ENERGY SYSTEMS AND COMPARISON OF POLLUTANTS

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Contents

Summary

Energy systems with their energy source from wind, water or the sun (WWS) are fundamentally clean and do not produce any pollutants in and of themselves. The thermal environmental impact of energy systems may be measured by the r_{II} ratio. For any energy system, the objective is reduce the r_{II} value to as close to zero as possible to minimize the thermal environmental impact. Of the pollutants produced by energy systems, greenhouse gases are of the most concern. For the Earth, the main greenhouse gases are carbon dioxide, water vapor, methane, ozone, nitrous oxides, and sulfur oxides with carbon dioxide being the most important. These gases affect the Earth's temperature by trapping radiation and warming the planet. These gases have been continuously emitted into the atmosphere through natural processes, but humans have

significantly increased the rate that they are emitted. Although gaseous effluents are globally more significant in being polluting and clearly in need of more attention, liquid effluents cannot be ignored. Water is used by the industries of nations in countless ways. Industrial activity is a huge part of the economy of many countries and this activity is linked to high levels of water consumption and therefore water pollution from liquid effluent discharges. These pollutants have the potential to be extremely detrimental to the water sources and environments. The world statuses of the green house gaseous pollutants, and their corresponding statuses in the three most populous countries, China, India, and the U.S.A., have been reviewed. The continued usage of fossil fuels in power generation will not help the carbon dioxide issue, even though the problem shows some signs of abatement worldwide. The reason is mainly as a result of the U.S. having significantly reduced carbon dioxide whereas China and India continue in their upward march.

1. Introduction

Energy systems with their energy source from wind, water or the sun (WWS) are basically clean and carry no pollutants with them. A carbon footprint may have been assigned to various WWS systems, which is based on the carbon dioxide produced when parts for these systems are manufactured, transported and then constructed on site to build the facility to generate electricity. This arguably flawed system at this time could change dramatically in the near future. In the simple example that if one uses electric transportation, only electricity used in its manufacturing and nuclear power to generate this electricity would yield a very low carbon footprint. This rather idealized scenario would be a good strategy to reduce greenhouse gases in the atmosphere. Certainly, WWS energy systems should not be penalized at this time because the various processes required to materialize WWS power generation systems themselves are significant carbon dioxide producers and need to be improved and updated.

Greenhouse gases are gases within the atmosphere that both absorb and emit radiation. For the Earth, the main greenhouse gases are carbon dioxide, water vapor, methane, ozone, nitrous oxides, and sulfur oxides with carbon dioxide being the most prominent of these gaseous effluents. These gases affect the Earth’s temperature by trapping radiation and warming the planet. These gases have been continuously emitted into the atmosphere through natural processes, but humans have significantly increased the rate that they are emitted. Before the Industrial Revolution, around 1750, humans had a noticeable effect upon the Earth’s ecosystems, but not to such a widespread extent. There was then a shift toward mechanization and manufacturing and therefore an increase in greenhouse effluents. With this new mechanized world, factories began to be erected and with them came the age of the burning of fossil fuels for energy. Humans have then begun to not only grow more industrialized, but more insatiable as well. As time progressed, the amount of effluents being released grew at an exponential rate. Now with a population nearing seven billion people, the Earth’s natural systems is no longer able to remove these effluents at the rate it is being released and greater effects from these gases are being realized.

Carbon dioxide gas receives the greatest amount of media coverage, but the effects of sulfurous oxides, methane, nitrous oxides, and other gaseous effluents still have great impacts upon the Earth's ecosystems. The emitters of these gases can be divided into 5 main categories: industrial, agricultural, commercial, transportation, and residential sectors. Throughout the years there have been increases in the emissions of these gases. Within the recent years, new legislation has been enacted to counteract the adverse effect that these pollutants have had on the ecosystems. Now, it is necessary for these new legislations to not only reverse the adverse effects, but to keep up with growing demand as well. The United States, India, and China are the three most populous countries in the world and are responsible for some of the highest emitting levels for these gaseous effluents.

