Front. Environ. Sci. Eng. 2024, 18(6): 67
https://doi.org/10.1007/s11783-024-1827-0

PERSPECTIVES

Pathways toward a pollution-free planet and challenges

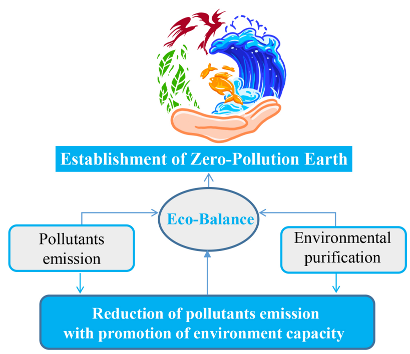
Jiuhui Qu (✉)[1], Jiaping Chen[2]

1 School of Environment, Tsinghua University, Beijing 100084, China
2 College of Chemistry and Environmental Engineering, Shenzhen University, Shenzhen 518060, China

HIGHLIGHTS

- Zero pollution does not mean no discharge of pollutants.
- Control of sound balance between pollution and decontamination capacities is important.
- Key pathways to achieve balance between pollution and decontamination capacities are given.

GRAPHIC ABSTRACT



ARTICLE INFO

Article history:
Received 5 March 2024
Revised 2 April 2024
Accepted 2 April 2024
Available online 19 April 2024

Keywords:
Wastewater treatment
Resources
Recovery
Greenhouse gases
Energy
Pollution-free

ABSTRACT

The mission of “Establishment of Zero-Pollution Earth” defined by United Nations Environment Programme aims at creation of a clean, safe and prosperous home for all human beings. It is of rational choice from each individual to protect our environment and demonstrates our great ambition to achieve our goals. The key message given in this article is that, zero pollution does not mean no discharge of pollutants and instead it can be achievable through optimizing and controlling a sound balance between pollutants discharge and capacities of decontamination through treatment and natural environmental accumulation, which can be termed as “Principle of Equilibrium” between pollution and decontamination. Based on this principle, we propose and illustrate several key factors and synergistic pathways toward a pollution-free planet: quantitative determination on purification and wastewater; source control through green measures; minimization of negative side-effects; precise management through digitalized systems; and keeping sound balance between pollutants and natural purification. It should be noted that we would face a series of difficulties and challenges in moving forward to “Zero-Pollution Earth”. We should further develop theories, principles and tools to achieve the balance between quantity of pollutants and decontamination capacities. Environmentalists should work together to break through the bottleneck limited by “Principle of equilibrium” to establish new environmental remediation systems leading to “Zero-Pollution Earth”.

1 Introduction

The third United Nations Environment Assembly (UNEA-3) in Year 2017 had set the theme as “Establishment of Zero-Pollution Earth” (United Nations Environment Programme, 2018). The then Director of the United Nations Environment Programme (UNEP), Mr. Erik Solheim gave the Assembly a report on “Towards a Zero-Pollution Earth”. He proposed a comprehensive action framework to combat the global pollution and set up over 50 solution plans. The consensus from the Assembly was that building a pollution-free planet is of great significance in protection and restoration of resources of air, water and food that humans rely on for survival.

In 2021, “The Strategy for Tackling Climate Change, Biodiversity and Nature Loss, and Pollution and Waste For Year 2022–2025” was further launched by the UNEP,

✉ Corresponding author
E-mail: jhqu@rcees.ac.cn

Special issue—Towards a pollution-free planet

to promote the measures for prevention and control of pollution so as to ensure every individual to have better environmental quality and improve public health and well-being (United Nations Environment Programme, 2021). Meanwhile, in the "Primary Action Programme on Chemicals and Pollution", the significant progress towards a pollution-free planet was projected to be achieved in Year 2030. It was anticipated by Year 2025 that, public health and environmental quality can be improved through the re-enforcement of management capacities and enhancement in management skills on chemicals and pollution; waste management would be improved through circular measures, recovery of secondary industrial raw materials, and progressive reduction of open burning and dumping of waste solids and liquids. Consequently, quantities of pollutants released into air, water, soil and oceans would be greatly minimized.

