Global Warming – Potential Problems and Possible Solutions

Dr. Bimal K. Bose, D.Sc., LFIEEE
Emeritus Chair Professor of Electrical Engineering
Department of Electrical Engineering and Computer Science
The University of Tennessee
Knoxville, TN 37996-2100
Tel: (865)974-8398, Fax: (865)974-5483
E-mail-bbose@utk.edu
https://en.wikipedia.org/wiki/Bimal_Kumar_Bose

Global warming due to man-made greenhouse gases appears to be a serious potential problem in our society. In 2007, Nobel Peace Prize was awarded to United Nations-IPCC (Inter-Governmental Panel of Climate Change) along with the U.S. Ex-Vice-President Al. Gore for their contributions in global warming. The root of this problem is the growth of astronomical energy consumption in the world. Energy has been the life-blood of our civilization, and per capita energy consumption has been the barometer of a nation's prosperity. In the olden days of pre-industrial revolution era, as indicated in Fig.1, mankind was mainly dependent on animal and manual labor. In this muscle age, our life style was very simple and unsophisticated, and the environment was clean. In 1785, James Watt of Scottland invented steam engine that ushered in the industrial revolution, and we were brought in the mechanical age, or age of machines. The industrial revolution gained momentum by the invention of internal combustion engine in the late nineteenth century. The wave of industrial revolution gradually spread from Europe to USA, and then to the rest of the world. The electrical revolution, or age of electricity started by the commercial availability of electricity in mid-1880's, when at the same time, commercial induction motor was invented (1888) by Nickola Tesla. The commercial dc motor was introduced at an earlier date (1873), and then the synchronous motor arrived at slightly later date (1891). The electronics revolution, or the age of modern solid state electronics was ushered by the invention of transistor in 1948 by Bardeen, Brattain and Shockley of U.S. Bell Telephone Lab. The same Bell Lab. also invented thyristor in 1956 that brought us in the age of solid state power electronics. Afterwards, gradually, came the eras of integrated circuits, computers, communication, and robotics. We now live in Internet age that brought revolution in communication. The whole world shrank into a global village. Human society is now more interdependent than ever. During these mechanical, electrical and electronics ages, the energy consumption in the world has been growing by leaps and bounds to cater the need of growing world population and improvement of living standard. So far, we hardly paid any attention to the adverse effect of energy consumption, i.e., environmental pollution problem.

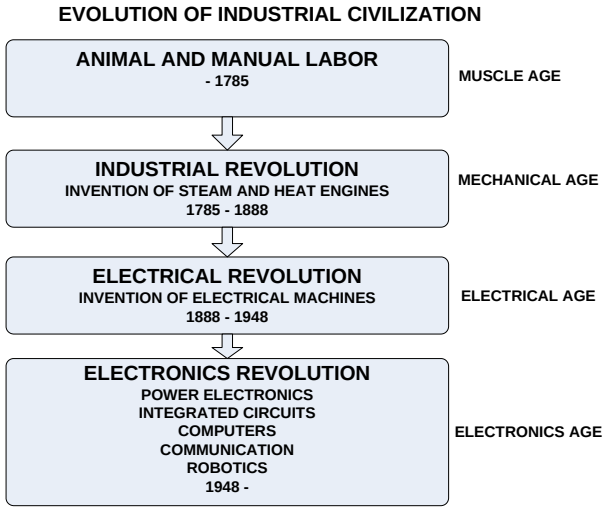

Fig.1. Evolution of industrial civilization

Global Energy Scenario

Fig.2 shows the global energy generation scenario, and the U.S. energy generation in the same perspective [1]. Globally, around 81% of our total energy is generated by fossil fuels, of which 27% comes from coal,