Although gaseous effluents are currently more responsible for the damage done to the Earth's ecosystems and clearly in need of more attention, liquid effluents cannot simply be ignored. Water is used by the industries of nations in countless ways. It is used to heat and cool substances; to produce steam; as a solvent; to transport substances dissolved within it; etc. Industrial activity is a huge part of the economy of many middle and lower income countries and this activity is linked to high levels of water consumption and therefore water pollution from liquid effluent discharges. These contaminants have the potential to be extremely detrimental to the water sources and environments that they are released into and thus also need to be addressed.

Greenhouse gases trap the Sun's infrared radiation entering our atmosphere on Earth. At naturally occurring, low-levels of greenhouse gases, the greenhouse effect is necessary and important for the existence of life on this planet. At excessive levels, however, the greenhouse gases can trap too much heat in the atmosphere, causing the Earth to heat to higher temperatures and leading to climate changes. Climate change refers to long lasting periods of distinct change in climate [1].

In 2006, carbon dioxide concentrations in the atmosphere had reached 382 parts per million (ppm), an increase of 36 percent since pre-industrial times [2]. This increase in the common greenhouse gas has contributed to the overall warming effect currently facing our global society. These carbon dioxide emissions can be divided into emissions by energy system and by end-use sector. This work will focus on the main fossil fuel energy systems of petroleum, coal, and natural gas, while the end-use sectors are divided into residential, commercial, industrial, and transportation. By analyzing the major gaseous pollutants for the world and for three of the most fossil fuel dependent countries with the largest populations, the United States, China, and India, we are able to better understand the sources of emission as they relate to energy systems.

Energy systems in the current work refer to any system which generates energy or uses energy. Currently, electric power generation is done by burning fossil fuels, nuclear reaction and from wind, water and solar sources. Since nuclear power generation does not create green house gases, it is not discussed. The major polluting culprits in the field of electric power generation are the power plants that burn fossil fuels. The energy systems that produce water pollution are typically users of energy. Water pollution is a local environmental problem, rather than a global one, as created by the green house gases. Thus, the energy systems that have liquid effluents are treated slightly differently.

2. Clean Energy from Wind, Water and the Sun

Wind and water energy are typically used to cause a shaft to rotate, and with that mechanical work is obtained and can be used to generate electricity without pollutants.

Water sources of energy are hydroelectricity and marine sources. Marine energy can be further subdivided to four major types at the present: marine current power captures the kinetic energy from marine currents, ocean thermal energy, which exploits the temperature difference between deep and shallow waters, tidal power, which captures energy from the tides in horizontal direction which is also a popular form of hydroelectric power generation, and wave power, the use of ocean surface waves to generate power. All these water sources of energy do not produce pollutants.

Energy systems that run on solar energy depend on the light and/or the heat of the sun. Light or heat energy from the sun does not produce pollutants. However, if human intervention causes solar energy to be focused and concentrated, temperatures over 1810 K may be obtained. At 1810 K and above, atmospheric nitrogen spontaneously combine with oxygen to from oxides of nitrogen such as nitric oxides and nitrogen dioxide. Hence, any energy system that depends on the sun but does not reach 1810K, do not produce pollutants.

3. Second Law of Thermodynamics Ratio to Measure Thermal Environmental Impact

From [3] and [4], a second law of thermodynamics ratio to measure thermal environmental impact has been defined, used and demonstrated to work. It can be seen that the exergy lost by any energy system may be reduced if the loss temperature T_{L} or T_{Loss} (T loss) is brought as close as possible to the environmental temperature T_{o}. Consider the internal combustion engine. If the combustion gases are exhausted to the environment at T_{o}, the exergy of the gases are wasted. Say, this occurs at a temperature T_{L1} or T_{Loss1} (loss 1). However, if a turbocharger is employed to extract part of this exergy of the combustion gases, the new lost temperature T_{Loss2} or T_{L2} is brought closer to T_{o}. Since $T_{\mathrm{L1}} > T_{\mathrm{L2}} > T_{\mathrm{o}}$, the heat loss is thus reduced in the exergy balance equation, and the second law efficiency gives appropriately a higher value.

