Nanotechnology based Mega Machine Design for Large Scale Air Cleaning – Prospects and Challenges

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ABSTRACT

Air pollution is a major component of environmental degradation in the 21st century worldwide due to the increased use of fossil fuels in various industries and their contribution to contaminating the natural atmosphere around us. Environmental pollution is posing a challenge to human existence and the continuation of human generation on this planet. Environmental degradation is considered a major affecting factor of climate change which includes both global warming driven by industrial emissions of green gases and large-scale shift in weather patterns.

This problem is growing on a large scale throughout the world and poses challenges to survival and sustainability. Nanotechnology being universal technology can be used to solve this problem of environmental degradation by cleaning the degraded air on large scale and can counter the contribution of natural and industrial pollution. In this paper, the proposal of construction and use of nanotechnology based mega machine is analyzed and the prospectus and challenges of such machine production and maintenance for large scale air cleaning are discussed. The advantages, benefits, constraints, and disadvantages of production and use of such mega machines from various stakeholders' points of view are identified. Finally, the idea of self-sustainable nanotechnology filters based mega machines is proposed using solar/wind energy supported systems for automatic and self-sustainable use.

Keywords: Nanotechnology, Nanomaterial air filters, Mega machines, Large scale air cleaning, Solar energy, sustainable use

1. INTRODUCTION:

The basic needs of human beings in society include nutritious food, potable drinking water, renewable energy, sustained health, and a clean and green environment. Due to uncontrolled industrialization and greediness of many people, the environment is currently degraded by means of air pollution, water pollution, and food pollution, leading to environmental degradation. Air pollution is a major component of environmental degradation in the 21st century worldwide due to the increased use of fossil fuels in various industries and their contribution to contaminating the natural atmosphere around us. Environmental pollution is posing a challenge to human existence and the continuation of human generation on this planet. Environmental degradation is considered a major affecting factor of climate change, which includes both global warming driven by industrial emissions of green gases and resulting in large scale shifts in weather patterns. This problem is growing on a large scale throughout the world and posing challenges to the survival and sustainability of all living beings. Environment degradation is associated with a reduction in the quality of environmental features due to various human activities in the name of civilization and development along with natural disasters [1]. The continuously increasing environmental degradation in an uncontrollable manner leads to depletion of natural resources, affecting biodiversity and ecosystems. Out of various types of environmental pollutions, air pollution and water pollution have major consequences on human life on this planet. It is known that air pollution usually occurs due to the addition of toxic substances and chemicals emitted from various activities like fossil fuel consumption, industrial wastes, emissions from automobiles, etc to the natural atmosphere [2]. Acute air pollution creates many health-related problems including acute respiratory effects [3]. Hence it is essential to think of the development of a system to clean the environment on a large scale along with controlling the causes of pollution to ensure the survival of all life on earth. Cleaning the environment systematically can reduce pollution, protect unique ecosystems, protects the extinction of living species, and conserves clean air and potable water. Cleaning

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the environment allows us to protect biodiversity and ecosystems and hence living creatures on earth. It is estimated that climate change and global warming will be at their peak during the end of the 21st century and if the precautions are not taken from now life on earth may extinguish due to various environment related disasters. These disasters like drought, heavy rainfalls and floods, melting ice caps and increasing sea levels, circulation of heatwaves, etc lead to further climate change and weather change. Manmade pollutants other than conventional pollutants, like toxic emissions and carbon dioxide emissions from various industries and motor vehicles, contribute to air pollution. These manmade pollutants along with conventional pollutants adversely affect and toxic human health, causing health hazards such as cholera, eye irritation, heart disease, cancer, and respiratory diseases leading to an increased rate of mortality [4].

It is understood that technology if used properly can support human beings to solve many problems. Water & Steam Power Systems using Mechanization technology for producing energy were supported Industry 1.0, Electricity and assembly line systems using Mass Production knowledge based technology were supported Industry 2.0, Computer and Communication technology systems which were skill based Automation Processes supported Industry 3.0, Internet of Things (IoT) and 3D printing systems used for Mass Customization supporting Industry 4.0, and ICCT underlying technologies including Artificial intelligence & Virtual reality and Nanotechnology will be used for mass automation and 3D production using ICCT controlled Super Intelligent Machine systems and Nanotechnology results in Industry 5.0. [5]. Though nanotechnology is got its birth during the second part of the 20th century, it is considered as the breakthrough technology of the 21st century [6] due to its potential ability to solve basic needs related, wants related, and desire related problems of human beings [7, 8]. Nanotechnology has initiated breakthrough changes in many major industries including agriculture & food processing [9], Potable water [10], renewable energy [11], Automobiles [12], and healthcare sectors [13]. It is predicted that nanotechnology has many features of green technology [14, 15] and is capable of realizing many characteristics of ideal technology [16].

Nanotechnology being universal technology [17, 18] can be used to solve the problem of environmental degradation by cleaning the degraded air on large scale and can counter the contribution of natural and industrial pollution. Recently our team (Shubhrajyotsna Aithal et al (2020)) has published an idea of using mega machines as air and water cleaners for cleaning the environment using Nanotechnology [2] and listed its advantages, benefits, constraints, and disadvantages. In this paper, the proposal of construction and use of nanotechnology based mega machine is analyzed and the prospectus and challenges of such machine production and maintenance for large scale air cleaning are discussed. The advantages, benefits, constraints, and disadvantages of production and use of such mega machines from various stakeholders' points of view are identified. Finally, the idea of self-sustainable nanotechnology filters based mega machines is proposed using solar/wind energy supported systems for automatic and self-sustainable use.

