"BUT IT'S ALL RIGHT NOW, IN FACT IT'S A GAS!"

Scoring — 2 points each.

The following text is reproduced from an advertisement of the American Gas Association:

> *Everyone agrees we'll soon be needing more electricity. But there's little agreement on how to get it. Especially with the environment at stake. Hydropower is limited by geography. Nuclear energy's problems continue to be debated. And the sun, the wind, the tides — they're all attractive, but none is economically practical on a broad scale yet. So, for at least the near future, we're going to have to rely, for the most part, on fossil fuels. But all fossil fuels are not created equal. One is clearly best for the environment. And that's natural gas. Natural gas produces less carbon dioxide emissions, it produces no sulfur dioxide, and it creates no particulates — the visible smoke you see. All of these are serious air pollutants. Further, because new high-efficiency, gas-powered generating plants are relatively simple to build, gas is also one of the quickest and cheapest ways for producers of electricity to increase their output. In short, if natural gas didn't exist, we'd have to invent it. As it is, nature has given us vast resources of natural gas right here in North America. It just seems natural to use them.*

(a) Consider the three pollutants listed. State why each of these is a "serious air pollutant."

(b) In comparison with coal, which is widely used for power generation, discuss whether these statements seem reasonable.

(c) Determine the amount of CO_2 generated per unit of heat energy released by combustion of natural gas. Express your answer in kg CO_2 generated per MJ of heat energy.

(d) Two combustion-related criteria pollutants are conspicuously missing from the advertisement. Name these two pollutants. For each, state whether power generation is an important source. Briefly discuss why the American Gas Association would not have included them in this presentation.

(e) Assume that natural gas is burned in dry air at an equivalence ratio of $\phi = 0.9$. Determine the adiabatic flame temperature for complete combustion. Why is the flame temperature significant in considering pollutant emissions from power generation?

Properties of Natural Gas

Effective chemical formula	CH_4
Heating value (MJ kg^{-1})	50.2

Additional Thermodynamic Data [a]

Species	**Δh_f^o (298 K) (J mol^{-1})**	**a (J mol^{-1} K^{-1})**	**b (J mol^{-1} K^{-2})**
natural gas	-74,980	44.2539	0.02273
N_2	0	29.2313	0.00307
O_2	0	30.5041	0.00349
H_2O	-242,174	32.4766	0.00862
CO_2	-394,088	44.3191	0.00730
CO	-110,700	29.6127	0.00301

[a] The sensible enthalpy change is estimated as $h_i(T) - h_i(T_o) = a_i \times (T-T_o) + (b_i/2) \times (T^2 - T_o^2)$.

Hint: In combustion analysis, air is commonly represented as a two component mixture, with mole fractions of 21% O_2 and 79% N_2.