In addition, the exhausted gases may be viewed as thermal environmental pollutants, as well as being chemical pollutants. If the loss temperature of the exhausted gases is lowered, they become less of a thermal problem. For example, consider an environmental temperature T_{o} of 25$^{\mathrm{o}}$C. If the combustion gases are exhausted at 50$^{\mathrm{o}}$C, they are more of a thermal contaminant than if they were exhausted at 35$^{\mathrm{o}}$C. The thermal environmental aspect of thermal systems may be measured by a ratio (losses)/input, where the ratio is

$$r_{\mathrm{II}} = \frac{(1 - T_{\mathrm{o}} / T_{\mathrm{L}})\dot{Q}_{\mathrm{L}}}{(1 - T_{\mathrm{o}} / T_{\mathrm{S}})\dot{Q}_{\mathrm{S}}} \quad (1)$$

The objective is to reduce this ratio to as close to zero as possible for minimum thermal environmental impact. Such a ratio is useful as a measure of the thermal environmental impact of energy systems.

The foregoing discussion provides the background for the statement that the *second law* of thermodynamics deals with the *quality* of energy, whereas the *first law* of thermodynamics deals with the *quantity* of energy. The exergy of a working fluid is a measure of the quality of energy it possesses. For the health of the planet, the quality as well as the quantity of energy that is wasted have to be reduced. In so doing, the adverse thermal environmental impact caused by the waste energy is also reduced.

4. State Of Carbon Dioxide Emissions Worldwide

Through viewing Table 1 below, the overall trend of an increase in the total carbon dioxide emissions worldwide becomes apparent.

1980	18,433.924	**2005**	28,366.150
1985	19,542.057	**2006**	28,939.222
1990	21,615.988	**2007**	29,724.505
1995	22,150.058	**2008**	30,399.503
2000	23,803.628	**2009**	30,302.722

Table 1. Total Carbon Dioxide Emissions Worldwide from the Consumption of Energy (Million Metric Tons) Per Year [5]

From [5], it is clear that in 2005, the major producers of carbon dioxide in descending order, were the U.S.A., China, Russia, Japan and India. In 2009, however, the order has shifted so that the descending order of the main producers were China, U.S.A., India, Russia and Japan. Hence, the selection of the top three for further examination in the current work.

Over the past three decades, individuals and businesses have lived lifestyles that disregarded energy consumption and thus carbon dioxide emission as well. Still, between the years 2008 and 2009, the world saw a decrease in carbon dioxide emissions of 96.781 million metric tons. While not a significant amount, this decrease in overall emissions quantifies the statement that as individuals are becoming more conscious of their carbon footprints, they are making greater efforts to minimize activities emitting carbon dioxide enough so that the carbon dioxide emissions are actually decreasing.

Regardless of current conscious efforts to minimize carbon emissions, however, the total yearly worldwide carbon dioxide emissions from the consumption of energy have nearly doubled in a span of 30 years. This extreme rate of increase can most likely be contributed to the increase in global population.

Total carbon dioxide emissions can be further broken up by the energy systems from which they are produced. The main energy systems producing carbon dioxide pollution are those of coal, petroleum, and natural gas. The general increase in carbon dioxide emissions from 1980 to 2009 and the energy systems from which they were produced is depicted in Figure 1.

The data trends for each individual energy system, as illustrated in Figure 2, help to provide a better understanding of which anthropogenic activities are leading producers of carbon dioxide effluents. Energy produced from both coal and natural gas contributes to carbon emissions for the residential, commercial, and industrial end-use sectors.

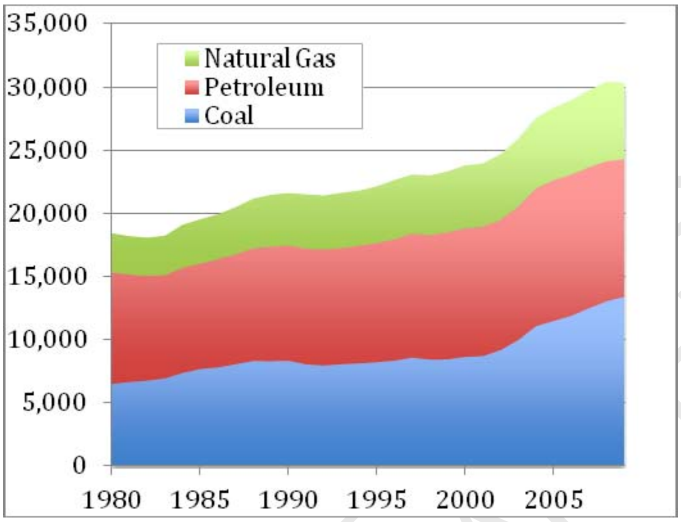

Figure 1. Total world carbon dioxide emissions in million metric tons per year. Emissions from each year are further divided by energy system (natural gas, petroleum, and coal). Data from [5].