2. RELATED WORKS:

Rickerby, D. G., et al. (2007) [19] argued that nanotechnology has the capability to provide more sensitive detection systems for air and water quality monitoring and control. Metal oxide nanocatalysts are potential candidates to prevent and control air pollution due to industrial emissions. They also proposed that it is possible to prevent air pollution due to industrial emissions using carbon nanotubes and the photocatalytic properties of titanium dioxide nanoparticles can be used to create self-cleaning surfaces that reduce existing air pollution.

Muller, C. O. et al (2015) [20] studied the effect of air pollution on morbidity and mortality in China and suggested the use of air cleaning systems to remove irritating and noxious gases and foul odours along with a respirable particulate matter to protect people health and to ensure good indoor air quality. They suggested using leading-edge air cleaning technologies including nanotechnology to effectively remove common air pollutants including PM_{10}, $PM_{2.5}$, formaldehyde, O_3, SO_2, NO_2, and volatile organic compounds.

Yunus, I. S., et al (2012) [21] discussed various types of pollutants emitted from human activities or industrial processes. They also suggested the use of nanomaterials like carbon nanotubes and gold particles to remove toxic gases in the polluted air using the process of adsorption. This includes adsorption of dioxins and related compounds which are toxin in nature to humans and mainly generated from the combustion of organic

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compounds in waste incineration, adsorption of NO_x (mixture of NO and NO_2) using carbon nanotubes (CNT), Capture of carbon dioxide (CO_2) using chemically modified CNTs, silica-based molecular baskets, Removal of other volatile organic compounds (VOCs) using highly porous manganese oxide with gold nanoparticles, Adsorption of isopropyl alcohol (IPA) vapour using Single walled carbon nanotubes (SWCNTs) oxidized by a solution of HNO_3 and NaClO, etc.

Aithal, S., et al (2020) [2] provided an idea for designing Mega-Machine for environmental cleaning of air with discussion related to causes of environmental pollution, constituents of polluted air and water, various technologies suitable for environmental cleaning, and ability of nanotechnology in air and water cleaning processes. The design idea includes a mega device to clean the polluted air using nanotechnology based filters. The suitability of the device is analyzed by listing its advantages, benefits, constraints, and disadvantages and suggested the pre-cautions to be taken while implementing such cleaning devices.

3. OBJECTIVES:

(1) To evaluate the need for mega air cleaner in industrial and public places to counter the climate change
(2) To discuss the technological solutions to air pollution
(3) To use of Nanotechnology to develop Mega-Machine for Environmental Air Cleaning
(4) To evaluate the functions of Nano-filters-based mega machine proposed earlier for large scale air cleaning
(5) To provide further details of mega air cleaners in terms of various polluting components.
(6) To analyze the prospects of such mega machines in the process of controlling climate change
(7) To suggest the use of renewable energy for self-sustainability of air cleaning mega machines.
(8) To discuss the challenges of developing mega air cleaning machines of variable size from design, construction, and maintenance points of view.
(9) To study the importance of such machines using ABCD Analysis framework from Various Stakeholders Point of Views.
(10) To suggest the precautions for implementation of such mega cleaning Devices and their suitability of fulfilling 17th goal of United Nations SDG.

4. NEED OF MEGA AIR CLEANER:

According to a damning report on outdoor air quality by the World Health Organization (WHO), almost 90% of people living in the cities are currently exposed to dangerous levels of air pollution. Based on its studies, out of 1,600 cities across 91 countries, only 12% of cities have complied with the guidelines of WHO and others have dangerous air pollution levels. Table 1 depicts the pollution index of 20 countries in the world map for the year 2020. Pollution Index is an estimation of the overall pollution in a city which includes air pollution (maximum weight), water pollution, and other types of pollution (minimum weight). It is recognized that carbon, sulphur, nitrogen compounds, ground level ozone, and particulate matter (PM) pollution produced by anthropogenic and of natural origin pose serious health risks.

Table 1 : Top 20 countries having highest pollution index as in Mid of 2020

Rank	Country	Pollution Index
1	Afghanistan	93.47
2	Mongolia	92.03
3	Myanmar	91.58
4	Lebanon	88.91
5	Ghana	88.51
6	Nigeria	86.89
7	Monaco	86.53
8	Vietnam	86.05

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Rank	Country	Pollution Index
9	Bangladesh	85.83
10	Nepal	84.80
11	Egypt	84.69
12	Peru	83.34
13	North Macedonia	80.23
14	China	79.88
15	Ethiopia	79.87
16	Chile	79.74
17	India	79.56
18	Albania	78.24
19	Cambodia	78.19
20	Laos	78.00

Reference: https://www.numbeo.com/pollution/rankings_by_country.jsp

The outdoor air pollution is one of the world's largest environmental problems due to industrialization of the countries and their transition from low to middle income countries. This leads to health related diseases and counts for 3.4 million premature deaths in the year 2017. These data are really threatening human health and decrease the life span too. The study of pollution levels all along with the world especially in cities suggests the immediate action using technology. Further, the development and installation of mega air cleaners in identified areas help to achieve five out of seventeen United Nations Sustainable Development Goals (SDGs) which include (1) Ensuring healthy lives and well-being for all at all ages by means of pollution free atmosphere (Goal 3), (2) To ensure availability and sustainable management of potable water and sanitation for all by controlling all kind of pollution which degrade potable water (Goal 6), (3) To build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation by controlling industrial pollution (Goal 9), (4) To make cities and human settlements inclusive, safe, resilient, and sustainable by controlling the pollution in the cities (Goal 11), and (5) To take urgent action to combat climate change and its impact by means of controlling all type of pollutions and environmental degradation (Goal 13).

