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Affordable Clean Water Using Advanced Materials

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EyeNetAqua Solutions Pvt. Ltd.
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Associate Editor
ACS
Sustainable
Resource Management

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Institute Professor, IIT Madras

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<https://pradeepresearch.org>

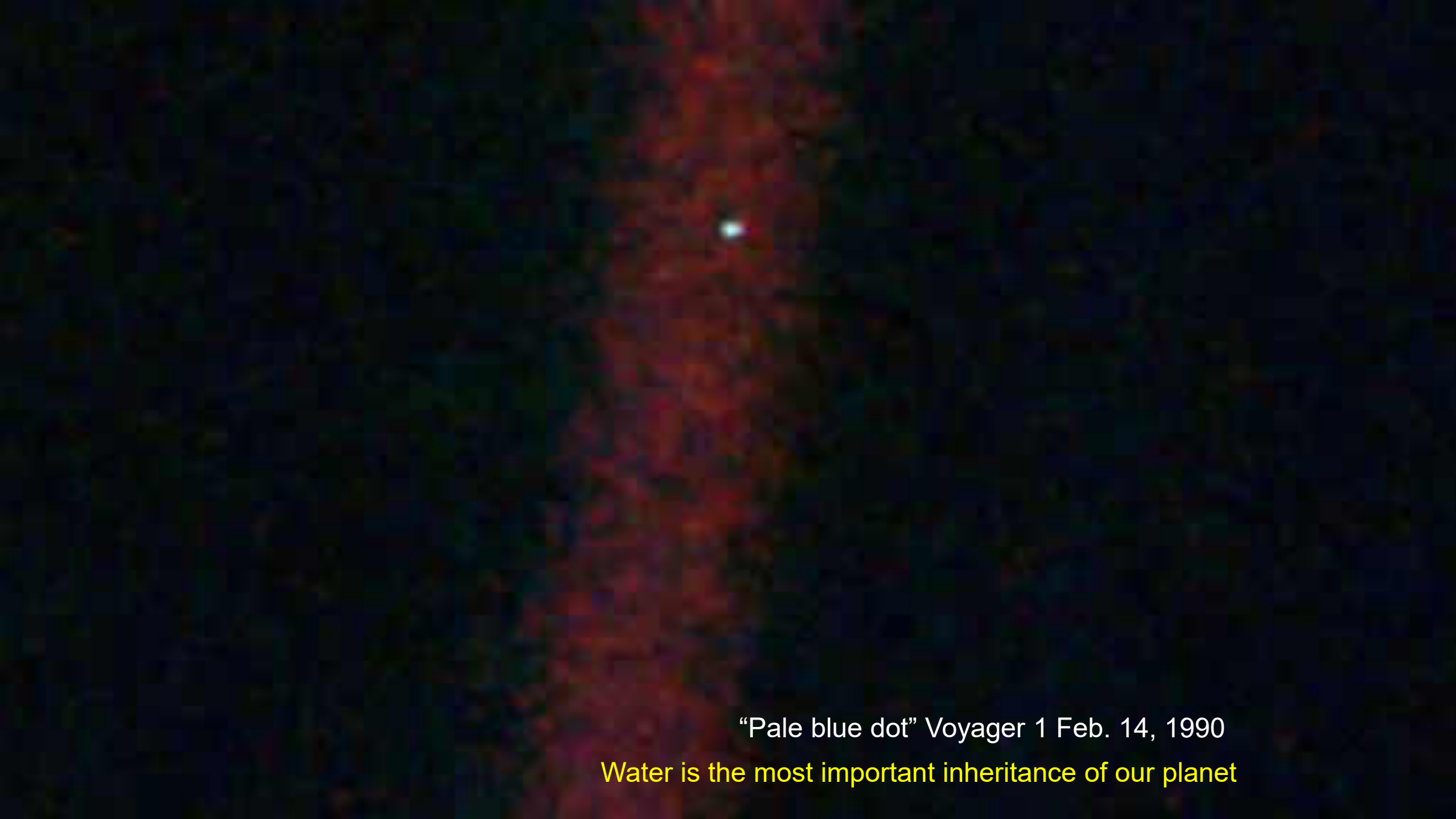
Professor-in-charge



International Centre for Clean Water



9th As2024 KIT, Bhuvaneshwar



“Pale blue dot” Voyager 1 Feb. 14, 1990

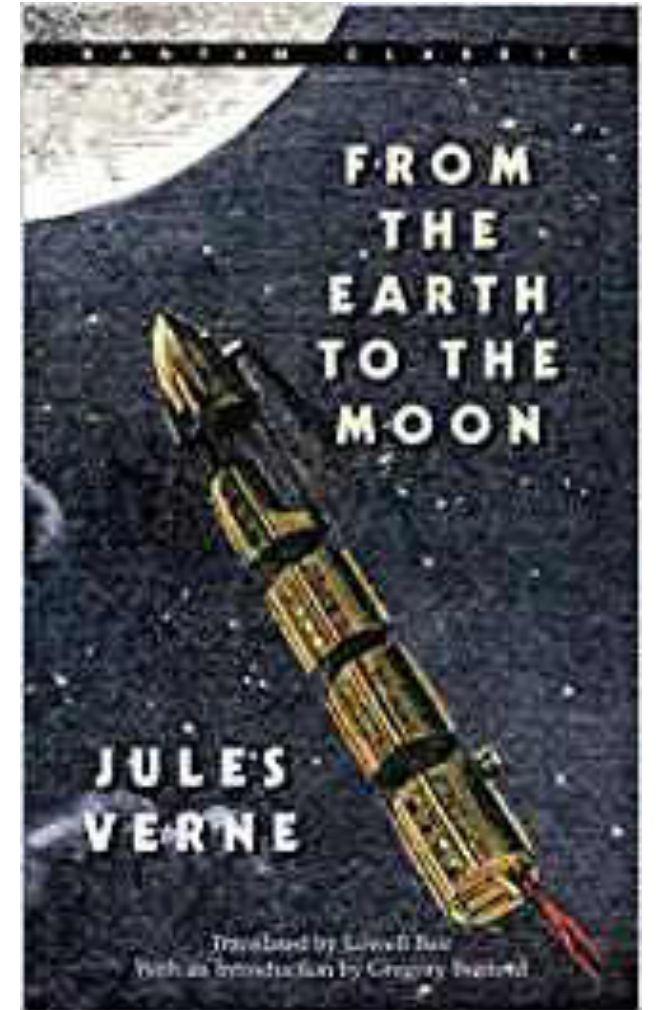
Water is the most important inheritance of our planet



From S. Vishwanath

© Robert Szucs/Grasshopper Geography

Our dreams become reality
with materials

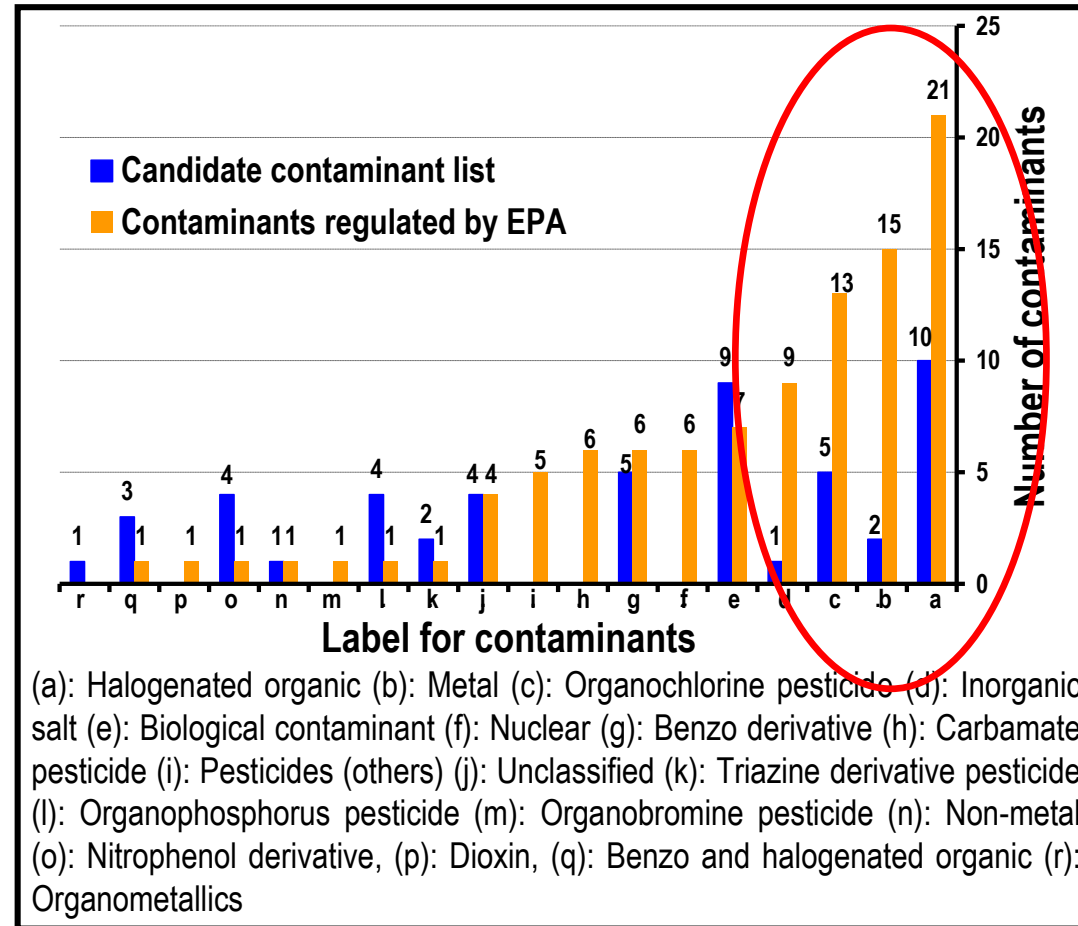


Water purification, history

Important milestones in the history of water purification (1800–2007) from the perspective of noble metal nanoparticles in water treatment (compiled from multiple sources on the World Wide Web).