Similarly, regional- and national-level plans have been formulated and put into industrial practices. In 2012, the "Zero pollution action plan towards zero pollution for air, water and soil" was put forward under the European Green Agreement in May 2021 (European Commission, 2021). The ultimate objectives of zero pollution are that,

1) level of water and soil pollution will be reduced by 2050 to the one that is no longer considered harmful to public health and ecosystems in nature;

2) limitation of what our planet can handle on pollution will well be taken into consideration and practices, by which a toxic-free environment can therefore be established;

3) water quality will be improved through a 50% reduction of municipal solids and waste plastics in the ocean as well as a 30% minimization in the release of microplastics into the environment.

2 Basic understanding of "zero pollution"

We understand the so-called "zero pollution" or "pollution-free" as follows:

1) it is impossible to have either zero discharge of pollutants to the environment or zero pollution in the environmental medium (e.g., waters) that receive pollutants;

2) pollutants can be allowed to be discharged, but must be below the threshold to prevent damaging the environment;

3) a sound balance can be established between the quantity of pollutants discharged into the environment and the capacities of decontamination through naturally occurring measures (e.g., wet-land or phytoremediation) and engineered treatment systems (e.g., activated sludge process, coagulation, advanced oxidation processes and adsorption).

Therefore, the capacities of pollutant treatment and the natural accumulation for pollutants play the most significant role in achieving zero-pollution, by which a sound balance can well be established between decontamination capacities (namely, treatment and environmental self-purification/restoration) and pollution loading. There are two key factors for success; the first one is the amount and characteristics of pollutants discharged into the environment, and the second one is treatment capacities and decontamination capacities that could be obtained through self-purification or self-restoration of the environment and the ecosystem. The balance point between these two is the pollution control threshold. We assume this equilibrium point as Point T. Pollution effect will occur if the pollutant situation is greater than Point T. On the other hand, no pollution effect will occur if the situation is below Point T.

Therefore, we need to carry out systematic work such as management, treatment, and formulating rules and regulations on all substances, multi-media, entire processes, and multi-dimensions, and build an environmental protection and governance system to balance pollutant emissions and environmental purification capabilities to realize the vision of "pollution-free". The five essential factors and pathways given in Fig. 1 are described as follows:

1) Quantitative determination on purification and contamination: it is essential to measure pollutant emissions and loads of pollutant(s) that can be purified and accumulated by the environment; we can then determine the balance between pollutant discharge and capacities of decontamination through treatment and natural environmental accumulation, which can be termed as "Principle of Equilibrium" between pollution and decontamination;

2) Source control through green measures: pollutants can be transformed into energy and resources to minimize the emission to the environment;

3) Minimization of negative side-effects: secondary pollution in the operations must be minimized, leading to safe transformation and cleaning processes;

4) Precise management through digitalized systems: a digital environmental management system based on the balance theory must be established;

5) Environmental systematic balancing: a balance between control of quantity of pollutant emission and environmental purification capacities must be systematically established. According to the aforementioned "Principle of Equilibrium", such balance is essential to achieving "pollution-free".

3 Key factors and pathways toward a "pollution-free planet"

3.1 Quantitative determination of purification and pollutant(s)

Accurate calculation of quantities of discharging

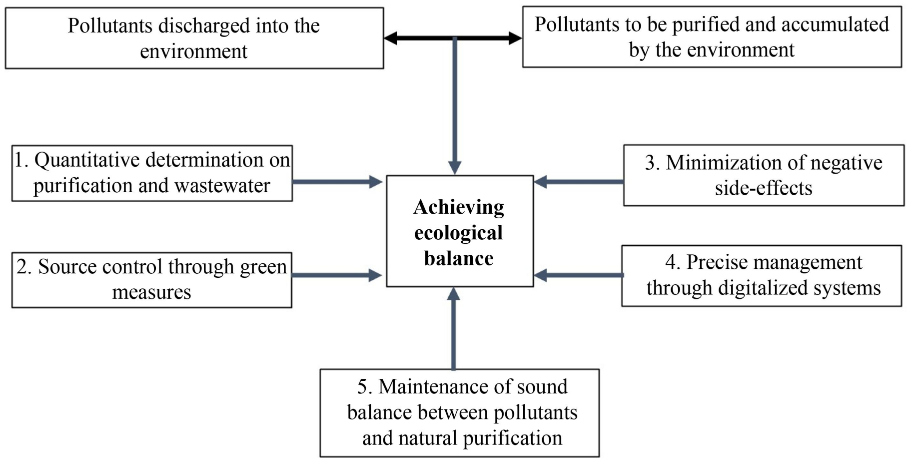


Fig. 1 Illustration of factors and pathways to achieve an ecological balance in nature.

