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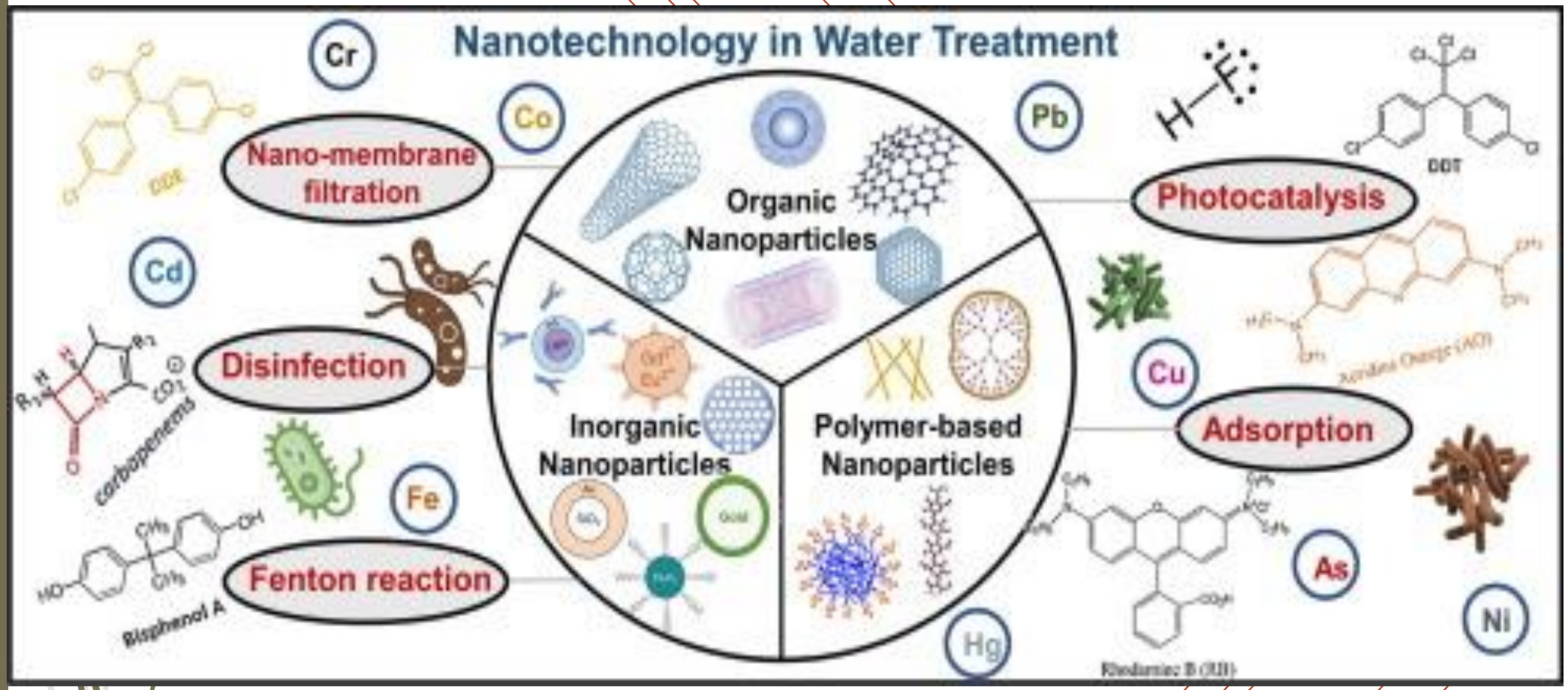

AquaEnergy Expo

WTEF

Nanotechnology for water treatment: recent advances and future trends

By/ Ahmed Hasham, Ph.D.

About the Speaker

- Member of the Board of scientists Egypt.
- Member of Scientific Professions Syndicate.
- Member of the Arab Society for experts and Safety Professionals.
- Member of the International Association of Engineers.
- Expert in water and wastewater treatment technologies.
- Certified trainer in the water treatment field.
- Certified trainer in the Quality Management Systems field.
- M.Sc. in Environmental Chemistry – Ain Shams University.
- Ph.D. in Inorganic and analytical chemistry. Suez Canal University- Egypt.

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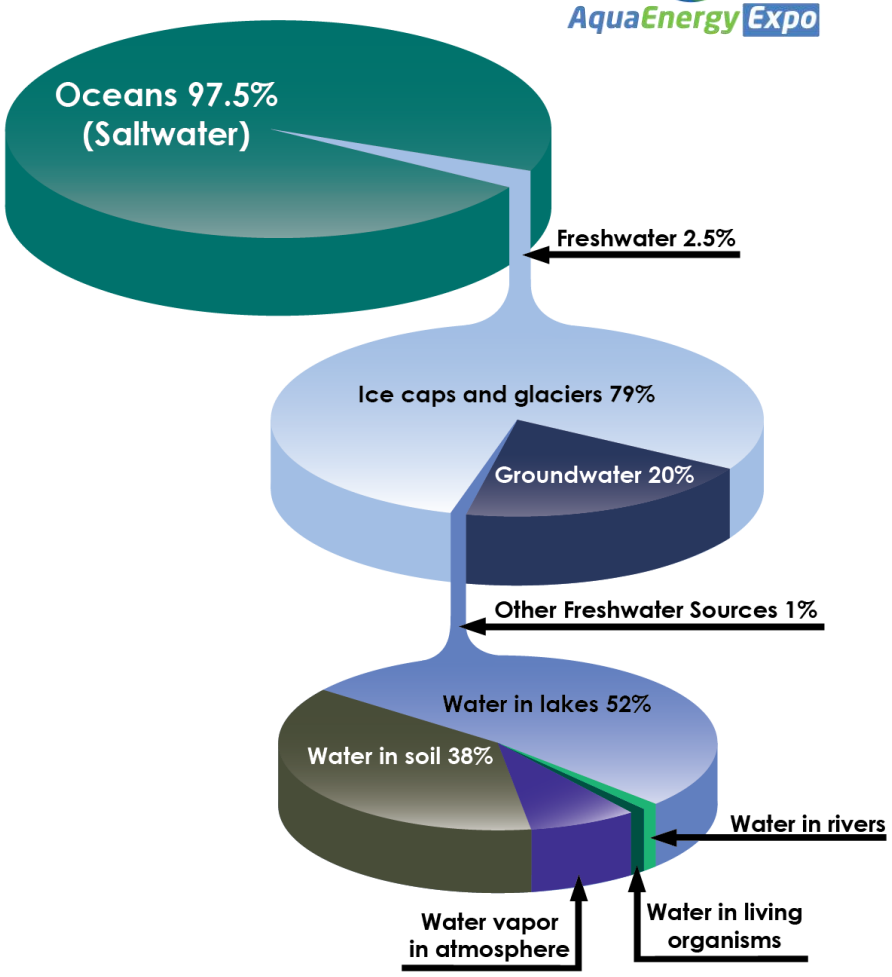
Contents

Introduction

- The world's current primary challenge is the paucity of safe drinking water. It is estimated that 1.2 billion people do not have access to safe drinking water, and 2.6 billion do not have access to water for basic sanitation **(Tom, 2021)**.
- Asia and Africa are home to most people who face pure water scarcity **(Hussain et al., 2022).**
- Conventional cleanup has frequently had very modest success in lowering pollution levels, particularly in soil and water**(Ifang et al., 2014)**.



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- Nanotechnology is determined to be promising in this circumstance. Nanotechnology is concerned with the manipulation of matter at the nanoscale scale to build new structures, gadgets, and systems. When compared to macro-particles, nanoscale particles have diverse chemical, physical, biological, optical, magnetic, and electrical properties **(Hasham, 2018, Hesham and Moustafa, 2019)**.

- Nano-materials are likely to exhibit novel, unexpected physicochemical features not found in bulk materials of similar composition **(Jahin et al., 2022)**

- Nanotechnology has recently gained popularity in soil, water, and air remediation. Sensing and detection, treatment and remediation, and pollution avoidance are the three main elements of nanoparticle-related water remediation **(Vijayakumar et al., 2022)**.

Nanotechnology Definition

The understanding and control of matter at dimensions between approximately 1 and 100 nm, where unique phenomena enable novel applications. *

Nanoparticles are sub-nanosized colloidal structures composed of synthetic or semi synthetic polymers.

* National Nanotechnology Initiative (NNI).

Semi-synthetic

Nanotechnology Market

- The nanotechnology is a promising market.
- It is expected to grow by 30 percent annually in the recent decade.
- This growth will enhance the individual's awareness of the nanotechnology impact on the world.

History of publications on this topic

In the past 10 years, 4318 publications related to the recent advancements in employing nanotechnology in water resource management sustainability

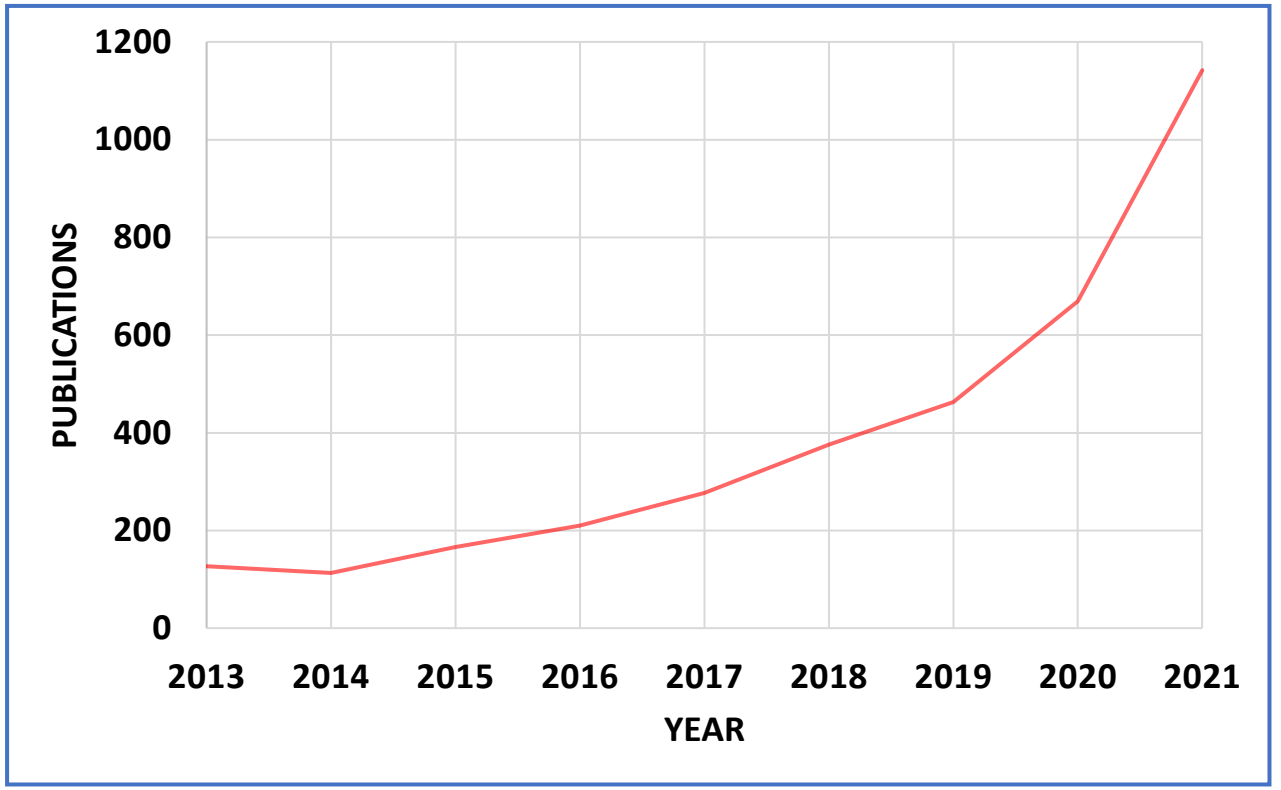


Figure 1 Publications related to the recent advancements in employing nanotechnology in water resource management sustainability.

Classification of nanomaterials

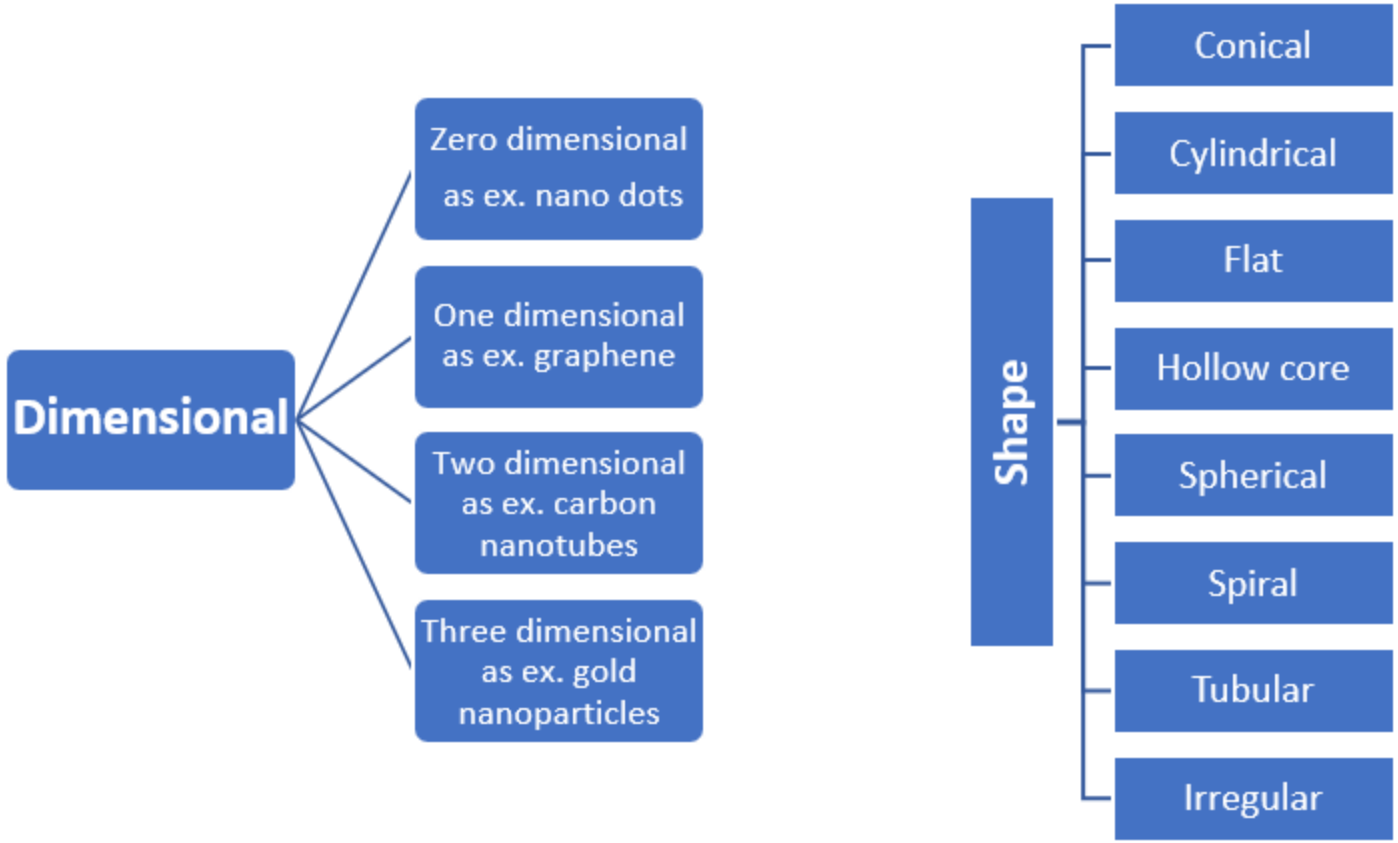
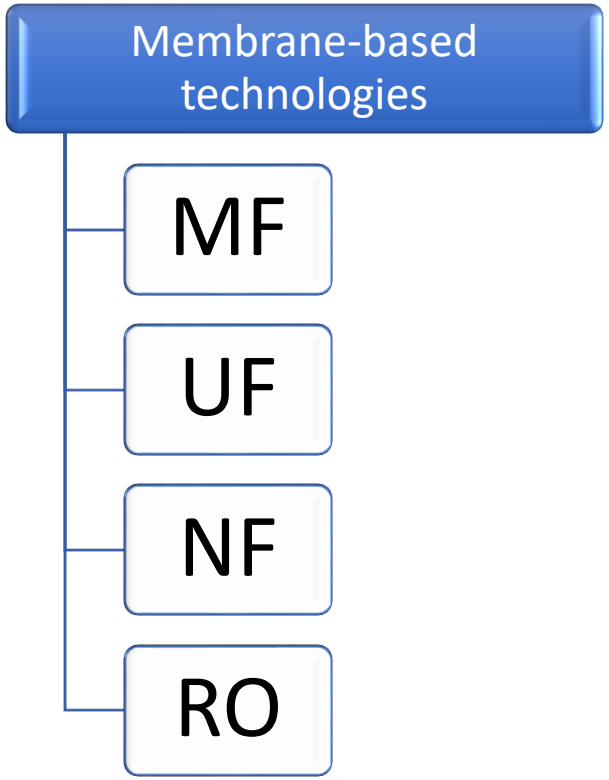