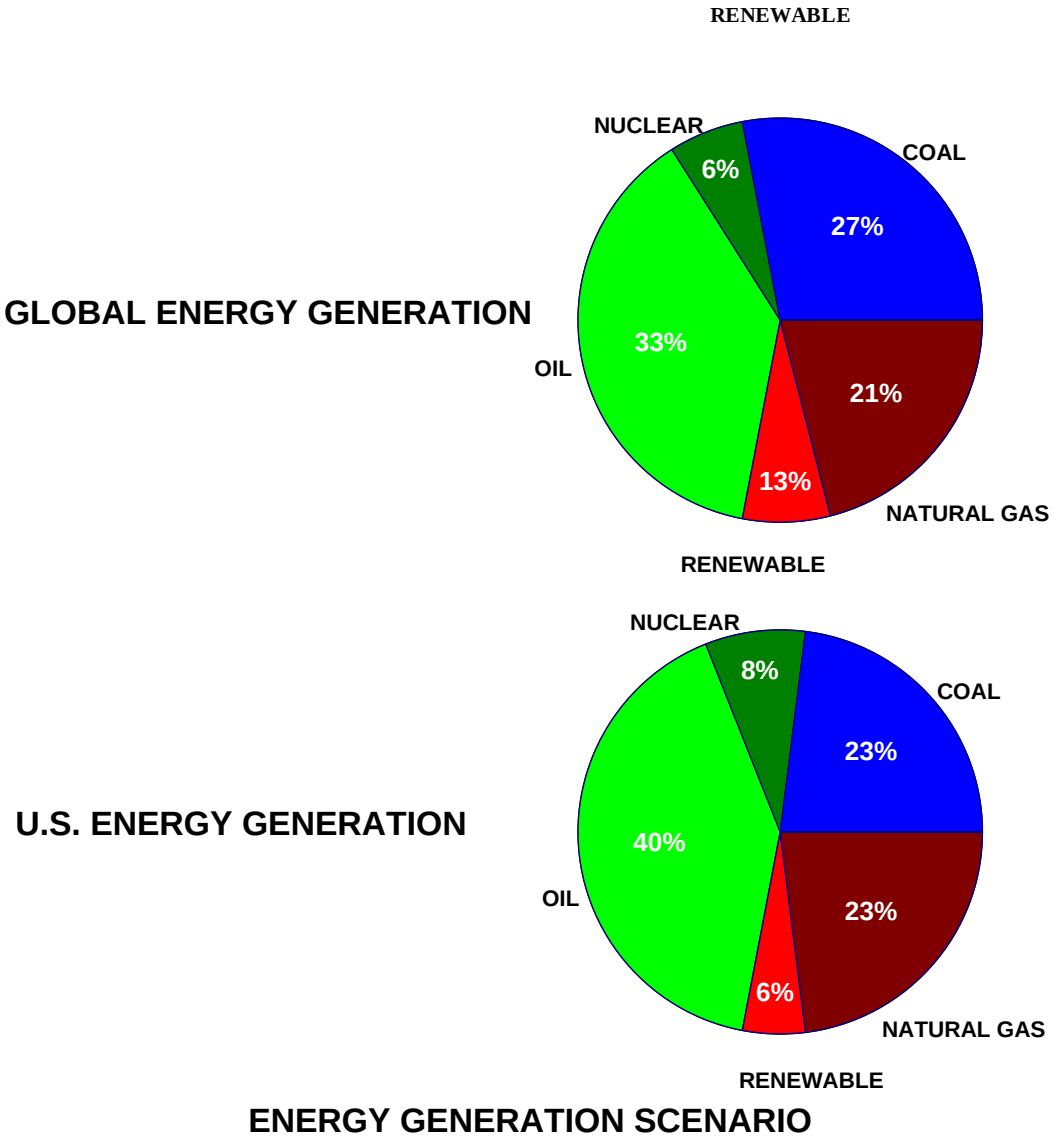

Fig.2. Global and U.S. energy generation scenario

21% comes from natural gas, and the remaining 33% comes from oil. About 6% of our total energy is generated in nuclear plants, and the remaining 13% comes from renewable resources, such as hydro (major part), wind, solar, geo-thermal and bio-fuels. The U.S. energy generation essentially follows the same pattern. About 40% of U.S. energy comes from oil which is mainly used in automobile transportation. It is interesting to note that about 70% of U.S. oil is imported from outside (draining the staggering cost of about $500 billion/year). A bulk of imported oil comes from the Middle East, and this the possible reason for so much turmoil there. It is interesting to note that per capita energy consumption in the world is highest in USA. With nearly 5% of world population, USA consumes

nearly 25% of global energy, and this reflects a very high living standard (Switzerland has now the highest living standard). In comparison, Japan, the world's third largest economy, with 2% of world population, consumes nearly 5% of the total energy. On the other hand, China and India together with 36% of world population, consumes nearly 3% of total energy. Of course, this scenario is changing fast due to rapid industrialization of these countries in recent years.

Unfortunately, the world has limited fossil and nuclear energy resources. Fig. 3 shows the idealized energy depletion curves [5] considering the present availability and the current rate of consumption. Note that the renewable energy resources, such as hydro, wind, solar, bio-fuels (such as ethanol and bio-diesel), geo-thermal and tidal power are not included in the figure for simplicity. The nature of the curves are typically Gaussian in nature.

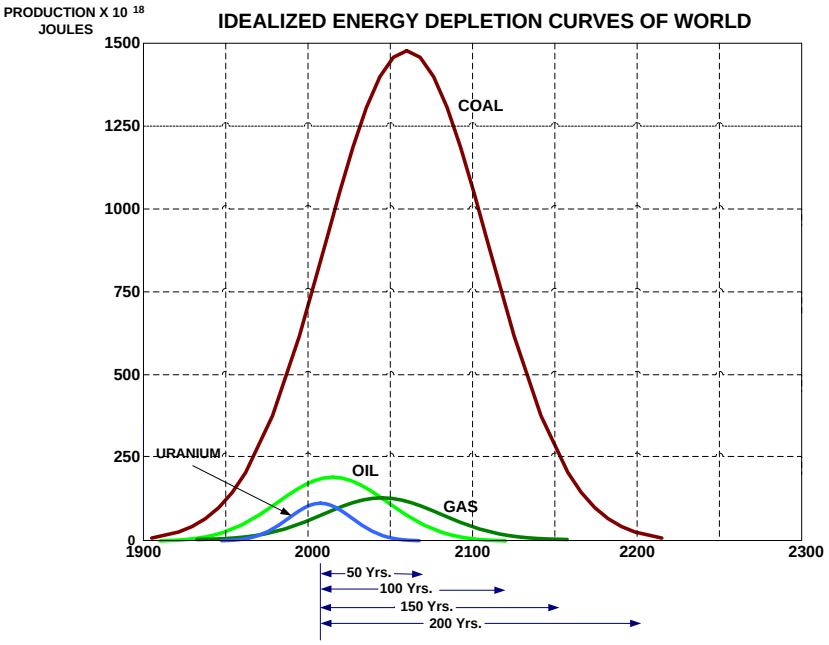

Fig. 3. Idealized energy depletion curves of world

Among all the fossil fuels, the world has enormous reserve of coal. With the present rate, the coal consumption will peak at around 2070, and is expected to last around 200 years. In comparison, natural gas reserve is small, and will last around 150 years. Looking at the oil depletion curve, it appears to be near the peak point at present, and is expected to last around 100 years. With the increasing demand, but at dwindling supply, the current trend of oil price rise is only natural. Natural uranium (U235) has the lowest reserve of all the fuels, and is expected to last nearly 50 years.

How will we fly our aeroplanes and run our automobiles when oil gets totally exhausted? Will the wheels of our civilization will come to a screeching hault when we run out of all the energy resources? Of course, some fossil fuels can be converted from one form to another. With conservation, the depletion curves in Fig. 3 can be flattened to last for longer time. There can be discovery of new fuel resources, particularly in off-shore areas. The Arctic ocean is believed to contain 25% of world's oil and gas reserves which will be discussed later. Of course, exploration of these resources will be expensive. With the added renewable energy resources, the energy availability in Fig.3 can theoretically extend to infinity. It is no wonder that because of competitive cost, extensive availability and environmentally clean in nature, the renewable energy resources are now getting increased emphasis all over the world. Fusion energy, at present, does not show yet any practical promise in spite of expensive R & D over a long period of time. Recently, we are talking about Hydrogen Economy, where our abundant renewable energy resources will be used to generate hydrogen gas by electrolysis of water and store as a clean fuel for future energy source.

Fig. 4 shows electricity generation by different fuel types for a few selected countries (USA, Japan, China and India) [1], which of course, are changing continuously. In USA, 40% of total energy is consumed in electrical form, of which 45% comes from coal, 1% from oil, 23% from gas, 20% from nuclear plants, and the remaining 11% comes from renewables (mainly hydro). Japan does not have much indigenous energy resources, and have to import most of them. This is the reason for its dominance in nuclear energy. It is interesting to note that the world's two fastest developing economies, i.e., China and India generate most of the electricity by burning coal.

