EFFECTS OF NANOTECHNOLOGY ON GLOBAL WARMING

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ABSTRACT

Currently, global warming is the major environmental concern in the world and will most likely continue with this priority for a long period of time. Global warming is usually caused by man-made carbon-associated gas emissions, also known as greenhouse gases, resulting in enormous climate change/concern. The major source of carbon emissions is from the combustion of fossil fuels, such as coal, oil, and gas in power plants, automobiles, other transportation vehicles, industrial facilities, and other natural and artificial sources. It is believed that nanotechnology will likely decrease the need for fossil fuels, thus having a positive impact on global warming. Nanotechnology and its products (or nanomaterials) mainly involve in the applications of renewable energies (e.g., solar and hydrogen fuel cells), which result in nearly zero emissions. Increasing the use and efficiency of renewable energy and at the same time decreasing the consumption of current fuels is one way to slow down and ultimately stop global warming. However, the manufacture of nanomaterials and devices may have negative impacts on global warming, as well.

Keyword: Nanotechnology, Global Warming, Renewable Energy, Other Alternatives.
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1. INTRODUCTION

Nanotechnology is concerned with the creation of particles and materials at nanoscale dimensions. These particles and materials are referred to as nanoparticles and nanomaterial, respectively, and they exhibit unusual and exotic properties that are not present in traditional bulk materials. Nanotechnology can be defined as systems or processes that provide goods and/or services that are obtained from matter at the nanometer level, *i.e.*, from sizes in the range of one-billionth of a meter [1]. To quote K. E. Drexler, "Nanotechnology is the principle of manipulation of the structure of matter at the molecular level. It entails the ability to build molecular systems with atom-by-atom precision, yielding a variety of nanomachines [1]." Nanoscience is the study of the fundamental principles of molecules and structures with at least one dimension between 1 and 100 nanometers. These structures are known as nanostructures. Nanotechnology is the application of these nanostructures into useful nanoscale devices [2].

The classic laws of science are not enough to deal with nanomaterials. Nanomaterials possess a large surface area, a high aspect ratio, and a high surface-to-mass ratio. The unique features of nanomaterials can significantly influence the physical, chemical, biological, mechanical, and electrical properties [1].

On December 29, 1959, at the California Institute of Technology, Richard Feynamnn gave a speech entitled "There's Plenty of Room at the Bottom," which raised discussion about nanoscience and nanotechnology. Feynman highlighted the importance of controlling and manipulating matter on a small scale [3]. However, Norio Taniguchi used the term "nanotechnology" for the first time in 1974. In the 1980s, IBM Zurich scientists invented the tunneling microscope, a landmark in nanotechnology development, which allowed scientists and researchers to analyze materials at the atomic level. Over the past few years, expenditure on nanotechnology research and development has increased drastically. Research in nanotechnology continues to expand around the globe, and in the next decade, nanotechnology could have a $1 trillion impact on the global economy. Nanotechnology is currently in a very infantile stage. However, we now have the ability to organize matter on the atomic scale, and there are already numerous products available as a direct result of our rapidly increasing ability to fabricate and characterize feature sizes less than 100 nm. Nanotechnology has the potential to change our standard of life. Some of the applications of nanotechnology are energy storage and production, information technology, medical purposes, manufacturing, food and water purification, instrumentation, and environmental uses. Several nanotechnology-based products already available on the market include electronic components, nanopaints, storage devices, stain-free fabrics, and medical components.

2. GLOBAL WARMING

Global warming is the unusually rapid increase in the Earth's average surface temperature over the last century primarily due to the high fossil-fuel usage resulting in greenhouse gas emissions. The average temperature has climbed 1.4 degrees Fahrenheit (0.8 degree Celsius) on the surface of the Earth since the 1880s. The rate of global warming is increasing. The 20^{th} century's last two decades were the hottest in 400 years. The Earth has experienced climate changes in the past, but the current climate changes are more rapid. Before the Industrial Revolution, the Earth experienced climate changes as the result of natural causes. These natural causes are still in play, but their overall impact is very small. Global warming in the Earth's ecosystem has become a dominant factor following the Industrial Revolution. We are consuming more fossil fuels than ever; therefore, greenhouse gas emissions will continue to climb and the Earth's average temperature will rise as well. According to some predictions, the Earth's average temperature could rise between 2°C and 6°C by the end of the 21^{st} century. The influence of global warming is far greater than just an increase in the temperature on the Earth's surface. Other impacts of global warming are primary and secondary pollutants, melting glaciers, coastal erosion, and some infectious diseases.