Figure 2: Classification of nanoparticles according dimensional and shape

Water purification processes which based on nanotechnologies

In water treatment facilities, membrane-based technologies are a practical method being investigated for a variety of separation and purification procedures.



	Micro-Filtration	Ultra-Filtration	Nano-Filtration	Reverse Osmosis
Pore Size	10 nm – 1 µm	3-10 nm	2-5 nm	Not detectable
Applied Pressure	0.005 – 0.2 MPa	0.01 – 0.3 MPa	0.3 – 1.5 MPa	1 – 10 MPa

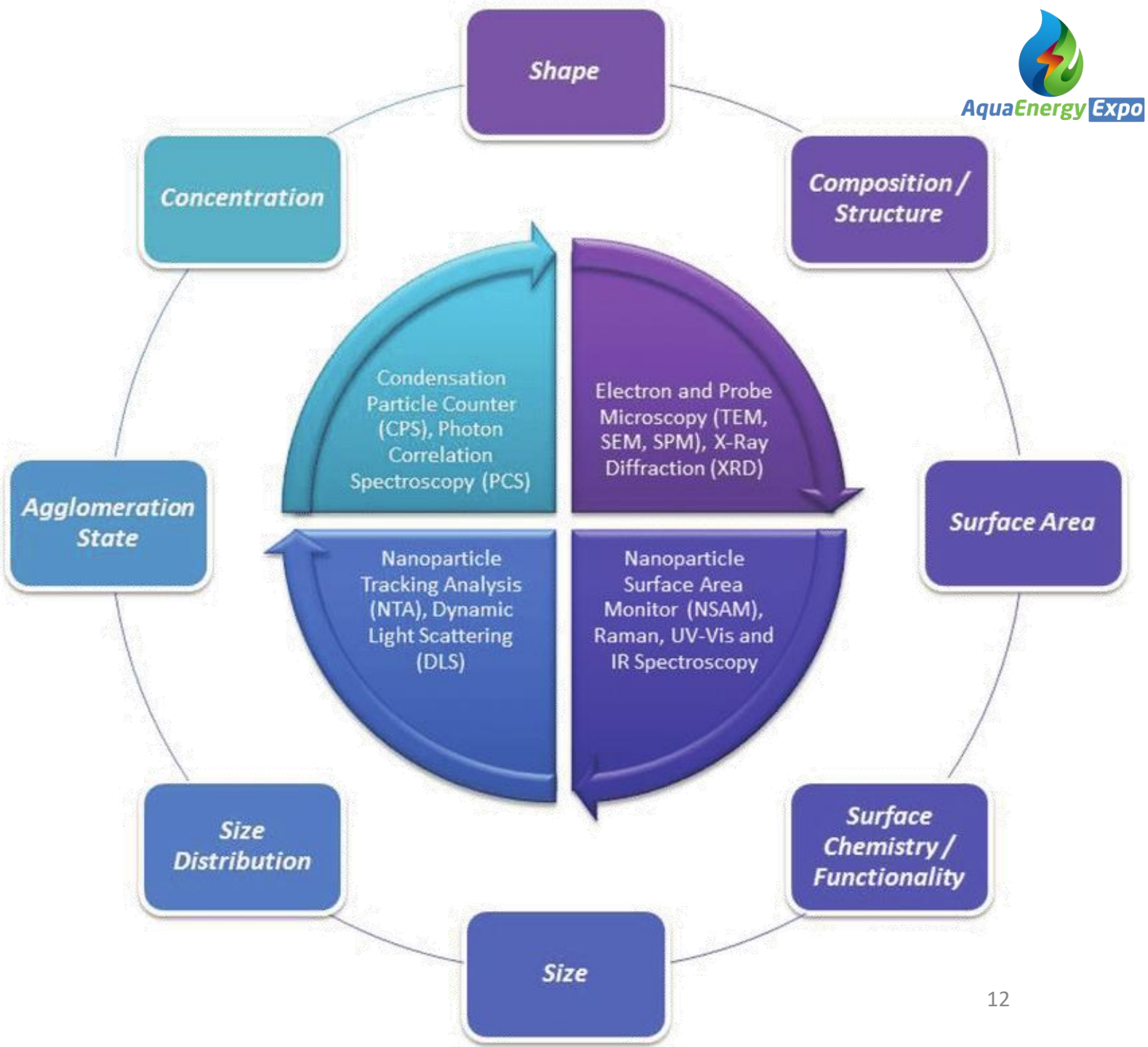
Nanoparticle's characterization

Chemical / Physical Characterization:

- Size and surface Morphology
- Specific Surface Area
- Surface Charge
- Density
- Molecular weight Measurements of Nanoparticles
- Kinetic Study
- Stability of Nanoparticles

Biological Characterization

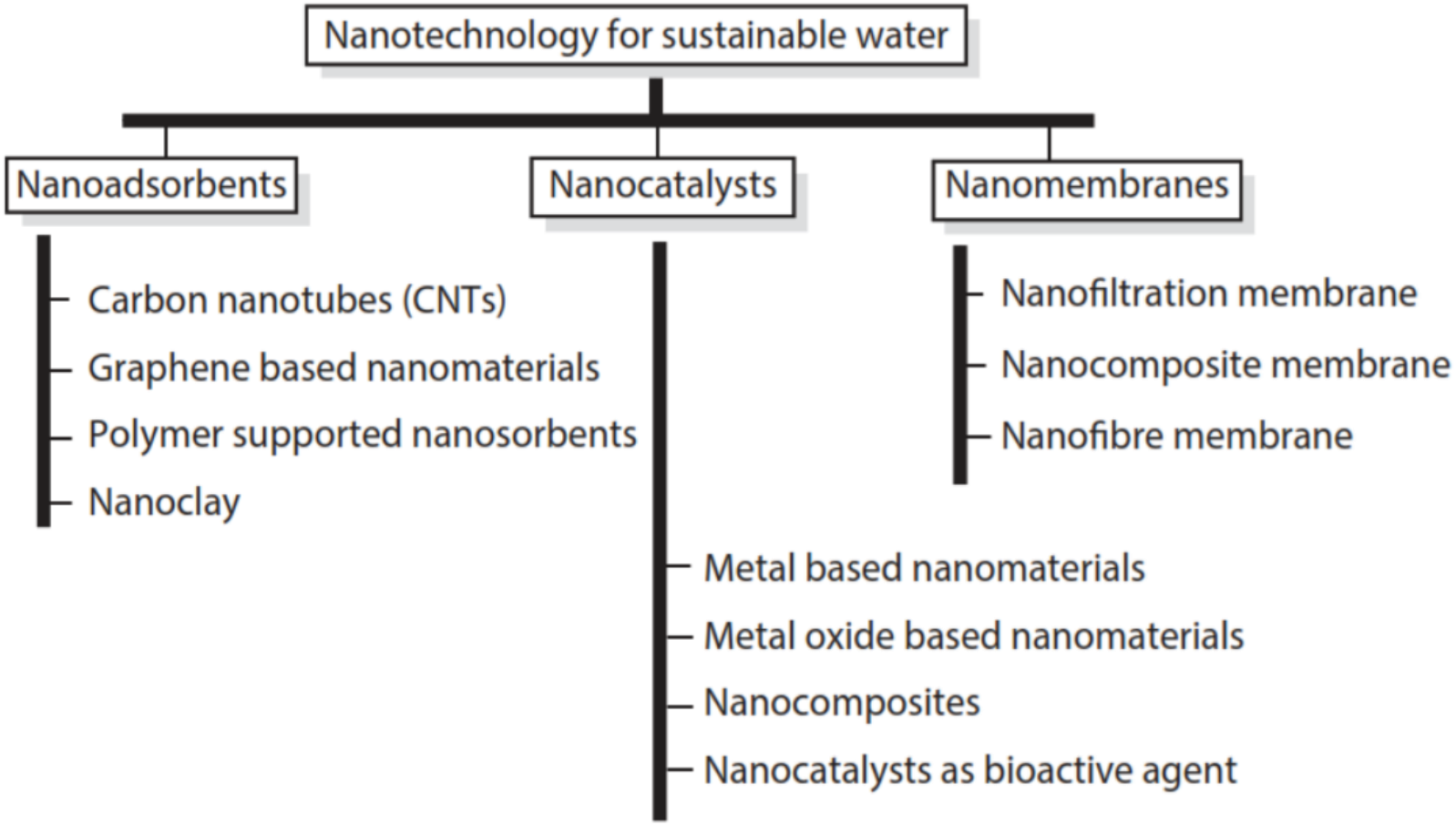
- Compatibility studies
- In-vitro Release Studies



Examples of nanoparticles and nanomaterials used for remediation of water

- Zeolites,
- Carbon nanotubes (CNTs),
- Self-assembled monolayers on mesoporous supports,
- Biopolymers,
- Single enzyme nanoparticles,
- Nanoparticles of zero valent iron (ZVI),
- Nanomembranes and so on

Classification of Nanomaterials for Wastewater Treatment



Applications of green nanotechnology in water and wastewater treatment

- The dyes are often made of organic compounds with an AZO link (R–N=N–R′) that discharge into rivers, lakes, and other bodies of water.

- These dyes could be broken down before being exposed to the atmosphere by using the enhanced photocatalytic ability of silver nanoparticles.

- After 8 hours of contact time, nano-silver complexes achieved around 75% dye degradation in the presence of solar exposure

Benefits of using Nanotechnology in Water and Wastewater Treatment

Increased effectiveness

contaminants could be more effectively removed , contaminants that were previously impossible to remove could now be removed, because of the expand specificity of nanotechnology and the advancement of smart filters tailored for utilization.

Simplification

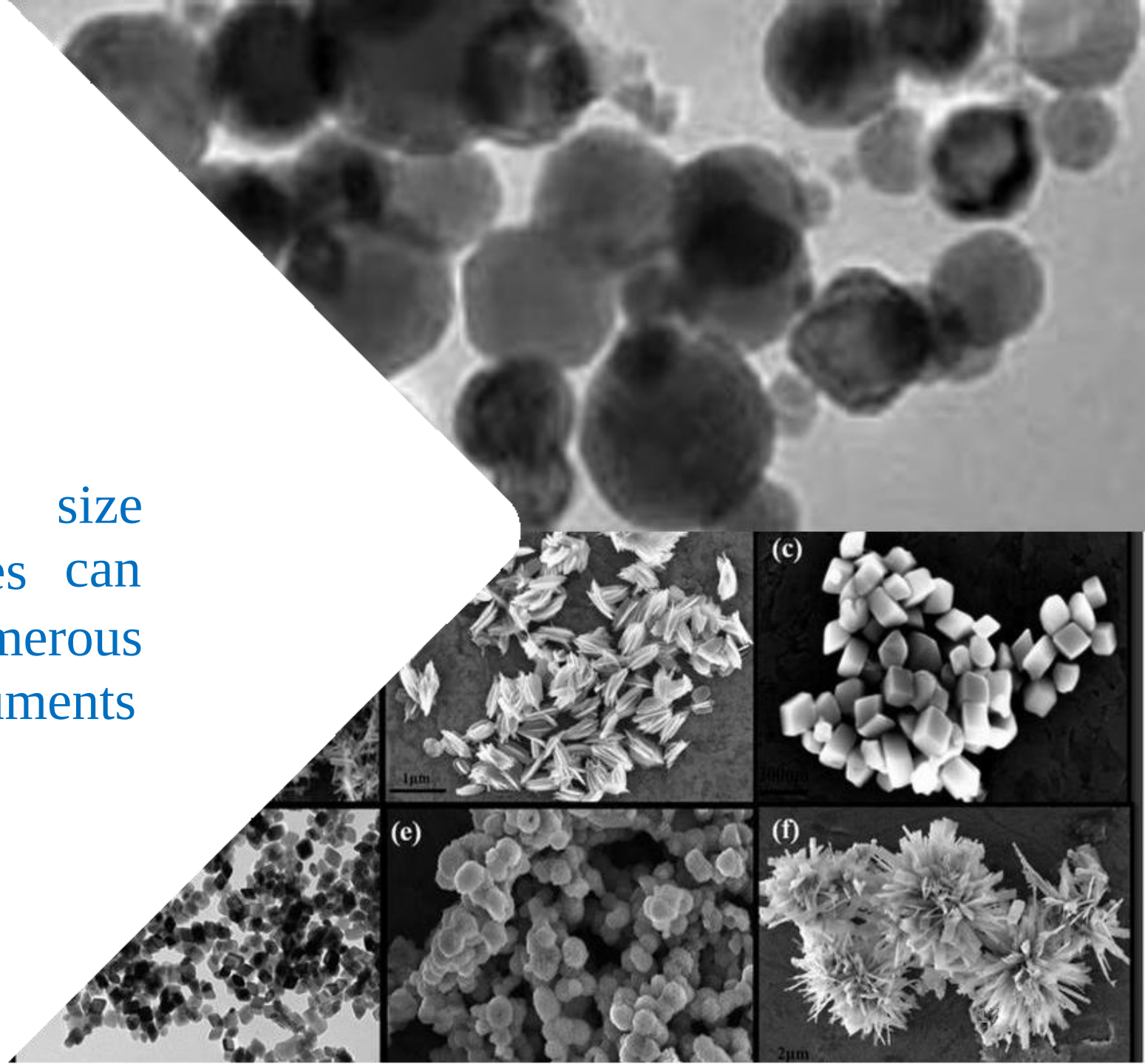
nanotechnology could radically reduce the number of steps , materials and energy required for water treatment , making it simpler to implement widely in rural areas.