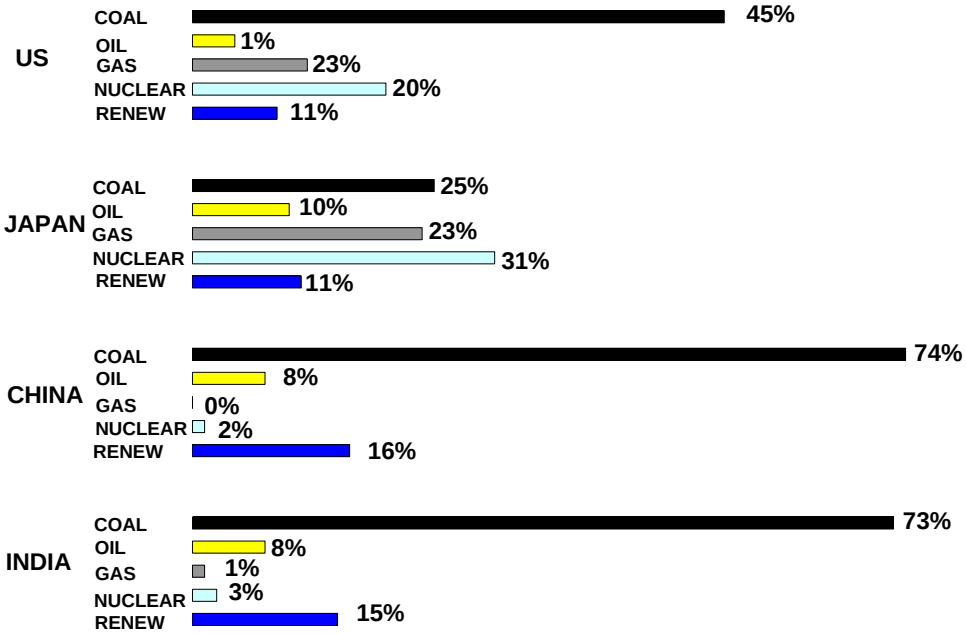

Fig.4. Electricity generation by fuel types for selected countries

Environmental Pollution – Global Warming Problem

Unfortunately, burning of fossil fuels (coal, oil and natural gas) generates pollutant gases, such as SO_2, CO, NO_x, HC and CO_2 that cause environmental pollution problems. For example, acid rain that destroys the vegetation is caused by SO_2 and NO_x, and urban pollution is caused mainly by automobile exhaust gases (CO, NO_x and HC). The more dominant effect of fossil fuel burning is the global warming problem that is mainly caused by CO_2 (the main greenhouse gas (GHG)) which traps the solar heat in the atmosphere (called greenhouse effect).

It may be mentioned here that nuclear power does not have the traditional environmental pollution problem, but safety of nuclear plant against radiation hazard is of serious concern. In the past, there have been several serious nuclear plant accidents, including that in recent Japanese Fukushima Daichi reactors. Another problem with nuclear power is that nuclear waste remains radioactive for thousands of years, and we do not know how to dispose off nuclear waste satisfactorily. There is possibility that in future leakage of this waste will cause extensive damage to our society.

Fig.5 summarizes different generation and absorption agents for greenhouse gases [6]-[8]. Although CO_2 is the main cause, methane (and some other gases) are also listed as GHG. Methane is considered 20 times more harmful than CO_2, but its concentration in the atmosphere is low, and migrates to the upper atmosphere because of lower density than air. All of our energy on the earth comes from the sun. Some of it is absorbed, and some is reflected, and a heat balance is maintained that stabilizes the earth's temperature. The major amount of CO_2 emission in the atmosphere is caused by burning of fossil fuels. In 2007, the IPCC of United Nations established **(**with 90% certainty**)** that man-made generation of CO_2 is the principal cause of global warming problem[9][10]. Note that human beings and other animals exhale GHG, but the trees absorb CO_2 by photosynthesis (called carbon fertilization

effect). A considerable amount of CO_2 is washed away by rain and dissolve as carbonic acid in the ocean. In normal condition, different natural sources and sinks of GHG maintain ecological balance that maintains the stable atmospheric temperature. A secondary cause of global warming is due to increasing world population and large scale deforestation that tend to upset the natural ecological balance. It should be noted, however, that a significant amount of greenhouse effect (not shown in Fig.5) is caused by water vapor and cloud that act as bias and helps to sustain plant and animal life on earth.

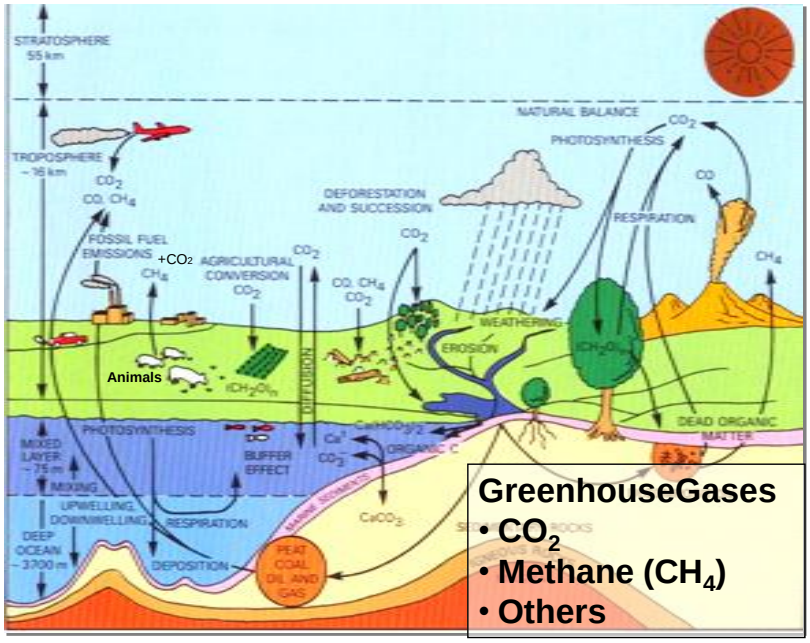

Fig. 5. How greenhouse gases are generated [6]

Global Warming Effects

As mentioned above, higher concentration of greenhouse gases in the atmosphere accumulates solar heat and raises the atmospheric temperature. The past measurements and future prediction by the climate scientists indicate that the rise in temperature is typically a few degrees in 100 years. However, the long term effect of global warming is serious which can be summarized as follows:

- Gradual melting of world's glaciers and polar ice caps will cause inundation of low-lying areas of the earth. This effect is very serious because 100 million of world population live within 3 feet of sea water level[11] .
- Severe droughts in tropical countries near the equator, such as Africa and India will cause damage to vegetation and agriculture and cause problem of fresh water supply.
- Circulation of more air with heavy moisture will cause more hurricanes, tornados, heavy rains and floods.
- Tropical climate with more moisture will induce spread of diseases.
- Some animal species (such as polar bears, penguins and corals) will be gradually extint from the earth[16] .

