NAME ____

GROUND RULES: This is a closed-book/closed-note exam, except that you are permitted one sheet of notes. Do your work on the paper provided. After the exam, staple your work to this exam sheet. Please be sure that your name is written on each page you submit. Also, please be sure that the problem number and your answer are clearly indicated.

The total score possible is 20 points, and the time allowed is 50 minutes. Use the time wisely. Good luck!

REMINDER: Read the questions **carefully**, and be certain you are responding appropriately.

HINTS:
(1) If you don't understand a question, state what you think the problem is asking for, then answer that.
(2) If you seem to be missing an important piece of information, assume a reasonable value, state your assumption, and proceed.
(3) Partial credit is granted, but only if your work can be understood (and your thinking is reasonable).
(4) See below for potentially relevant data.

PROBLEM #1 (8 possible) ________

PROBLEM #2 (6 possible) ________

PROBLEM #3 (6 possible) ________

TOTAL SCORE (out of 20) $\boxed{}$

DATA (some of which may be useful)
ATOMIC MASSES (g/mol): H - 1, C - 12, N - 14, O - 16
COMBUSTION STOICHIOMETRY: $CH_4 + 2\,(O_2 + 3.78\,N_2) \rightarrow CO_2 + 2\,H_2O + 7.56\,N_2$
IDEAL GAS RELATION: $PV = nRT$; $R = 82.05 \times 10^{-5}$ atm m^3 mol^{-1} K^{-1}
UNIT CONVERSIONS: 1 h = 3600 s; 1 kW = 1000 W; 1 MJ = 10^6 J; 1 J s^{-1} = 1 W

1. CONCEPTS IN CLIMATE-CHANGE MITIGATION (8 points; 1 each)
Provide brief answers to each of the following questions. No more than a few sentences are required in each case; less will suffice in many cases.

(a) Explain what is meant by the term *albedo*.

(b) Name two fundamentally distinct mechanisms that can contribute to sea level rise.

(c) Nitrous oxide (N_2O) is removed from the atmosphere by a first-order process and its lifetime is 120 y (using the IPCC definition of lifetime). Given this fact and assuming we know the emissions vs time (E(t)), write a governing differential equation to predict the atmospheric abundance of N_2O.

(d) How does the release of SO_2 from coal combustion affect climate?

(e) Our reading for week 4 included an article in Science by Hoffert et al. ("Advanced technology paths to global climate stability…"). The assigned reading also included a critique of this article by Rosenfeld et al. What was the central criticism of the Hoffert et al. piece?

(f) "Fossil fuels will likely remain the principal energy sources for most of the world, including the United States, well into the middle of the [21st] century" (PCAST report, 1997, Chapter 4). State three characteristics of fossil fuels that support this conclusion.

(g) Describe briefly the technology by which coal is used to generate electricity in the US today.

(h) Why does burning biomass pose a lesser concern for climate change than burning petroleum?

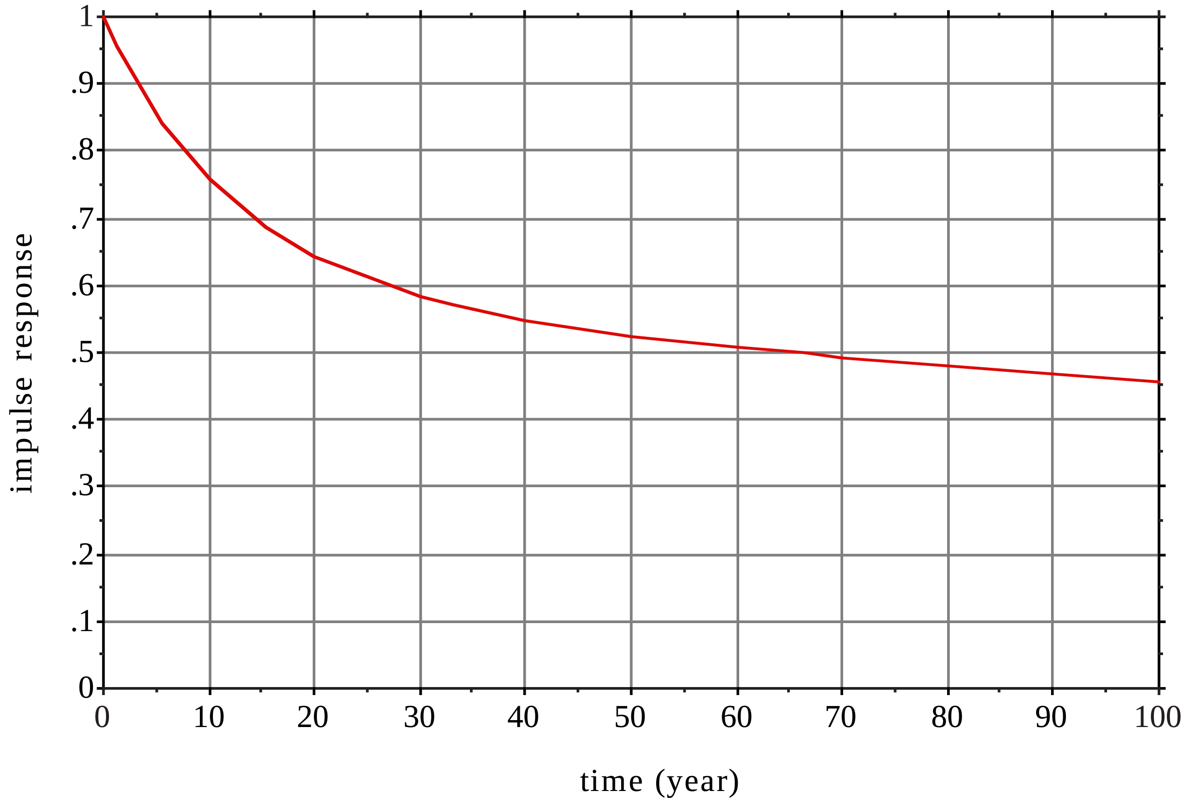
2. EVALUATING ELECTRICITY GENERATION BY NATURAL GAS (6 points)
Natural gas (= methane, CH_4) is used in a combined cycle power plant to produce electricity. The thermal efficiency for generating efficiency is 55%, based on the higher heating value for natural gas of 56 MJ kg^{-1}.

(a) Determine the carbon intensity for electricity generation by this power plant (gC/kWh). (3 points)

(b) Methane losses occur during extraction, processing, and delivery. Assume that x = 0.02 is the ratio of methane lost during handling to methane burned to produce electricity. The global warming potential for methane is 23, based on a 100-y time horizon. Evaluate the contribution of these methane losses to climate change by computing the equivalent carbon intensity of the methane losses in units of gC_{eq}/kWh. (3 points)

3. IMPULSE RESPONSE (6 points)

The figure below shows the impulse response function for species X following its injection into the atmosphere. Use this information to solve the problems posed.



(a) At t = 2000, the atmospheric stock of X is zero. In year 2000, 10 Tg of X is emitted into the atmosphere. In 2020, an additional 5 Tg of X is emitted. What is the atmospheric abundance of X in 2050? (3 points)

(b) Consider a different emissions scenario. Again, the atmospheric stock of X is zero in 2000. Emissions occur at a constant rate of 10 Tg/y for 2000-2050. After 2050, emissions are zero. What is the atmospheric abundance of X in 2100? (*Hint:* Given the time limit for this exam, I recommend that you devise an alternative to adding the contributions from 50 separate years.) (3 points)