Year	Milestone
1804	Setup of world's first city-wide municipal water treatment plant (Scotland, sand-filter technology)
1810	Discovery of chlorine as a disinfectant (H. Davy)
1852	Formulation of Metropolis Water Act (England)
1879	Formulation of Germ Theory (L. Pasteur)
1902	Use of chlorine as a disinfectant in drinking water supply (calcium hypochlorite, Belgium)
1906	Use of ozone as a disinfectant (France)
1908	Use of chlorine as a disinfectant in municipal supply, New Jersey
1914	Federal regulation of drinking water quality (USPHS)
1916	Use of UV treatment in municipal supplies
1935	Discovery of synthetic ion exchange resin (B. A. Adams, E. L. Holmes)
1948	Nobel Prize to Paul Hermann Muller (insecticidal properties of DDT)
1959	Discovery of synthetic reverse osmosis membrane (S. Yuster, S. Loeb, S. Sourirajan)
1962	<i>Silent Spring</i> published, first report on harmful effects of DDT (R. Carson)
1965	World's first commercial RO plant launched
1974	Reports on carcinogenic by-products of disinfection with chlorine Formulation of Safe Drinking Water Act (USEPA)
1975	Development of carbon block for drinking water purification
1994	Report on use of zerovalent iron for degradation of halogenated organics (R. W. Gillham, S. F. O'Hannesin)
1997	Report on use of zerovalent iron nanoparticles for degradation of halogenated organics (C-B. Wang, W.-X. Zhang)
1998	Drinking Water Directive applied in EU
2000	Adoption of Millennium Declaration during the UN Millennium Summit (UN Millennium Development Goals)
2003	Report on use of noble metal nanoparticles for the degradation of pesticides (A.S. Nair, R. T. Tom, T. Pradeep)
2004	Stockholm Convention, banning the use of persistent organic pollutants
2007	Launch of noble metal nanoparticle-based domestic water purifier (T. Pradeep, A. S. Nair, Eureka Forbes Limited)

Future of water purification: An enigma with some pointers



Category-wise distribution of contaminants regulated by USEPA and future contaminants

Noble metal nanoparticles for water purification: A critical review, T. Pradeep and Anshup, Invited critical review, Thin Solid Films, 517 (2009) 6441-6478 (DOI: 10.1016/j.tsf.2009.03.195).

Affordable clean water is a problem of advanced materials

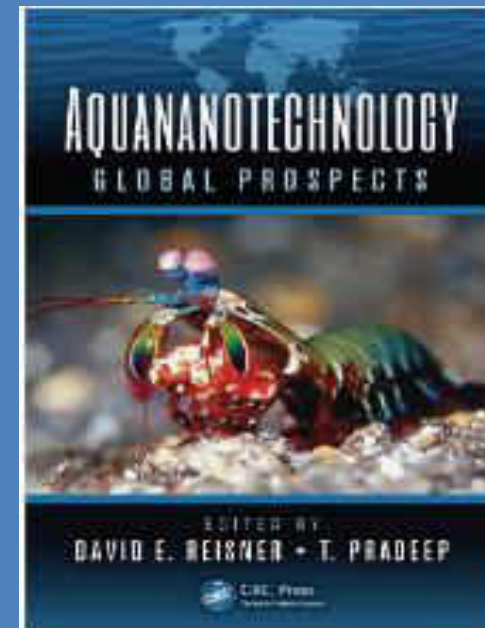
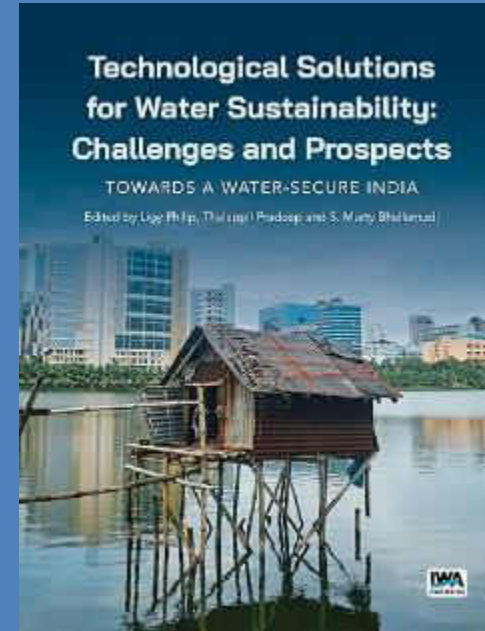
New adsorbents

New sensors

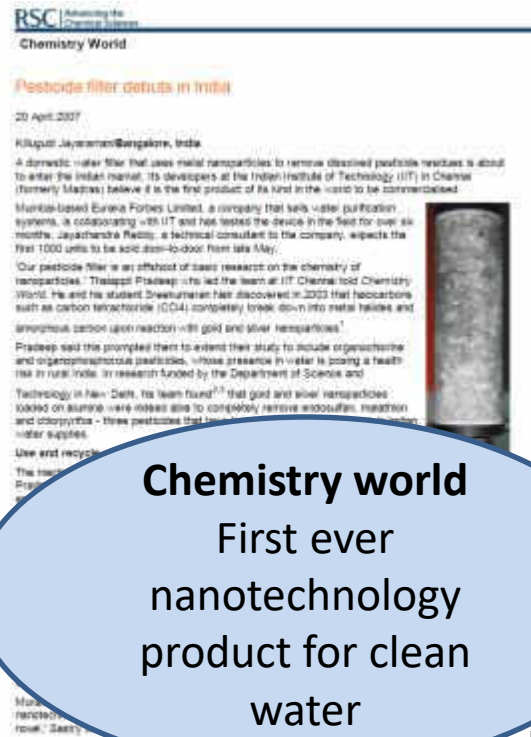
New catalysts

Novel phenomena

New devices



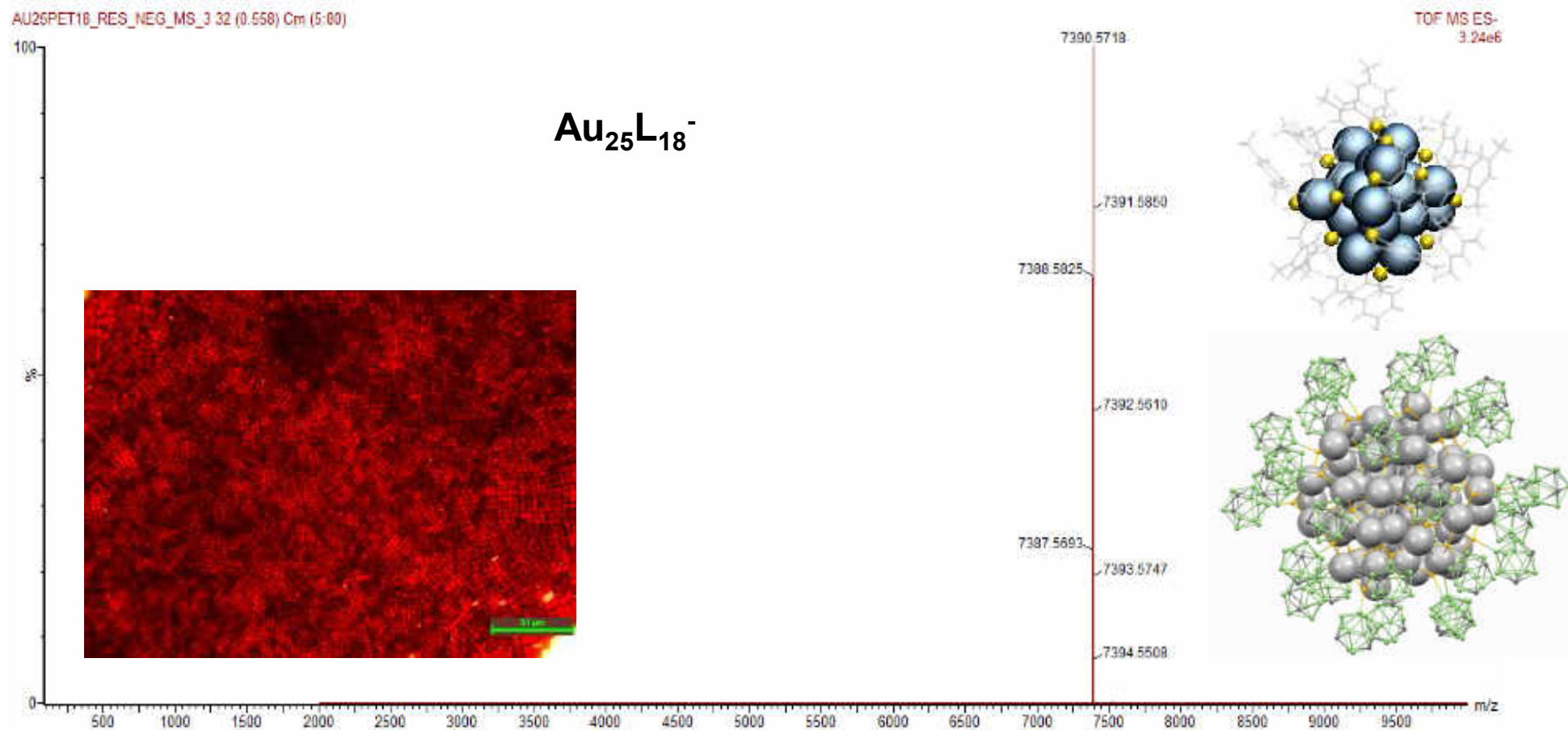
World's first nanochemistry-based water purifier



A plant to make supported nanomaterials for water purification; with capacity of 4.5 tons per month, 2007

1. Patents: A method of preparing purified water from water containing pesticides, **Indian patent 200767**
 2. Extraction of malathion and chlorpyrifos from drinking water by nanoparticles , **US 7,968,493** A method for decontaminating water containing pesticides, **EP 17,15,947**
- Product is marketed now by a Eureka Forbes Ltd.
Several new technologies are now available

Nanomaterials are now atomically precise



T. Pradeep et. al. *Acc. Chem. Res.* 2018; 2019.

Clean water for everyone



ACS Sustainable Chemistry & Engineering Editorial,
December 2016

Water positive materials

Biopolymer-reinforced synthetic granular nanocomposites for affordable point-of-use water purification

Mohan Udhaya Sankar¹, Sahaja Aigal, Kamallesh Chaudhari, and Thalappil Pradeep¹

¹Unit of Nanoscience and Thematic Unit of Excellence, Indian Institute of Technology Madras, Chennai 600 075, India

Edited by Eric Hoek, University of California, Los Angeles, CA, and approved for publication November 21, 2012

Abstract: Creation of affordable materials for constant point-of-use water purification is one of the most promising ways to ensure access to drinking water for all. Combining the capabilities of nanocomposites to scavenge toxic species such as heavy metals and other contaminants along with the above-mentioned materials to provide an affordable, all-inclusive drinking water purification system without electricity. The critical problem in the synthesis of stable materials that can reliably function in the presence of complex species in drinking water that deposit and cause scaling on surfaces. Here we show that such composites can be synthesized in a simple and effective fashion without the use of electrical power. The nanocomposites exhibit sand-like properties, such as higher shear strength and stability. These materials have been used in a water purifier to deliver clean drinking water. The ability to prepare nanostructures at ambient temperature has wide relevance for water purification.