5. NANOMATERIALS USED FOR CLEANING OF AIR-POLLUTANTS:

Nanotechnology is the application of nanoscience where the materials of the dimensions of the order of 10^{-9} m show special physical and chemical characteristics including electrical conductivity, mechanical strength, colour, etc. are different from their bulk properties. For example, some metals at the nanoscale size behave like semiconductors or insulators. This is due to either increased surface area to volume ratio, or increased mechanical strength, or improved thermal stability, or varied catalytic activity, or changed electrical conductivity, magnetic properties, and optical properties. These special properties of nanomaterials allow the users to prepare lightweight but very strong nano-systems for device fabrications including nano-purifier both for indoor and outdoor air purifications. These air purifiers use three types of principles identified as Adsorption based nano-purifiers, Degradation based nano-purifiers, and Filtration based nano-purifiers [2].

In adsorption based air purifiers, nanomaterial acts as a super adsorbent for several air pollutants due to their high selectivity, affinity, and capacity adsorption of harmful gases and volatile organics using their hydrogen bonding, electrostatic forces, π-π interactions, and van der Waals forces. For example, carbon nanotubes deposited on quartz filters are used to eliminate and monitor volatile organic compounds (VOCs) and other air

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pollutants by means of adsorption [22]. Adsorption based air purifiers also capable to remove dioxin related compounds. It is known that Dioxin and related compounds (e.g. polychlorinated dibenzofuran and polychlorinated biphenyls) are stable and highly toxic pollutants. Dioxin compounds are mainly generated from the combustion of organic compounds in waste incineration. Through the adsorption process, carbon nanotubes are effective to remove dioxin from impure air. Similarly, No, SO_2, and CO_2 are also adsorbed by carbon nanotubes.

In degradation based air purifiers, nanocatalysts are used for reducing air pollutants in the air. Compared to conventional catalysts, nanocatalytic system allows rapid and selective chemical transformations with an efficient yield at output along with the opportunity of catalyst recovery. It is found that using the principle of oxidization, photocatalysts are able to oxidize organic pollutants into nontoxic materials. At a sufficient level of light irradiation, the charge transfer process will occur from the valence band to the conduction band causing the surrounding substance to be oxidized. Many nanomaterials serve as efficient photocatalysts. For example, titanium dioxide (TiO_2), zinc oxide (ZnO), and tungsten oxide (WO_3) are tested as efficient photocatalysts in many cases [23]. Degradation is also possible with highly porous manganese oxide with gold nanoparticles that are grown into it. Titanium dioxide (TiO_2) when being irradiated with ultraviolet (UV) light creates an excited-state of the electron (e^-) and hole (h^+) pairs which are able to react with O_2 and water vapor in the atmosphere to produce superoxide ions (O_2^-) and hydroxyl radicals ($OH^{\bullet}$). Both O_2^- and $OH^{\bullet}$ are extremely powerful agents in destroying chemical compounds as well as bacterial cells to form CO_2 and H_2O [24- 30].

The filtration based air purifier uses nanometer sized membranes that have pore sizes from 1-10 nanometers. Membranes used are predominantly created from polymer thin films. Materials that are commonly used include polyethylene terephthalate or metals such as aluminum. Nanofiltration uses pressure as the driving force. Nanofiltration membranes provide higher thrust or rejection of multivalent ions, pesticides and heavy metals compared with conventional treatment methods and act as high-efficiency particulate air filters. Silver nanoparticles are used for nanofiltration because of their antibacterial properties and low toxicity to mammalian cells. Nanosilver is incorporated into different filtering membranes through various impregnation techniques. Two types of nanotechnology filters are (1) Carbon tube membrane filters, and (2) Nanofiber filters.

Table 2 depicts the causes of air pollution, its constituents, and the consequences as listed in reference [2]. Table 3 lists various nanomaterials used in air filters and Table 4 gives ideas about air filters of different materials.

Table 2 : Causes of Air Pollution and its constituents [2]

S. No.	Cause for Air pollution	Affecting Constituents of polluted Air	Consequences
1	**Particulate Matter**	Gaseous primary pollutants and compounds in photochemical smog.	Respiratory Problems leading to Infant mortality
2	Persistent free radicals	Airborne fine particles	Cardiopulmonary disease leading Death
3	Toxic Metals	Lead, Mercury, etc.	Brain function leading to Death
4	Radioactive pollutants	High energy radiations & ions	Possibly tuberculosis
5	Traffic pollution	CO, NOx,	Poisoning and fatalities, including Eutrophication
6	Biomass fuel	Greenhouse gases	Higher incidence of pneumonia
7	Volatile Organic Compounds (VOCs)	Methane (CH_4) and non-methane (NMVOCs) like benzene, toluene and xylene	Leukaemia through prolonged exposure
8	Ammonia (NH_3)	Emitted from agricultural processes	Caustic and hazardous

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Table 3 : Nanomaterials used in Air filters [2]

S. No.	Nanomaterial Used	Pollutants	Reference
1	Carbon nanotubes	N_2, CO, CO_2	Li, P. et al. (2014) [31-32 66-67]
2	Silica Nanoparticles	Pb (Lead)	Saleh, T. A. (2016) [33 68]
3	Nanocellulose aerogel	VOCs (Aniline & Benzene)	Nemoto, J. et al. (2015) [34 69]
4	ZnO nanorods	CS_2 (Carbon Disulphide)	Zhong, Z. et al. (2015) [35-36 70-71]
5	Silver Nanoparticles	CO (Carbon monoxide)	Siva, S. et al. (2015) [37 72]
6	Titanium dioxide (TiO_2)	SO_2, Ethylene	Baltrusaitis, J. et al. (2011) [38 73]
7	Tungsten oxide (WO_3)	NOx Sensing	Wang, C. et al. (2014) [39 74]
8	Nanofibers of natural protein	Particulate pollutants and toxic gases	Souzandeh, H. et al. (2016) [40 75]
9	Gold nanoparticles	Bacterial removal	García, A. et al. (2012) [41 76]