Reduced cost

significant introductory investment would be required to incorporate or switch to nanotechnology-based water treatments.

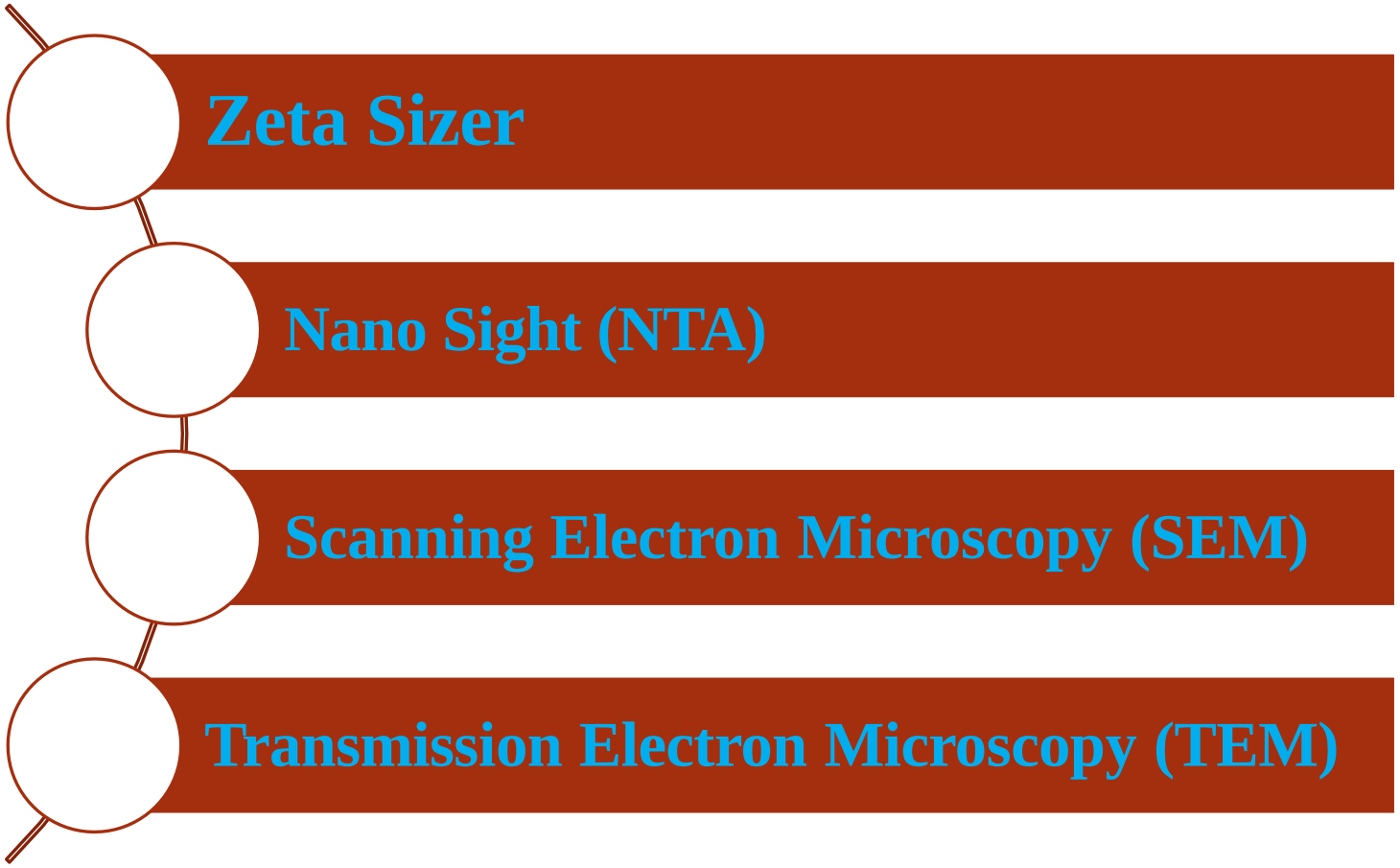
Nanoparticle's characterization

The particle size and size distribution of nanoparticles can be determined using numerous commercially available instruments



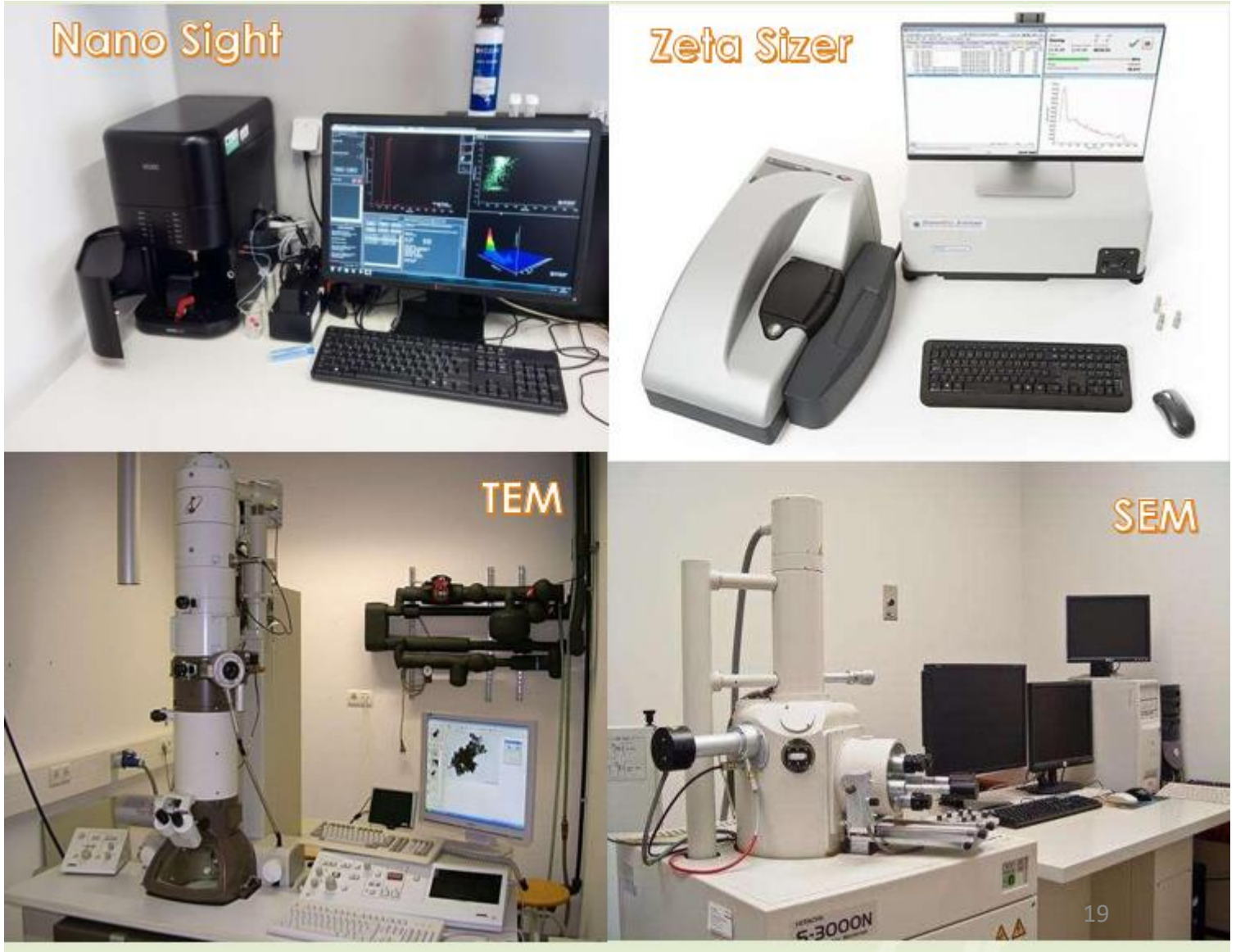
Examples for devices can be used for particle size determination

Nanoparticle's characterization



Examples for devices can be used for particle size determination:

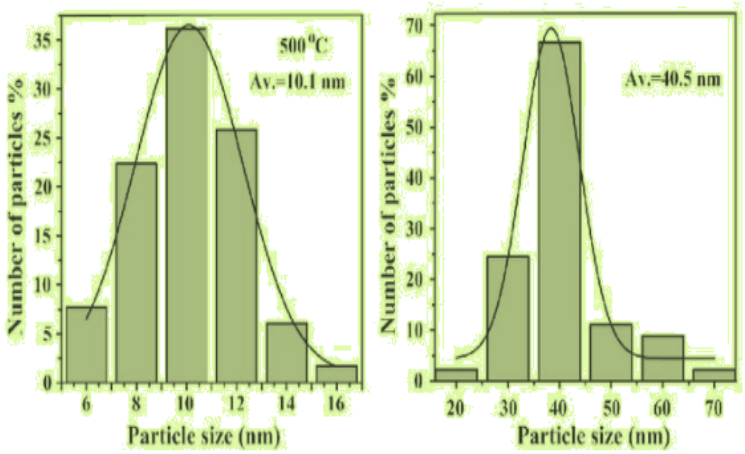
Nanoparticle's characterization

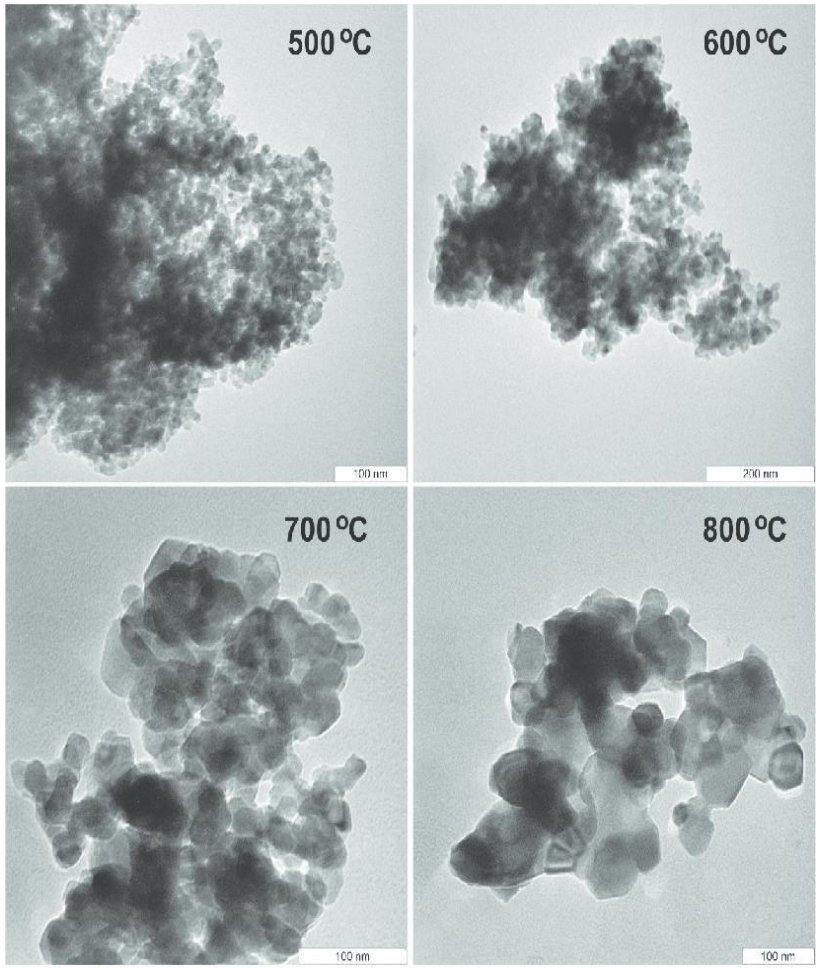


Morphology

- The shape, surface morphology commonly determined by SEM and TEM.

Nanoparticle's characterization





Transmission electron microscopy (TEM) images of TiO2 nanoparticles at different calcination temperatures and the size distribution histogram

Nanoparticle's characterization

Brunauer Emmett Teller (BET)

- Gas adsorption or Nitrogen adsorption.
  - Measure the specific surface area of nanoparticles including pore size distribution.
  - Determine porosity.

Surface Charge

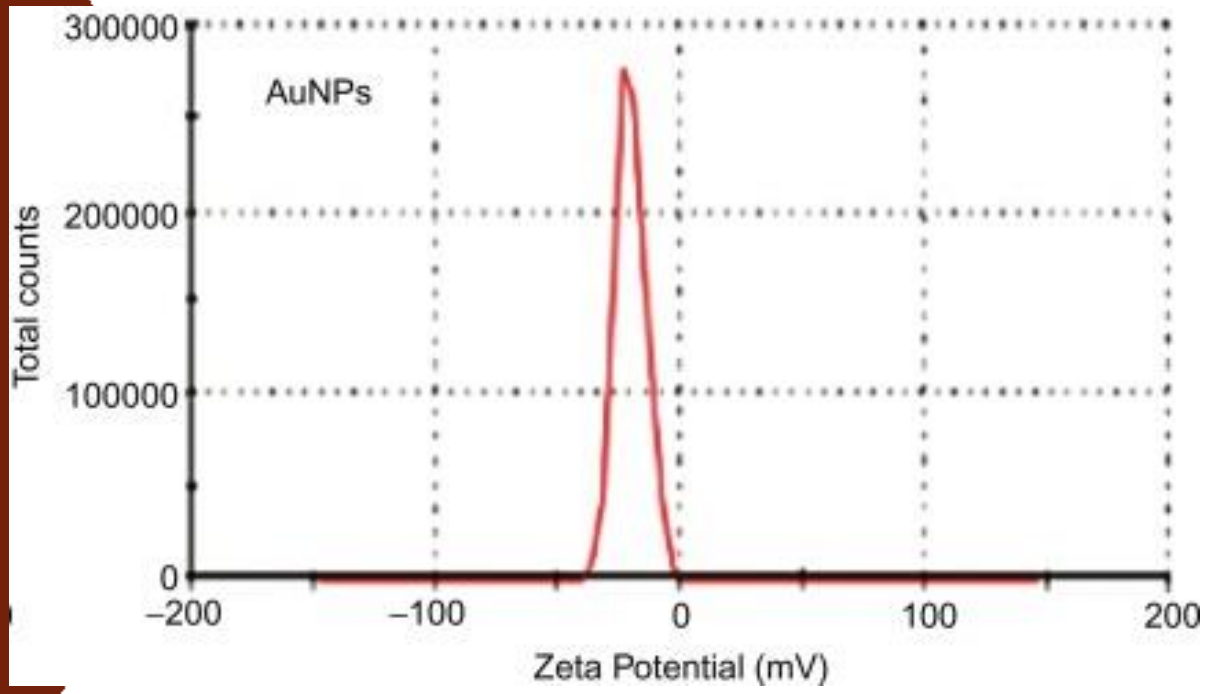
The colloidal stability is analyzed through zeta potential of nanoparticles.