- Gulf stream warm water in the "ocean water conveyer belt" can be interrupted inducing freezing weather in some parts of the world [12].

Another harmful effect is the increased acidity of sea water due to carbonic acid (by dissolved CO_2) which threatens the marine life in the long run. Systematic scientific study has started on this aspect.

Carbon Emission Curves

Scientists have studied carbon (or CO_2) concentration variation in atmosphere over a long period of time by ice core studies which will be described later. Fig.6 shows CO_2 concentration curves in the atmosphere over many thousand years in the past [8][13].

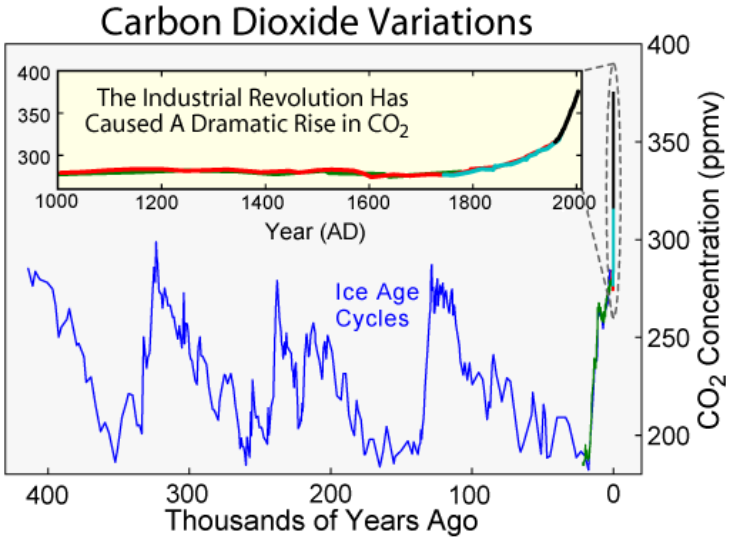

Fig.6. CO_2 variations in atmosphere –thousands of years ago

The cause for cyclic variation of CO_2 (ice age cycles) in the atmosphere is not exactly known. There is one theory of periodic large methane bursts from the ocean floor or earth, but it is not certain. However, there is one thing we are sure is that in the past 1000 years (includes post-industrial revolution), the CO_2 concentration has increased dramatically (see upper curve in the figure) which is much larger than the upper limit of normal cyclic variation. Scientists believe that this peaking is due to man-made burning of fossil fuels and it is irreversible, and therefore, the consequences are serious. Fig. 7 shows the global carbon emission curves in the last 200 years (post industrial revolution era) due to burning of different fossil fuels [8].

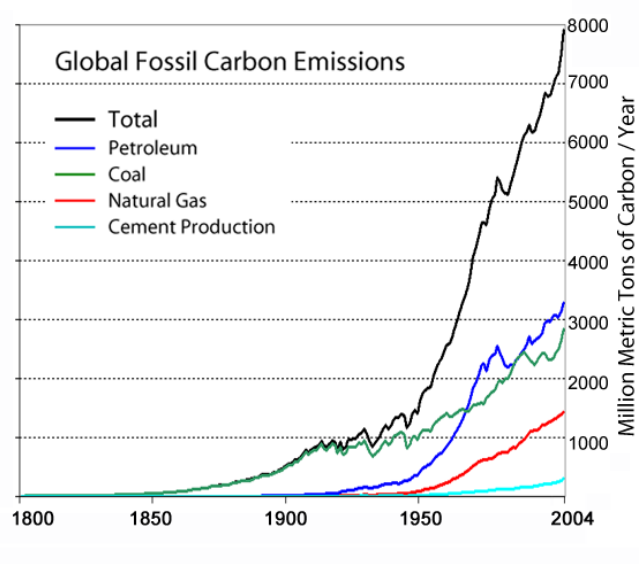

Fig. 7. Global fossil fuel CO_2 emissions

It has been estimated that 80% of atmospheric CO_2 (i.e., 8000 million metric tons of carbon/year) is generated by man-made fossil fuel burning, of which typically 50% is due to electric power generation, and 40% is due to oil-based transportation. Fig. 8 shows per capita CO_2 emission versus population of some selected countries [8][13]. The horizontal axis shows the population (in millions)