Table 4: Air filters of different materials

S. No.	Types of filters	Filtrate	Reference
1	Multifunctional and Efficient Air Filtration	Natural Nanofilter Prepared with Zein and Polyvinyl Alcohol	Li, K. et al. (2020) [42]
2	Air purification systems	Legionella: Bioactive nano-filters	Rodrigues, et al. (2011) [43]
3	Air Treatment Filters	Ag-TiO2 Nanorod	Wang, S. J. et al. (2020) [44]
4	Oodour adsorbent nanofilters	cyclodextrin molecules into electrospun cellulose acetate webs	Ghorani, B. et al. (2019) [45]
5	Air purification and self-cleaning	Photocatalytic nanomaterials	Rafique, M. S., et al. (2020) [46]
6	Effective air purifier to remove PM and to reduce NO from automobile exhaust	Nickel nanofiber	Tang, X. et al. (2020). [47]
7	Poly (Vinyl Alcohol) Nanofilters	Photocatalytic Property of Titanium Dioxide	Yeo, J. H. et al. (2020). [48]
8	Hepatitis E virus elimination filter	Plasma based Fibrinogen	Yunoki, M. et al (2008). [49]
9	Virus removing Nano filters	Carbon nanotube-silver composites	Kim, J. P., (2016). [50]
10	Bacteria Removing Nano filters	Graphene oxide nanomaterials	Ruiz, O. N. et al. (2015). [51]
11	Separate SF6 gas from a mixture of gases SF6 + N2	Ion irradiated Polyethyleneterephthalate (PET) film as nanofilters	Vijay, Y. K. et al. (2009). [52]

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12	Nanofibrous filter with low air resistance for high-efficiency filtration of particulate matter	Electrospun poly (vinyl alcohol)/cellulose nanocrystals composite	Zhang, Q. et al. (2019). [53]
13	Air purification	Titanium carbide Ti3C2Tx (MXene) enhanced PAN nanofiber membrane	Gao, X. et al. (2019). [54]

6. DESIGN A MEGA MACHINE DEVICE CONSISTING OF NANOTECHNOLOGY BASED CASCADED FILTERS TO CLEAN POLLUTED AIR:

Based on the research results published in the area of nanotechnology, now it is possible to remove many hazardous pollutants from polluted air. Hence it is possible to design and develop an air cleaner both for indoor and outdoor, for small scale and large scale cleaning purposes respectively. To remove many polluted constituents that are mixed in the air, a cascaded filters principle can be used. A cascaded design based nanotechnology filters can give additive effects while purifying input pollute air as clean air at the output. A cascaded mega air-cleaner machine consists of many filters made of different nanomaterials to filter different components of polluted air, cascaded serially with the airflow direction.

The design is based on the imagination of an ideal environment cleaner with 100% efficiency as shown in Figure 1 where, the system with ideal fan as the first stage takes impure air of any impurity level as input and by passing it through many nanotechnology supported filter stages of different characteristics, the clean air without any impurity is taken at the output. The system uses an ideal Fan or ideal Pump as the first stage which is driven by a perfectly renewable energy source. The energy source called ideal energy source [55] considered in an ideal air purifier is analogous to the one used in an ideal water purifier [56].

By keeping the ideal air purifier machine shown in figure 1 as a reference, we have discussed the design of a practical air cleaning machine for outdoor air cleaning called mega machine [2] consisting of four stages of filtering systems using nanotechnology-based filtering membranes. The machine is driven by solar energy or wind energy supported high speed fan to pump the polluted air from indoor or outdoor into the machine. Depending on the capacity of this solar pumped fan, the impure air from open space is pushed to cascaded filters to purify the air in different stages and finally, the pure air free from all impurities pushed out from the machine. The filtering stages are designed using different varieties of nanotechnology membranes as per the information listed in table 3. The block diagram of Practical Air Cleaning Machine using Nanotechnology is shown in figure 2. The various stages are :

(1) Renewable/Solar Energy based Fan: A big fan is used to suck the impure air from a polluted place. The fan being the first component forces polluted air towards a series of nano-filter stages at high speed. This high-speed fan is driven by continuous electric power generated either a solar energy power plant or wind energy power plant as a renewable energy source.

(2) Nanofilter Stage for Particulate matter: The first stage of mega filter is designed to remove and separate all particulate matters which are considered as serious threats to public health. Suspended particulate matter consists of a mixture of particles and droplets in the air of both organic and inorganic particles such as dust, soil, acids, metals, nitrates, smoke, soot, and liquid droplets. The particulate matter particles vary in size, composition, and origin. The particulate matter particles of size between 100 nm to 2.5 µm are called fine fraction and above size 2.5 µm are called coarse particles. The particulate matter particles of size below 100 nm are called ultrafine particles and are accounted for over 90% of the numbers. Various techniques are used to separate these particulates which include mechanical filtration, electrostatic filtration, and nanofibers. Mechanical filtration includes mechanical collectors like dust cyclones, multi-cyclones, etc., electrostatic filtration includes electrostatic precipitators and particulate scrubbers. The nanofilter stage is made up of nanofibers of natural proteins, electrostatic polyesters composed of conductive nanowires, etc.