This potential is an indirect measure of the surface charge.

Zeta potential:

The Zeta potential value that ranges from:

±0 - 10 mV shows a highly unstable colloid.
±10 - 20 mV shows relatively stable colloid.
±20 - 30 mV shows moderately stable colloid.
± 30 mV shows highly stable colloid.



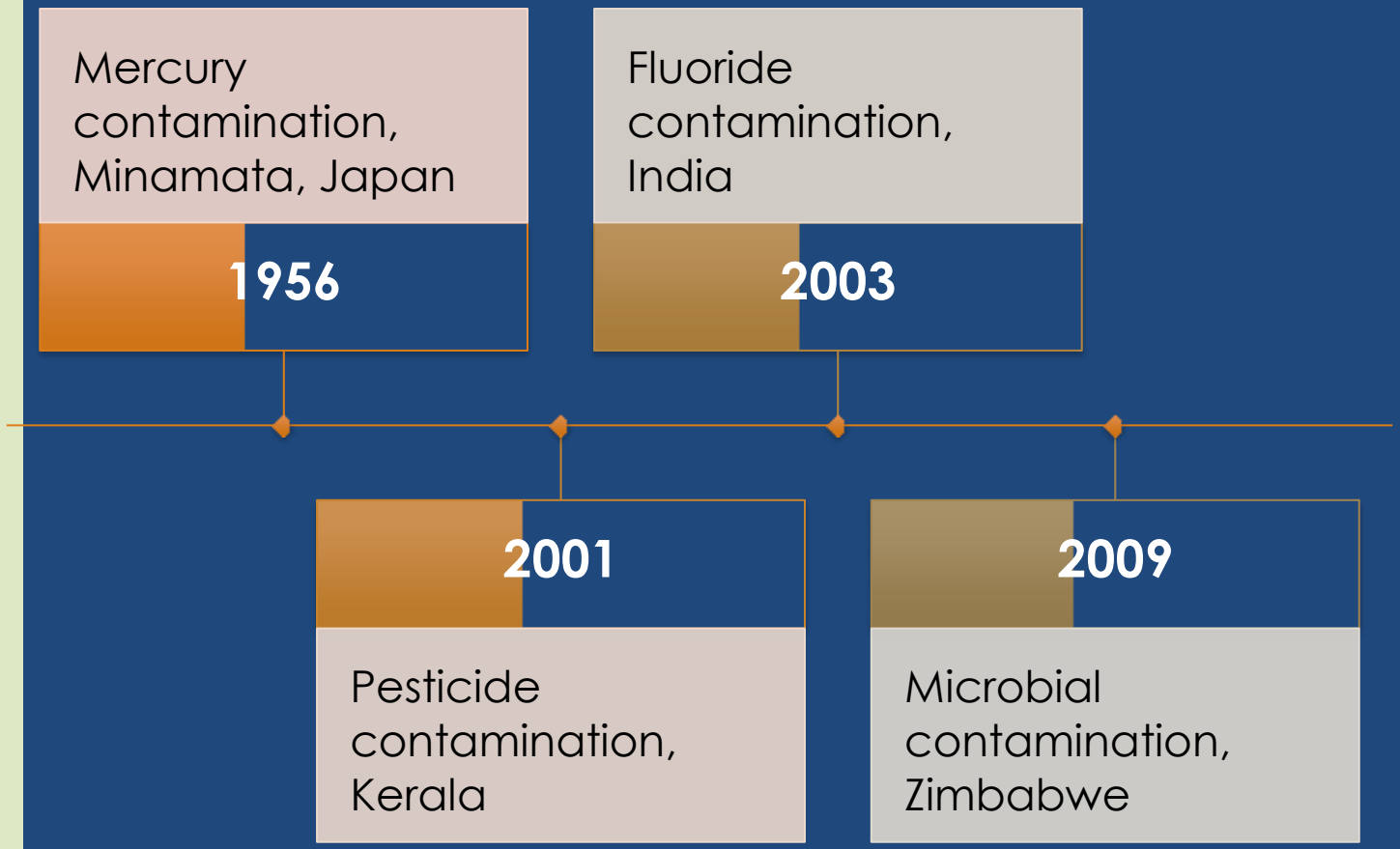
CONVENTIONAL WATER / WASTEWATER TREATM ENT METHODS

- Coagulation
- Chlorination
- Flocculation
- Lime softening
- Ozonation
- Membrane separation processes
  - etc ....

Why is research still going on?

- Day to day Change in water /wastewater composition
- Requirement of stable methods
- Requirement of economical methods
- Requirement of effective methods
- Search for reliable methods

UNSOLVED TECHNOLOGY PROBLEMS..



Benefits of using Nanotechnology in Water and Wastewater Treatment

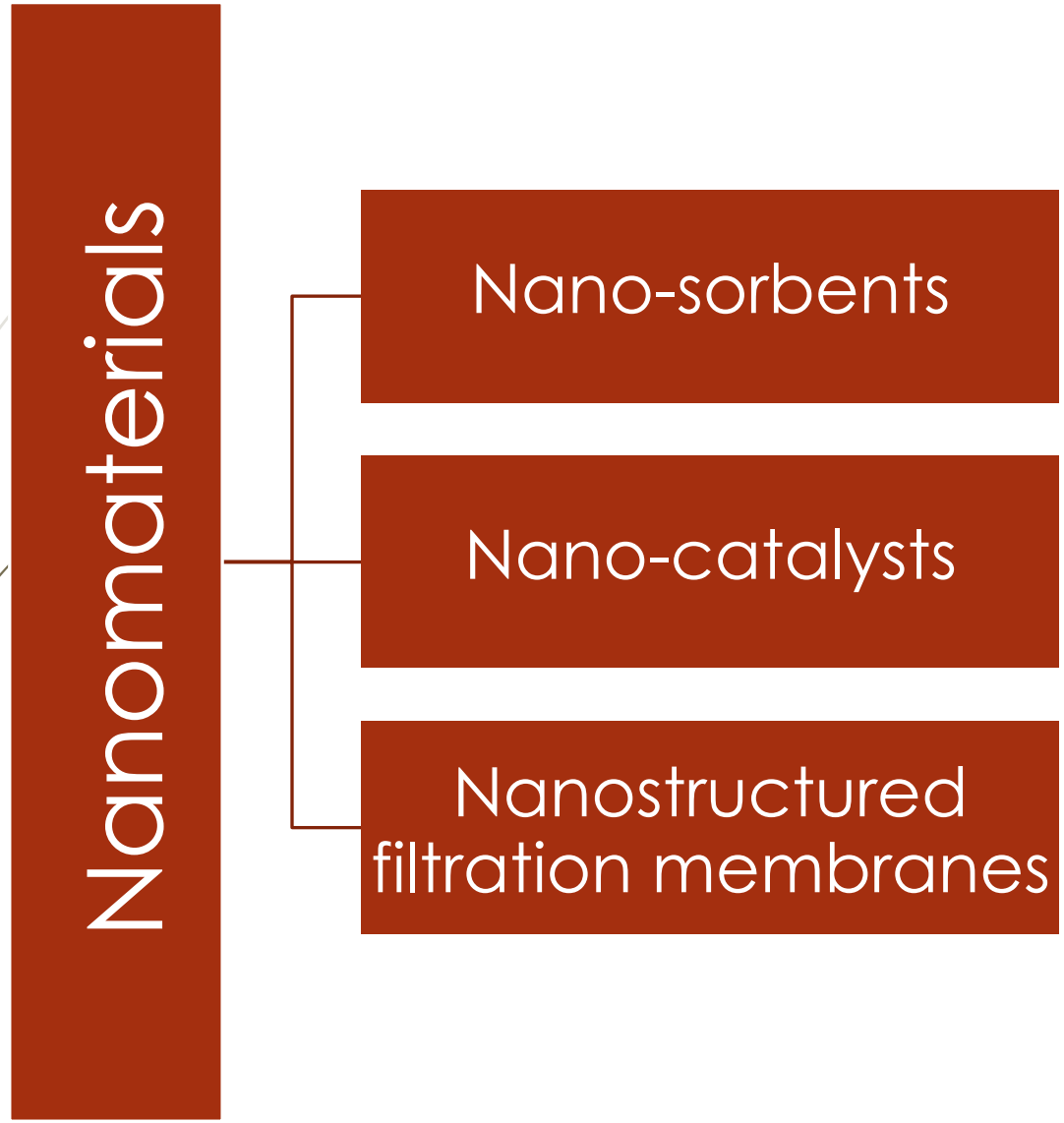
Increased effectiveness	contaminants could be more effectively removed , contaminants that were previously impossible to remove could now be removed, because of the expand specificity of nanotechnology and the advancement of smart filters tailored for utilization.
Simplification	nanotechnology could radically reduce the number of steps , materials and energy required for water treatment , making it simpler to implement widely in rural areas.
Reduced cost	significant introductory investment would be required to incorporate or switch to nanotechnology-based water treatments.

Nanoparticle's Benefits

The use of nanomaterials to remedy environmental hazards can be called "**nano-remediation**". Nanotechnology has reformed almost all fields of science and engineering, and remediation of the environment is no exception.

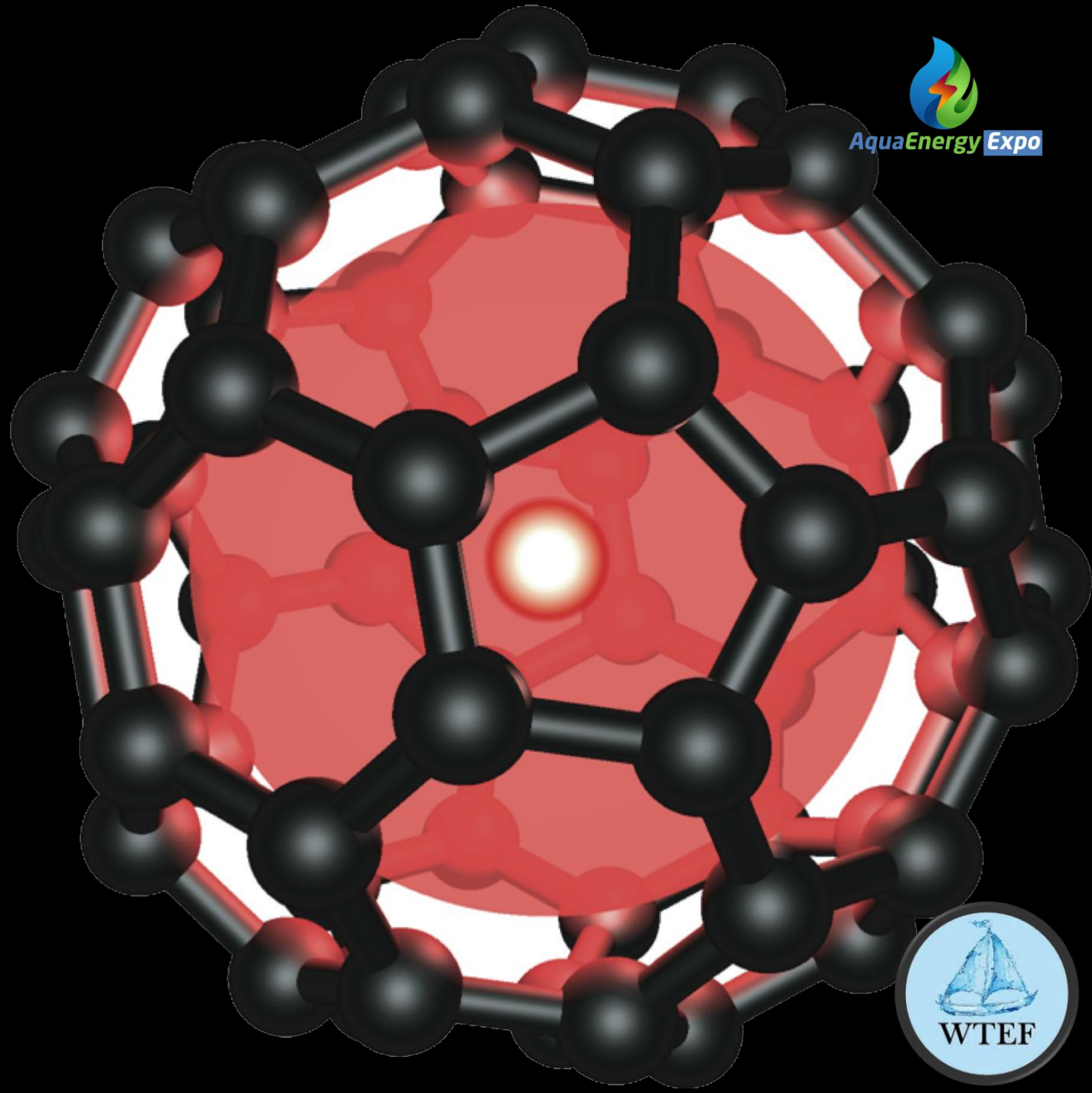
Nanoparticles (< 100 nm) with a high surface-to-volume ratio have a large reactive surface area compared to bulk materials and play an important role in the remediation of the environment