The amount of carbon dioxide emissions due to the use of natural gas is significantly less than that due to the use of coal because natural gas is the cleanest fossil fuel. This is clear by comparing the pounds of carbon dioxide produced per billion Btu of energy input; natural gas produces 117,000 pounds, oil produces 164,000 pounds, and coal produces 208,000 pounds[6].

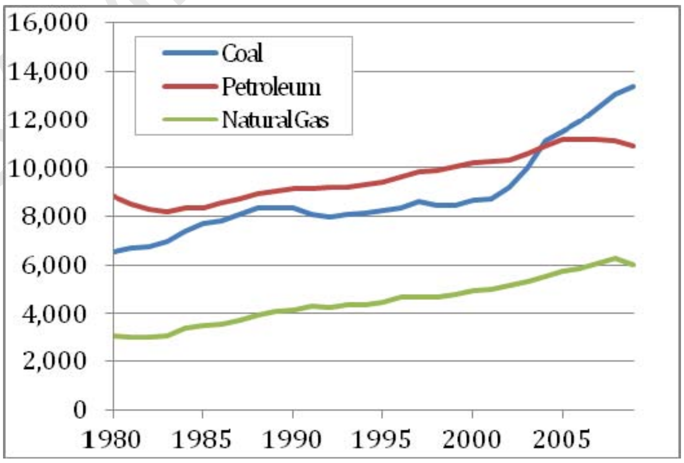

Figure 2. Carbon dioxide emissions in million metric tons per year for three energy systems. Data from [5].

As can be seen in Figure 3, the vast majority of petroleum consumption is due to the transportation end-use sector—it is burned in combustion engines as vehicular fuel. From Figure 2 , it is evident that carbon dioxide emissions from petroleum have decreased slowly since 2005.