(3) Nanofilter Stage for VOC:
The second stage of mega filter is designed to remove and separate all volatile organic compounds

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(VOCs) which are also considered as serious threats to public health [57]. Various techniques used for VOC removal include Thermal oxidizers, Adsorption using activated carbon, Cryogenic condensers, Biofilters, etc. Photocatalysis that utilizes semiconductor nanoparticles can decompose VOCs in gaseous pollutants directly into harmless CO_2 and H_2O under ambient conditions. The principles of photocatalytic degradation of VOCs using visible light and photocatalyst deactivation of VOCs can be used in this stage. Various metal nanoparticles can be used for the degradation of VOCs. This include :

(i) Metallic nickel nanoparticles were employed as catalysts for the thermal decomposition of methane to produce hydrogen.

(ii) Nanosilver-decorated titanium dioxide (TiO_2) nanofibers can be used to remove Nitrogen oxide (NOx), volatile organic compounds (VOCs), microbial activity.

(iii) Titanium dioxide nanoparticles (TNPs) can be used for photocatalytic degradation of ethylene which is a VOC.

(iv) Air filtration technology using antimicrobial materials such as silver nanoparticles, copper nanoparticles, CNTs, and natural products is considered the most applied and effective technique to remove bioaerosols through ventilation processes.

(v) Electrospun nanofibers (NF) (hydroxypropyl-beta-cyclodextrin (HPβCD), NF, and hydroxypropyl-gamma-cyclodextrin (HPγCD) NF) for entrapping VOCs like aniline and benzene.

(vi) Nanometalic decorated TiO_2 can be used for the degradation of biological substances, such as viruses, bacteria, parasites, and antibiotics.

(4) Nanofilter Stage for Toxic Gases:
The third stage of mega machine is designed to remove and separate all toxic gases present in polluted incoming air which are also considered as serious threats to public health. Toxic gases like NO_2, Ozone, SO_2, CO, CO_2, CH4, CS_2, NH_3, etc. This include :

(i) Titanate nanotubes (TNTs) and their derivatives have been widely reported for the photocatalytic oxidation of NOx.

(ii) Modified TiO_2 with different loads of silver was used for the photocatalytic decomposition of (N_2O) to nitrogen and oxygen.

(iii) SO_2 adsorption is possible on the surface of $COFe_2O_4$ magnetic nanoparticles.

(iv) Horn-shaped carbon nanotubes can be used to remove Carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), and nitrogen (N_2).

(v) Single-walled carbon nanotubes can be used to remove Nitrogen (N_2), methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2).

(vi) Zinc oxide and zirconium hydroxide nanoparticles can be used to remove Nitrogen oxide (NO_2), sulfur oxides (SO_2).

(vii) Aligned carbon nanotubes can be used for filtering Aerosols.

(viii) Ag/SBA-15 nanocomposites can be used to filter Carbon monoxide (CO).

(ix) $Zn_{12}O_{12}$ nanocage can be used to adsorb Carbon disulfide (CS_2).

(x) Silica nanoparticle (SiNPs) can be used to capture Atmospheric lead (Pb).

(xi) Ruthenium nanoparticle catalysts ($Ru/\gamma\text{-}Al_2O_3$) can be used to decompose Nitrogen oxide (N_2O).

(xii) Mg ferrite nanospheres ($MgFe_2O_4$) and Titanium dioxide nanoparticles (TNPs) can be used to adsorb Sulfur dioxide (SO_2).

(5) Nanooxygenator:
Nanooxygenator emits oxygen through various chemical processes by converting CO_x, NO_x, SO_x, etc. into pure oxygen and hence increases oxygen contents in outgoing purified air.
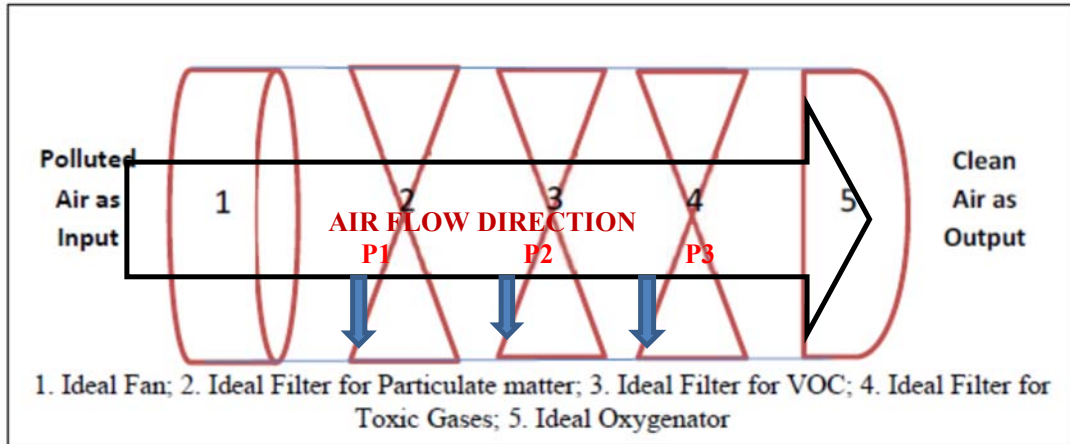
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1. Ideal Fan; 2. Ideal Filter for Particulate matter; 3. Ideal Filter for VOC; 4. Ideal Filter for Toxic Gases; 5. Ideal Oxygenator

Fig. 1: Block diagram of Ideal Environment Cleaner [2]