2.1 Greenhouse Gases

Many greenhouse gases are found naturally: carbon dioxide, methane, nitrous oxide, volatile organic compound, water vapors, and ozone. Others, such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), result exclusively from human industrial processes. Human activities add significantly to greenhouse gases:

- Carbon dioxide is released into atmosphere by the burning of fossil fuels. It is present in the Earth's atmosphere at a low concentration and acts as a greenhouse gas.
- Nitrous oxide is emitted from industrial activities, as well as during the combustion of fossil fuels and solid waste**.**
- Methane is emitted when organic waste decomposes in landfills. Methane emissions also occur during production and transportation of fossil fuels.
- Volatile organic compounds (VOCs) are organic chemical compounds that have a high enough vapor pressure under normal conditions to significantly vaporize and enter the atmosphere.
- Water vapor is the most important greenhouse gas.
- Ozone is formed due to the interaction between oxygen and ultraviolet radiation from sunlight. Ozone exists in a broad band commonly called the ozone layer. When emissions from automobiles and factories in the form of carbon and nitrogen react with sunlight, they produce ozone.

Life on Earth depends on sunlight. A part of sunlight is deflected by the outer atmosphere and scattered back into space. Some of it reaches the planet's surface and is reflected upward again in the form of infrared radiation. Greenhouse gases absorb infrared radiation and regulate the climate by trapping heat and holding it in the form of an envelope that surrounds the planet. This phenomenon is called the greenhouse effect. When the emissions of greenhouse gases from various activities increases, the infrared radiation trapped and held will be greater, thus resulting in a gradual increase in temperature on the Earth's surface. Figure 1 shows the greenhouse effect.

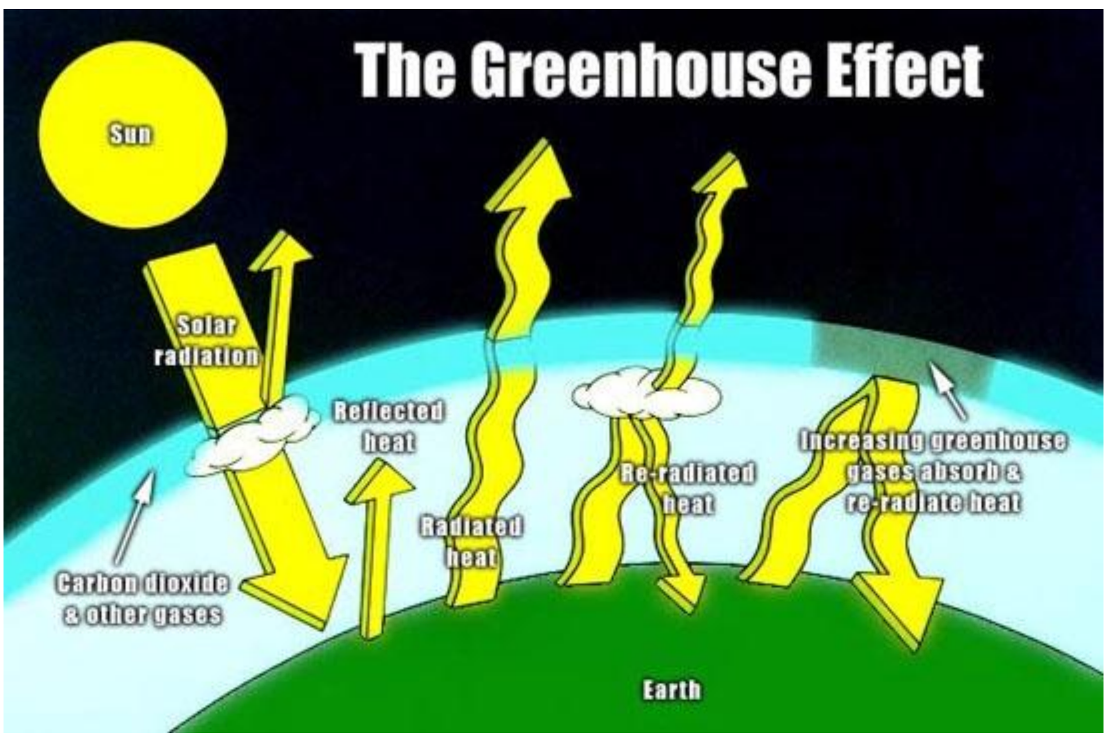


Figure 1: Greenhouse effect on the Earth's surface [4].