pollutants and that on environmental self-purification capabilities is of great importance. Take the water environment of a river basin as an example. It is important to accurately assess the natural landscape, self-restoration and self-purification capabilities of the environment, and the aquatic ecology. Hence, precise methods can be established for the assessment of the overall situation. It is important to perform a comprehensive and quantitative assessment on types of pollutants, concentrations, environmental metabolism cycles, reactivity, reactions driven by external energy sources such as light and heat, sources of discharge, transformation and transportation, and ecological effects. We can therefore establish a standardized protocol for the assessment on pollutants being discharged and treatment capacities, and natural self-purification and accumulation.

The accurate assessment of the complex processes could effectively be achieved through assistance of such tools as big data (mega data) and machine learning. A platform for decision-making on quantitative and precise management can also be established. The quantity of total pollutants and that of individual pollutants being discharged or to be discharged to environment can be precisely evaluated. The capacities of decontamination, self-purification and accumulation from environment can be determined and the balancing point can be obtained.

3.2 Source control through green measures

Discharge of pollutants to environment can be minimized through conversion of them to resources and energy. To achieve "zero pollution", comprehensive work on source control through sophistical, systematic and green measures must be carried out. It is of great importance to develop new theories and technologies, by which utilization of high-value resources and conversion of pollutants to green energy can be achieved. The two cases below show the greater benefits of control and utilization of pollutants and zero emission through the pathways of material recovery and energy conversion.

Case 1. Decontamination of hexavalent chromium with simultaneous energy production

Industrial wastewater often contains a variety of pollutants, some of which have higher valencies, such as hexavalent chromium. During the treatment, it is normally reduced to trivalent chromium through receiving three electrons so as to reduce the toxicity and improve the treatability. It is known that the high-valent chromium is rich in energy (Cao et al., 2021). As such, a battery-based system can be designed, fabricated and used for energy generation during the reduction of hexavalent chromium, as illustrated in Fig. 2. With the assistance of light, synchronized energy production would become more efficient. Both photoelectric decontamination and energy production can therefore be achieved.

Case 2. Resource recovery and energy self-sufficiency in Yixing China Concept Wastewater Treatment Plant

In 2014, an expert committee of "Concept Urban Wastewater Resources Plant", comprising six leading professionals in China's water sector, proposed to build a series of "China Concept Wastewater Treatment Plants" to attain four main objectives, namely, *sustainable water quality, energy self-sufficiency, resource recovery, and environmental friendliness*. In December 2018, the first version of the concept plant was launched in Sui County, Henan Province, China, with a daily treatment capacity of 40000 m^3; the treated water with high-quality is sent back to rivers and lakes to top-up the water for domestic uses. More than 50% energy for operation was self-supplied through utilization of biogases from the digestion of waste sludge and other solid waste, and the organic fertilizer was produced by residual sludge and used in the farmland.

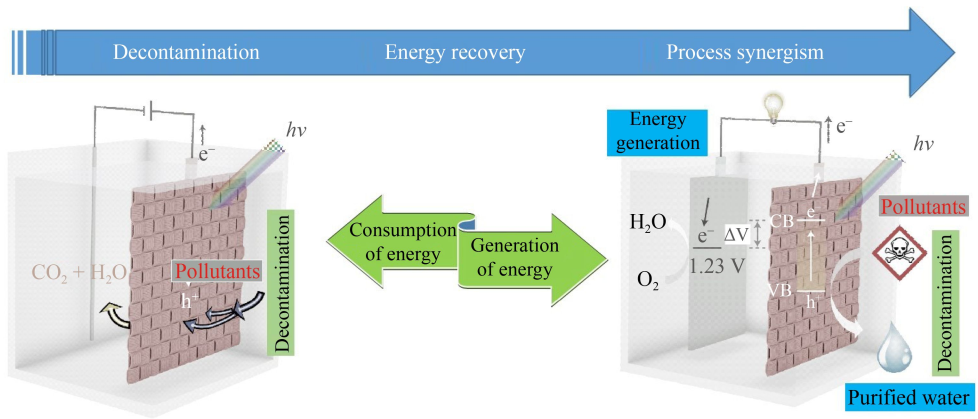


Fig. 2 Photoelectric decontamination with energy production in treatment of hexavalent chromium.

