Natural Gas Cleanliness

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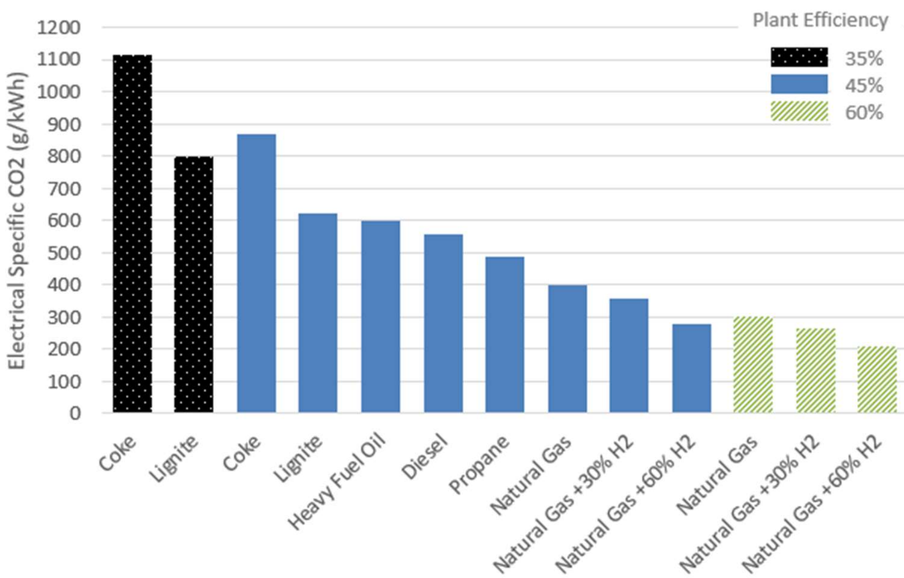
Natural gas is the cleanest fossil fuel energy source with 30% less CO_2 emissions per kWh than oil and close to 50% less than coal. Natural gas and coal are the two biggest sources of energy for electricity production with respectively 35% and 27% in 2018 in the US. As a result, natural gas is naturally a strong contributor to the carbon reduction and has an even stronger role to play in Electricity generation (28% of Green House Gas (82% of which are CO_2 in US) are generated by electricity production, 29% by transports and 22% by the industry, 12% and 9% are respectively due to Commercial & Residential and Agriculture). Not only the specific CO_2 release by natural gas combustion is much lower than coal, but the plants to convert to electricity are also much more efficient: Typically, 30 to 45% efficiency for coal plants, 37 to 45% for simple cycle gas turbine plants, 45% for reciprocating engine plants and 55 to 63% for combined cycle gas turbine ones. Beyond Green House Gas emissions, US coal content an average of 14% mass of ash and 0.9% sulfur, absent from natural gas.



The recent shift in electricity generation from coal to gas already provides significant CO_2 reduction: Whereas the combined contribution of coal and gas in electricity production has reduced by 10% between 2007 and 2018, CO_2 emission of these sources have reduced by 22% due to a balance coal/gas shift from 69/31 in 2007 to 44/56 in 2018, boosted by the availability and low cost of shale gas, greater flexibility of gas plants and greater environmental concerns.

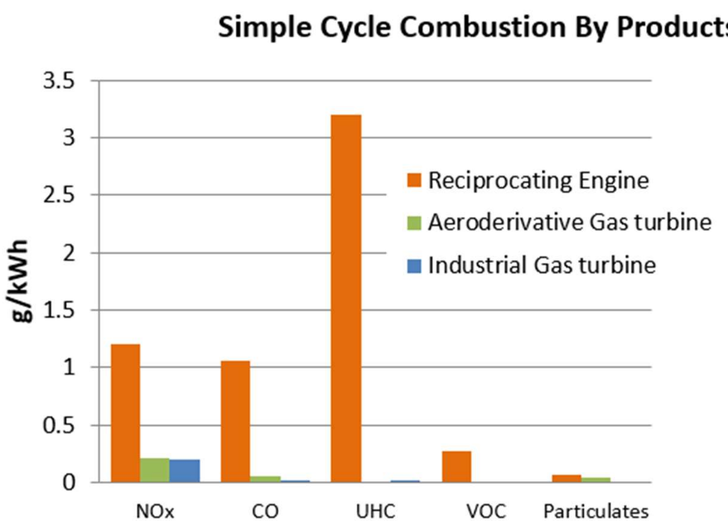
This shift from coal to gas saved 93.5 billions metric tons of CO_2 annually in 2018 only when compared to 2007 (with a 2007 production normalized to that of 2018); a reduction of almost 15% of 2018 CO_2 emissions generated by electricity production (i.e. combined coal, gas and oil).

		Fossil Fuel						
Power per year (TWh)	Coal	Oil	Gas	Subtotal	Nuclear	Renewable	Misc	Total
2018	**1 146.4**	**24.6**	**1 480.2**	**2 651.2**	**807.1**	**712.8**	**51.3**	**4 222.3**
Proportion 2018	27.15%	0.58%	35.06%	62.79%	19.11%	16.88%	1.21%	
2007	**2 016.5**	**65.7**	**910.0**	**2 992.2**	**806.4**	**352.7**	**36.6**	**4 187.9**
Proportion 2007	48.15%	1.57%	21.73%	71.45%	19.26%	8.42%	0.87%	

	Coal	Oil	Gas	**Total**	Coal+Gas
kg CO2/kWh	0.32	0.27	0.18		
Billions metric tons CO2					
2018	366.8	6.6	266.4	**639.9**	633.3
2007	645.3	17.7	163.8	**826.8**	809.1

While the renewable portion of electricity generation has doubled between 2007 and 2018 (16.9% in 2018 of total) wind and solar have become major contributors today (8% of total electricity), 10 times more than in 2007 and are challenging the grid stability. Whereas, as discussed, natural gas as the cleanest fossil fuel is the natural back-up to avoid the effects of dark doll drums, the technology to convert it to electricity is also critical to maintain greenhouse gas emissions in check.