Keywords: hybrid | green | appropriate technology | frugal science | developing world



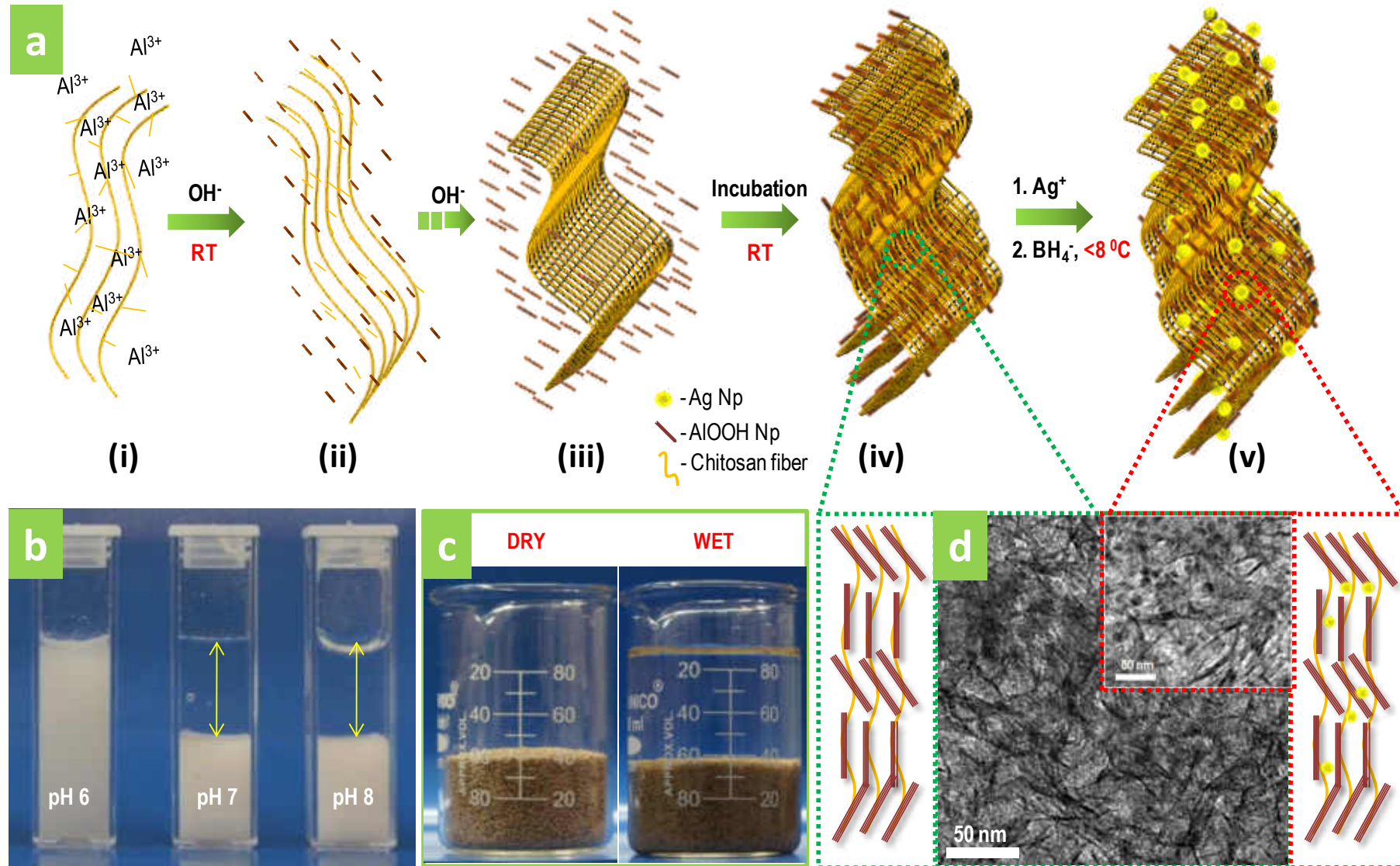
Anil Kumar, *et al.*, India (November 21, 2012)

Introduction: The need for affordable, all-inclusive drinking water purification systems without electricity is a global challenge. The critical problem in the synthesis of stable materials that can reliably function in the presence of complex species in drinking water that deposit and cause scaling on surfaces. Here we show that such composites can be synthesized in a simple and effective fashion without the use of electrical power. The nanocomposites exhibit sand-like properties, such as higher shear strength and stability. These materials have been used in a water purifier to deliver clean drinking water. The ability to prepare nanostructures at ambient temperature has wide relevance for water purification.

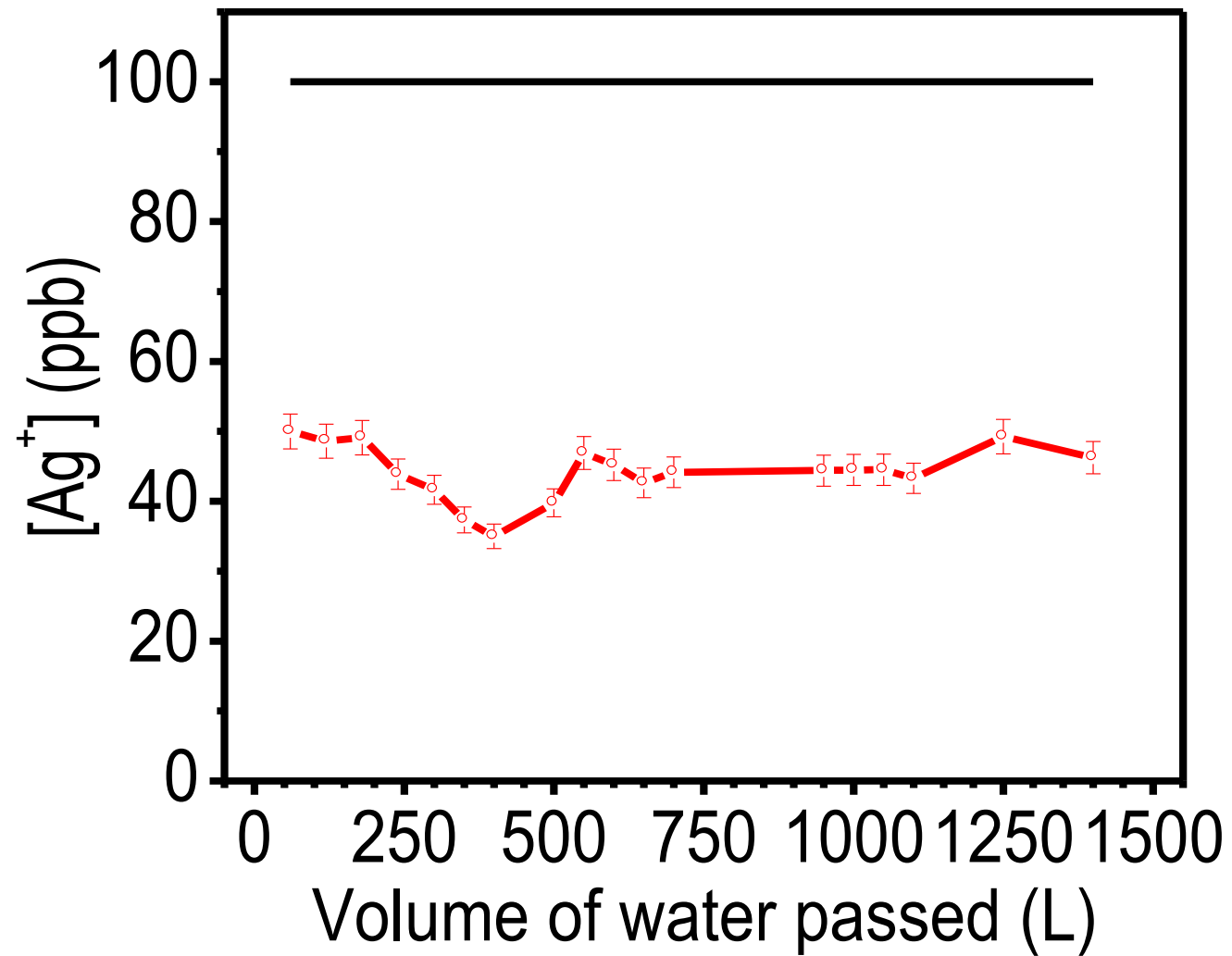
Discussion: The nanocomposites exhibit sand-like properties, such as higher shear strength and stability. These materials have been used in a water purifier to deliver clean drinking water. The ability to prepare nanostructures at ambient temperature has wide relevance for water purification.