Throughout the 20th century, the world's population quadrupled, and energy consumption climbed sixteen fold [5]. Figure 2 shows the increases in temperature, carbon dioxide emissions, and world population from year 1000 to 2000 [5].

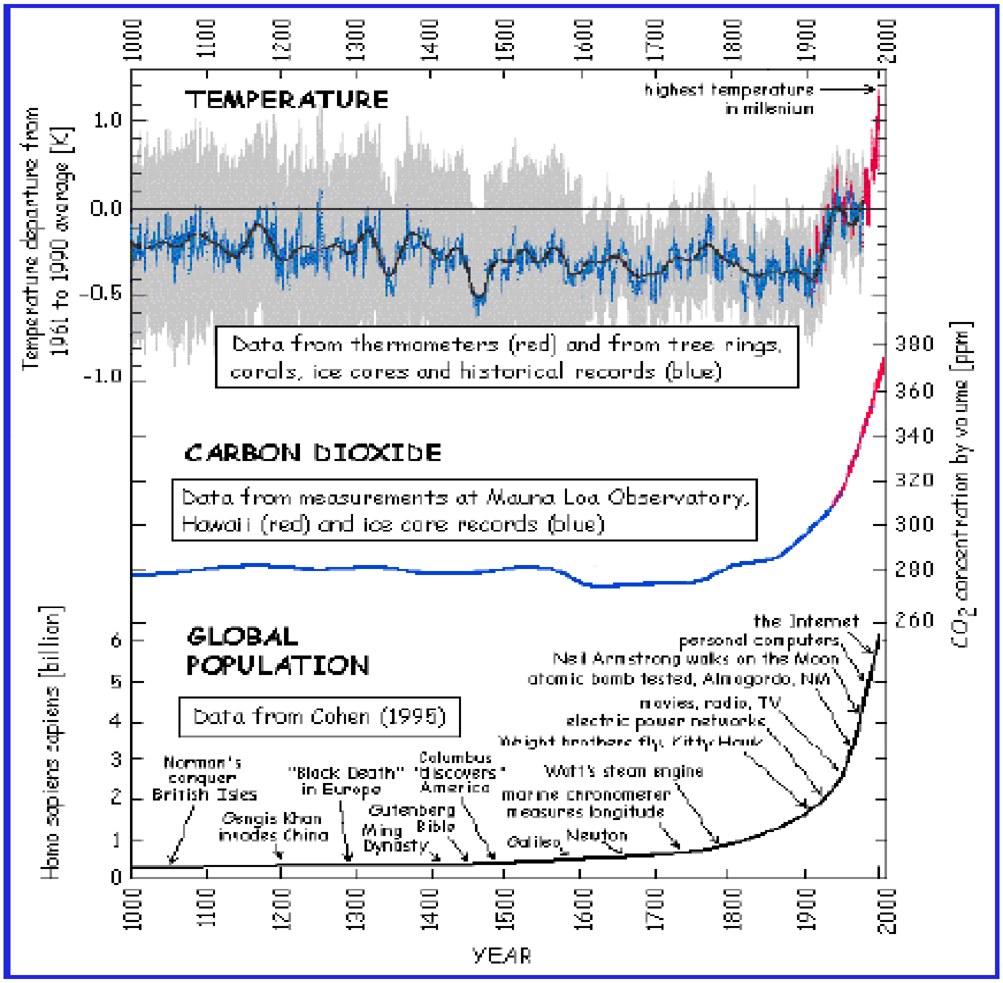


Figure 2: Comparison of increases in temperature, carbon dioxide emissions, and world population from year 1000 to 2000 [5].

3. NANOTECHNOLOGY REDUCES GLOBAL WARMING

Our addiction to fossil fuels is a dominant factor in global warming. This is one of the greatest environmental concerns in the near future. In recent times, a drastic increase in greenhouse gases, particularly carbon dioxide, has resulted from automobiles and industries. According to the U.S. National Oceanic and Atmospheric Administration (NOAA), carbon dioxide levels in the atmosphere are 387 parts per million (ppm), almost 40% higher since the industrial revolution [6]. The largest source of carbon dioxide emissions in the atmosphere is the combustion of fossil fuels such as oil, gas, and coal [6]. Greenhouse gases cause irreparable damage to the ozone layer, the environment, and health. Global warming has become an international issue and needs immediate attention from all countries. Various strategies can be adopted to address this issue [1-6]:

1. Decrease energy consumption, and increase the efficiency of existing technologies.

2. Stop the luxurious usage of fossil fuels in automobiles and industries, and use renewable energy resources.
3. Become involved in carbon management, which involves separating and converting carbon into useful products.