Nano-remediation



Categories of Nanomaterials utilized for water treatment

Nano-sorbents



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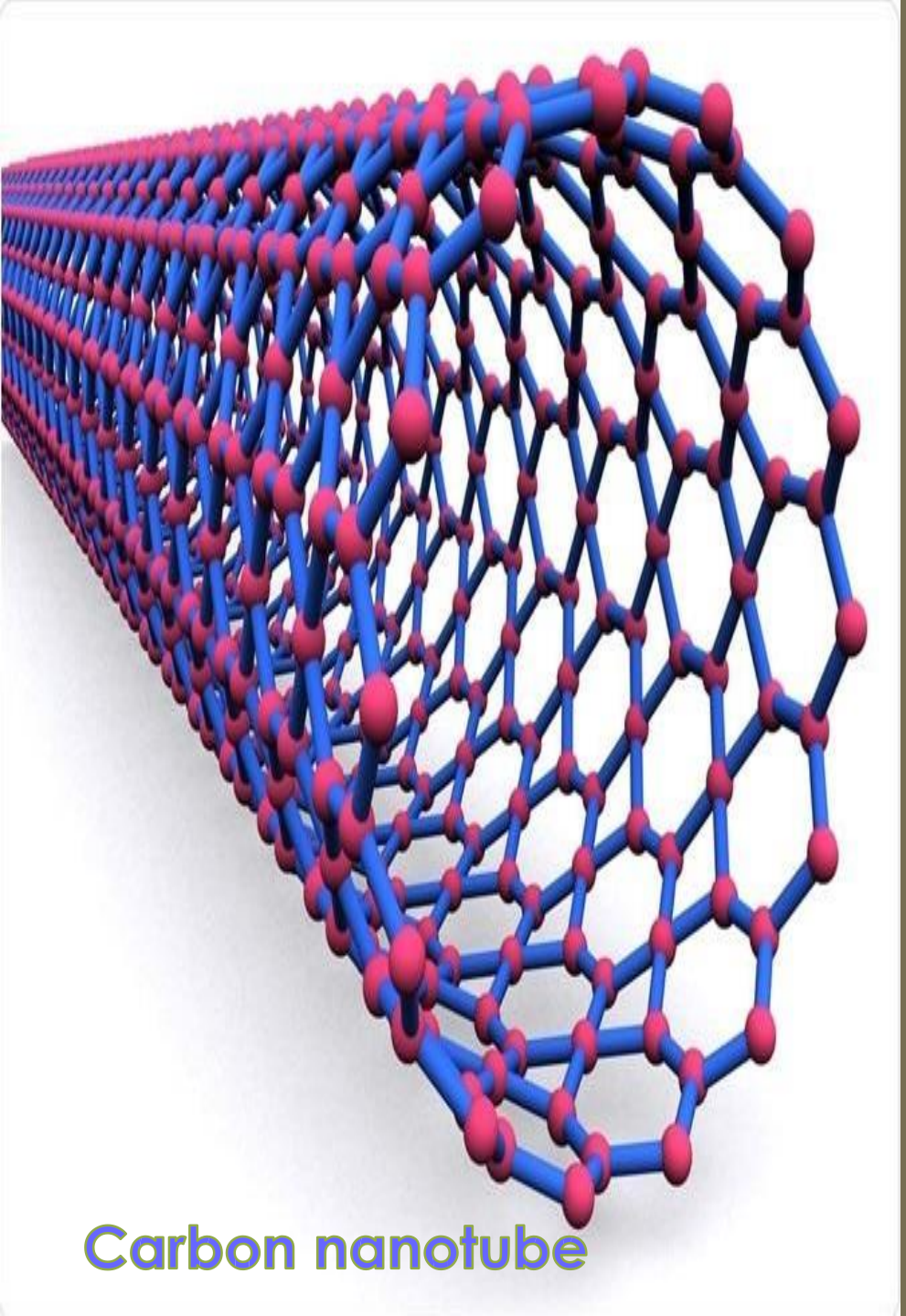
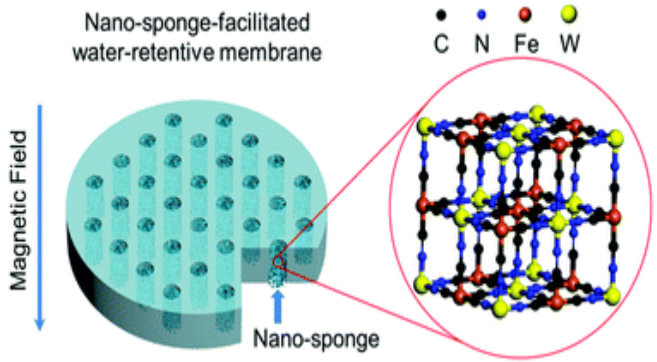


Carbon nanotube

Nano-sorbents

- Nano-sorbents are nanosized particles onto which some inorganic and organic molecules could be absorbed.
- Several nano have been synthesized tested for their application in water treatment.
- Examples:
  - Carbon nanotubes,
  - Metal nanoparticles,
  - Nano-sponges
  - Zeolites



Nano-catalysts

- These are mostly zero- valent metallic nanoparticles that have solid catalytic properties.
- These nano-catalysts can also be bimetallic to enhance the catalytic properties.
- Nano-catalysts catalyze basically the reduction of metal ions in solution and can catalyze de-chlorination of chlorinated organic pollutants.

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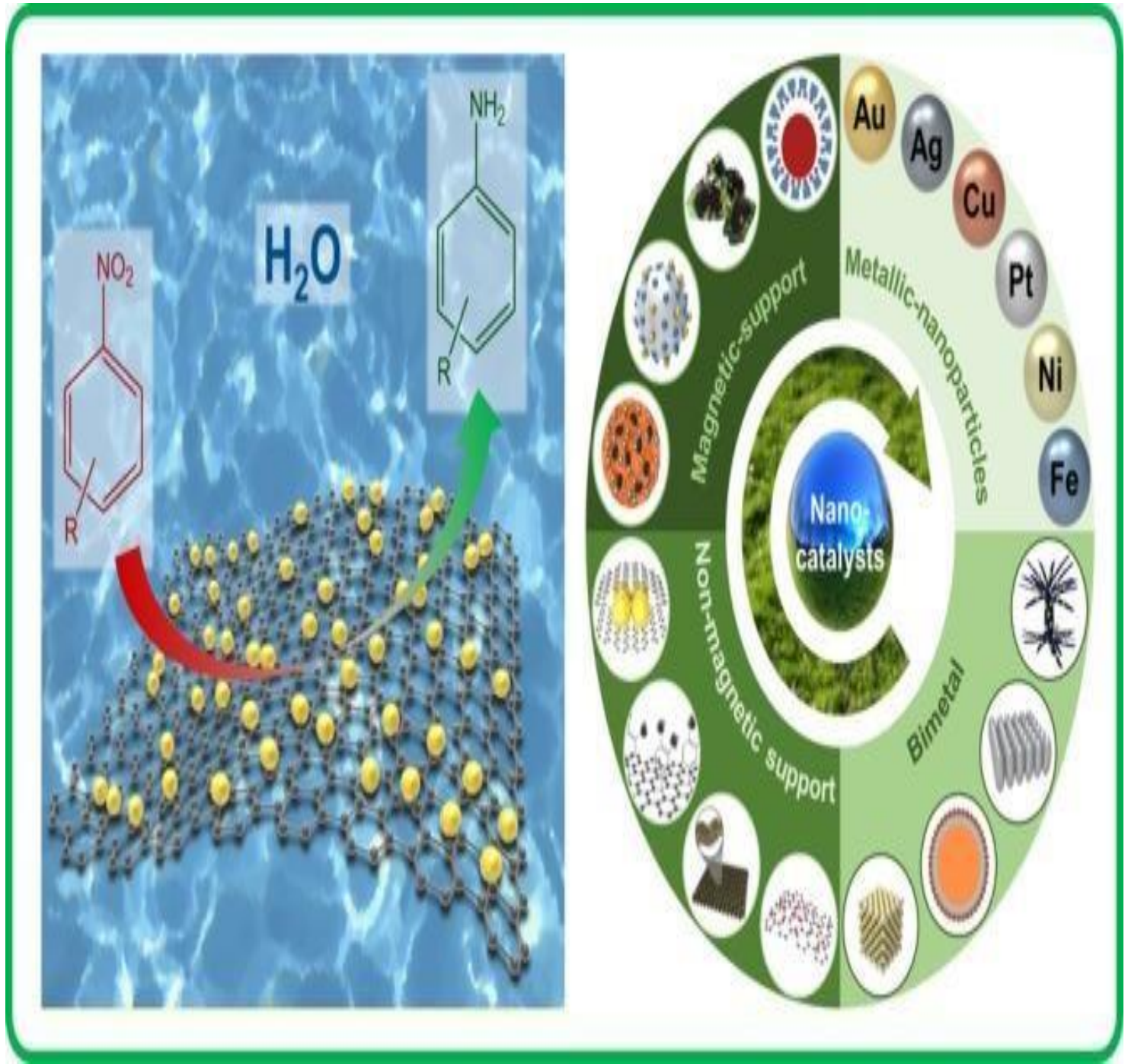
Nano-catalysts



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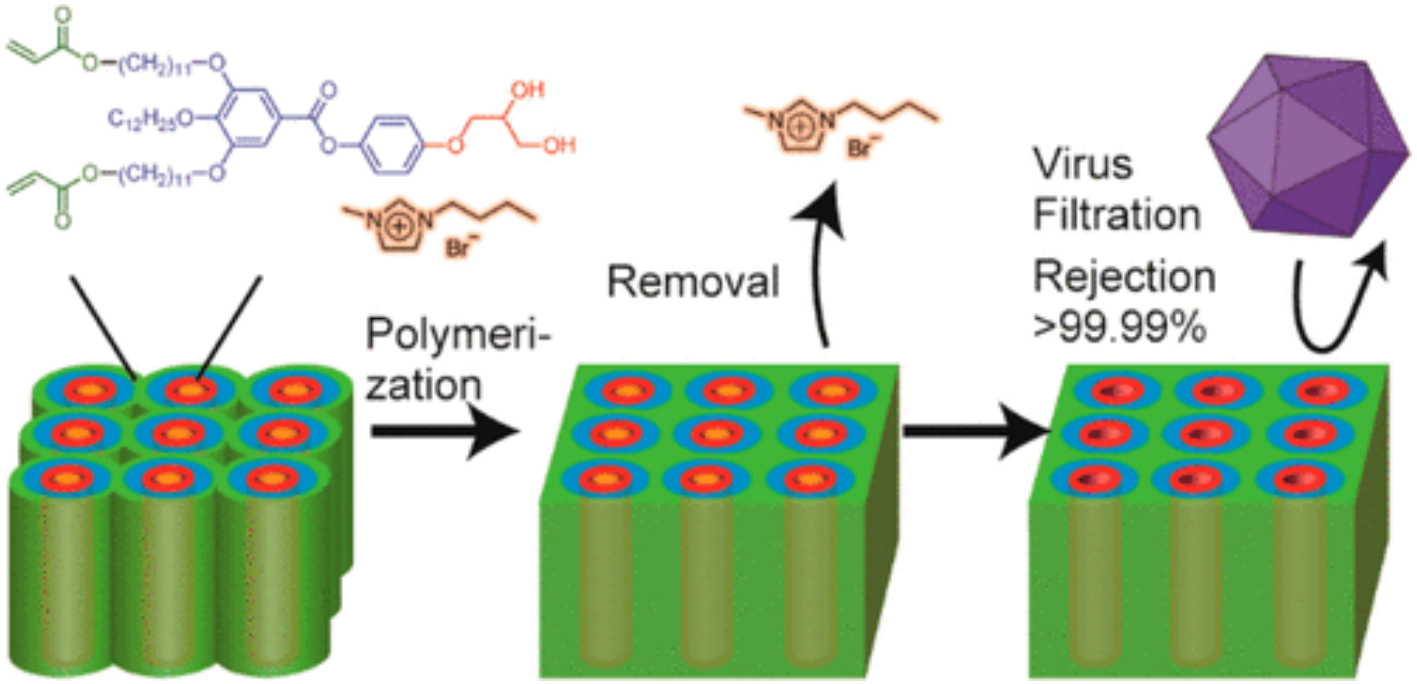
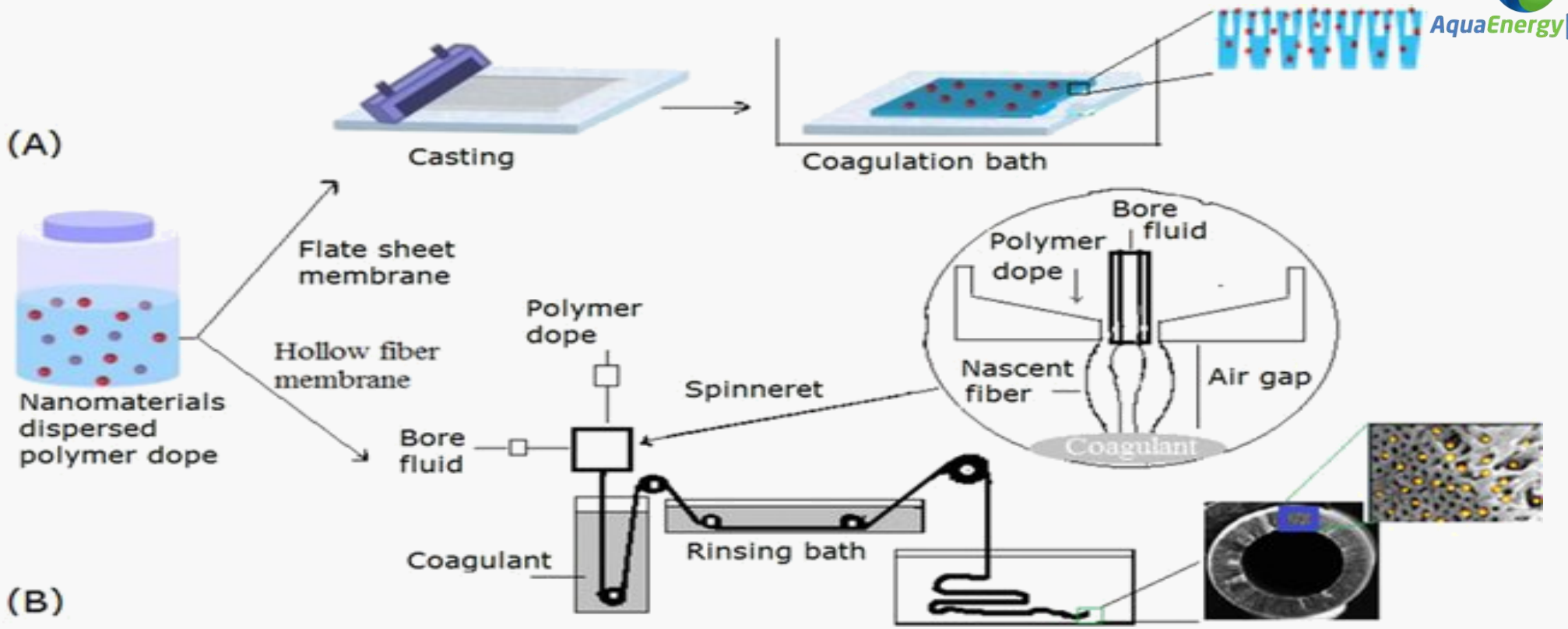
Nanostructured filtration membranes

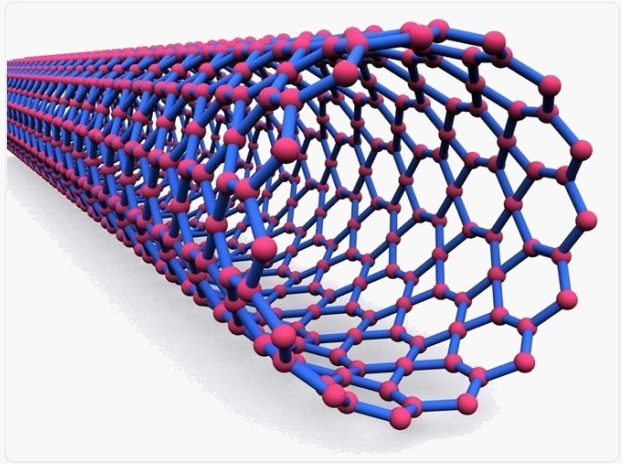
- nanostructures filtration membranes are polymeric permeable membranes that have nanosized pores.