1. Renewable/Solar Energy based Fan; 2. Nanofilter for Particulate matter; 3. Nanofilter for VOC; 4. Nanofilter for Toxic Gases; 5. Nanooxygenator
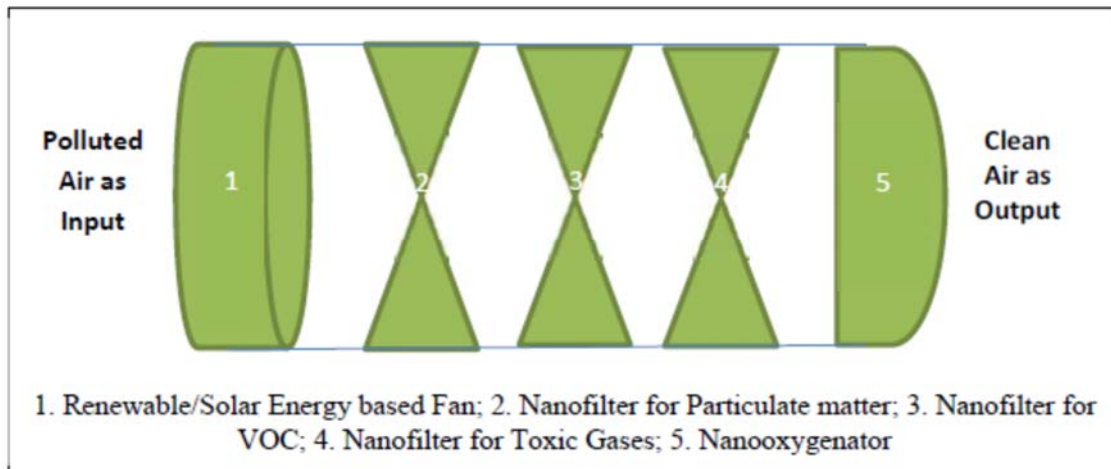
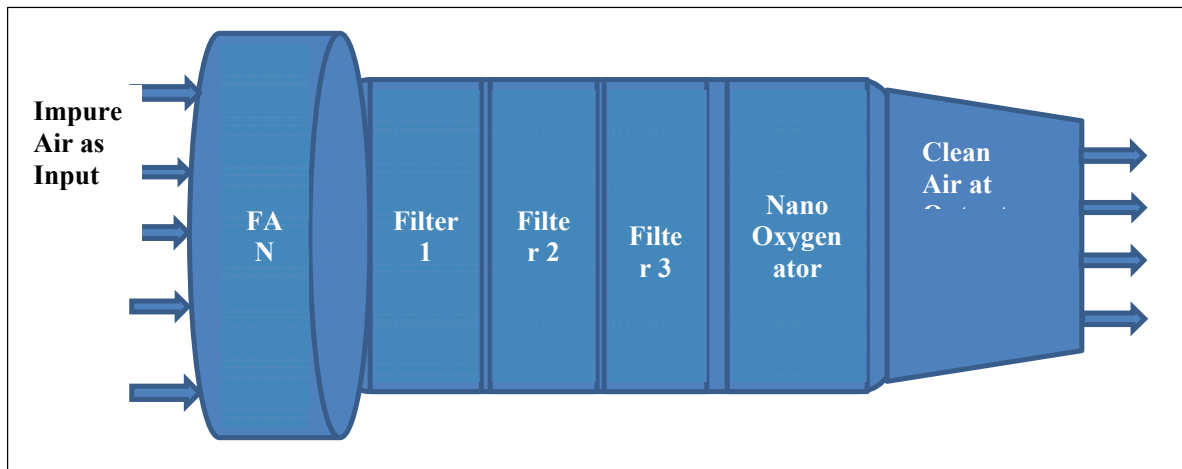**Fig. 2:** Block diagram of Practical Air Cleaning Machine using Nanotechnology [2]

Fig. 3: Structural Design of Mega Air Cleaning Machine

The mega machine can be scalable to different sizes and different capacities by increasing the capacity of the air inhaling pump and the size of the other four stages of air filtration. The structural design of the proposed

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mega air cleaner machine is visualized in figure 3. This mega machine can be made long by maintaining a considerably long distance between each stage in a long pipe kind of structure for avoiding the mix of output cleaned air with input polluted air. Depending upon the necessity of air quality requirements of a given place, both the size and number of these mega air cleaning machines can be increased or vice-versa.

7. PROSPECTS OF THE AIR CLEANING MEGA MACHINES:

7.1 World-wide Requirement:
The nanotechnology based mega air cleaning machine is an immediate requirement for both indoor and outdoor air cleaning and pollution control. Based on the current exceptionally high air pollution index measured in different places of the countries and depicted in table 1, an immediate and compulsory decision is required by country governments worldwide to develop and install many such systems for controlling the pollution.

7.2 Combating with Health Hazardous Pollutants:
It is found that the components in the polluted air contain toxic gases, volatile organic compounds (VOCs), particulates, and various microorganisms like viruses, bacteria, parasites, and antibiotics which are considered serious threats to public health. Combating with such health hazardous issues and finding an acceptable solution at least to decrease the effects of these pollutants on the life of living beings is an immediate requirement to maintain a sustainable and supportive climate around the earth.

7.3 Seamless Industrialization:
In the process of improving comfortability in human lifestyle by using technology, the process of industrialization is spread in primary, secondary, tertiary, and quaternary sectors. However, this seamless industrialization has led to the growth of many manufacturing industries and the associated waste generated by them. Part of this waste along with various byproducts contributing to the environment as pollutants. Hence seamless industrialization without effective precaution on pollution control is a major cause of air and water pollution.

7.4 Accelerated development:
While there are many advantages of the rapid development of cities, often unplanned urbanization brings risks of profound social instability, resource crises, and potential for devastating spread of disease due to environmental pollution. A systematic plan and its implementation of controlling pollution are essential in every city.

