greenhouse gas effects of water vapor in the atmosphere have an important impact on the global climate change models. As the air temperature increases the air holds more water vapor, and so water vapor “amplifies” the effect of CO_2 and methane emissions. This understanding was an important evolution in global climate change models.

But there is an important fundamental difference between emissions of water vapor and emissions of CO_2 and methane. Unlike carbon dioxide and methane, the concentration of water vapor in atmosphere fluctuates rapidly with changes in the temperature and pressure of the air. That is, a molecule of water vapor emitted from a power plant will condense out if and when the air gets cold, and the associated greenhouse gas effect will end. Not so with CO_2 and methane - they stay in the atmosphere and redirect photons until they undergo a chemical reaction. Once emitted, these molecules can remain in the atmosphere for decades or centuries.

The natural water cycle maintains a relatively constant humidity in the global atmosphere and so the effective lifetime of water vapor emissions is a few weeks or less. It is because of this effect, the very short “lifetime” of water vapor emissions in the atmosphere, that water vapor emissions do not exert significant direct greenhouse effects.

The effect of clouds on the climate system is complicated and probably the least understood mechanism of the planet’s climate. Clouds reflect sunlight, which reduces solar radiation input to the atmosphere. However, clouds also trap heat radiation emitted by the Earth, as does water vapor. Further complicating the analysis is that clouds are highly interactive with the Earth's surface. They regulate the amount of sunlight received by the surface and so influence evaporation from the surface, which in turn influences cloud formation. Precipitation from clouds, in turn, influences soil moisture and evaporation rates. Most climate models treat clouds as providing positive feedback to temperature increases in the atmosphere[i]. Local perturbations in water vapor concentrations due to human actions have been observed[ii,iii], but no evidence of global climate effects has been found.

For completeness of argument, the following analysis compares the magnitude of (1) water vapor emissions from fossil fuel conversion in a thermoelectric power plant and (2) the amount of water cycled in the natural evaporation/precipitation cycle.

In a thermoelectric power plant, a fuel is combusted to produce heat, which then generates steam that turns an electrical turbine. Fuels containing hydrogen and carbon (coal, petroleum, natural gas, etc.) which are combusted in the presence of oxygen produce carbon dioxide (CO_2) and water (H_2O) in vapor form. The table below shows how much water vapor would be produced if the current resources of all worldwide fossil fuels were combusted at once.

Table 1. Water vapor emissions if all worldwide fossil fuel resources were combusted

Fuel	Worldwide resources[iv]		Fuel conversion factor		Weight of fuel (B mt)[v]	H_2O emissions factor from combustion[vi] (mt H_2O/ mt fuel)	H_2O emissions (B mt)
Coal	1,000	B tons	0.908	B mt/ B tons	726	0.45	327
Crude oil	2,300	B bbls	0.140	B mt/ B bbls	323	1.42	458
Natural gas	13,650	Tcf	0.020	B mt/ Tcf	278	2.25	625
Total water vapor emissions from fossil fuel combustion							1,410
B= billion, bbl = barrel, mt = metric ton, Tcf = trillion cubic feet							

After a thermoelectric power plant's steam has passed through the electrical turbine, it must be cooled back to a liquid, typically by an external source of water. As this external water absorbs heat from the power plant's steam, it evaporates and enters the atmosphere as water vapor. To estimate water vapor production from cooling water evaporation, an evaporation factor was developed using the typical water consumption, heat rate and energy content for power plants using each fuel type.

Table 2. Water vapor emissions from coal drying and cooling evaporation for all worldwide fossil fuels

Fuel	Weight of fuel (B mt)[vii]	H_2O emissions factor from coal drying[viii] (mt H2O/ mt fuel)	H_2O emissions factor from cooling water[ix] (mt H2O/ mt fuel)	H_2O emissions (B mt)
Coal	726	0.2	5.6	4,211
Crude oil	323	N/A	3.0	969
Natural gas	278	N/A	6.6	1,834
Total water vapor emissions from coal drying and cooling towers				7,014
B= billion, bbl = barrel, mt = metric ton, Tcf = trillion cubic feet				

The final significant source of water vapor emissions from thermoelectric power production is from coal drying. Coal used for power production is typically 10 to 30% moisture by weight. Many plants heat their coal before combustion in order to remove this moisture which enters the atmosphere as water vapor. Table 2 includes both emissions of water vapor from fuel drying and cooling towers. It is important to note that coal drying and cooling systems are active areas of research and development within the Department of Energy and elsewhere, and that advances in these areas will lead to even fewer water vapor emissions.