Nanostructured filtration membranes fabrication

Examples of applications in Environmental applications



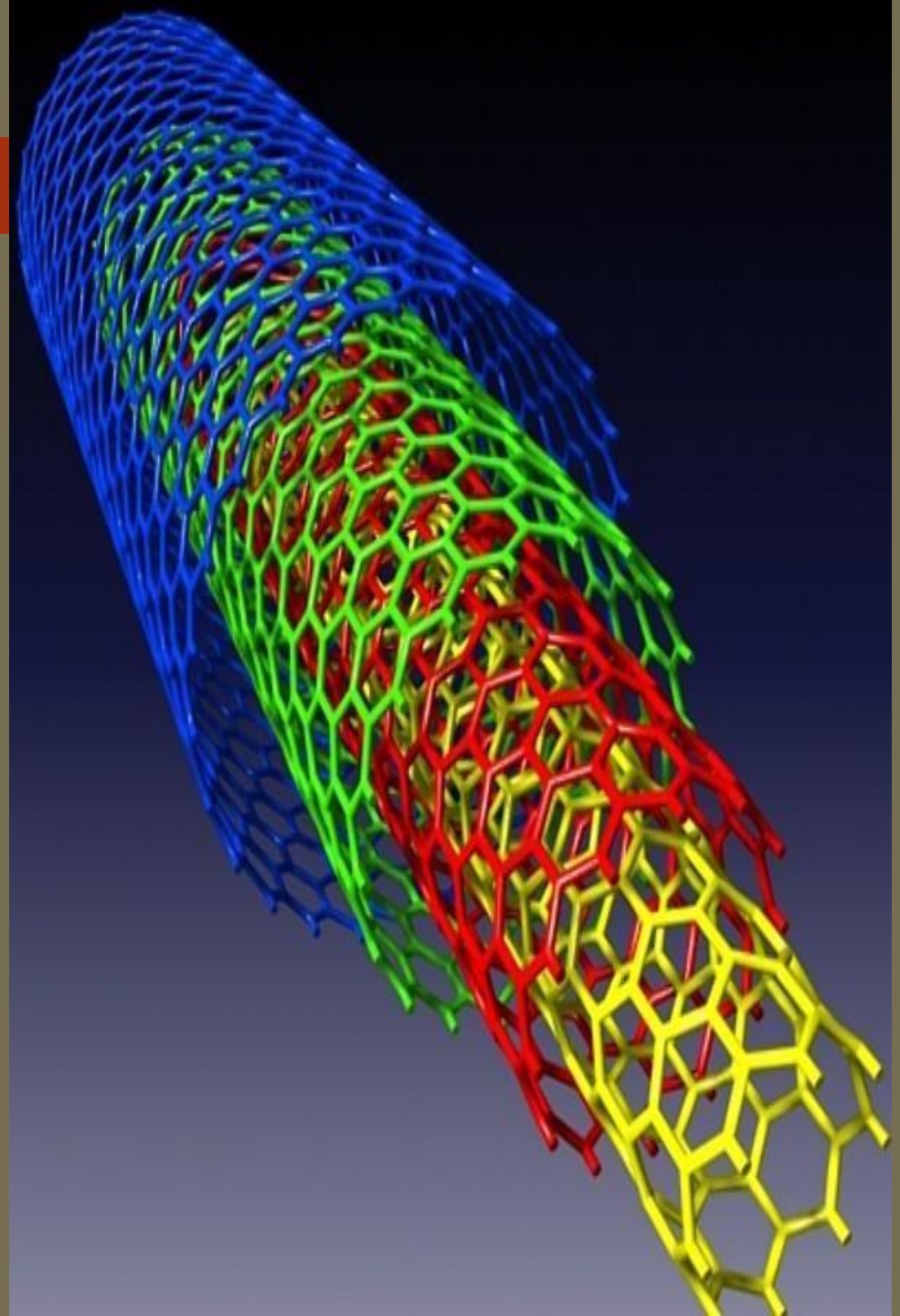
Carbon Nanotubes

The unique properties of Carbon Nano

- **High strength**
- **Resistance to acidic and basic media**
- **High surface area**
- **Good thermal, electrical, and conductive properties**
- **Novel structure with extra -ordinary properties.**

The CNTs consist of very thin honeycomb structures of graphene sheets rolled up in **cylindrical** shape with **a few nanometer diameter** and many micron or even centimeters length.

- **Single walled CNTs (SWCNTs)**
- **Multi-walled CNTs (MWCNTs)** distinguished by the layer's numbers.



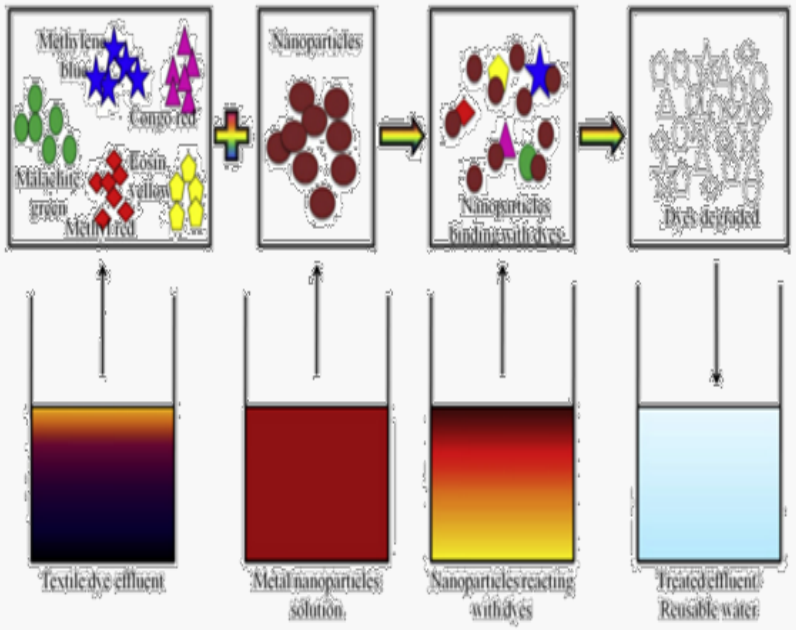
Examples of CNTs applications

- Various organic pollutants adsorption.
- Heavy metals adsorption.
- Control microbial pathogens.
- They are not strong oxidants and relatively inert in water resulting in avoiding the formation of carcogenic disinfection byproducts (DBPs).

Other applications

- DYES DEGRADATION
- MERCURY DETECTORS
- NITRATE, AND PHOSPHATE REMOVAL
- HEAVY METALS REMOVAL
- ANTIMICROBIAL

Examples of applications - DYES DEGRADATION



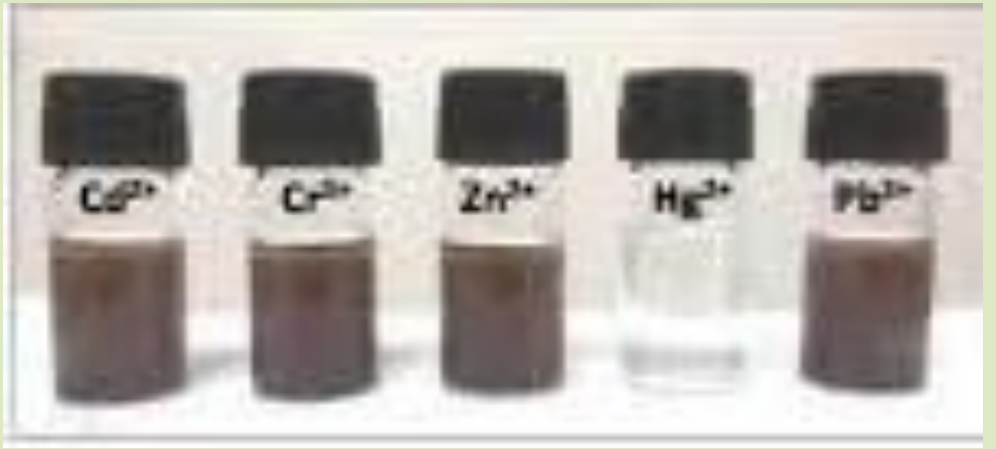
The dyes, in most cases based on organic compounds with AZO bond (R–N=N–R′) that flow discharging into canals and rivers and other water bodies.

- Using the enhanced photocatalytic property of metal nanoparticles, these dyes could be degraded before exposure to the atmosphere.
- Nano-silver compounds achieved around 75% dye degradation in the presence of solar exposure after 8 hours as contact time.

Dyes Degradation

Examples of applications - silver nanoparticles as mercury detector

- During 2015 silver nanoparticles was used as green synthesized suspension for colorimetric detection of Hg^{2+} . The dark brown suspension of nano silver was only decolorizing by Hg^{2+} contrariwise Cd^{2+}, Pb^{2+}, Zn^{2+} , Cr^{3+} not affect the color of the dark brown suspension of nano silver.



Examples of applications - NITRATE, AND PHOSPHATE REMOVAL

NITRATE, AND PHOSPHATE REMOVAL

Nano-composite was prepared from chitosan and Fe_3O_4/ZrO_2 under mild conditions.

The nanocomposite had the ability to adsorb both nitrate and phosphate.

The maximum adsorption process fitted well to the pseudo-first-order kinetic rate model, and the mechanism involved simultaneous adsorption and intraparticle diffusion.

Examples of applications - HEAVY METALS REMOVAL

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HEAVY METALS REMOVAL

- The commonly used nanoparticles for the wastewater treatment are made of alumina, cadmium sulfide, cobalt ferrite, copper oxide, gold, iron, iron oxide, iron hydroxide, nickel oxide, silica, titanium oxide, zinc oxide, zinc sulfide, zirconia, and some alloys.

- Most notably, ZnO hollow nanospheres and ZnO nanoplates showed complete removal of Cu(II) in binary compound solutions.

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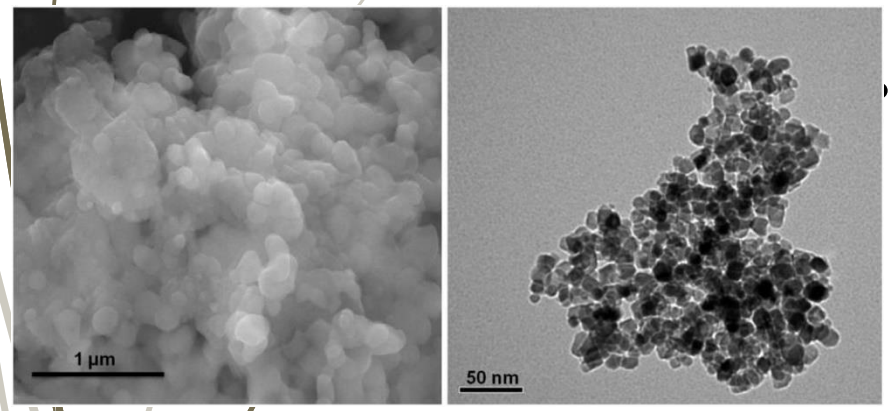
Examples of applications - HEAVY METALS REMOVAL



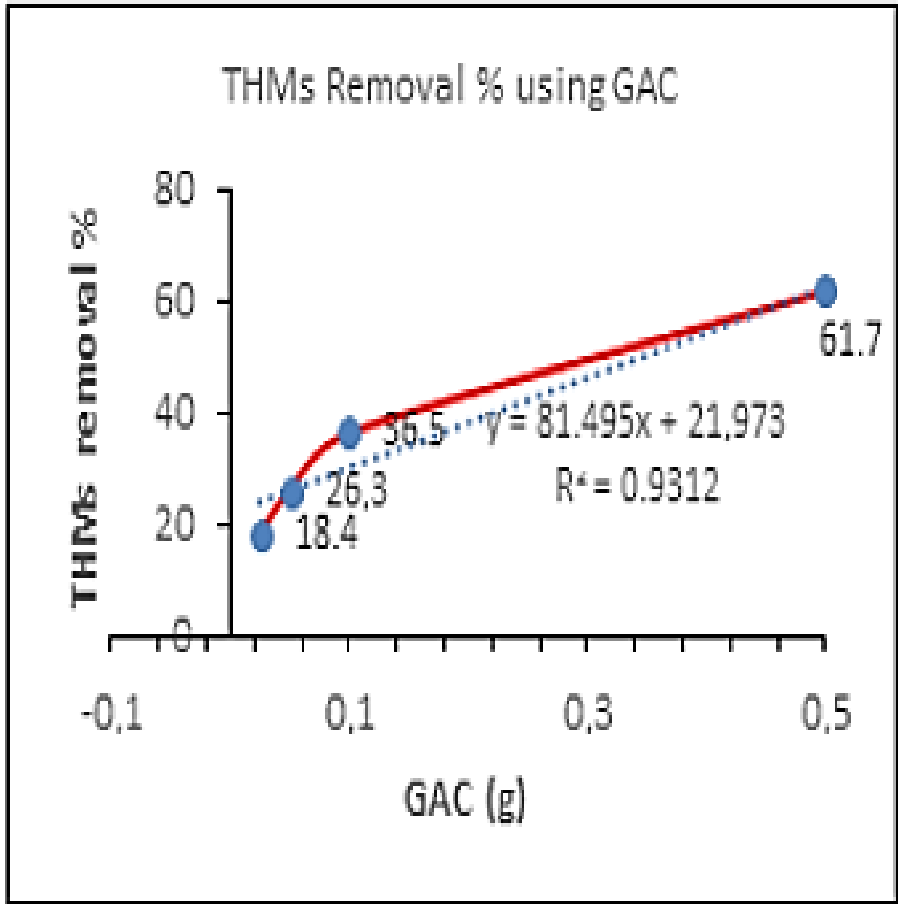
HEAVY METALS REMOVAL

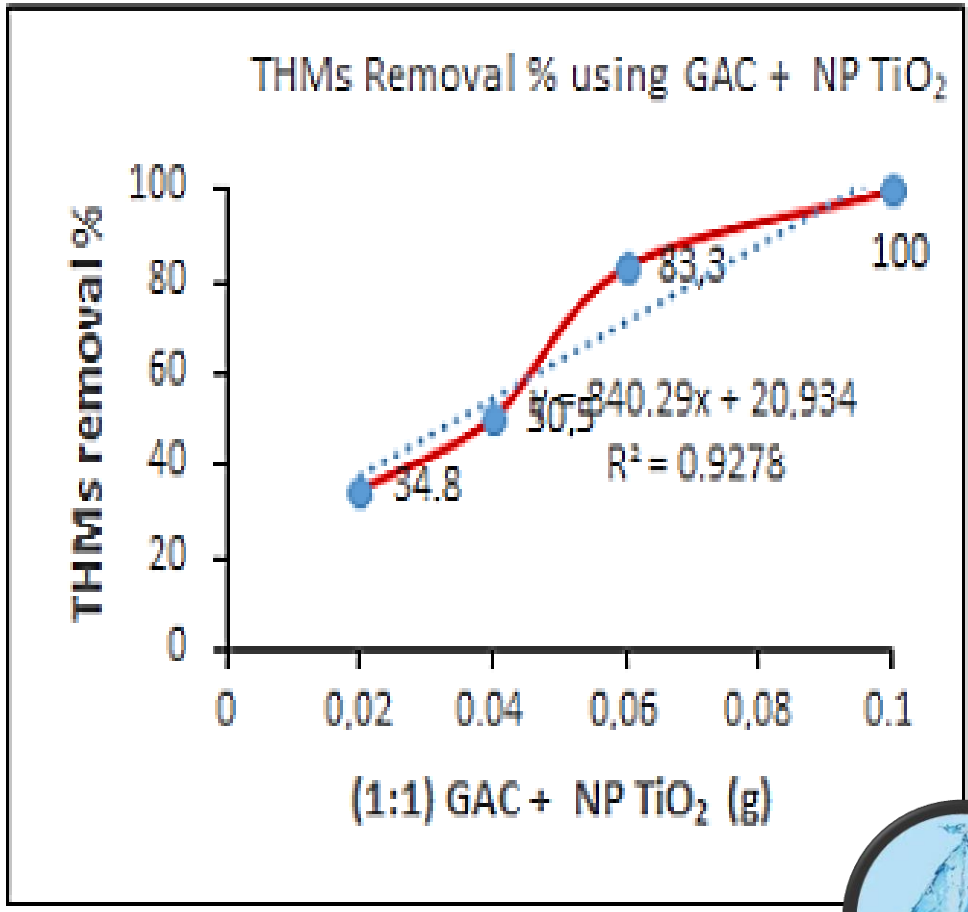
- A novel adsorbent, titanium dioxide nanowire (TiO_2), is prepared using hydrothermal methods and subsequently used for the removal of heavy metals.