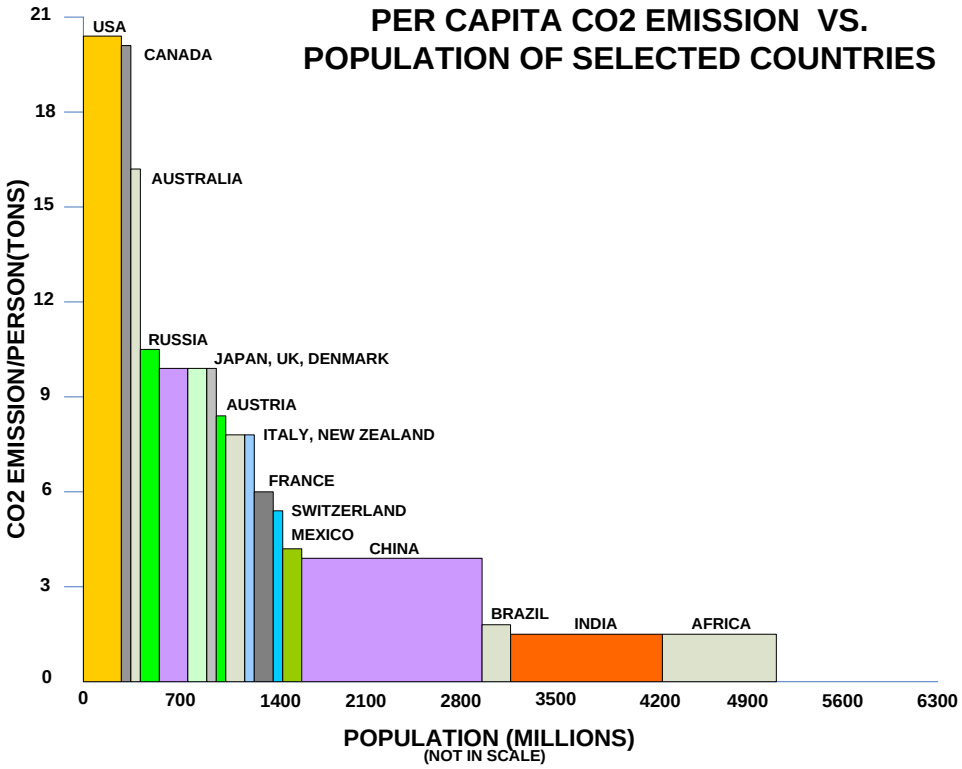

Fig.8. Per capita CO_2 emission vs. population of some selected countries (2004)

of the countries, and the vertical axis shows CO_2 emission per person (in tons). It is interesting to note that USA has the highest per capita emission in the world (because of highest per capita energy consumption), and

the emission in Canada is very close to that of USA. Australia comes somewhat below Canada. The European nations including Russia and Japan are typically less than 50% of that of USA. Note that although Switzerland has the highest living standard in the world (above USA), but its emission level is moderate. The total emission of a country, given by the area of the rectangle, is very important. The living standard of China is much lower than that of USA, and its per capita emission is very low (4 instead of 20.3). However, because of large population (1.3 billion instead of 310 million), the total emission of China is large. In fact, from the year 2006, the total emission of China exceeded that of USA. Former U.S. president Bush refused to accept mandatory emission control for USA unless China takes adequate remedial action. China blames USA and other industrialized nations for creating this mess, and is not willing to sacrifice its growing living standard by reducing energy consumption. Brazil is an emerging country with good living standard, but low per capita emission. In Brazil, typically, 95% of energy (in electrical form) comes from hydro, it has large CO_2 sinking Amazon rain forest, and 50% of its automobiles run on renewable bio-fuel (sugar cane based ethanol). Bio-fuels are considered to have carbon neutralization effect, because they absorb CO_2 during plant growth, but emit CO_2 at burning.

With the present rate of growth of world energy consumption (if no remedial actions are taken), the potential CO_2 rise during 2002 to 2030 is given in Fig. 9[10][14].

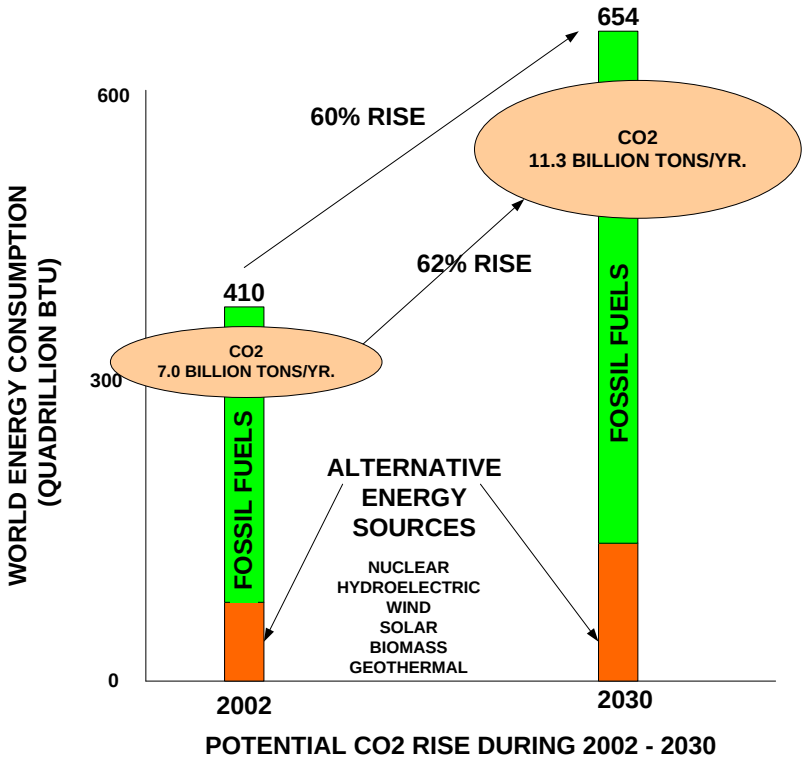

Fig.9. Potential CO_2 rise during 2002-2030

In 2002, the total energy consumption in the world was typically 410 quadrillion BTU (1 quadrillion = 10^{24} Units), of which the share between fossil fuels and alternative energy sources is shown. The alternative energy sources consist of nuclear and renewable sources, as indicated in the figure. The corresponding generation of CO_2 was typically 7.0 billion tons/year. The world energy consumption is expected to grow typically 60% during the 28 years, and the corresponding CO_2 will rise by 62% (11.3 billion tons/year) due to some increased share of the fossil fuels. Evidently, as a result, the global warming effect will be significant.

Temperature and Sea Level Rise

The United Nations IPCC estimates that atmospheric temperature will rise typically between 1.1 ^{0}C to 6.4 ^{0}C in the next 100 years due to greenhouses gases, if no remedial actions are taken. Various climate research organizations in the world (summarized in Fig.10) have attempted to generate climate models of the world and make extensive simulation studies in supercomputers, and have come up with global warming projections, as shown in Fig.10. The initial part of the curves for past 100 years (1900-2000) shows that the temperature, in fact, rose between 0.6 ^{0}C and 1.0 ^{0}C. The worst case temperature rise projection for the next 100 years is 5^0 C, whereas the most optimistic projection is 2^0 C. Similar studies have been made by U.S. National Academy of Sciences. The large error in the projection is due to inaccuracy of climate model which is extremely complex, and will possibly take long time to correct. Note that none of the studies disagree that there will not be any global warming.