M. Udhaya Sankar, et. al. *Proc. Natl. Acad. Sci.*, 110 (2013) 8459-8464.

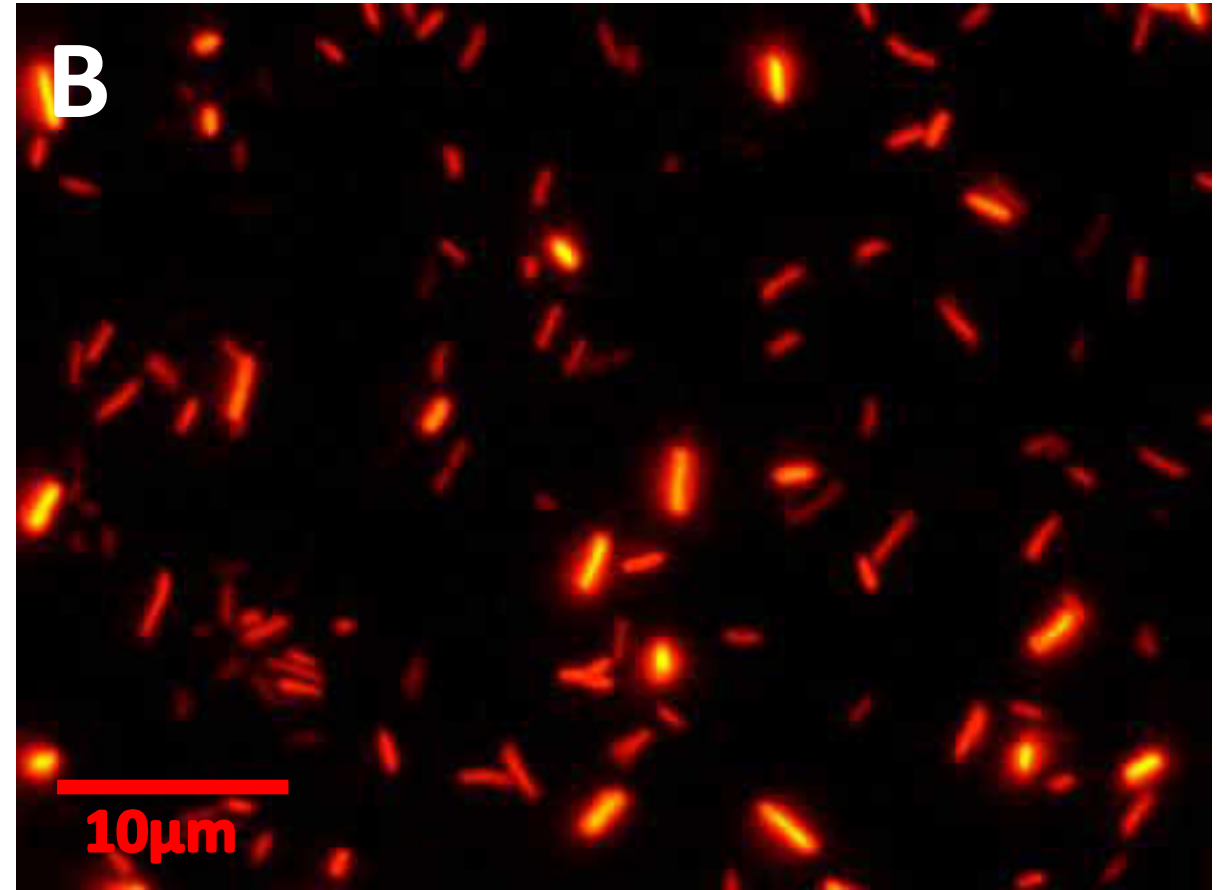
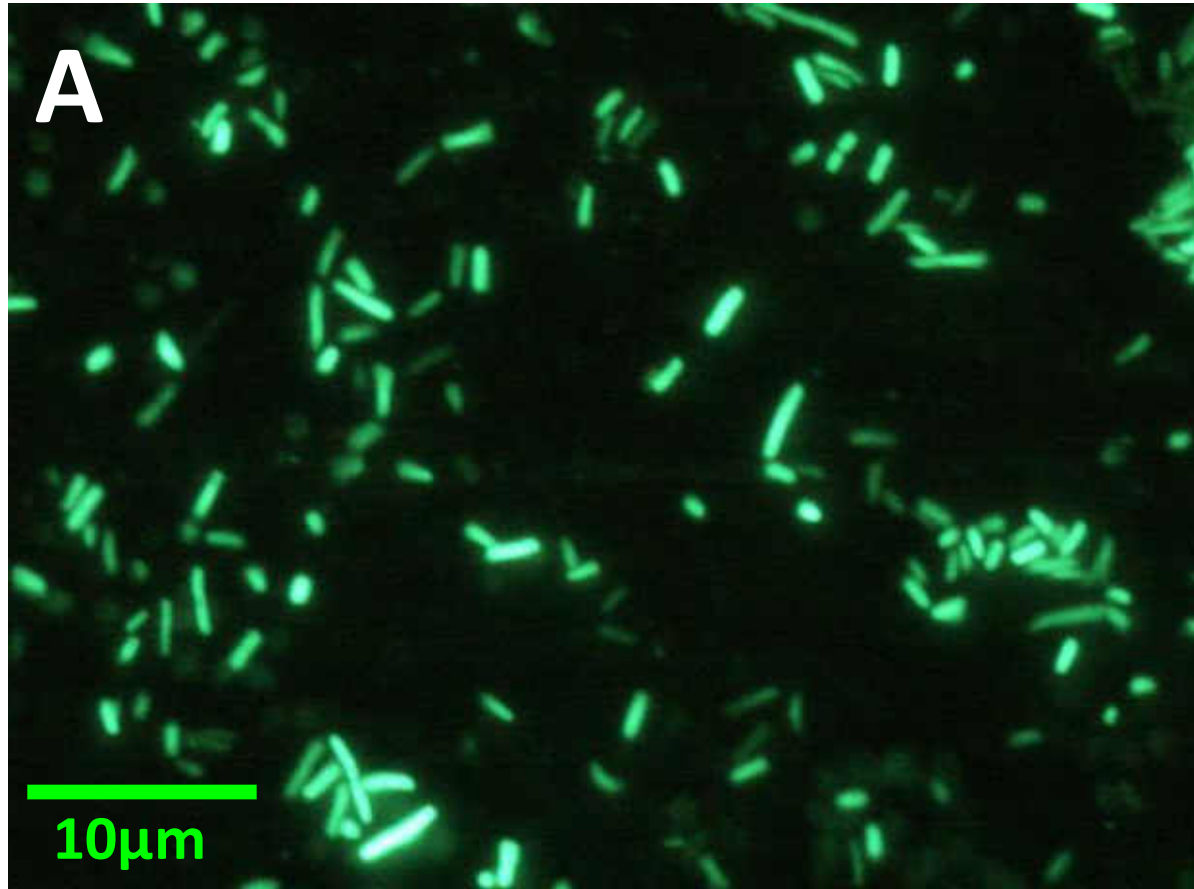
How to make?



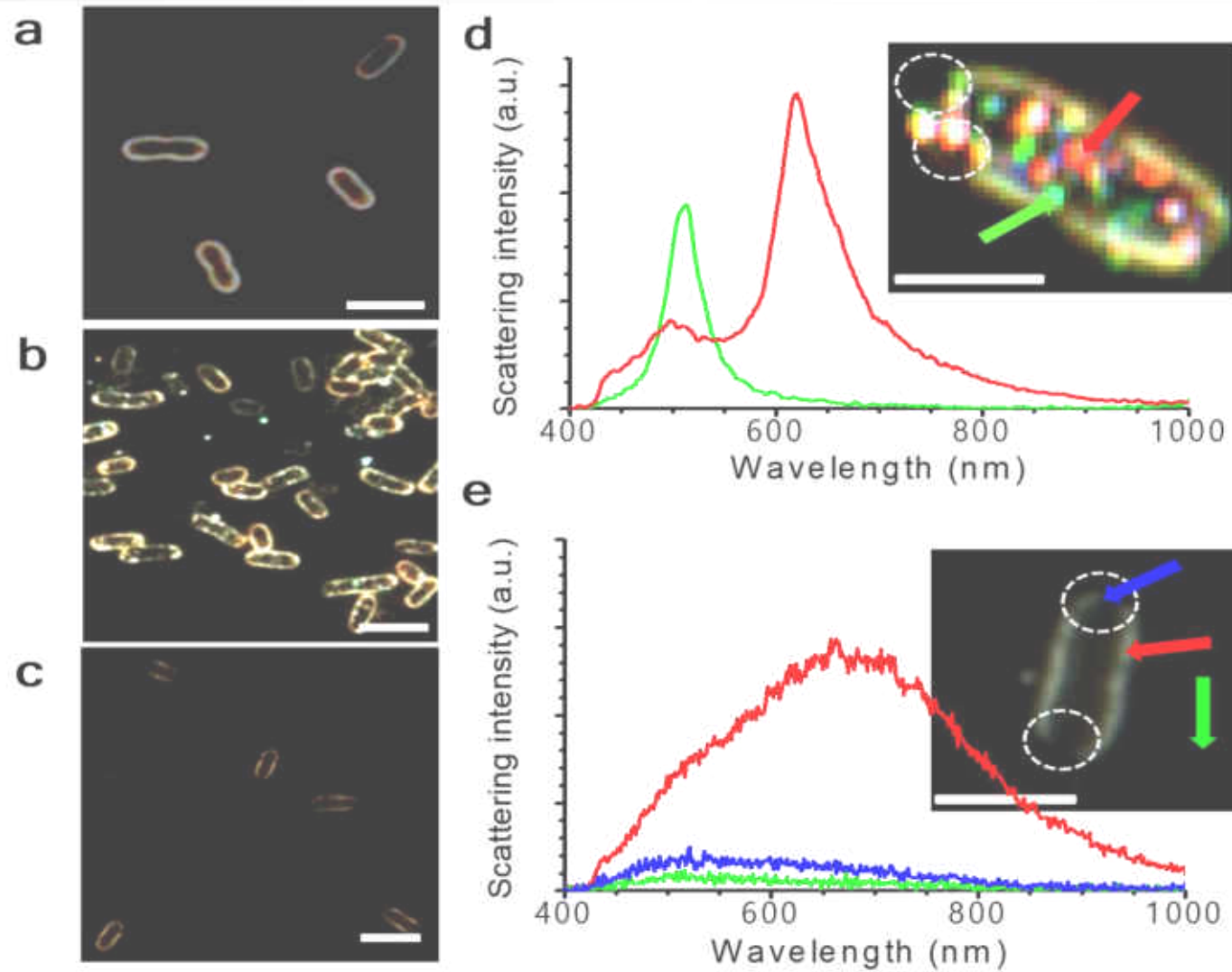
What is special?