There are various approaches in many major areas to reducing energy consumption and thereby reducing greenhouse gas emissions. Nanotechnology has greatly impacted our lives by providing a possible alternative to fossil fuels and thereby reducing greenhouse gases. Transportation and industry are the two major contributors of greenhouse emissions in the atmosphere. According to the U.S. Environmental Protection Agency, the transportation sector contributes 28% of carbon dioxide emissions [6]. By reducing the weight of vehicles using nanocomposites instead of metal can reduce fuel consumption. It has been determined that a 10% reduction in fuel consumption could be achieved with a 10% weight reduction in vehicles, thereby leading to a proportionate reduction in greenhouse gas emissions [6].

Nanotechnology has the potential to harvest solar power, just one of many nanoapplications that may be used to combat greenhouse gas emissions [7]. Scientists and researchers are designing nanoscale sieves that can filter out toxic agents in fuels and fuel byproducts. Newly designed porous nanoparticles can extract more clean gas from every barrel of oil. Engineers and scientists are designing nanosieves that can capture carbon dioxide before it can enter the atmosphere. A UK-based company, Oxonica [OXN.L], incorporates its product, Envirox Fuel Borne Catalyst, into premium commercial diesel fuel, which reduces fuel consumption by up to 10% and reduces carbon dioxide emissions by up to 15% [7].

Nanotechnology is also playing an important role in increasing the efficiency of existing technology. A new concept of “green” nanotechnology involves the development of clean technologies to minimize potential environmental and health hazards associated with the use of nanomanufacturing and nanoproducts, and also the design and development of new products or the replacement of existing nanoproducts that are friendly to the environment and humans throughout their life cycle. Green nanotechnology has two main purposes: producing engineered nanomaterials without causing damage to the environment or any hazardous conditions to human health, and producing nanomaterials that provide a solution to environmental problems [15,16]. This concept uses the principles of green chemistry and green engineering to fabricate nanomaterials without toxicity, using less energy and renewable resources and using lifecycle thinking at all stages. Green nanotechnology aims to make nanomanufacturing processes more environmentally friendly.

Decreasing energy consumption and increasing the efficiency of existing technologies are two possible solutions to addressing global warming, as mentioned previously. However, the adversity of the problem demands more than these solutions. Reducing the weight of automobiles is not the only solution for reducing greenhouse emissions. Other possible ways of reducing greenhouse emissions include replacing fuel-burning internal combustion engines with powerful batteries using fuel cells. Altair Nanotechnologies, a U.S.-based company, has introduced nanolithium ion batteries that take only six minutes to recharge and can be recharged up to 20,000 times. The charge rate and lifecycles of these batteries are up to a hundred times higher than any other commercially available batteries [7]. Hybrid cars are being used in developed countries to reduce fossil fuel usage. Automobiles powered by fuel cells are possible alternatives for internal combustion automobiles. Fuel cells generate power by converting hydrogen into electricity without combustion. However, currently the high cost of fuel cells is preventing them from making an impact on the market [7].

Using carbon nanotube-reinforced polymer (CNRP) in aircraft structures has impacted aircraft design, the most obvious of which is a significant reduction in airframe weight, which in turn results in a reduction of fuel consumption [8]. A lighter aircraft requires lesser weight to remain airborne and produces less intense wake turbulence [8]. Another way of reducing fuel consumption is to incorporate nanocatalysts. Electrical energy can be produced at higher rates with nanocatalyst by promoting complete combustion of fuel. This will help decrease the fuel consumption and also reduce the air, water and soil contaminations/pollutions [6]. Reducing the friction between moving parts and improving wear resistance in locomotives can lower fuel consumption and thereby reduce carbon dioxide emissions [6]. Nanolubricants and nanocoatings can effectively reduce the coefficient of friction resulting in lower fuel consumption. A UK-based company, NanoBoron, has developed BORPower® to reduce fuel consumption by reducing friction and abrasion during motion by miniaturizing the ball-bearing effect and hard-coating [6]. The use of BORPower® can effectively reduce fuel consumption by 8-15% and lower carbon dioxide emissions by 8-15% [6]. Biodiesel and emulsified diesel are being used to reduce emissions from diesel engines and save energy [9]. Artificial chemical additives are also being used in diesel engines for increasing combustion efficiency.