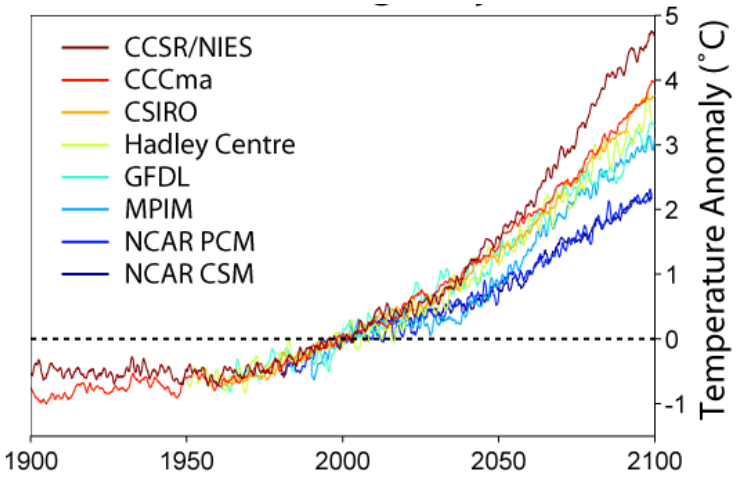

Fig. 10. Global warming projections by different research agencies

How to get atmospheric temperature data and the related information for the past? The ice core studies in Antarctica by U.S. NSF (National Science Foundation), shown in Fig.11, provide invaluable data of past weather conditions for thousands of years [7]. These steel tubes are inserted deep in the ice for miles to extract samples for thousands of years. Layer-by-layer, these ice cores keep finger print of weather conditions, such as (1) chemical composition (such as CO_2) of the atmosphere, (2) dust particle composition, (3) air temperature, (4) any unusual event, such as volcanic eruptions, and (5) nuclear radiation leaks. The ice age CO_2 variations in Fig. 6 were obtained by the ice core study.

Fig. 11. Ice core studies in Antarctica

As mentioned before, one of the harmful effects of global warming is droughts which will be particularly serious in the tropical countries near the equator, such as Africa. Droughts will cause loss of agricultural production, damage of vegetation, reduction of fresh water supply, and thus will tend to induce famines. Studies of droughts are being made in different parts of the world. An example of drought is lake Chad (one of the largest lakes in the world) in Central Africa which has been studied extensively by NASA satellites [9]. It is a shallow lake that supplies water to 20 million people of the four neighbouring countries of Chad, Cameroon, Niger and Nigeria. The lake has shrunk from 10,000 sq.miles to 839 sq. miles (less than one-tenth the size) in last 35 years. Similar observations have been made in other lakes around the world. The drought problems on agriculture and vegetation in tropical countries near the equator are equally serious. For example, the Peterson Economical Institute has made studies that by 2080, India's agricultural production will decrease by 38%, however, the CO_2 fertilization effect will offset it by 9% [15]. There are similar projections for other equatorial countries.

The more serious effect of global warming is melting of ice in Arctic, Antarctic, Greenland, Himalayas, and thousands of glaciers around the world. In fact, the actual melting is much faster than the prediction, which is baffling to the scientists. Fig.12 shows the melting ice of Arctic ocean (bordering the regions of Greenland, Northern Canada and Northern Russia).

Fig. 12. Melting Arctic ice in Summer (2006)

Arctic ice shrank by 500,000 square miles in 2006 alone, which was three times faster rate than the original prediction by the climate scientists. It is now being predicted that Arctic regions will be virtually free from ice by the Summer of 2070. Similar melting is occurring in Greenland, Antarctica[1] and other glaciers. The melting of ice is raising the sea level with potential inundation of low lying areas of the world. Note that 90% of solar incident heat is absorbed by water, whereas ice absorbs only 10% heat. This gives a positive feedback effect in the accelerated melting of polar ice cap. Also, note that floating ice in the Arctic ocean does not cause any sea level rise, because ice shrinks while melting. However, sea level rises by a small amount due to thermal expansion of water. Melting of Arctic ice is removing habitats of polar bears and penguins with the expected extinction of these species. They also need to swim longer distance to find food for survival. The highly sensitive corals in the sea are dying due to higher water temperature and acidity of dissolved CO_2[16].

---

[1] Although Antarctica shows an overall warming trend, the region of East Antarctica which includes the South Pole, is at a much higher elevation and shows a cooling trend. This contradicts the computer climate models, and is baffling to the climate scientists. It is believed that the ozone hole in Antarctica due to CFC gases is the reason for this cooling. The scientists believe that the ozone hole will eventually heal, and then the warming trend will start.

The NASA/JPL (National Aeronautics and Space Administration/Jet Propulsion Laboratory) of USA recently made extensive studies on rise of ocean surface topography by satellites. Fig. 13 shows the average sea level rise during the ten year period (1992-2002) by the TOPEX/Poseidon project of NASA/JPL [13]. It indicates the rise of 24 mm, i.e.

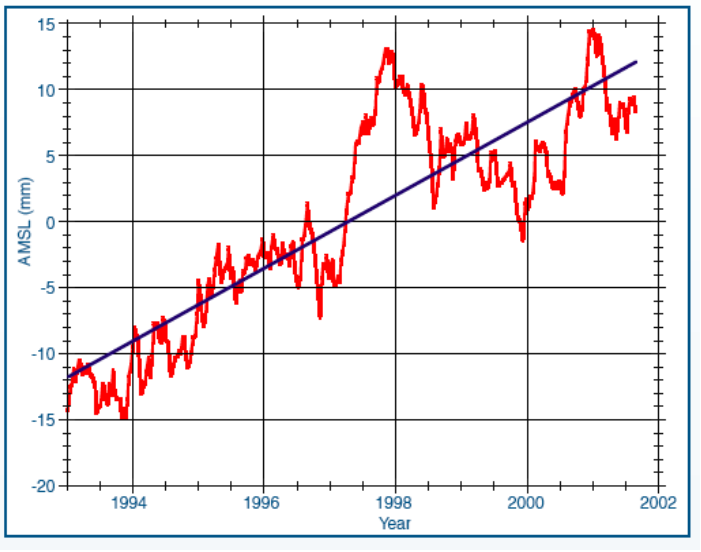

Fig. 13. Sea level rise in a decade due to global warming (NASA/JPL TOPEX/Poseidon data)