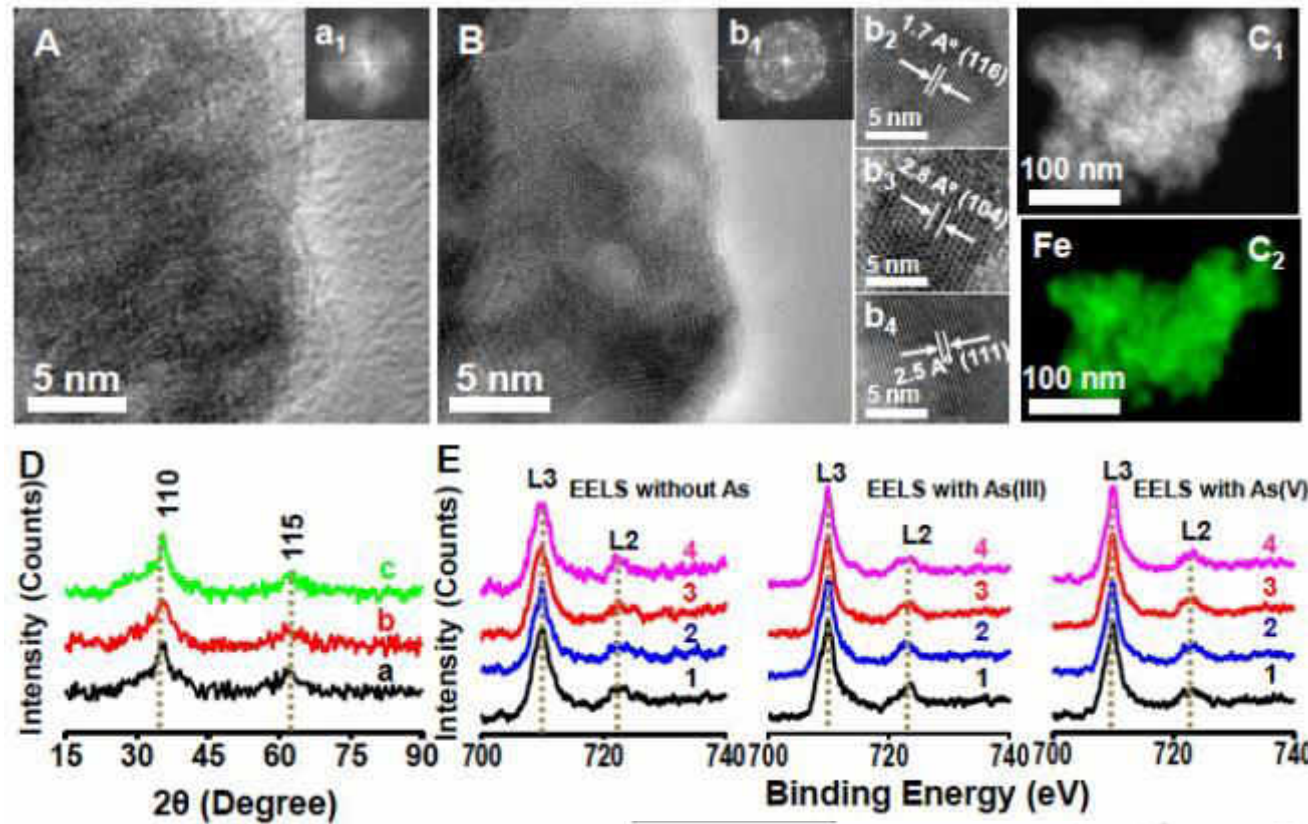
Live/dead staining experiments



No nanotoxicity



Variety of materials



www.advmat.de

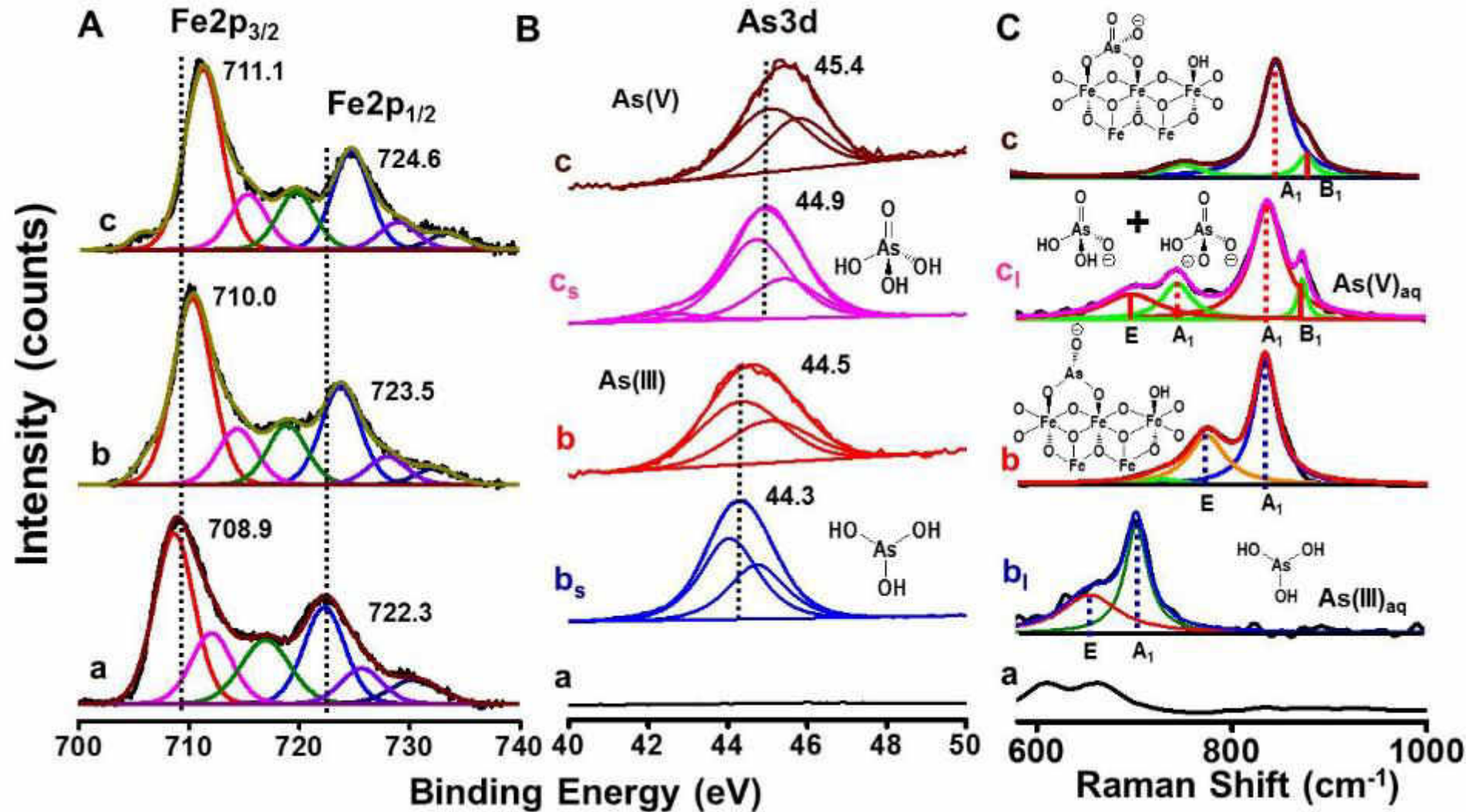
Author Pr ADVANCED MATERIALS

Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

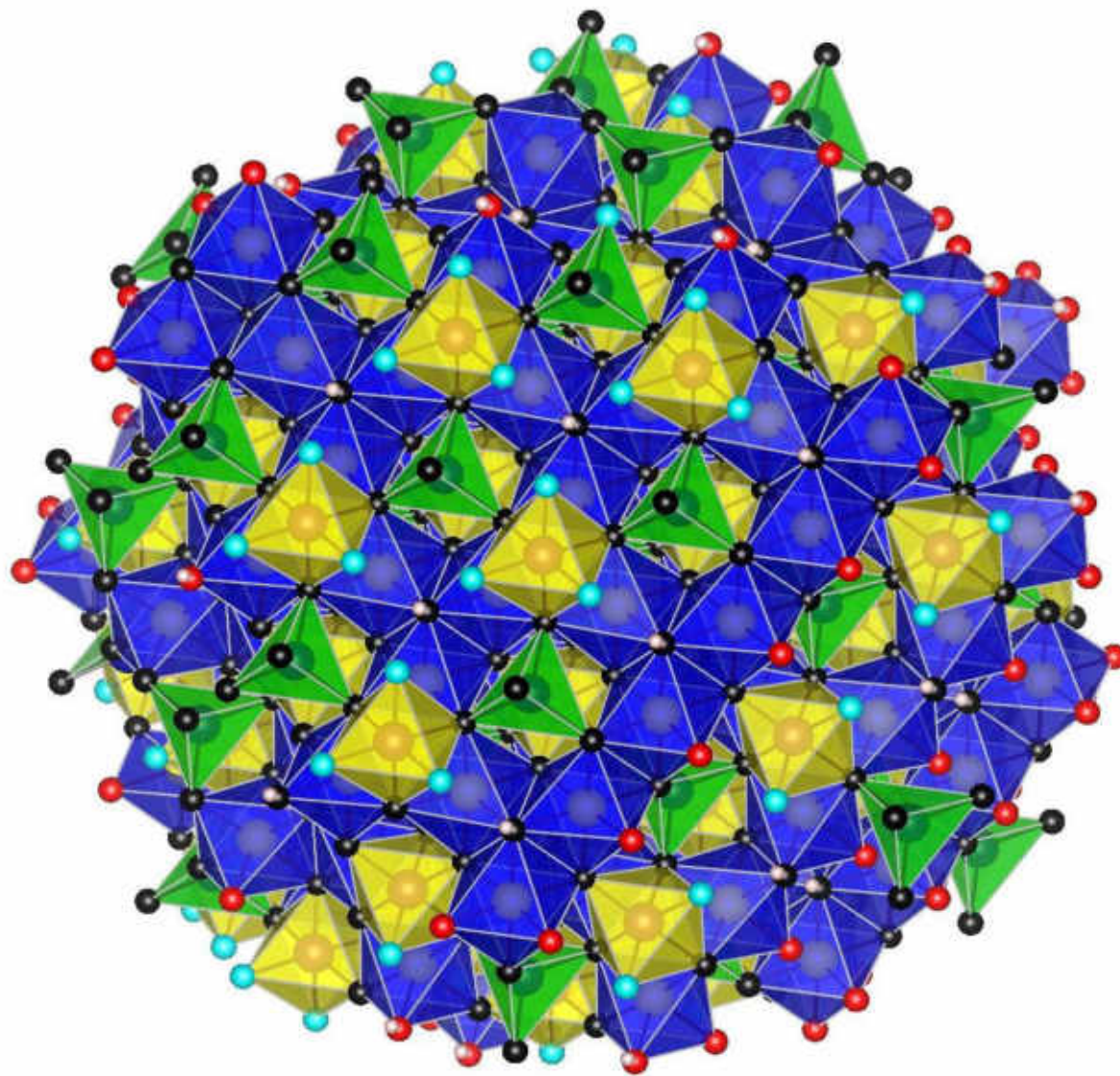
By Avula Anil Kumar, Anirban Som, Paolo Longo, Chennu Sudhakar, Radha Gobinda Bhui, Soujit Sen Gupta, Anshup, Mohan Udhaya Sankar, Amrita Chaudhary, Ramesh Kumar, and T. Pradeep*

Communication

Mechanism – molecular tools

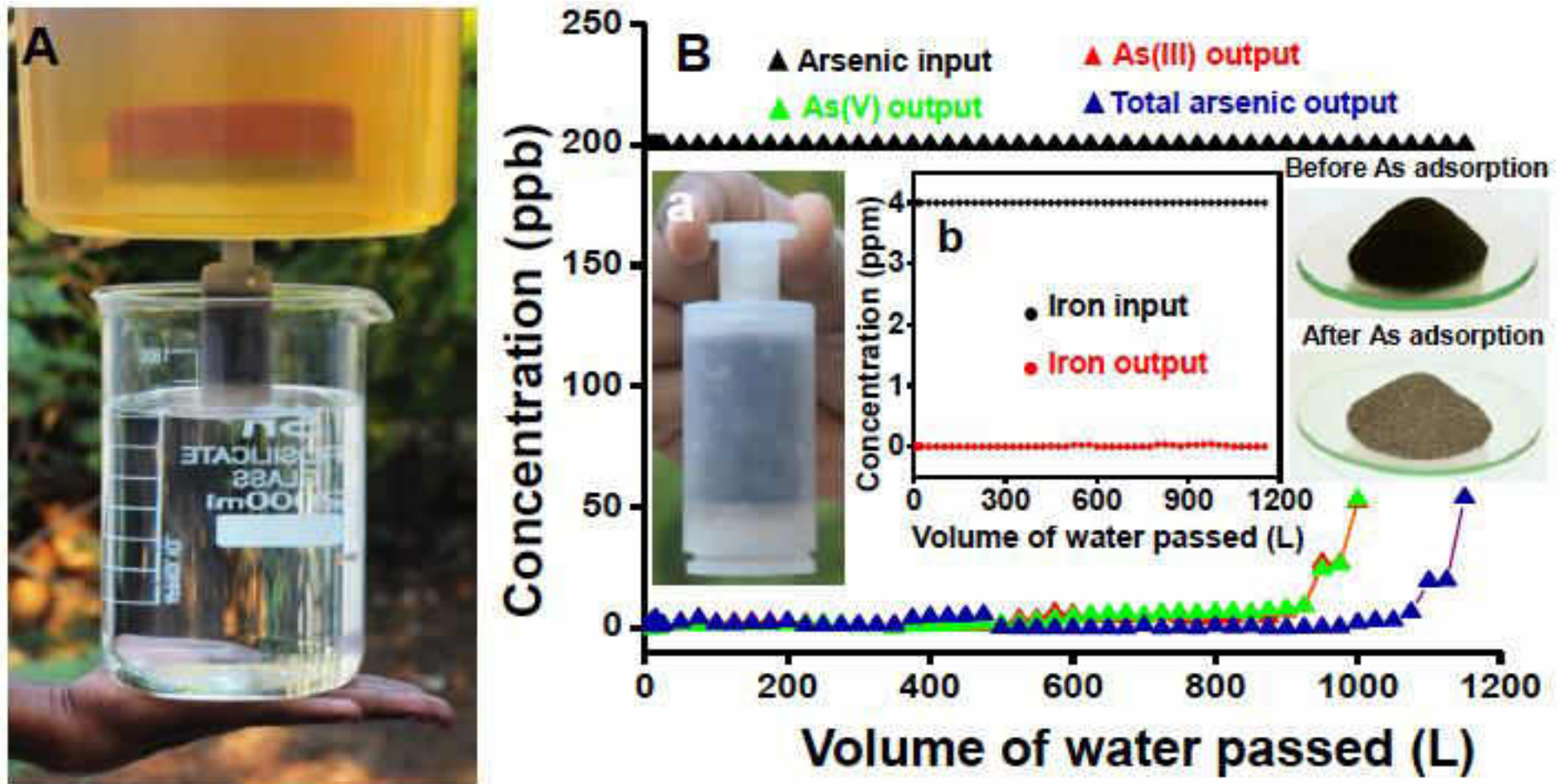


Modeling surfaces



Chennu Sudhakar, et al. *ACS Sustainable Chemistry & Engineering*, 6 (2018) 9990-10000.