Table 3. Worldwide potential emissions from power production

Water vapor source	Amount (Billion metric tons)
Combustion-based	1,410
Drying and cooling water	7,014
Total from thermoelectric power (all worldwide fossil fuel resources)	**8,424**

This conservative estimate calculates that conversion of all worldwide fossil fuels for thermoelectric power will generate roughly 1 x 10^{16} kilograms (kg) of water vapor, Table 3. To put this in perspective, the current amount of water vapor in the atmosphere is 1.3 x 10^{16} kg water[x]. Spreading the effect of the conversion over 100 years gives a water vapor emissions rate of 1 x 10^{14} kg water vapor per year. This is roughly 1% of the total amount of water vapor in the atmosphere or 0.02% of annual rainfall worldwide (5 x 10^{17} kg water).

Summary

Although it is widely accepted that water vapor amplifies the forcing effects of CO_2, methane, and other greenhouse gases, it does not appear likely that anthropogenic additions of water vapor to the atmosphere have a direct effect. The small scale of water vapor emissions from thermoelectric power plants and the rapid natural response of the water cycle to changes in water vapor concentration both indicate that this is probably not an area of concern.

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[i] Soden, B. and Held, I., *An Assessment of Climate Feedbacks in Coupled Ocean–Atmosphere Models,* Journal of Climate. 19, 3354-3360, (2006)

[ii] Robinson, P. J. *Temporal trends in United States dew point temperatures*. International Journal of Climatology. 20, 985–1002 (2000).

[iii] Wang, J. X. L. & Gaffen, D. J. *Late-twentieth-century climatology and trends of surface humidity and temperature in China*. Journal of Climatology. 14, 2833–2845 (2001).

[iv] U.S. Department of Energy, National Energy Technology Laboratory, *2006 Carbon Sequestration Technology Roadmap*
www.fossil.energy.gov/**sequestration**/publications/programplans/**2006**/**2006_sequestration_roadmap**.pdf
Does not include hydrates and oil-bearing shales

[v] Product of the worldwide resources and conversion factor to metric tons. For coal, it is assumed that 20% of the mass is water. Of the total 908 B mt of coal worldwide, stoichiometric analysis is then applied to the 80% of that as dry coal.

[vi] The emissions factor were developed using the stoichiometric equations of combusting the different fuels. This calculation assumes that the fuels are completely pure and that these are the only reactions that take place, providing a conservatively large estimate. The equations below show the stoichiometrics of combusting the different fuels:

Natural gas: $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

Crude oil: $2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$

Coal: $2\ C_8H_5 + 21\ O_2 \rightarrow 8\ CO_2 + 5\ H_2O$

[vii] From Table 1.

[viii] Assumes coal used in power production is 20% moisture

[ix] Emissions factors calculated by the following product:

Water consumption	1/ heat rate	Energy content of fuel	Water to vapor conversion factor	Fuel conversion factor
gal / kWh	kWh / BTU	BTU / lb, scf, bbl	mt (H_2O) / gal	lb, scf, bbl / mt (fuel)

Sub-critical pulverized coal power plant
0.39 gal/kWh * (1/ 9,500 Btu coal/kWh) * 11,000 btu/lb coal * 0.00376 mt steam /gal water * 2,200 lb/mt coal = 5.6 mt steam per mt coal

Natual gas combined cycle power plant
0.13 gal/kWh * (1/8,500 Btu NG/kWh) * 1000 btu/scf * 0.00376 mt steam /gal water * 50,000 scf / mt NG = 6.6 mt steam per mt natural gas

Oil-fired steam power plant
0.16 gal/kWh * (1/9,000 Btu petroleum/kWh) * 6,287,000 BTU/bbl * 0.00376 mt steam /gal water * 7.14 bbl / mt petroleum = 3.0 mt steam per mt petroleum

Water consumption factors from:
Steigel, Gary etal. “Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements” Report DOE/NETL-2006/1235, August 2006.
http://www.netl.doe.gov/technologies/coalpower/ewr/pubs/WaterNeedsAnalysisPhaseI1006.pdf

Heat rates are estimates of typical plant.

[x] Trenberth, K. and Smith, L., *The Mass of the Atmosphere: a Constraint on Global Analyses*, National Center for Atmospheric Research, CLIVAR 2004 Conference, June 21-25, 2004 in Baltimore, Maryland, USA (2004).
http://www.cgd.ucar.edu/cas/abstracts/files/kevin2003_6.html