Based on the success of the plant in Sui County, the first full-scale China Concept Plant in the world was launched in Yixing City, China, on 18 October 2021, and has perfectly demonstrated the four objectives aforementioned (Qu et al., 2022). The advanced biological treatment technology without an external carbon source is used to efficiently treat 20000 m^3 of wastewater per day. Without increasing the cost compared to conventional plants, the effluent quality reaches chemical oxygen demand (COD) < 20 mg/L, total nitrogen (TN) < 3 mg/L, and total phosphate (TP) < 0.1 mg/L, strictly complying with the water discharge requirements of China and international standards. The anaerobic digestion system is adopted for coprocessing of waste sludge, blue-green algae mud, and organic waste from nearby agriculture and animal husbandry (around 20% to total solids used). The electricity generation can be up to 8000 kWh/d, achieving energy self-sufficiency in wastewater treatment while synergistically utilizing organic wastes around the plant. It is estimated that, from June 2023 to December 2024, the unit carbon emission of wastewater treatment in the plant is 0.754 kg/m^3, which is in line with the reported figures in China (Du et al., 2023). Furthermore, carbon neutrality for the operation can be achieved through utilization of energy obtained from the coprocessing of organic matters. The residual from digestion is used to produce "nutrient soil", which is used in the farms. This has reduced fertilizer usage and hence carbon emissions, leading to new pathways for agricultural operations.

Domestic and industrial wastewater contains large amounts of resourceful substances (mainly carbon, nitrogen and phosphorous), which can be used for energy generation and resource recovery. Such substances however would become hazardous if we just discharge them to the environment. On the other hand, they could become resources if we adopt sophisticated measures to recover them. Therefore it is the best strategy toward a pollution-free planet among many currently practiced ones.

3.3 Minimization of negative side-effects

It is of great importance to avoid or minimize secondary pollution and ecological damage during practices in environmental remediation. The environmental remediation is essentially to improve ecological quality and achieve ecological integrity. In many industrial exercises, such objectives however are not fully taken into account and practiced, and systematic background check-up and planning are not carefully performed. The engineering measures that may meet the environmental rules and regulations for a short-term are often adopted; some of such work may even cause potential environmental risks and ecological damages.

For example, when treating black-odorous waterbodies in several places, such chemicals as coagulants or oxidants were added to make the water temporarily clear, however this would cause chemical pollution (secondary pollution). Some transitional projects for environmental remediation caused ecological damage to the waters; the black-odorous water bodies even re-surfaced after execution of a large number of transitional projects.

Therefore, environmental remediation must be designed according to the objectives of decontamination and ecological restoration. It is important to better understand the physical, chemical and biological characteristics of the water body to be treated; green and ecological restoration can be executed and completed by nature-based measures. To move toward "pollution-free", we must fully take the natural attributes of the environment into account, minimize the interference from human factors, and should not adopt chemicals and reagents that can cause damages to the environment in remediation operations.

3.4 Precise management through digitalized systems

The digitalized environment management systems are based on the “Principle of equilibrium”. To achieve precise management and control of the balance between pollutant emission and purification, multi-dimensional digitalized management systems need to be established. It is necessary to build a database, to create the model(s) that can accurately describe each key element, and to integrate and optimize the model(s). Collection of historical data are of great importance in order to comprehensively understand the whole system. A quantitative, precise and digitalized management and control platform can therefore be established. It can take key factors into account, including control of pollution sources, process control on contaminants, environmental accumulation capacity for pollutants, self-purification capabilities, and social and economic factors

The digitalized software and hardware for the management system(s) can be developed, such as sensors, detection and communication equipment, modeling simulation and computing software, and decision-making systems. A simulator on the balance between decontamination capacities and loading of pollutants should be developed so that methodologies and systems on estimation, control, and decision-making on pollution can be formulated. Such work would provide strong technical support for the precise management and control of “pollution-free”.