Commercial and residential buildings account for 11% of greenhouse gas emissions, and nanostructured materials can significantly reduce heat transfer through buildings, thereby reducing heating/cooling requirements in buildings [6]. Applying nanotechnology principles in all sectors can effectively reduce greenhouse gas emissions and fuel consumption. Table 1 shows the environmental benefits of products associated with nanotechnology.

3.1 Utilization of Renewable Energy and Energy Storage Technologies

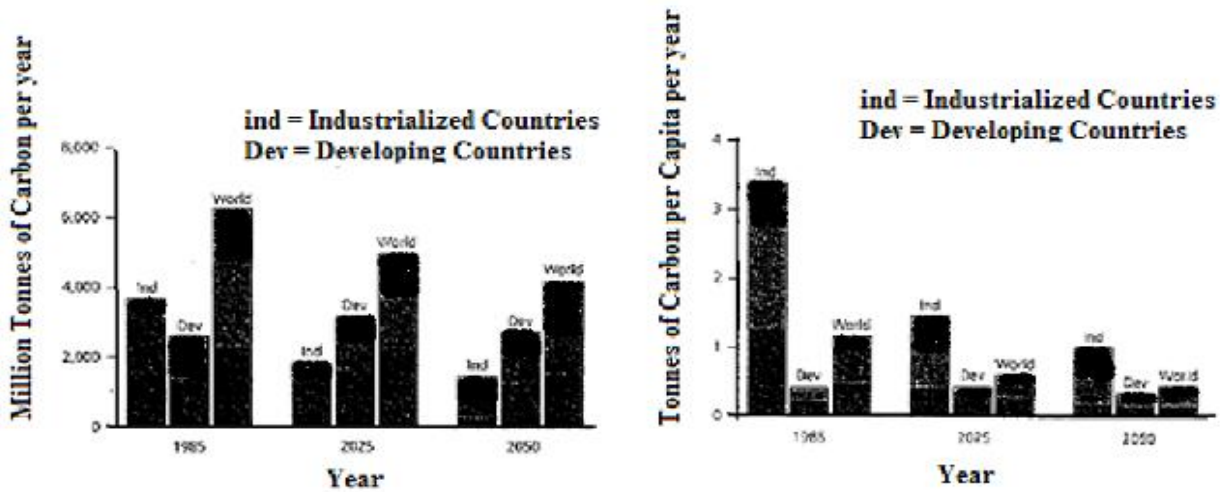
Renewable energy technologies can meet much of the energy demand at prices lower than conventional technologies. By the middle of the 21st century, renewable sources of energy could account for three-fifths of the world's electricity and two-fifths of the fuel used [11]. Renewable energy sources provide not only economic benefits but also environmental benefits. Carbon dioxide emissions would be reduced to 75% of their 1985 levels if energy-efficient and renewable technologies were both used effectively [11]. Production of renewable energy using biomass can provide economic benefits and employment opportunities as well [11]. Renewable energy technologies such as methanol or hydrogen for fuel cells produce no emissions [10]. Renewable energy use does not produce carbon dioxide and other greenhouse gases that would otherwise endanger our climate [11]. Electricity can be generated by various combinations of hydroelectric; intermittent renewable sources such as wind, solar, and photovoltaic; biomass; and geothermal power. Fuel can be provided by ethanol, methanol, hydrogen, and methane derived from biomass supplemented by hydrogen derived electrolytically from intermittent renewables.

With renewable energy sources, the emissions of carbon dioxide from fossil fuels would be reduced to 12% by 2015 and 26% by 2025. Similarly, emissions of carbon dioxide per capita using renewable energy sources would reduce to half by 2025 and around three-fifths by 2050 [11].

Table 1: Environmental benefits of products for different nanotechnology sectors [10].