7.5 To achieve Sustainable Development Goals (SDGs):
The development and installation of mega air cleaners based on suitable technology to control air pollution is essential all over the world to realize the five out of seventeen United Nations Sustainable Development Goals (SDGs) which include (1) Ensuring healthy lives and wellbeing for all at all ages by means of the pollution free atmosphere (Goal 3), (2) To ensure availability and sustainable management of potable water and sanitation for all by controlling all kind of pollution which degrade potable water (Goal 6), (3) To build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation by controlling industrial pollution (Goal 9), (4) To make cities and human settlements inclusive, safe, resilient, and sustainable by controlling the pollution in the cities (Goal 11), and (5) To take urgent action to combat climate change and its impact by means of controlling all type of pollutions and environmental degradation (Goal 13). Thus, urgent action on developing, manufacturing, and installing such high speed, mega air cleaner at considerably low cost should be a priority for all countries.

7.6 Enhanced Human life-span:
By controlling the toxic, VOC, and hazardous microorganism pollutants in the atmospheric air in a large quantity using renewable natural resources like solar and wind energy, it is possible to maintain satisfactory health for living beings. Alternately, it is possible to control many health-related human diseases leading to life span enhancement at least for a few years with a healthy and comfortable life.

7.7 Sustainable climate for Future Generations:

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In the name of growing civilization and economic development, countries are harnessing the environment in an unhealthy way. The aim of sustainable development is to balance the economic, environmental, and social needs to allow prosperity for present and future generations. This includes social progress through equality, environmental protection, and stable economical and technological growth. Protecting the environment by means of decreasing pollution is the need of the hour and the responsibility of every country for gifting a safe and livable environment for future generations.

8. CHALLENGES OF AIR CLEANING MEGA MACHINES:

8.1 Challenges of Design:

The design of mega air cleaner using nanotechnology contains a systematic plan and specification for construction of the system in the most effective manner to fulfill the planned objectives. The design of mega air cleaner should have various parts called stages to suck the polluted air in large quantity from the atmosphere and force it toward various stages of cleaning. As per the current industry standard, a big and strong fan called a rotor is suitable for this purpose and is the first stage of the device. To make this stage continuously functioning huge and continuous electric power should be supplied to the stage. Using electric power generated by a renewable energy source like a mega solar plant and energy storage facility or wind energy plant the device can be powered continuously for unstopped functioning. Depending on the size and strength of sir sucking,

The second stage should focus on filtering all particulate matters from micro size to nano size. By designing different pore size filters these particles can be separated and collected at the bottom of the system. Care should be taken to avoid the mix of these particulate matters to the next stages of air cleaning. The polluted air which is free from particulate matter will enter the next stage called the second stage. If required some structural design can be modified to provide another fan between the second and third stages to speed up the cleaning process in the third stage.

The third stage should be designed to remove and separate all volatile organic compounds (VOCs) and hazardous microorganism pollutants which are also considered serious threats to public health. Nanosystems working based on photocatalytic deactivation, adsorption, and nanofiltration of pollutants. The cleaned air free from VOC and microorganisms will enter the next stage called the fourth stage. The pollutants collected in this stage should be handled properly to avoid the mix of them with the next level.

The fourth stage is the nano-filter for toxic gases and should include a series of components to remove all toxic gases present in the incoming air. The efficiency of this stage can be increased by providing an internal fan to force the filtered air from stage 3 to stage 4. Stage 4 contains the nanotechnology components designed to filter toxic gases like NO_2, Ozone, SO_2, CO, CO_2, CH_4, CS_2, NH_3, etc. The output of stage 4 will be pure air free from all pollutants. Here we can add an additional stage to enrich the oxygen ratio of pure air by adding a nanotechnology based oxygenator. The oxygenator collects toxic gases from the fourth stage and converts them into oxygen and adds the resultant oxygen to cleaned air at the output. Thus, the designed mega air cleaner collects polluted air and converts it into pure and oxygen-rich air without using any external stimulation. This design of air cleaner is fully sustainable design and except for periodic nanomaterial based filter replacement, is completely self-sufficient in all aspects and capable to clean the air continuously for years together.

8.2 Challenges of Construction:

The construction of nanotechnology based air cleaning mega machine is more challenging in terms of cost, time, and availability of raw materials. Construction of particulate removal stage, VOC and micro-organisms removal stage, and toxic gases removal stage are complex and tedious. Construction of oxygenator by converting toxic gases into oxygen through proper chemical reactions is also a complex and costly process initially for a few years until the nanotechnology reaches its saturation stage. The technology of supporting stages like solar or wind powered fans are reached an almost saturation stage and manageable with comparatively low investment.

8.3 Challenges of Maintenance:

Proper maintenance of mega cleaning machines installed in outdoor industrial locations as well as in the cities is essential as the filters may get blocked periodically. Many times, the maintenance of the nano-filter stages needs total replacement of nanomembranes which may be a costly, complicated, and tedious process.

8.4 Challenges of handling by-products:

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The toxic items separated and the by-products produced during the air cleaning process should be handled with proper care. Otherwise, they may further mix with atmospheric air and end up polluting the air further. The mega machine proposed here is a self-manageable system where many byproducts are recycled to produce pure oxygen in nano-oxygenator stage.

By means of a suitable commercialization model, these nanotechnologies based mega air cleaner machines can be marketed after systematic development [58-61]. The engineering aspects of the production process of such mega cleaner is under development and will be patented soon. The commercialization process involves marketing the machine for various countries through the world environment consortium and installing such machines in mega-cities and industrial areas to promote a pollution free environment for the future generation and is considered as an essential and urgent requirement.