3.5 Maintenance of sound balance between pollutants and natural purification

Systemic control should be made on pollutant discharge and purification capabilities of mother nature. Changes in environment and risks caused by pollutant discharge have systemic characteristics. Variations in one factor may have an impact on the entire environment. The interactions among factors may enlarge the degree of responses from environment and ecosystem. For example, the discharge of sewage into receiving water bodies may cause damage to sensitive organisms and the communities; the interactions between the contaminants and the organisms would trigger a decline in the health level of the entire aquatic ecosystem. Therefore, in a complicated environmental network system, any change in the key factors and the associated components may cause changes in the entire system, which may affect the balance between purification and discharging pollutant(s). Therefore, we must research and develop new theories, methods and implementation tools according to the holistic considerations of all important materials, key factors, and the whole life cycle. The scientific basis and technical support can be obtained for making “pollution-free” plans and policies for river basins, regions, cities, and so on.

4 Challenges facing in moving toward a pollution-free planet

Moving toward a “pollution-free” planet is vision and ideal of humans for protection and improvement of environment and ecology, and an inevitable choice for our survival and development. However, we face many obstacles and huge challenges. Our understanding of “pollution-free” is still preliminary and superficial. The scientific theories, evaluation methods and implementation tools for zero pollution have yet to be well developed. Environmental, ecological, social, economic and public foundations for achieving zero pollution are in the early stage. Pollution control is still the most difficult task for environmental governance in China and many developing countries. Therefore, we must combat global pollution and greenhouse crisis. We must moderately and continuously reduce the generation and emission of pollutants to achieve synergy in reducing pollution and carbon emission, establish and implement a high degree of coordination and balance between the environment and social economy, develop scientific principles and systematic methods to support purification-emission balance, and eventually use the balance to support the creation of a “pollution-free planet”.

Acknowledgements The authors would like to thank Chinese Academy of Engineering, under the Brand Project Scheme Funding (Project Number: 2022-30-35-02) for the financial support.

Conflict of Interests Jiuhui Qu is the editor-in-chief of *Frontiers of Environmental Science & Engineering*. The authors declare that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Cao T N, Chen S S, Chang H M, Sinha Ray S, Hai F I, Xuan Bui T, Mukhtar H (2021). Simultaneous hexavalent chromium removal, water reclamation and electricity generation in osmotic bioelectrochemical system. Separation and Purification Technology, 263: 118155

Du W J, Lu J Y, Hu Y R, Xiao J X, Yang C, Wu J, Huang B C, Cui S, Wang Y, Li W W (2023). Spatiotemporal pattern of greenhouse gas emissions in China's wastewater sector and pathways towards carbon neutrality. Nature Water, 1(2): 166–175

European Commission (2021). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Pathway to a Healthy Planet for All, EU Action Plan: "Towards Zero Pollution for Air, Water and Soil". Brussels: European Commission

Qu J H, Ren H Q, Wang H C, Wang K J, Yu G, Ke B, Yu H Q, Zheng X C, Li J (2022). Chapter 15, Concept wastewater treatment plants in China. In: Ren Z Y J, Pagilla K, eds. Pathways to Water Sector Decarbonization, Carbon Capture and Utilization. London: IWA Publishing

United Nations Environment Programme (2018). Environmental Sustainability Report: The Third United Nations Environment Assembly－A Carbon Neutral and Green Event. Nairobi: United Nations Environment Programme

United Nations Environment Programme (2021). For People and Plant, The United Nations Environment Programme Strategy for Tacking Climate Change, Biodiversity and Nature Loss, and Pollution and Waste from 2022–2025. Nairobi: United Nations Environment Programme

Author Biography

Prof. Qu is a distinguished professor of Tsinghua University and a research professor of Research Center for Eco-Environmental Sciences of Chinese Academy of Sciences (CAS). He is a member of the Chinese Academy of Engineering (CAE), a foreign member of the U.S. National Academy of Engineering (NAE), a fellow of the World Academy of Sciences for developing countries (TWAS), and a distinguished fellow of International Water Association (IWA). He is now serving as the editor-in-chief of the journal *Frontiers of Environmental Science & Engineering* and the section editor-in-chief of the journal *Engineering*. Prof. Qu has focused on advocating and developing innovative water pollution control technologies in China. He has played a key role in the development of China's water industry, and the establishment of drinking water technological systems suitable for China and other developing countries. He has received numerous awards, including the National Technology Invention Award of China, the IWA Global Project Innovation Award, and the IWA East Asia Regional Project Innovation Award.