Sectors of nanotechnology	Examples products	Environmental advantages
Nano electronic	Electronic component, bioelectronic component	Energy efficiency, speed data processing, replacement of silicon
Nano optic	Optoelectronic component	Higher data transfer rate, miniaturisation
Nano fabrication	Nano structures for electronic components, ultra thin layers of tools and components,	Energy efficiency, speed data processing, longer life time
Nano chemistry, nanomaterials	Nanoparticles (as part) from new materials or new composites	New mechanical, electrical, magnetically active, optical properties and therefore, unknown material functions less weight and volume, improvement of properties
Nanobiotechnology	Bio-based micro manufacturing of electronic components, bio sensors, bio catalyst, cellular engine	Medical early warning system energy efficiency
Nano analytics	Measuring instruments of quanta effects	Analysing nano structures

Solar cell or photovoltaic cells are possible alternatives of fossil fuels. Since solar cells are based on silicon, which is expensive, the high cost of these cells is a barrier to their widespread acceptance [6]. Recently, organic or plastic thin-film solar cells, which are less expensive and based on nanoparticles and polymers, are now being used to manufacture flexible solar cells [6]. Hydrogen fuel cells are also possible alternatives of fossil fuel. They eliminate all toxic pollutants from environment; however, some challenges must be addressed before these cells become dominant in the market. Their high cost, methods of producing hydrogen, and storage of hydrogen are the main obstacles in their widespread acceptance in the market [6-10]. Hybrid locomotives reduce pollutant emissions to the environment and thereby reduce global warming. They also reduce our dependence on fossil fuel. The chemical company BASF has developed a new engineering plastic (Ultradur® High Speed) by incorporating a nanoadditive, which has improved flowability (lower viscosity) and thus saves energy (Figure 4). This makes the manufacture of injection-molded plastic components not only more cost-effective but also conserves energy and reduces the environmental impact. Ultradur® High Speed is the BASF's first engineering plastic to receive the "Eco-Efficiency Label" [12].



(a) (b)

Figure 3: (a) Emissions of carbon dioxide for renewable intensive global scenario; (b) per capita emissions of carbon dioxide for renewable intensive global energy scenario [11].

Figure 4: Ultradur® High Speed engineering plastics [12,17].

BASF is using nanostructuring on ship hulls (Figure 5) to prevent the adherence of algae and mollusks in order to control the fouling process without the use of biocides. Ships with fouled hulls require 40% more fossil fuel to travel at the same speed as unfouled vessels [12-17].

BASF has developed a new material for organic-emitting diodes, also known as OLEDs. This is an organic semiconductor material consisting of very thin layers (5 to 150 nm). In addition to other advantages, OLEDs do not become hot when emitting light, which means that lesser energy is lost in radiation than with a conventional light source. OLEDS use only half as much electricity. With an organic photovoltaic, a nanometer layer of dye is encapsulated in solar cells in order to use the energy of sunlight to generate electricity. They become more cost effective and have more and wide-ranging applications [12].

Figure 5: Reduced fouling with nanostructured materials [12].

4. NANOTECHNOLOGY INCREASES GLOBAL WARMING

The fast-growing field of nanotechnology has invigorated tremendous interest from the scientific community in recent years and is often termed as one of the biggest breakthroughs of this century. Nanotechnology has unlimited usage and unlimited advantages in our daily lives. It is appearing in a wide range of customer products, from cosmetics to nanopaints to automobiles, etc. The use of nanotechnology is spreading in almost all fields, including engineering, science, medical, polymer science, chemistry, etc. In addition to the advantages of nanotechnology, some disadvantages are associated with nanotechnology. Isaacs and colleagues determined that the life cycle of single-walled nanotubes (SWNTs) is highly energy intensive, with numbers ranging from 1,440,000 to 2,800,000 mega joules per kilogram of carbon nanotubes (CNTs) [13]. The life cycle energy requirements for CNTs are 13 to 50 times that of primary aluminum on an equal mass basis [13-16]. A comparison can be made of the damage and midpoint indicators evaluated in the process life cycle assessment of carbon nanofibers. There are several reasons for this difference. First, the high-temperature vapor-phase procedure required for carbon nanofiber (CNF) synthesis has low efficiency and requires important energy investment. Second, the processes required for manufacturing traditional materials are well-studied and have been optimized with respect to energy consumption and material over the last century or so [13]. Figure 6 shows the damage indicators obtained via Eco-indicator 99.

5. EDUCATIONAL IMPACTS OF NANOTECHNOLOGY

Nanotechnology offers amazing benefits to human life and the environment, but it can lead to educational consequences, as well. Research and development on nanotechnology and nanoproducts have been growing rapidly for more than a decade; however, educational progress has not been as rapid as technological development. In other words, technical training is not sufficient for individuals working in the field; parallel training is required, which will be useful for the societal and ethical implications of the technology.