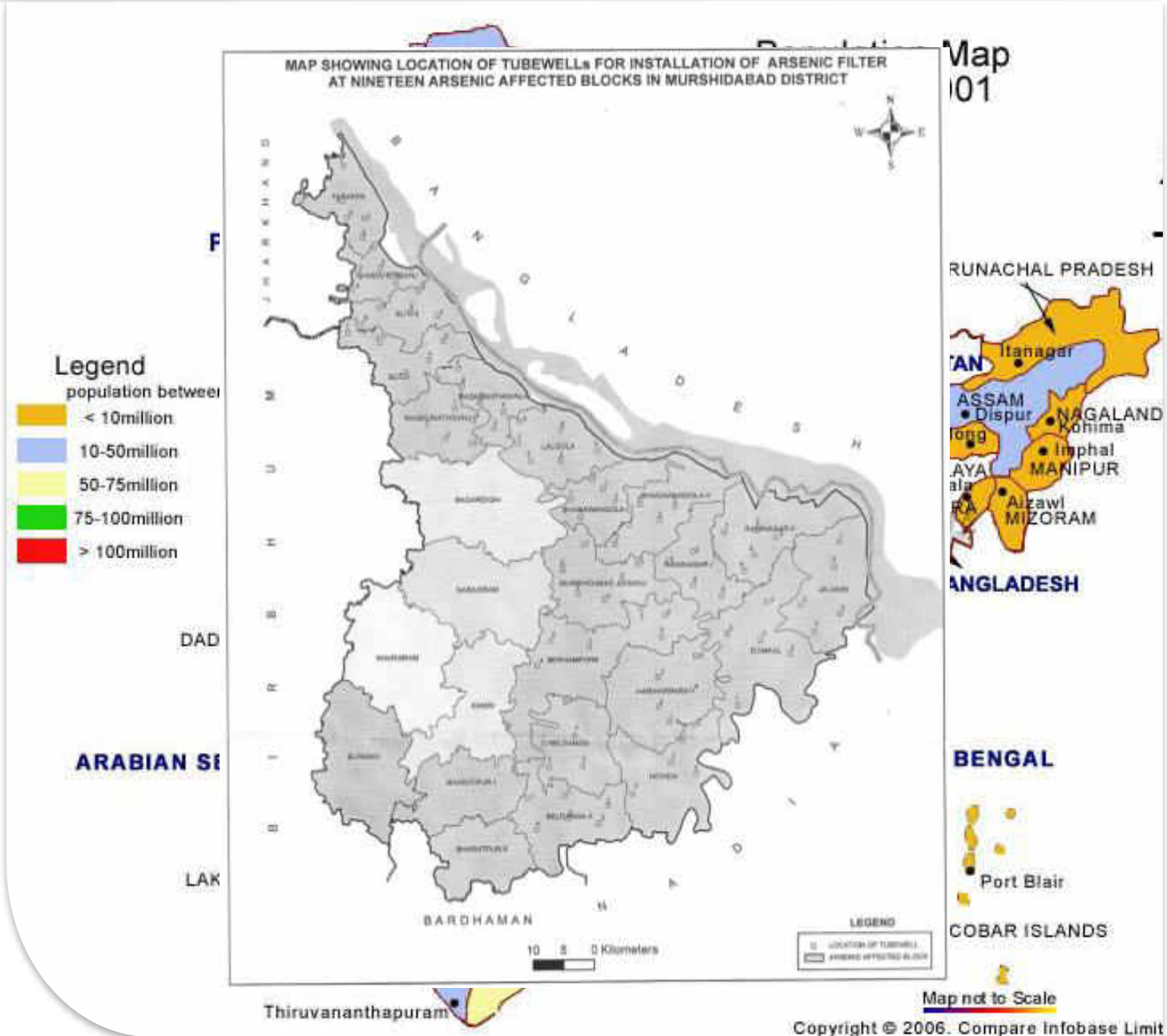
Lab studies



Initial pilot studies



Larger pilot studies



Changing the dynamics in the field



Existing plant in 40 cents

- Existing unit for iron and arsenic removal – 20 m³/h
- Uses activated alumina and iron oxide (old generation of adsorbents)



New plant in 3 cents

- Existing unit for iron and arsenic removal – 18 m³/h
- Uses iron oxyhydroxide (new generation of adsorbents)
- Input arsenic concentration: 168 ppb
- Output arsenic concentration: 2 ppb

Completed 3 years maintenance (stipulated: 2 years)
for 330 bamboo unit project in Nadia, WB



স্বপ্নলাল
- 03471-250221
ফোন-03471-
লক্স-03471-

Minimum uptime: 91%, Maximum: 98%
Only 4/330 have reported arsenic above 10 ppb
Benefiting over 100,000 children and villagers

Glimpse of Installed units (330 nos)

Implementation - From 25 KLD to 1 MLD



**Large water supply schemes
Capacity: above 1 MLD**

5 schemes in use across India



**Retrofitted Water Purification Plant
Capacity: 0.1-1 MLD**

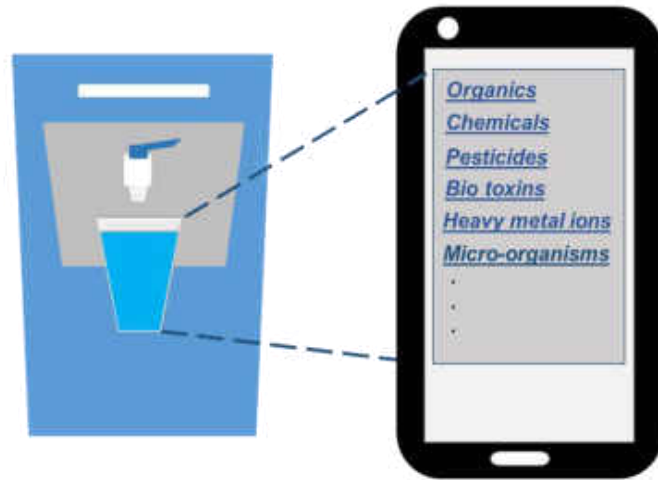
Over 180 units in use across India

Clean water at 2.1 paise per litre!

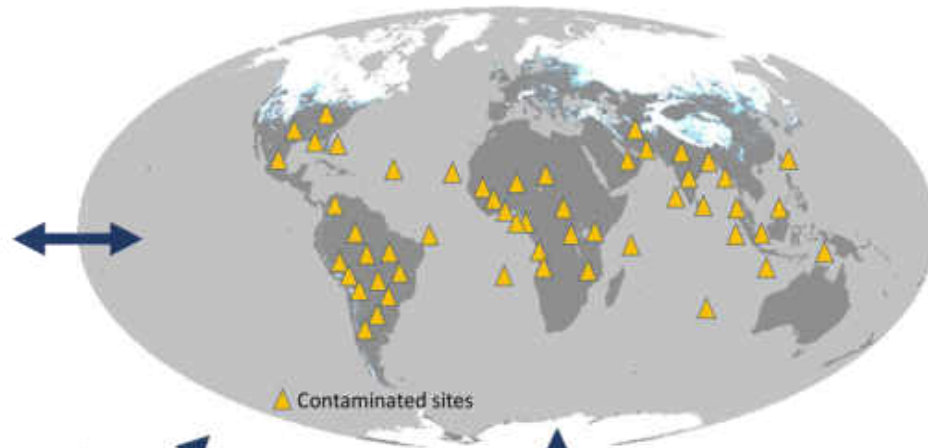
Calculation for the Tariff to be collected for treated water (Revision if Required)			
	Design population	1,071	Plant capacity/70 LPCD
Sr.No.	Item/Description	Cost / Quantity	Remarks
1	Cost of Replacement of Iron removal media	56400	After minimum two years if Iron concentration is more than 5 ppm. But iron concentration is more than 5 ppm at only two to three places. Therefore media may work for 3 years also.
2	Cost of Replacement of Arsenic removal media	978660	After minimum two years if Arsenic concentration is more than 100 ppb. But arsenic concentration is more than 100 ppb at only two to three places. Therefore media may work for 3 years also.
3	Cost of replacement of Activated Carbon	28560	
4	Total cost of Replacement of media	1063620	After minimum two years.
5	Total cost of Replacement of media for one year	531810	
6	Plant capacity	75000	ltr per day
7	Design population	1,071	Plant capacity/70 LPCD
8	Cost per liter of water	2.1 Paise per ltr	0.025 cents
9	Cost of replacement of media	1.36	Rs. per head per day =Media replacement cost per year/365/Design population
		<u>40.80</u>	per head per month for 70 LPCD water

Smart water purifiers and big data

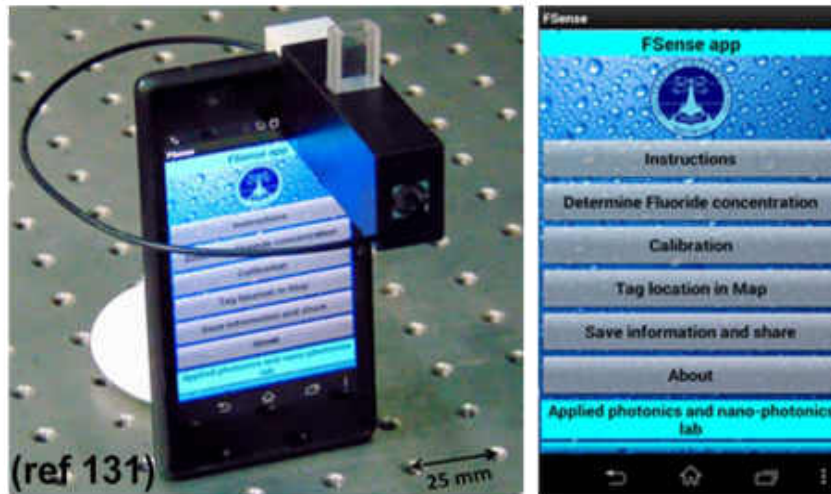
Smart Water Purifiers linked to IoT



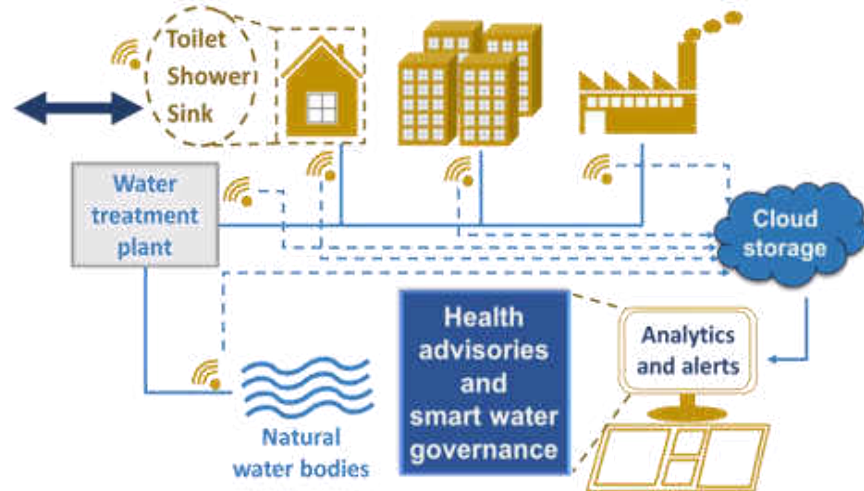
Global Map of Water Health



Cost-effective sensor accessory for point-of-use applications



IoT-enabled sensing for households and distribution networks



Waste management

- Adsorbents conform to toxicity characteristic leaching procedure
- Elemental waste goes back to local environment
- Safe disposal of arsenic (or any other) laden waste
- Additional protection could be considered, if necessary
- Exploring viable uses