approximately 1.0 in. The U.S. National Academy of Engineering has made measurement of sea level rise by 6 inches during the period 1950-2000. Fig.14 shows the projection of sea level rise in 100 years [11][13]. The worst case scenario is 3.0 ft. rise in 2100 with the corresponding atmospheric CO_2 concentration of 971 ppm (the current figure is around 380 ppm as shown in Fig.6), whereas the best case scenario is 3 in. with CO_2 concentration of 478 ppm. The results vary widely because of the inaccuracy of the models and complexity of the studies. As mentioned before, about 100 million of world population that live within 3 ft. of sea level, will have inundation of their habitats. It has been estimated that if all the ice in Greenland and Antarctica melts, the sea level will rise by 200 ft. The city of Manhatten in USA will be under 200 ft. of water if all the ice in two polar ice caps melt [13]. With the projected rise of sea level, it is estimated that 50% of Bangladesh will be under water in 300 years displacing 75 million people. Several island nations in Pacific Ocean (such as Tuvalu) will be under water within 100 years, and they have already applied to United Nations for help. In fact, if fossil fuel burning is completely stopped today, theoretically the sea level will rise by 4.6 ft. in the next 1000 years until ecological equillibrium condition of CO_2 is reached in the atmosphere. Again, melting of Arctic ice cap and glaciers will dump huge quantity of fresh water in the Gulf stream of warm water in North Atlantic ocean that may break the "conveyer belt" of ocean currents over a long period of time and bring frigid weather in some parts of the world [12]. This phenomena are not well-understood and require extensive study. There is no doubt that global warming effect will bring tremendous unrest and instability in the world. Fortunately, these effects are very slow over a long period of time, and human beings have tremendous capability for adaptation.

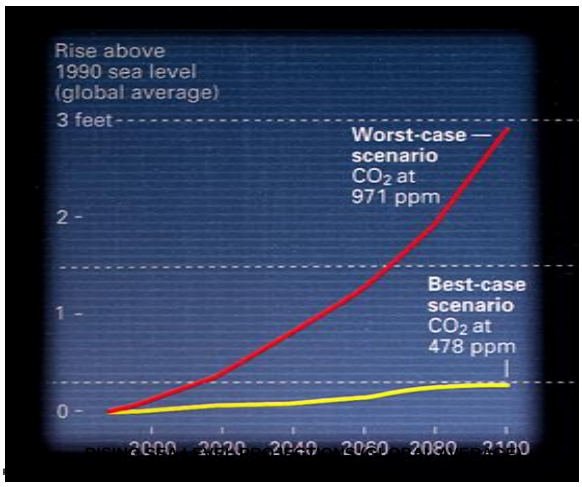

Fig. 14. Sea level rise projection in 100 years

Among all the grim effects of global warming, there are however a few beneficial sides. As mentioned before, CO_2 absorption by photosynthesis helps nutrition of agriculture and plants (carbon fertilization effect) that will promote growth of agriculture, but will be offset by droughts. Melting of polar ice caps opens new and shorter navigation routes **(**in Summer only**)**. For example, shrinking of arctic ice from 1.5 million square miles to 1.0 million miles in 2006 alone, has opened new shipping route in Arctic ocean that has reduced navigation distance between London and Tokyo by 48% (13,000 miles to 8,100 miles). It is estimated that around 25% of world's oil and gas reserves are below the Arctic ocean, which will be available soon for exploration [13]. However, this exploration will be expensive. Besides, melting of ice will recover new lands that will be available for habitation and agriculture. Canada, Russia and Greenland are beaming with joy with these new expectations. In addition, warming of weather in cold climates will reduce the heating bills.

Kyoto Treaty and Carbon Emission Control

Considering the serious consequences, the United Nations called a series of international meetings to discuss the challenges posed by global temperature and climate change. Finally, as a result, Kyoto Protocol (an international agreement) emerged in 1997 [7]. According to the protocol of this treaty, many industrialized nations must reduce by 2012 greenhouse gas emissions 5%-8% below the 1990 levels. For example, European Union countries should make 8% reduction **(**varies among the member nations**)**, whereas USA should make 7% reduction. USA and Australia refused to participate in this mandatory reduction formula (however, Australia recently joined the treaty). For Russia, no further growth of emission was permitted. Since China and India were developing economies, no emission curbing was mandated during 2008-2012. As mentioned before, per capita emission of these countries is low, although the total emission is significant because of their large population. The Kyoto Protocol went into effect from the year 2005. Now (at the time of this writing), it has 191 member countries covering nearly 62% of global greenhouse gas emission.

As mentioned before, according to the terms of the treaty, each member country is assigned a cap or quota (in tons of CO_2) for emission, and emission must be limited within the quota. Otherwise, a country with higher emission, can purchase credits from a country which has lower than the assigned quota of emission (called cap-and-trade policy). For example, UK, with higher than quota emission, can purchase credits from Brazil which has emission below its quota. Within a country, a quota is assigned to each industry which can buy or sell credits from another industry to satisfy the quota. The same principle is also applicable to individual persons or families. There are trading organizations which control buying and selling of credits like share transactions. It is difficult to monitor and enforce the cap-and-trade policy. Alternatively, carbon tax can be imposed on individuals or industries. In 1990 USA Clean Air Act, similar cap-and-trade policy was enforced successfully for auto and power plant acid rain emissions, which is now more than a $3B industry. European countries have taken leadership position in enforcing the cap-and-trade policy. However, in USA, it is yet a controversial policy, although EPA (Environmental Protection

Agency) is attempting to control air pollution as mandated by Clean Air Act. In December 2009, the representatives from 170 countries met in a Climate Conference of Copenhagen, Denmark to formulate climate control policy beyond 2012, but could not make much progress.

How to Solve or Mitigate Global Warming Problem?

The question is how can we solve or mitigate the global warming problem? The first step we can take is to promote all of our energy consumption in electrical form. Instead of distributed consumption of fossil fuels, centralized fossil fuel based power generating stations can use advanced emission control standards. As emission control technologies advance, it is somewhat easy to apply such technologies in central power stations. As mentioned before, coal is the most abundant fossil fuel on earth, but it is also the dirtiest fuel for environmental pollution. Some are demanding to stop coal based power generation altogether, but practically that may not happen easily because of our abundant resources of coal. Coal power stations, at present, have very poor efficiency (typically 35%) which can be improved significantly to reduce pollution. Currently, there is ongoing research on clean coal technologies, which can be classified as CCS (Carbon Capture and Sequestration) and IGCC (Integrasted Gasification Combined Cycle). In the CCS technology, CO_2 is captured from the power station chimney, compressed, transported, and then stored underground. In the IGCC process, coal is pulverized, gasified with the help of steam, and then impurities are separated. None of these technologies have been successful commercially. Nuclear power is claimed "environmentally clean", and currently, there is demand for increasing nuclear power generation. However, the nuclear accident in Fukushima Daichi plant of Japan has caused a set back in that direction.