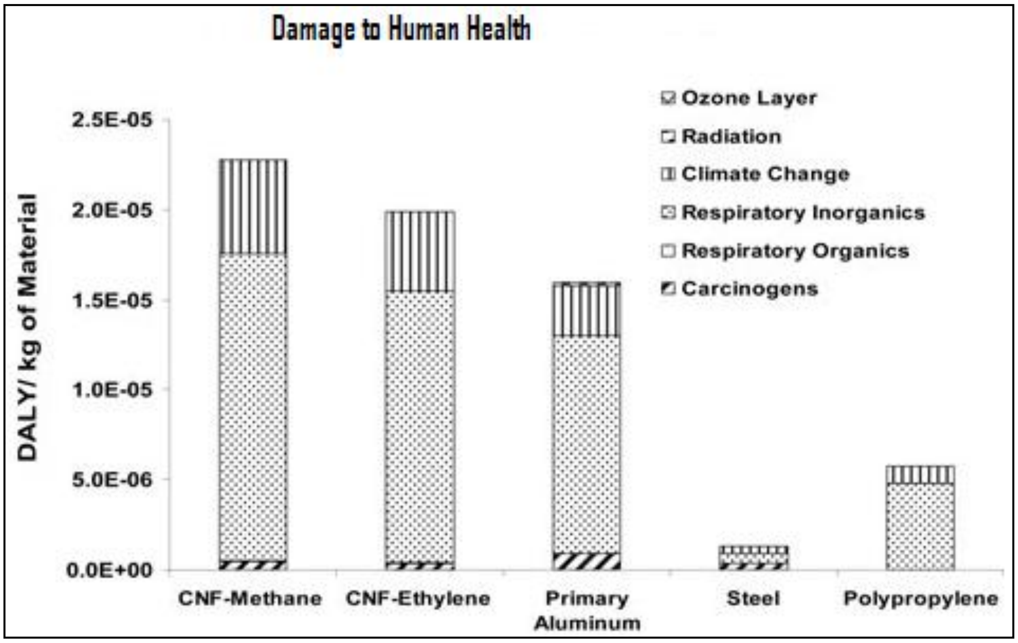


Figure 6: Vapor-grown carbon nanofibers life cycle assessment (VGCNF-LCA): damage indicators (disability-adjusted life years) [13].

Providing interdisciplinary and multidisciplinary training of nanoethics for students and scientists, as well as technologists, engineers, medical practitioners, social scientists, workers, and humanists in every discipline will offer great benefits. This training can be accomplished through new class developments, seminars, conferences, invited talks, and other individuals who are experts in nanotechnology and nanoethics. For the undergraduate and graduate students who are preparing themselves for careers in nanoscale science and technology, whether as biologists, chemists, physicists, or engineers, new courses should be introduced to provide a needed focus on nanoethics. These courses should be taught by different professors from various departments and should be mandatory for students working in the field of nanotechnology.

In addition to these measures, other actions may include television, media, and online news to inform students and the public. A departmental website should be prepared and continuously uploaded, and should display the most current information. Government agencies, such as the Food and Drug Administration, Environmental Protection Agency, National Institutes of Health, Department of Health and Human Services, and private companies (IBM, GE, GM, etc.) should have financial support and actively participate in the educational issues of nanoethics.

For nanotechnology to reach its full potential, it must have a trained workforce for research, manufacturing, and development [14]. In creating such a workforce, it is essential to attract students to nanotechnology and training programs. Training programs must address two groups: the scientific and engineering workforce, and the technician workforce. The basic understanding needed in a nanotechnology workforce is to have students, parents, and teachers who are aware of the unlimited and unprecedented advantages of nanotechnology in our daily life. The key factor is to inform students about nanotechnology in middle and high schools and colleges through lectures and seminars. The teachers must outline the role of nanotechnology in society, the environment, medical science, and daily life, and the requirement of the nanotechnology workforce. Educators must create workforce training programs that provide technicians with the background and skills to use nanotechnology [14]. A nanotechnology training program must be scientific and skilled-based. A two-year degree program in colleges with appropriate curricula and laboratory facilities is needed to provide students with general and fundamental knowledge in nanotechnology.