Now they are across the country



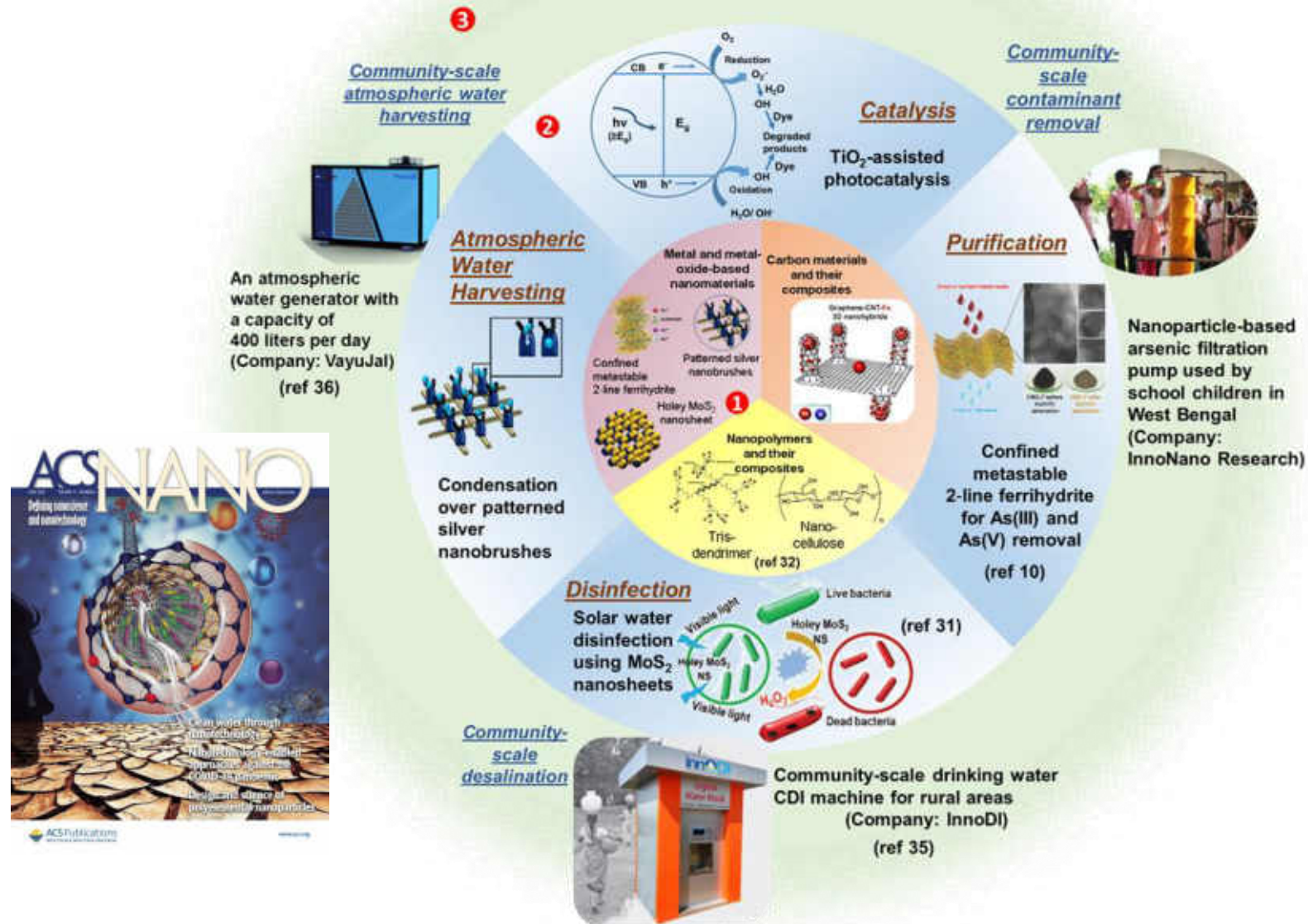
Components of IoT architecture implemented by DWSS, GoP



Typical IoT architecture comprises various sensors and meters, communication gateway, Cloud Server, SMS gateway, Webservices and mobile phone application for operator



Evolution of materials to products



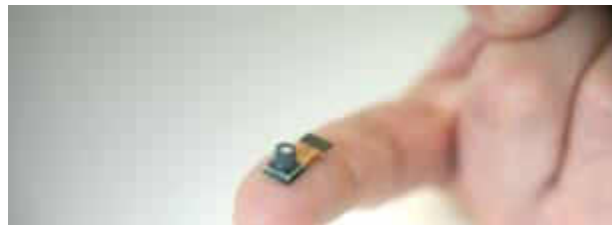
Sensors and new opportunities



Analog/Grating
Equipment
\$ 5~6 Billion (2017)
a few **100k units** (2017)