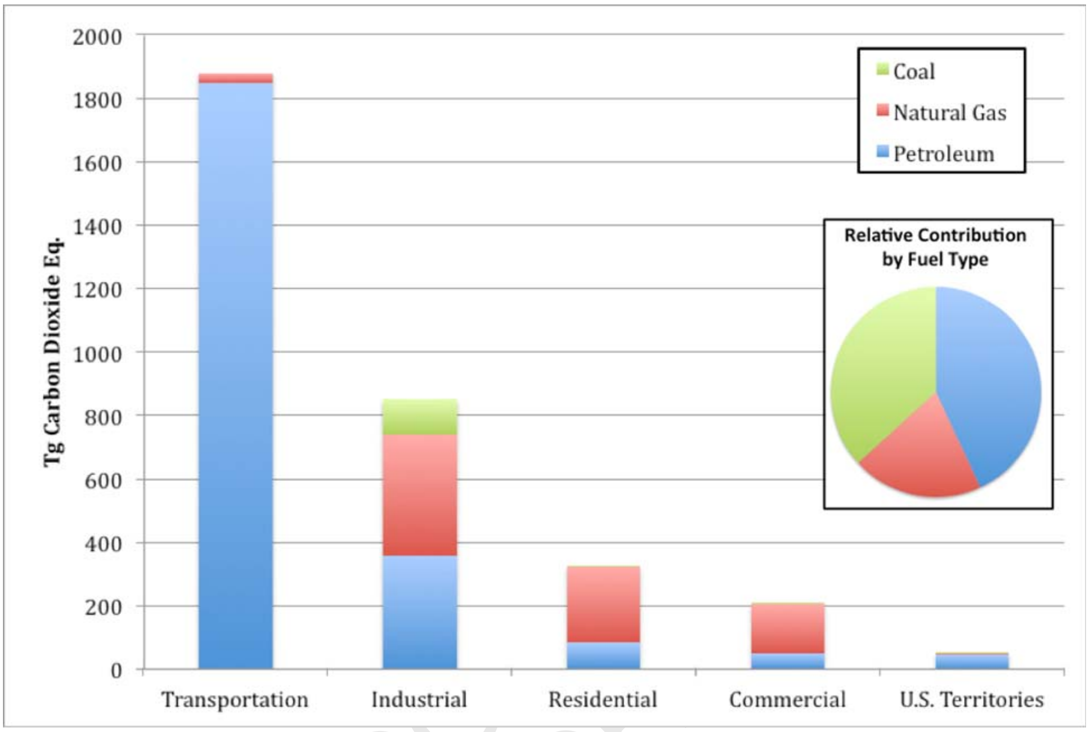

Figure 3. 2006 CO2 emissions from fossil fuel combustion, organized by sector and fuel type[6].

These results can most likely be attributed to the technological advancements in vehicle design. In addition to creating more fuel-efficient vehicles, various companies have developed commercially viable hybrid cars, including Toyota, Honda, Lexus, Mercedes, Chevrolet, Lincoln, and more. Hybrid vehicles decrease the amount of gasoline necessary to power the engine, and are proof that vehicle design is beginning to distance itself from petroleum fuel. Plug-in, all-electric vehicles are expected to appear in the consumer market within the next five to ten years, which would further decrease global carbon dioxide emissions from petroleum fuel and the transportation end-use sector [7]. In fact, the current U.S. President's plan to reduce carbon emissions predicts that carbon emissions due to motor transportation will be essentially zero by the year 2050[8]. In addition, the rising costs of petroleum fuel have lead many individuals to shorten their driving distances, begin carpooling, begin using public transportation, and/or start finding other methods of reducing their budget expenditures on fuel. These innovations in combination with increasing gas prices have decreased the carbon dioxide emissions owing to petroleum consumption.

Despite this decrease, the International Energy Association's Reference Scenario predicts that the world will see a general increase in total carbon dioxide emissions due to petroleum of 1.3% p.a. from the year 2004 to the year 2030. It also projects a growth in carbon dioxide emissions of 1.9% p.a. due to oil consumption, 2.0% p.a. due to natural gas consumption, and an overall growth of 1.7% p.a. over the same time frame [9].

5. State Of Carbon Dioxide Emissions in the United States

The United States has historically had one of the highest overall total carbon dioxide emissions values amongst all countries in the world over the last thirty years (see Table 2). The values generally increased slightly on a yearly basis, however, beginning in 2005, typically began to decrease on a yearly basis, until the value of carbon dioxide emissions in 2009 was only slightly higher than that in 1995. This decrease can almost certainly be contributed to the United States' increased devotion to "going green" and being more environmentally friendly, a trend that has become popular only very recently. In order to successfully decrease carbon emissions, it is helpful to assess from where these emissions are coming, in order to directly combat the sources of emissions.

1980	4,776.569	**2005**	5,991.446
1985	4,604.840	**2006**	5,913.676
1990	5,040.997	**2007**	6,018.131
1995	5,319.886	**2008**	5,833.133
2000	5,861.819	**2009**	5,424.530

Table 2. Total Carbon Dioxide Emissions in the United States from the Consumption of Energy (Million Metric Tons) Per Year [5]

Table 3 displays the carbon dioxide emissions in million metric tons per year from 1990 to 2008, divided into the end-use sectors of residential, commercial, industrial, and transportation. As expected from Table 2, the carbon emission values in all end-use sectors generally increase from 1990 to 2005, but after 2005 we begin to see decreases in some of the end-use sectors. The data shows a definite decrease in residential carbon emissions after 2005, as well as a decrease in industrial carbon emissions. The decrease in residential carbon emissions can be attributed to higher individual awareness of one's own carbon footprint, and the decrease in industrial carbon emissions can most likely be attributed to the engineering of more efficient machinery and the development of more energy saving industrial processes for areas such as power plants and textiles.

The ever-increasing carbon dioxide emissions due to the transportation end-use sector can be attributed to many things, most of which deal with the lifestyle choices of U.S.A. citizens.

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