6. CONCLUSIONS

Nanotechnology has the potential of reducing greenhouse gases emissions significantly and thereby mitigating global warming. The rate at which global warming is increasing could endanger this planet in the future. The last two decades of the 20th century were the hottest in 400 years. The Earth has experienced climate changes in the past but the current changes in climate are more rapid and destructive. Our addiction to fossil fuels is most likely the major reason for global warming. There has been a dramatic increase in greenhouse gases, particularly carbon dioxide in recent times from automobiles and industries. Nanotechnology addresses the global warming issue by minimizing/eliminating fossil fuels, decreasing energy consumption, and increasing the efficiency of existing technologies. On the other hand, nanotechnology consistently involves the use of nanomaterials (nanomembranes, nanocatalysts, aerogels, nanoparticles, etc.), and their manufacture requires a significant amount of energy input. Currently, fossil fuels are the source of this energy input, which means that the entire purpose of reducing CO_2 gas emissions and preventing global warming is nullified. The only alternative available at our disposal is to use renewable sources of energy. In addition, the economics of applying nanotechnologies to solve the problem of global warming must be closely observed and thus the need for a detailed cost-benefit analysis. Needless to say, firm commitments from major industries and governments alike to reduce greenhouse gases are also essential for our future.

REFERENCES

1. Leo Stander and Louis Theodore, “Environmental Implications of Nanotechnology—An Update,” *Int. J. Environ. Res. Public Health*, vol. 8, 2011, pp. 470-479.
2. Mark Ratner and Daniel Ratner, *Nanotechnology: A Gentle Introduction to the Next Big Idea*, Prentice Hall, November, 2002.
3. Bharat Bhushan, *Springer Handbook of Nanotechnology*, Springer-Verlag, Heidelberg, New York, 2004.
4. http://mrsdlovesscience.com/greenhouse/greenhouse_effect.jpg (accessed June 2, 2012).
5. R.E. Smalley, Our Energy Challenge, 27th Illinois Junior Science and Humanities Symposium, April 3, 2005.
6. http://www.nanowerk.com/spotlight/spotid=16126.php (accessed June 2, 2012).
7. Forbes/Wolfe, Nanotech Report, Nanotech could give Global Warming a Big Chill, Forbes Inc. and Angstrom, 5,7, 2006.

8. Sarah E. O'Donnell, Impact of Nanomaterials in Airframes on Commercial Aviation, The MITRE Corporation, Center for Advanced Aviation System Development (CAASD), McLean, Virginia.
9. Yuan- Chung Lin, Wen-Jhy Leen, How-Ran Chao, Shu-Li Wang, Tsui-Chun Tsou, Guo-Ping Chang-Chien, and Perng-Jy Tsai, "Approach for Energy Saving and Pollution Reducing by Fueling Diesel Engines with Emulsified Biosolution/ Biodiesel/Diesel Blends," *Environ. Sci. Technol.*, vol. 42, 2008, pp. 3849-3855.
10. C. Bauer, J. Buchgeister, R. Hischier, W.R. Poganietz, L. Schebek, and J. Warsen, "Towards a Framework for Life Cycle Thinking in the Assessment of Nanotechnology," *J. Cleaner Production*, vol. 16, 2008, pp. 910-926.
11. Thomas B. Johansson, Henry Kelly, Amulya K.N. Reddy, and Robert H. Williams, "Renewable Fuels and Electricity for a Growing World Economy: Defining and Achieving the Potential," *Energy Studies Review*, vol. 4, iss. 3, art. 6, 1992, pp. 201-212.
12. http://www.basf.com/group/corporate/en/sustainability/dialogue/in-dialogue-with-politics/nanotechnology/environmentally-friendly (retrieved on May05, 2012).
13. Vikas Khanna, Bhavik R. Bakshi, and L. James Lee, "Carbon Nanofiber Production: Life Cycle Energy Consumption and Environmental Impact," *J. Industrial Ecology*, vol. 12, no. 3, 2008, pp. 394-410.
14. Stephen J. Fonash, "Education and Training of the Nanotechnology Workforce," *J. Nanoparticle Research*, vol. 3, 2001, pp. 79–82.
15. R. Asmatulu "Toxicity of Nanomaterials and Recent Developments in Lung Disease," Chapter 6 in *Bronchitis*, InTec, ed. P. Zobic, 2011, pp. 95-108.
16. R. Asmatulu, E. Asmatulu, and A. Yourdkhani "Toxicity of Nanomaterials and Recent Developments in the Protection Methods," SAMPE Fall Technical Conference, Wichita, KS, October 19–22, 2009, 12 pages.
17. http://www.dexigner.com/news/14585, accessed in August 2, 2012.

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