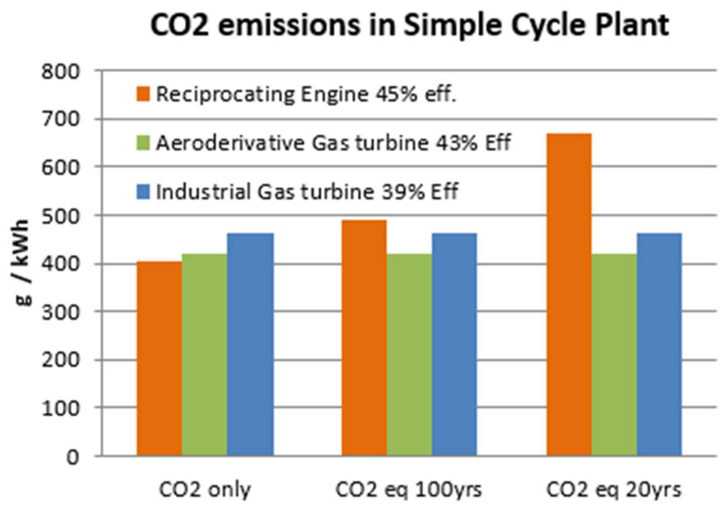
When comparing conventional gas plant technologies available for converting natural gas to electricity while minimizing GHG emissions, efficiency is an obvious parameter as CO_2 directly relate to fuel burnt, but efficiency should not be the only parameter as combustion by products greatly differs for the most common technologies in gas plants.



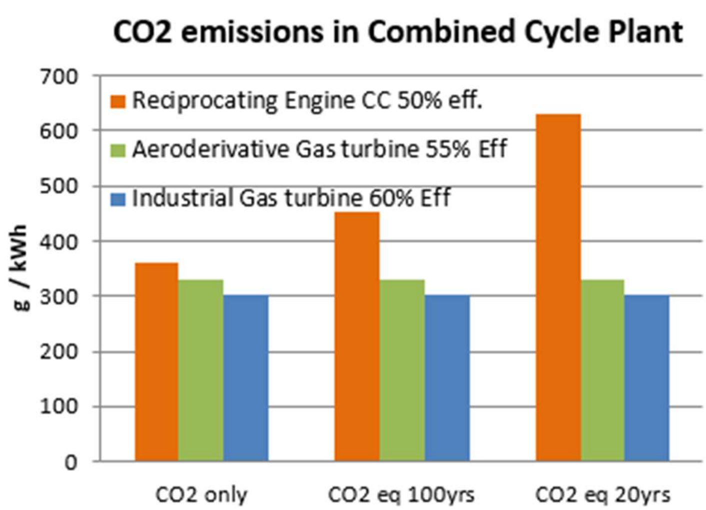
Additionally, reciprocating engines will burn lube oil on the cylinder walls (about 0.5g/kWh) which will result in emissions of approximately 9mg/Nm^3 SO_x on gas fuel, typically not treated by emission abatement processes. In gas turbines the lube oil is not exposed to combustion or hot gas path and as a result does not end-up in exhaust gas. Oil consumption is orders of magnitude smaller in gas turbines than in reciprocating engines.

Beyond NO_x and CO, the most striking difference is unburned hydrocarbons, which would include what is referred to as 'methane slip'. Due to an explosive combustion cycle, RICE units will have unburned hydrocarbons escaping through the exhaust. This amounts to between 3g to 6g/kWh at 100% load and from 13g up to 40g/kWh at 25% load. A GT will typically emit UHC over two orders of magnitude less than a full load RICE unit.

Methane, which degrades slowly over time when released into the atmosphere, is 84 times more potent a Green House Gas (GHG) compared to CO_2 over a 20-year horizon, 38 to 36 times over a 100-year horizon, and as a result 'methane slip' negates RICE environmental benefit of higher efficiency and less fossil fuel burn.



Due to higher exhaust flows and temperatures, gas turbines plants benefit more of combined cycles than reciprocating engines. The environmental footprint of both technologies is dramatically impacted.



Natural gas fuel cleanliness can be further increased by mixing green H_2, adding non carbonized energy to the system.

During the combustion process though, one must be careful not to trade CO_2 for thermal NO_x generated by hydrogen high temperature combustion, which Global Warming Potential (or CO_2 equivalent) is estimated at 30 – 33 over a 20-year time horizon, 7 to 10 over a 100-year time horizon. NOx emission while burning H_2 mix should remain around 20vppm; i.e. 0.2g/kWh for a large aero derivative gas turbine such that the GWP remains well under that of natural gas burning (i.e. 7g/kWh CO_2 equivalent with 100% H_2, over 20 year horizon, vs 400g/kWh using natural gas at 43% efficiency)

Natural gas, with its abundance, low cost, general ease of transport and cleanliness is an efficient step toward electricity decarbonization. Due to the flexibility, efficiency and dispatchability of gas turbine plants fueled by natural gas, it is also an efficient and necessary complement to renewable energy to guaranty the grid stability and address dark doldrums. Furthermore, gas turbines capability to burn hydrogen enriched natural gas mixture with up to 100% hydrogen is a progressive path towards complete decarbonization of the electricity production without stranded assets.

Published by

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