- Some studies were tested the potential of using the TiO_2 nanowire to remove residues of heavy metals such as (Pb^{2+}, Cu^{2+}, Fe^{3+}, Cd^{2+}, and Zn^{2+}) from contaminated water.

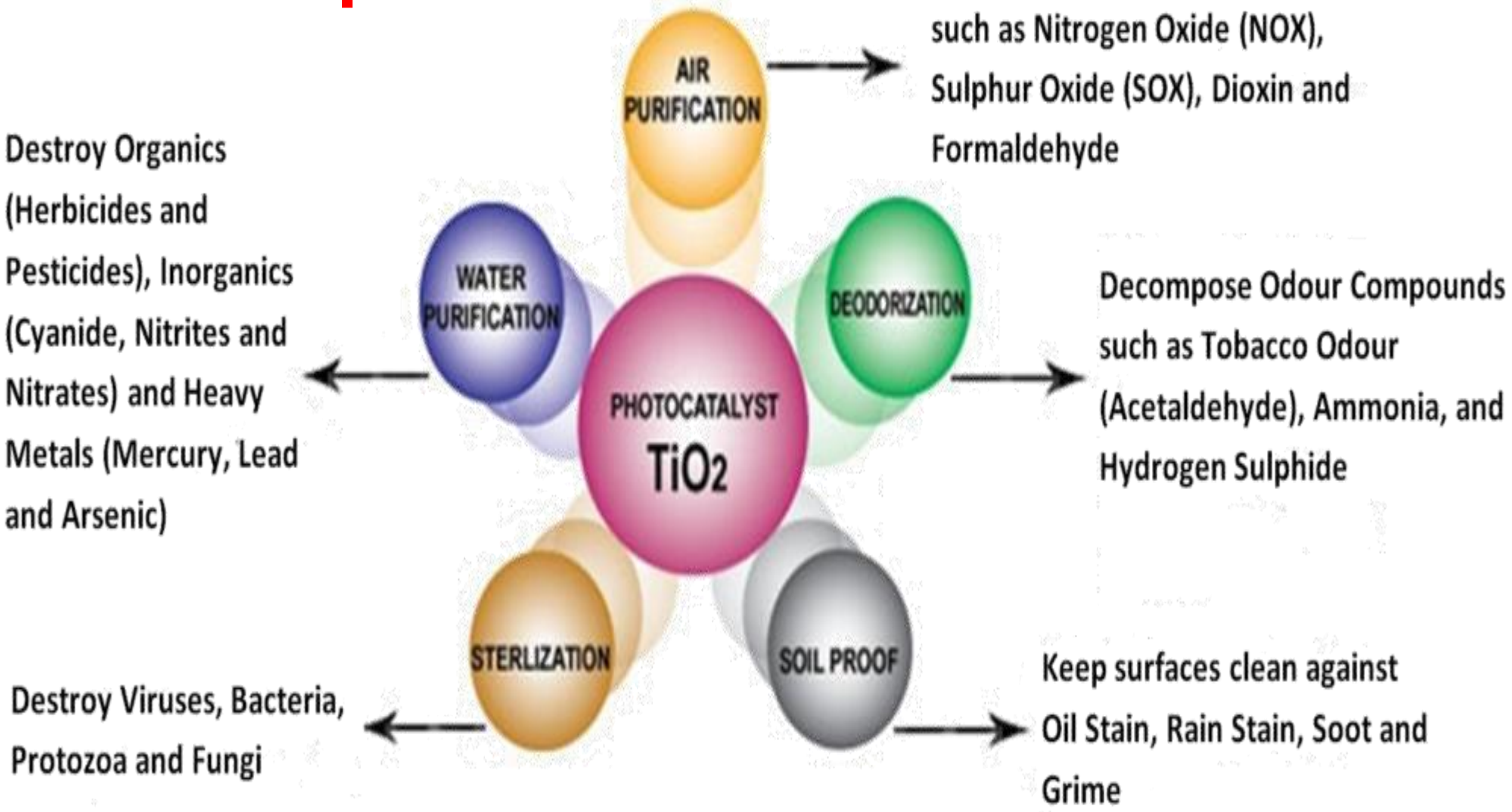
- Due to its magnetic nature, TiO_2 nanowire is an exceptional adsorbent material. The highest efficiency of absorption was 97.06 % with Pb^{2+}

DBPs Removal Using TiO_2 Nanoparticles

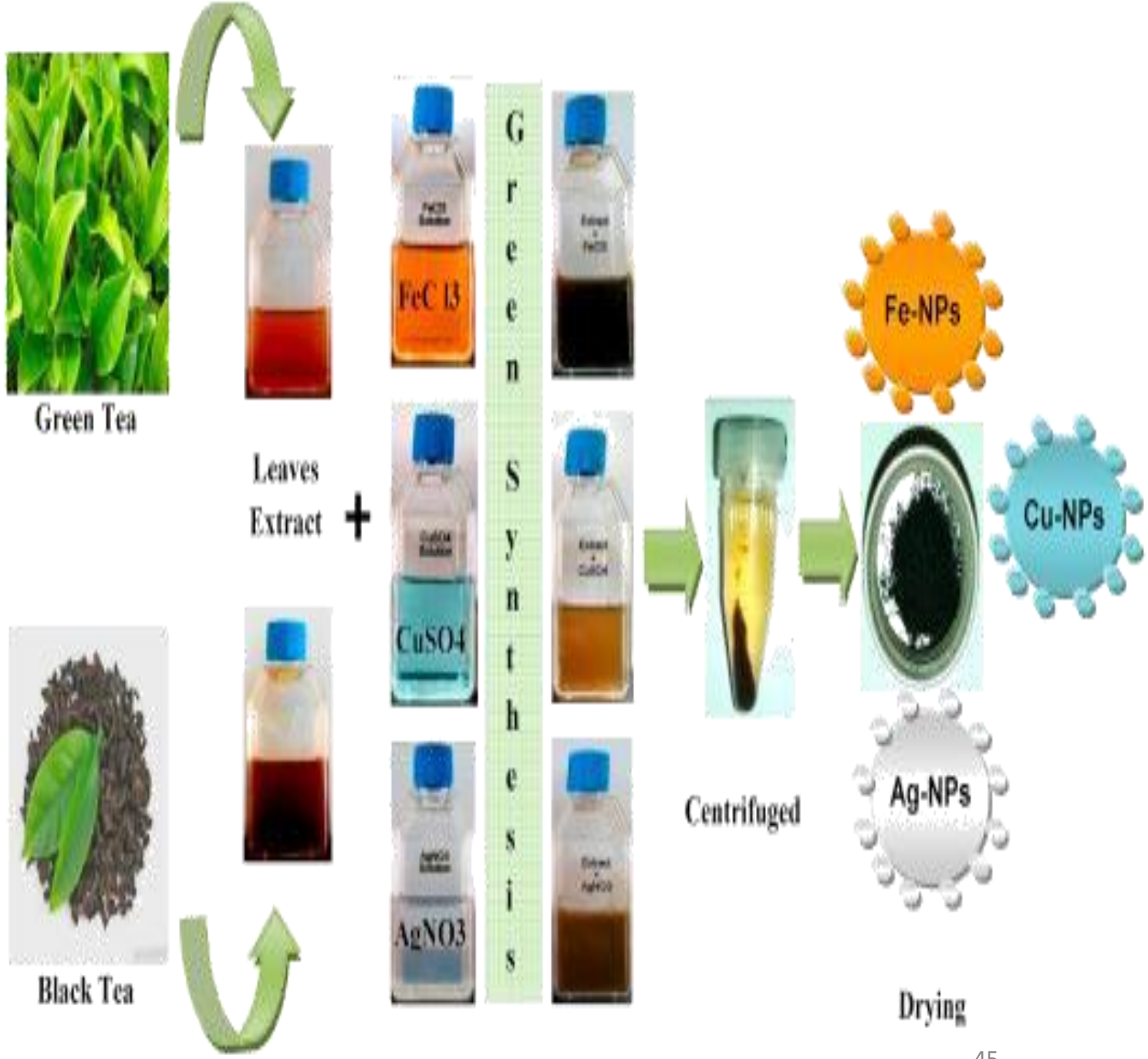




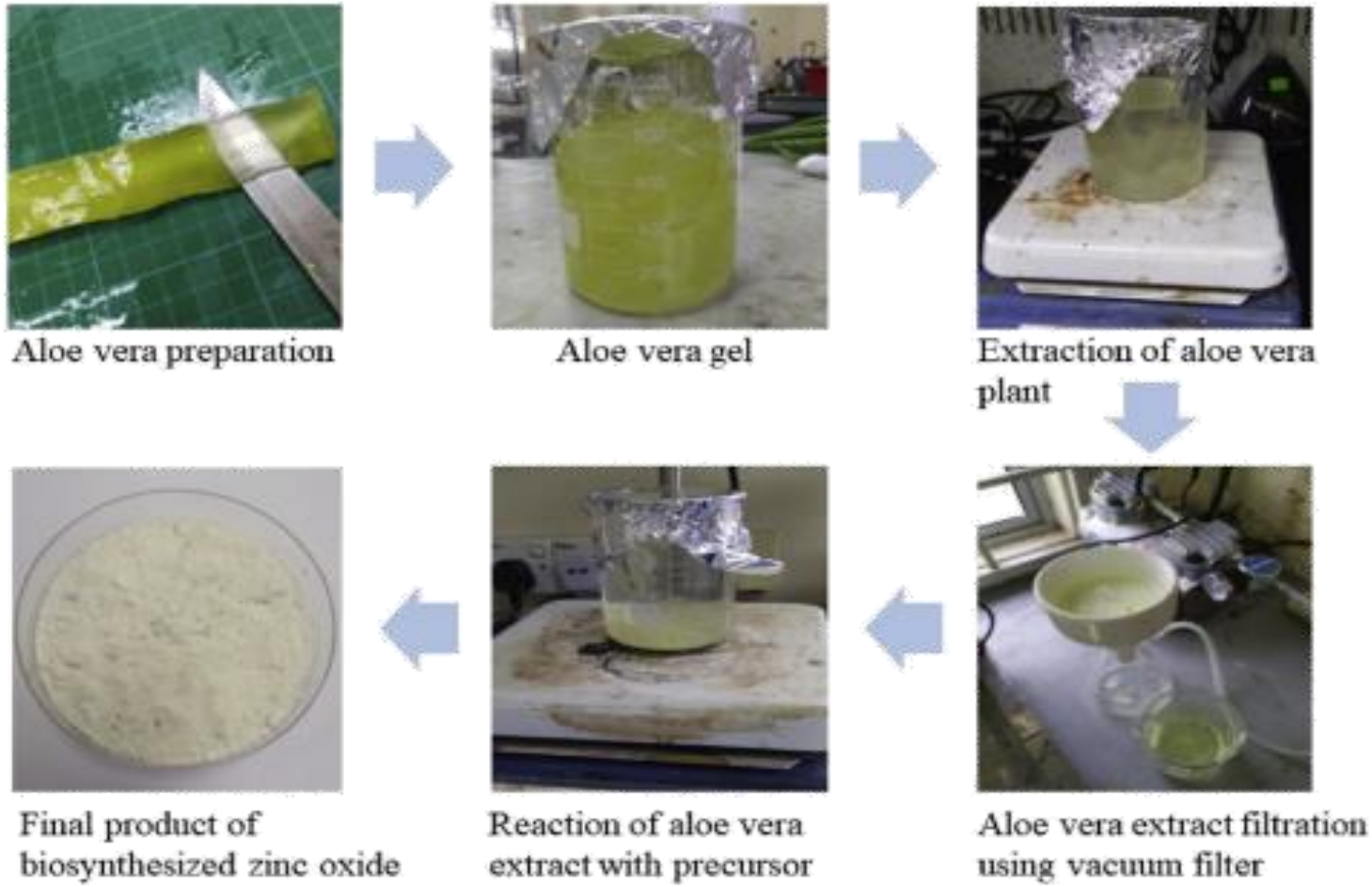
Examples of applications TiO_2 Nanoparticles



Easy green synthesis for Nanoparticles



Easy green synthesis for ZnO Nanoparticles



Heavy metals removal

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Carbon Nanotubes applications

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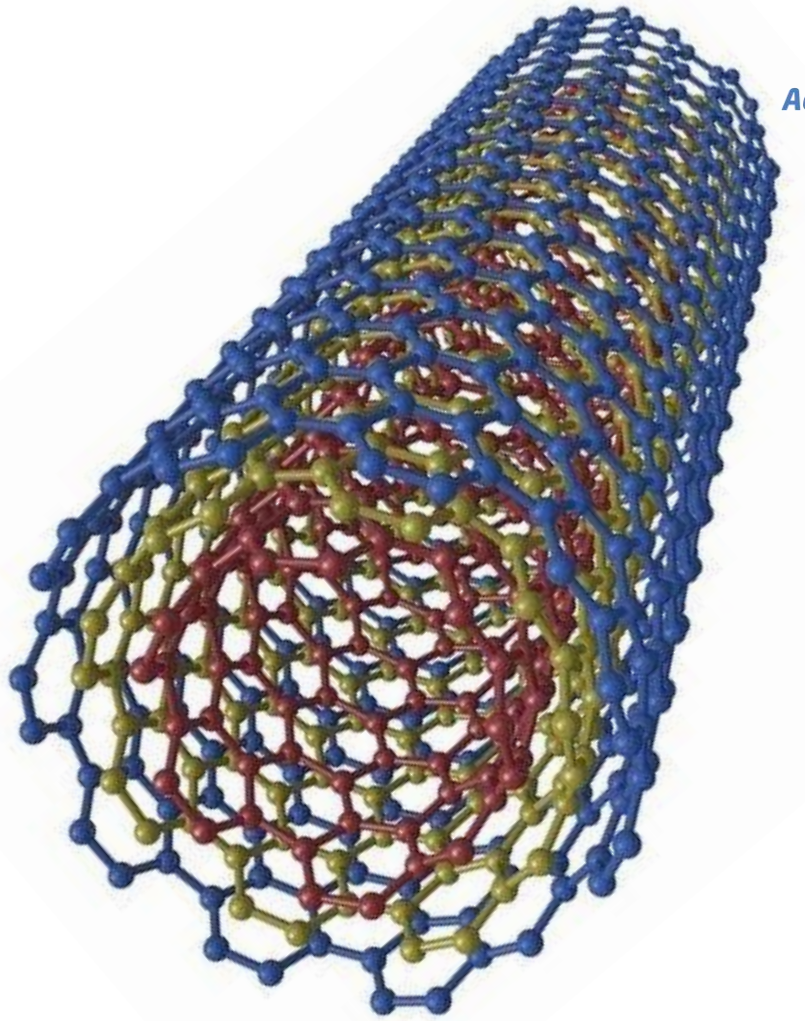