9. ABCD ANALYSIS FROM VARIOUS STAKEHOLDERS POINT OF VIEWS:

In this section, the nanotechnology based air cleaning mega machine is analyzed using a system analysis method called ABCD analysis framework developed by Aithal et al [62-80]. Table 5 lists the advantages, benefits, constraints, and disadvantages of mega air cleaning machines using nanotechnology, and Table 6 lists the advantages, benefits, constraints, and disadvantages of mega air cleaning machines using nanotechnology ABCD Analysis from various Stakeholders point of view. ABCD analysis shows that the advantages and benefits of these machines are overtaking the constraints and disadvantages, leading to the practicality of the usage.

Table 5 : ABCD listings of proposed Mega Air Cleaner Machine [2]

S. No.	Constructs	Affecting Factors
1	Advantages	(1) Optimum cleaning of all the four types of impurities are possible (2) Uses renewable energy (either solar or wind) (3) Scalable system (4) Low cost system for large scale deployment (5) Simple cascade design (6) Oxygenator stage monitors the oxygen level in output air (7) Large volume of air can be cleaned every day (8) Can be used both indoor and outdoor (9) Each filter stage separates the respective impurities as by-products
2	Benefits	(1) Continuous output of Clean air decreases the pollution (2) Renewable energy leads to less pollution (3) Scalability leads to optimum usage in different locations (4) Least maintenance cost if deployed in large scale (5) Cascade design o provides customization (6) Maintenance of optimum oxygen level in the surroundings due to continuous circulation of air in the machine (7) Air pollution can be drastically reduced (8) Air pollution can be stopped at its starting stage (9) The by-products generated at each stage can be utilized effectively
3	Constraints	(1) Nanofiltration membranes are an expensive part of the process (2) Periodic maintenance is required to clean filter membranes (3) Use of solar energy hinder the mobility of the system
4	Disadvantages	(1) Comparatively high initial investment is required. (2) Periodic maintenance cost adds to the total cost (3) Machine is fixed at a given location due to its immobility which is due to the use of renewable energy

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Table 6 : ABCD Analysis of installing mega air cleaner from various Stakeholders point of view

S. No.	Determinant Issue	Key Attributes	Advantages	Benefits	Constraints	Disadvantages
1	Country	Air Quality	Pollution control	Clean environment	Political & Bureaucratic mindset	Maintenance to manage the quality
		Cost	Low cost at high volume	Clean air and remedy for pollution	Mass production in every country	Initial investment
		Health	Decreased air pollution	Improved health condition of citizens	Installing required number of machines	-
2	Companies	Air Quality	Emission control	Clean environment	Deciding the number of machines to be installed in their premises	Maintenance of sir quality
		Cost	Govt support and subsidy	Tax Benefits and Green business	Investment for installation	Maintenance cost
		Health	Environment friendliness	Better employees health	Systematic disposal of by-products	-
3	Citizens	Air Quality	Clean & oxygen enriched air	Clean and pollution free environment	Anticipated nanotechnology based side effects	-
		Health	Pollution free air	No pollution based health hazards	Worry on disposal of byproducts	-
4	Society	Air Quality	Pollution less environment	Clean and green environment	Deciding the number of machines to be installed due to variation in air quality	-
		Health	Low pollution content in air	Decreased pollution based health hazards	Managing the byproducts	Anticipated new problems if improper management of by products

10. SUGGESTIONS:

(1) The proposed nanotechnology-based air cleaning mega machine can be used both for indoor and outdoor applications by making suitable modifications in the design structure.

(2) The mega machine of different sizes & capacities can be used in identified locations using traditional

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electricity also without developing solar or wind energy infrastructure.

(3) By varying the length of the mega machine suitably, it is possible to avoid the mix of output cleaned air with input polluted air.

(4) Variable size and capacity machines can be installed at industry locations, cities, and other places based on the pollution level of the location.

(5) Proper periodical maintenance of the machine is required to get reliable efficiency.

(6) The cleaning stages can be altered depending on the density of constituents to be separated in input pollutant air.

(7) Development and installation of mega air cleaner can be further analyzed country specific by means of Cost-Benefit Analysis [81].

(8) The nanotechnology-based air cleaner can be customized for individual industry requirements and accordingly the number of stages and substages of filtering can be decided.

(9) The oxygenator stage must be compulsory for mega machines installed in cities whereas they can be optional for industrial areas.

(10) United Nations member countries should involve in the commercialization of the machine for large scale usage.

11. CONCLUSION:

It is known that environmental pollution is the byproducts of industrialization and civilization. For leading a comfortable and happy life for human beings, industrialization, and civilization using advanced technology is essential. The control of environmental pollution or a reverse operation to decrease pollution is essential to avoid any disasters for living a peaceful life on mother earth. Advancement in technology has not only provided more opportunity to pollute the environment but also provided the ability to control it. By utilizing, the recently identified universal technologies which include Nanotechnology for innovating real processes and ICCT for innovating intelligent machines and virtual processes [82-87], human beings can control bad things and initiate good things for human prosperity. Maintaining free resources like air, water, and food given by mother earth for our future generations is our responsibility and is possible only by using suitable technology. In this paper, we have disclosed and analyzed an idea and design on how to use nanotechnology effectively to solve our long existing man-made problem of reversing the polluted environment for further use by present and future generations. This mega air cleaner can be also a boon to the living beings of society to maintain good health for long period and hence priority should be given to realize by providing financial support by country governments/World Bank or United Nations Organization immediately.

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