Since trees absorb CO_2, the tropical rain forests (such as Amazon rain forest) can be preserved, or widespread forestation can be promoted to mitigate the global warming problem. Some countries are actively promoting tree plantation as new housing estates are being developed. Controlling human and animal population to reduce GHG is not easy. Since human beings exhale CO_2 as well as demand energy for living standard, population control gives benefit in two dimensions. A substantial portion of global energy demand can be met by promoting environmentally clean renewable energy sources (hydro, wind, solar, geo-thermal, and fuel cells), and the current trend in the world is to explore them vigorously. Fuel cells can be defined as clean if clean energy is used to produce hydrogen fuel. Recent studies [38] has indicated that hydro, wind and solar technologies (with adequate storage) can provide 100% of world energy eliminating all fossil fuels. The ICE vehicles can be replaced by electric vehicles (with the interim phase of hybrid vehicles possibly with bio-fuels), and if electricity is generated by clean sources, GHG pollution by transportation will be mitigated substantially. The study also indicates that mass-produced EVs (with Li-Ion or Ni-MH batteries) the life-cycle cost (with battery replacement cost) is comparable with ICEV if gasoline price is more than a threshold value. Promoting mass transportation, particularly by railways, as in Japan and Europe, will mitigate global warming problem. Again, considerable amount of energy can be saved by improving efficiency in generation, transmission, distribution and utilization of electrical energy.

Unfortunately, a considerable amount of energy is simply wasted in the world because of bad consumer habits or affluence of people. For example, it has been estimated that 33% of total energy in USA is simply wasted [19]. Saving the wasted energy (i.e. promoting conservation) in different countries can play significant role in curbing global warming problem.

Conclusion

The energy consumption in the world is increasing dramatically due to our quest for higher living standard and rising world population. Most of our energy comes from fossil fuels, and burning these fuels causes environmental, and particularly, the global warming problem. Global warming raises the sea level, brings drought in tropical regions near the equator, increases hurricanes, tornadoes and floods, and spreads diseases. The consequences are serious, and will tend to bring tremendous unrest in the world. Various measures to solve or mitigate the global warming problem have been outlined in the paper. It has been estimated that the widespread energy efficiency improvement and other methods with the existing technologies can save 20% of global energy demand, and another 20% can be

saved by preventing waste, i.e., by various conservation methods. Finally, the global warming problem is solvable by the united effort of the humanity.

Selected References

[1] International Energy Agency website: http://www.iea.org
[2] S. Rahman and A. D. Castro, "Environmental impacts of electricity generation: a global perspective", *IEEE Trans. Energy Conv*., vol. 10, pp. 307-313, June 1995.
[3] G. R. Davis, "Energy for planet earth", *Scientific American*, pp. 1-10, 1991.
[4] U. S. EPA website: http://www.epa.gov/climatechange/
[5] J. R. Roth, Long term global energy issues, in Industrial Plasma Engineering, Institute of Physics Publication, Philadelphia, PA, vol.1, 1995.
[6] F. T. Ulaby, "Global change: how radar connects to carbon economics", *IEEE Proc. Editorial Board presentation*, Piscataway, June 9, 2006.
[7] IPCC website: http://www.ipcc.ch/
[8] Wikipedia encyclopedia website: http://en.wikipedia.org/wiki/Global_warming
[9] Al. Gore, "The Inconvenient Truth", documentary movie, 2006.
[10] EPRI Discussion Paper, "The power to reduce CO_2 emissions – the full portfolio", EPRI Energy Technology Assessment Center, August 2007.
[11] Wikipedia Encyclopedia, http://en.wikipedia.org/wiki/Sea_level_rise
[12] R. C. Armstrong, "The global energy challenge and MIT's response", *University of Tennessee seminar*, Knoxville, February 6, 2007.
[13] J. Graff, "Fight for the top of the world", *TIME*, pp. 28-36, October 1, 2007.
[14] M. Parfit, "Future Power", *National Geographic Magazine*, pp. 4-31, August 2005.
[15] Peterson Inst. of Int'l. Economic Affairs website: http://search.petersoninstitute.org.
[16] G. K. Chesterton, "The curse of carbon in troubled waters", A Special Report on the Sea", pp. 3-18, The Economist, January 3, 2009.
[17] B. K. Bose, "Global warming", IEEE IE Society Magazine, pp. 6-17, March 2010.
[18] B. K. Bose, "Energy, environment and importance of power electronics", keynote address, *IEEE POWERENG Conf.*, Setubal, Portugal, April, 2007.
[19] B. K. Bose, "Energy, environment, and advancing frontier of power electronics", keynote address, *IASTED AfricaPES Conf.*, Gaborone, Botswana, September, 2008.
[20] B.K.Bose, "Global Warming – how power electronics can help solving the problem", keynote paper, Proc. of 4th IEEE Conference on Industrial Electronics and Applications, Xi'an, China, May 26, 2009.
[21] B.K.Bose, "Energy, global warming and power electronics", keynote address, 19th Australian Universities Power Engineering Conference (AUPEC), Adelaide, Australia, September 28, 2009.
[22] B. K. Bose, "Energy, environment and advances in power electronics", *IEEE Trans. Power Electron*., vol. 15, pp. 688-701, July 2000.
[23] M. Grunwald, "Wasting our watts" *TIME*, pp. 33-36, January 12, 2009.
[24] T. Fukao, "Energy, environment and power electronics", *Int'l. Power Electronic Conf. Rec*., Japan, pp. 56-68, April 2005.
[25] S. R. Bull, "Renewable energy today and tomorrow", *Proc. IEEE*, vol. 89, no. 8, pp. 1216-1226, August 2001.
[26] Wikipedia encyclopedia website://http://en.Wikipedia.org/wiki/wind_power.
[27] National Geographic Special Issue on Energy for Tomorrow, June 2009.
[28] M.Z. Jacobson and M.A. Delucchi, "A path to sustainable energy by 2030", Scientific American, pp. 58-65, Nov. 2009.

---

* The article is an abbreviated and modified version of the paper "Global Warming" which was first published in IEEE Industrial Electronics Society Magazine, vol.4, No. 1,pp. 6-17, March 2010.

Author's note – The facts and figures presented in the paper are changing continuously because the sciences related to global warming are evolutionary in nature.