Other applications of CNTs

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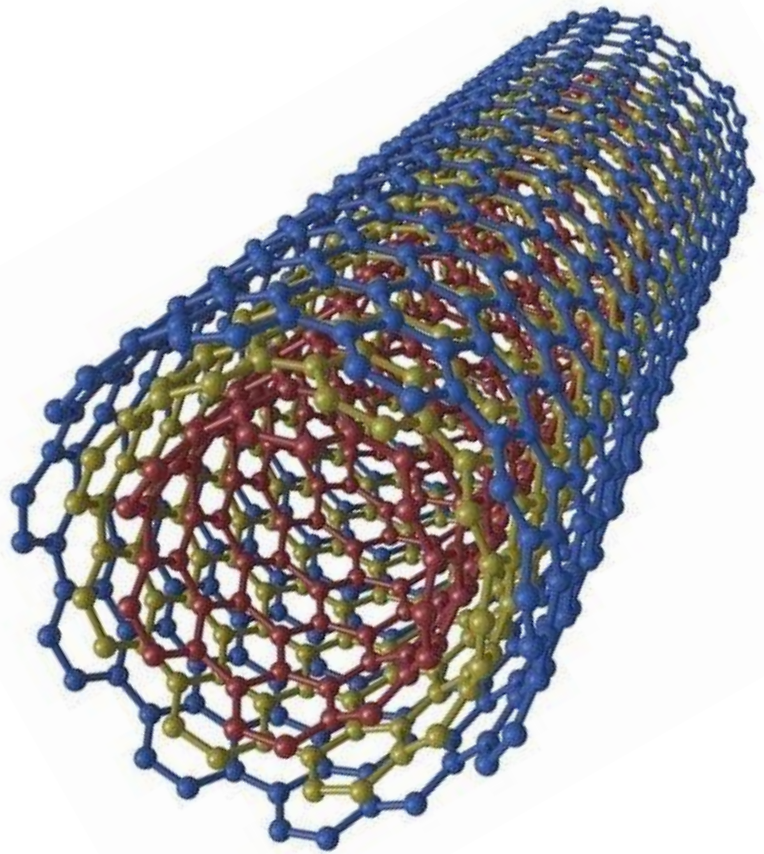

8 December 2023

The unique properties of Carbon Nanotubes

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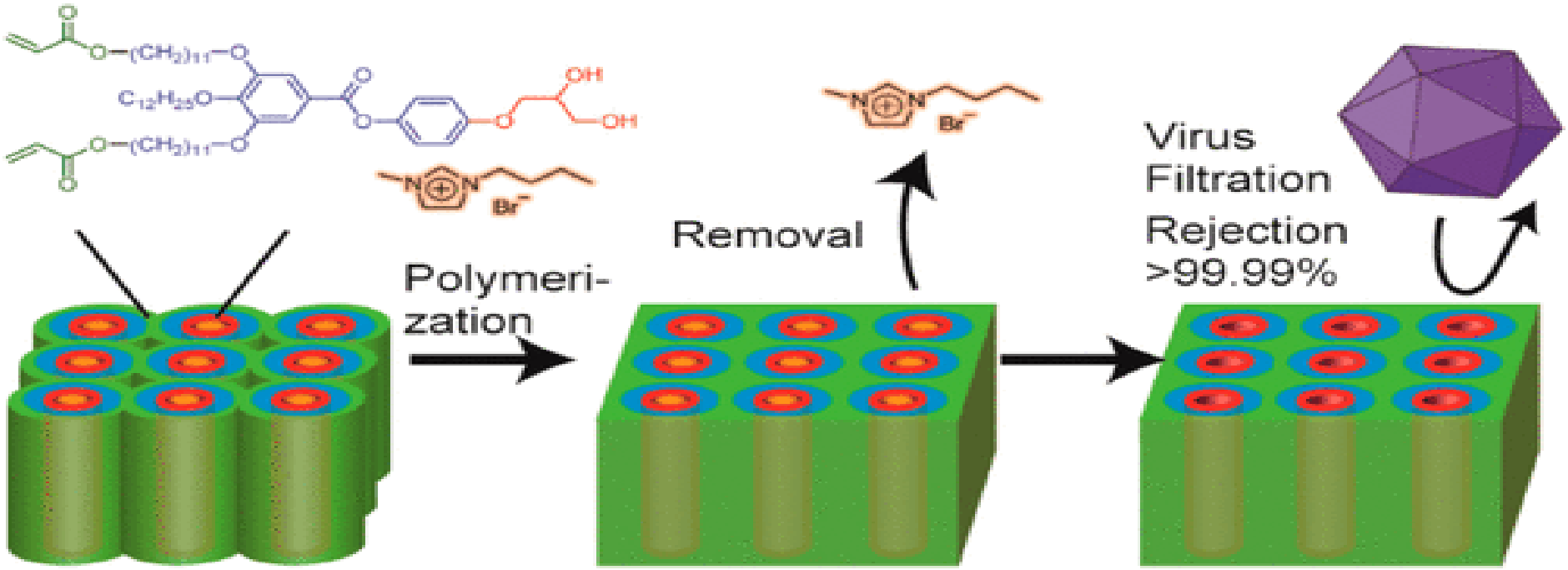
- **Single walled CNTs (SWCNTs)**
- **Multi-walled CNTs (MWCNTs)** distinguished by the layer's numbers.

Examples of Nano polymer membrane

Cellulose acetate,	Cellulose nitrate,	Polyacrylonitrile (PAN),	Polyvinylchloride,	PVC copolymer,
Aromatic polyamide,	Aliphatic polyamide,	Polysulfone,	Polycarbonate,	Polypropylene,

Nanostructured filtration membranes

- **Nanostructures filtration membranes are polymeric permeable membranes that have nanosized pores.**



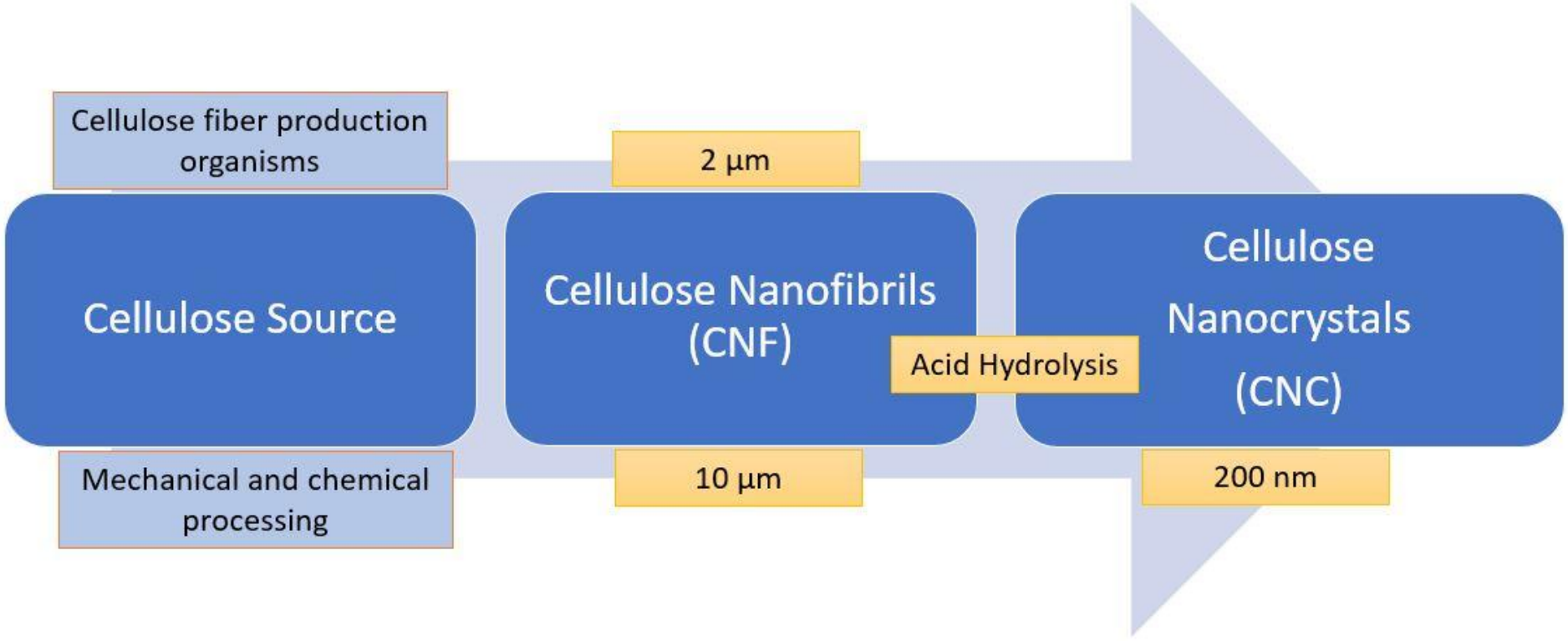
Metal oxide nanoparticles application in water purification field

Youssef and co-authors study's tests the potential of using the TiO_2 nanowire to remove residues of heavy metals such as (Pb^{2+}, Cu^{2+}, Fe^{3+}, Cd^{2+}, and Zn^{2+}) from contaminated water. Due to its magnetic nature, TiO_2 nanowire is an exceptional adsorbent material. The highest efficiency of absorption was 97.06 percent with Pb^{2+} and the lowest was 35.18 percent with Zn^{2+} **(Youssef and Malhat, 2014)**.

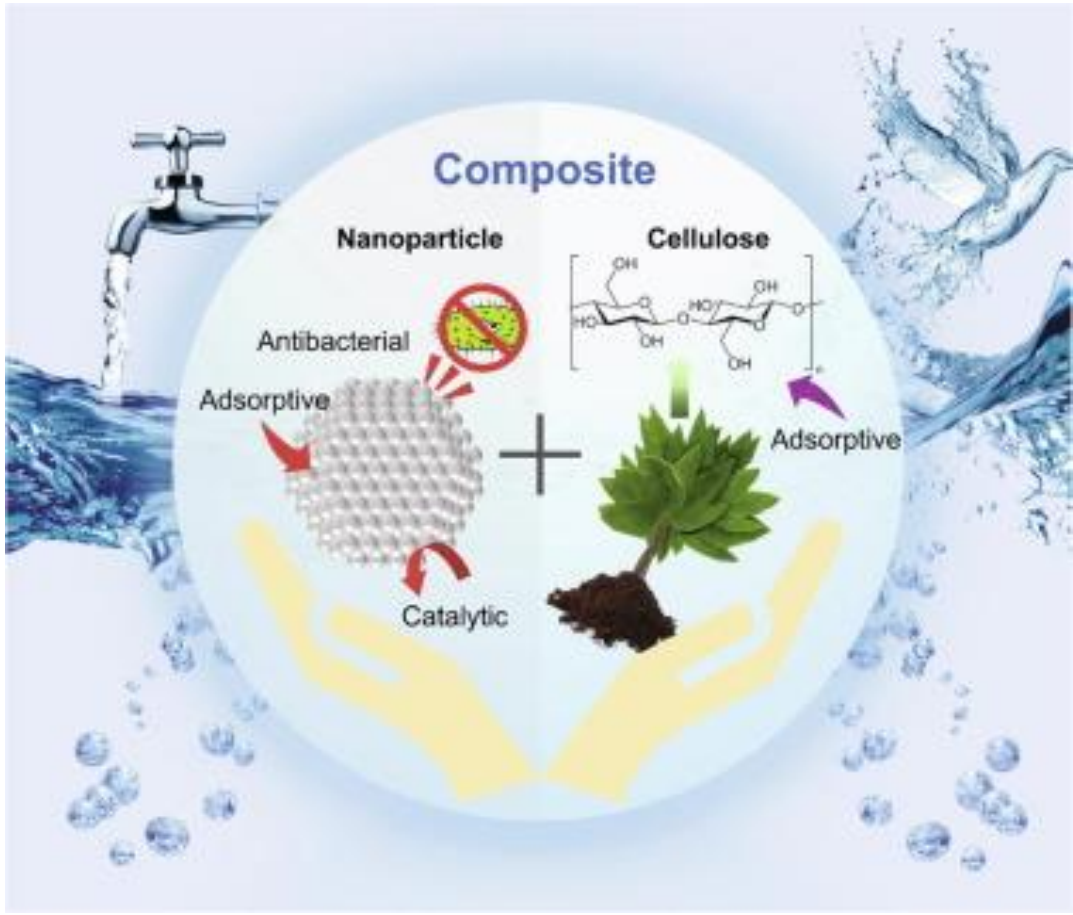
The nanoparticles have an inherent ability to separate charges, which distinguishes them from metals.

Sol-gel or hydrothermal processes were used to make a variety of metal oxides, including titanium dioxide (TiO_2), zinc oxide (ZnO), zirconium dioxide (ZrO_2), and aluminum oxide (Al_2O_3), from solutions of the respective metal salt.

Cellulose nanomaterials fabrication



In 2021 it was discovered by Georgouvelas and co-authors that cellulose functional membranes have strong adsorption capabilities for the metal ions Au (III), Co (II), and Fe (III), as well as the cationic organic dye methylene blue, due to the presence of active sites such hydroxyl, carbonyl, thioethers, and amines (MB).



Applications of iron nanoparticles for groundwater remediation

Due to the unrivaled surface chemical properties and molecular of Iron nanoparticles, they are stratified in the treatment of heavy metals, such as Cd^{2+}, Zn^{2+}, Hg^{2+}, Cu^{2+}, and Mn^{2+} **(Gong et al., 2017, Zhou et al., 2019)**.

Opportunities and Challenges

- The US government contributed $5.97 billion, or 33% of the total amount invested in 2015.
- Japan is currently the second-largest investor in nanotechnology research, behind the United States.
- Japan's Advanced Industrial Science and Technology (AIST) is an applied research Centre with about an US$800 million annual budget.
- The advancement of scientific research that is relevant to industrial competitiveness is its fundamental goal

Conclusion

The application of nanoparticles (NPs) in many applications in water sector such as heavy metals removal, Dyes removal and Nano-filtration giving a very promising result. Our work highlighted the state of art in Carbon, Cellulose, Metallic based nanoparticles, and carbon nanotubes applications in water sector.

Form this review it can be concluded that the rapid and ongoing development of nanotechnology knowledges has a lot of advantage and a lot of potential risks because the risks of nanoparticles associated with human health and accumulation in the environment still need more research.

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