**Ultra compact Low Cost
Spectral Sensor Module
~ Billions units (? 2027)**

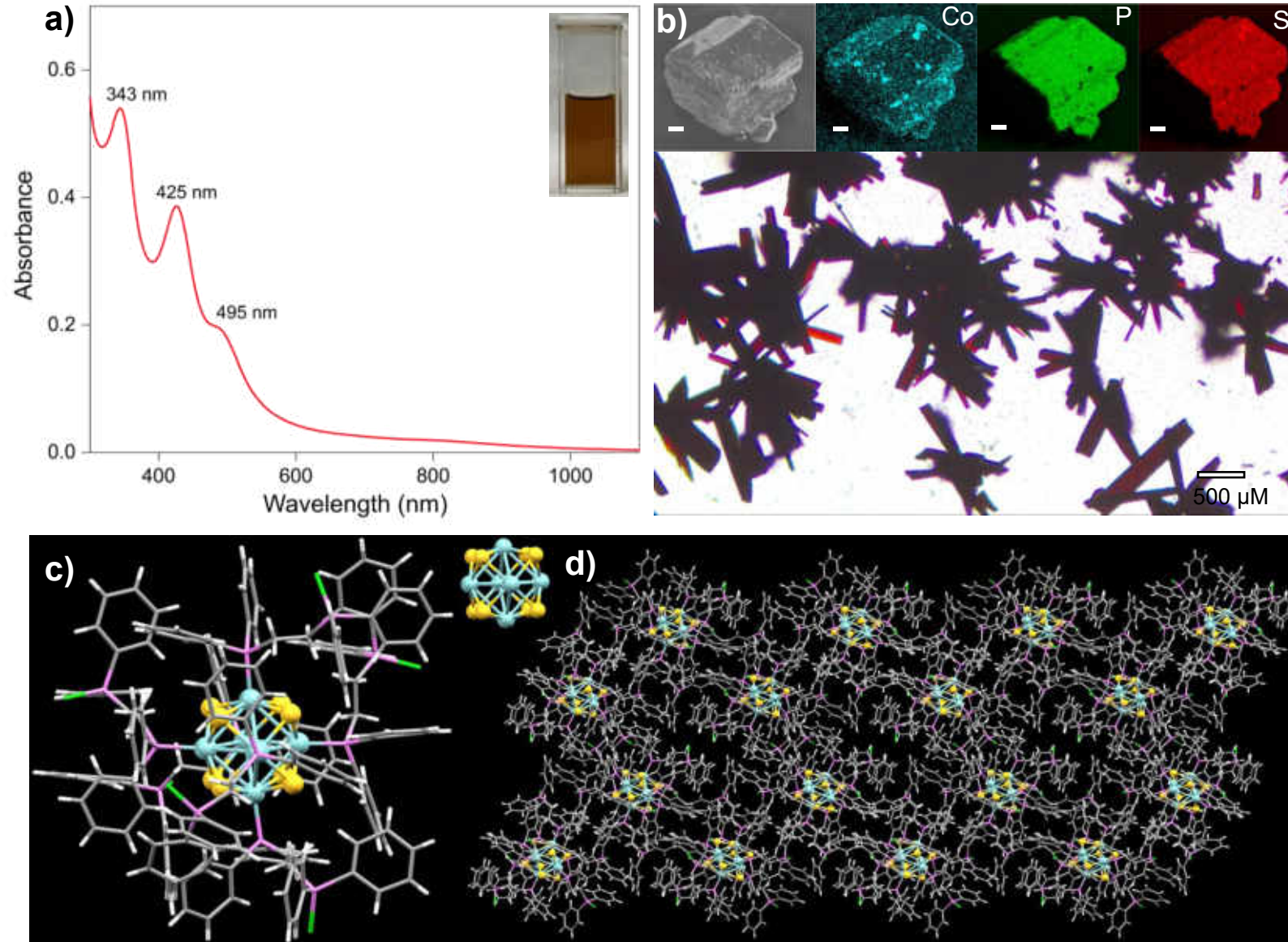


Water quality measurement – In the pipeline

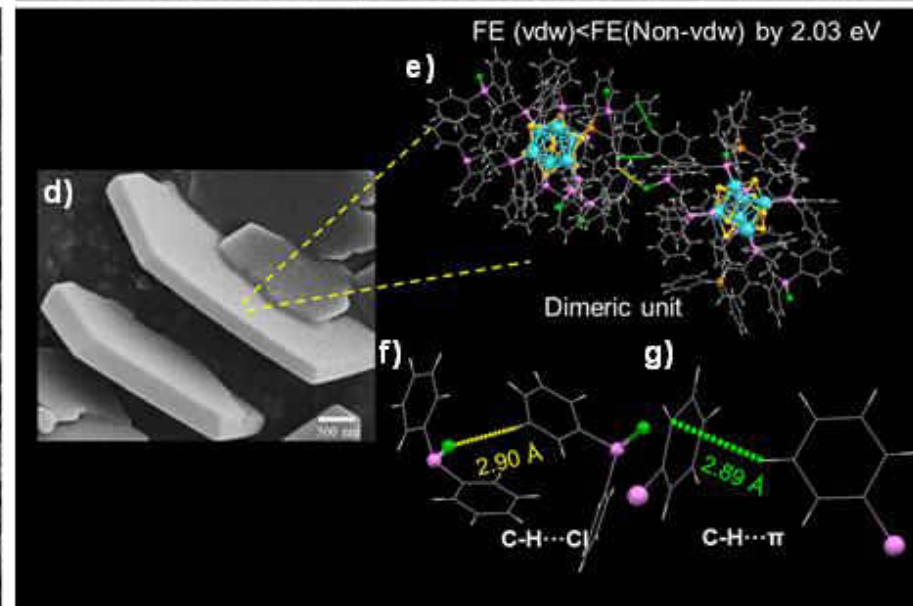
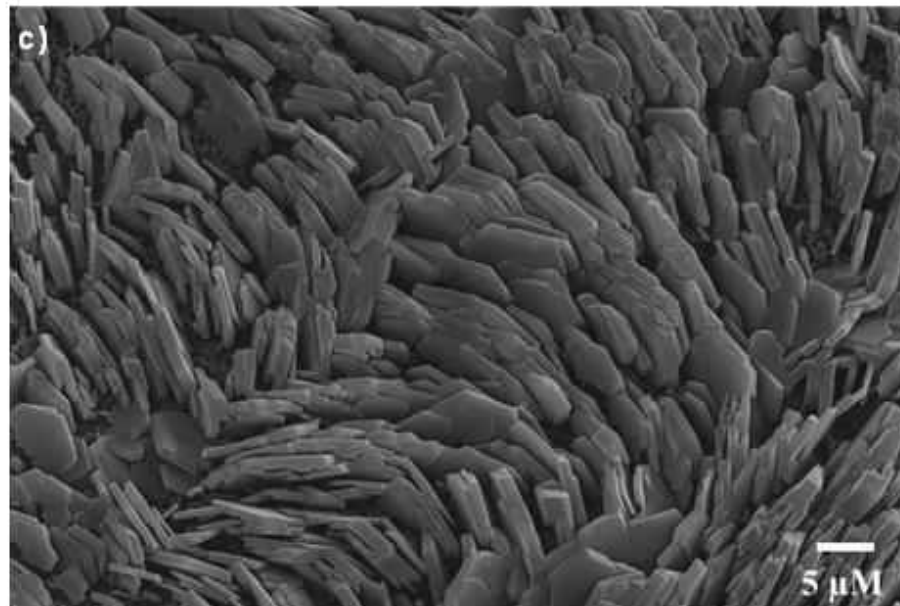
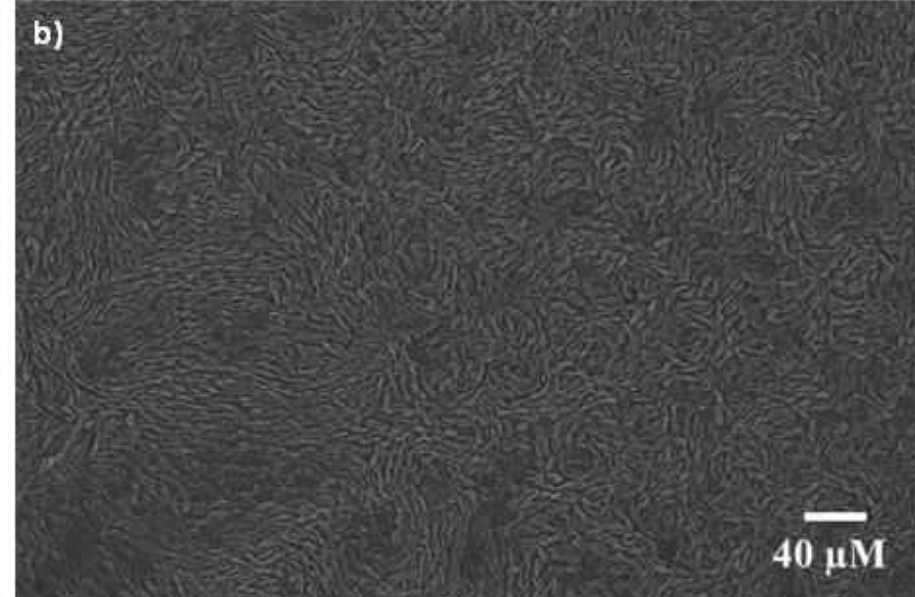
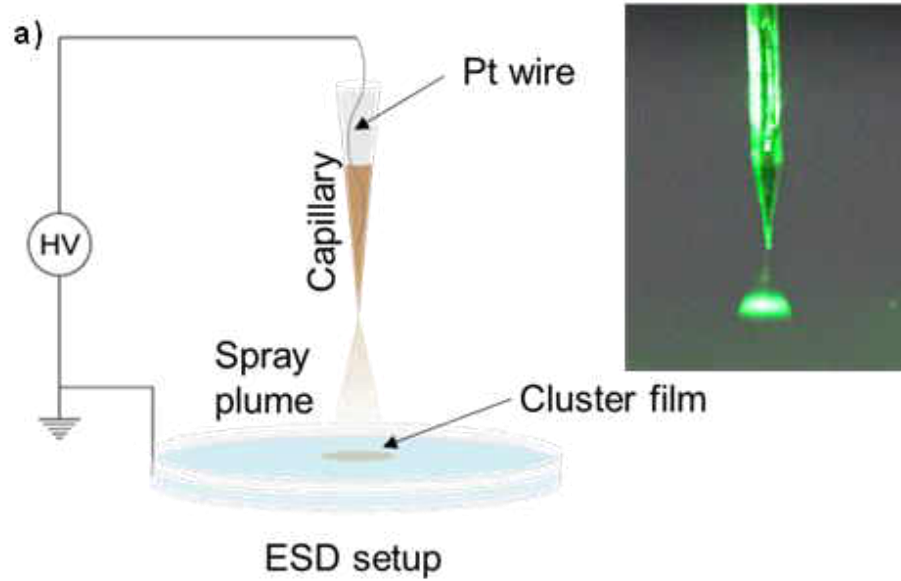
nano λ

New electrodes - Aligned nanoplates of Co_6S_8

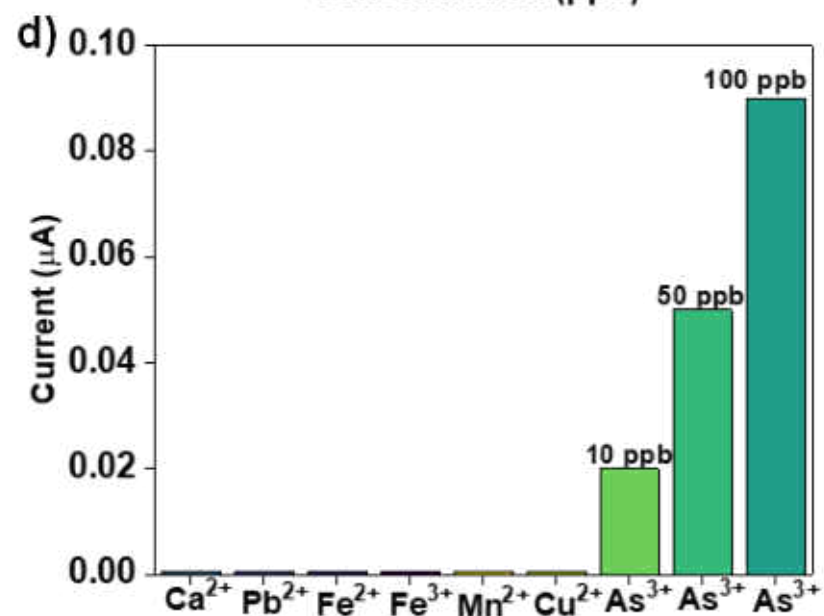
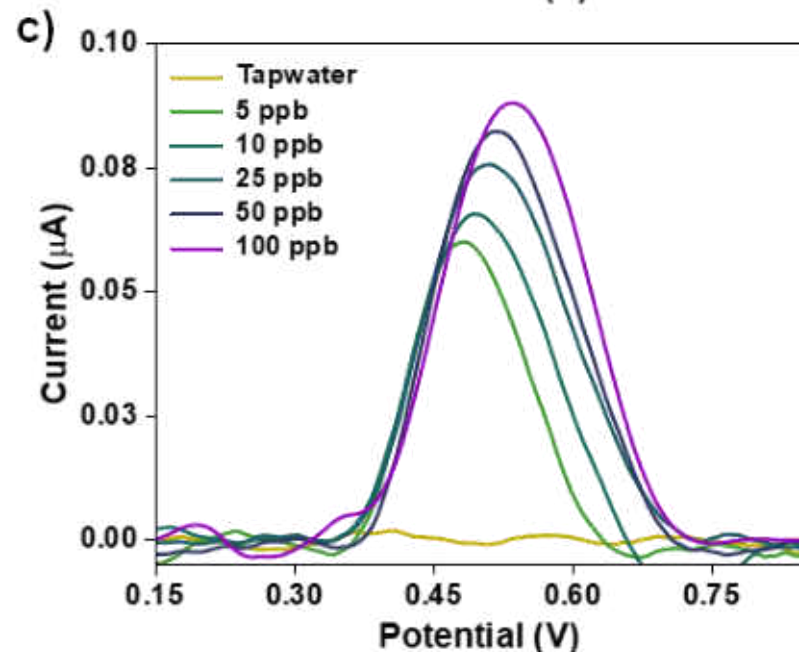
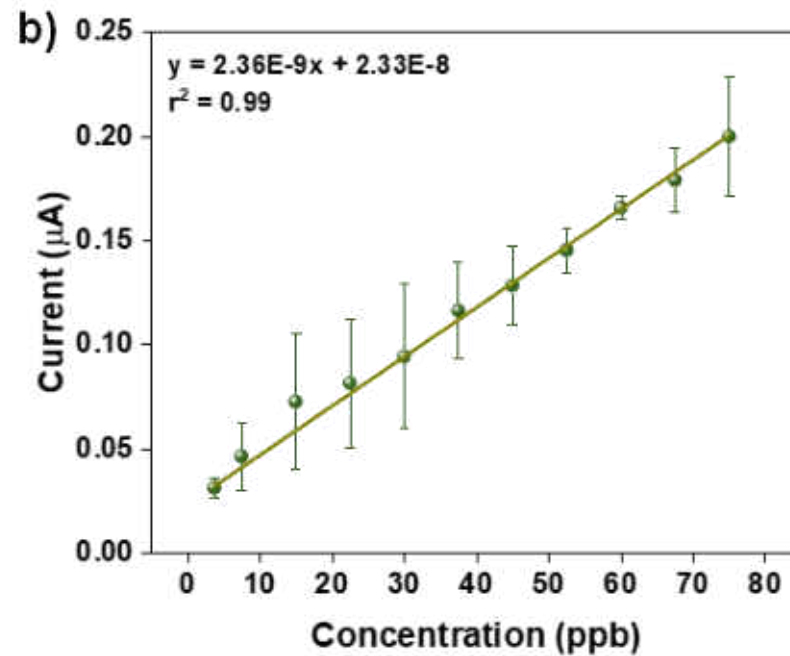
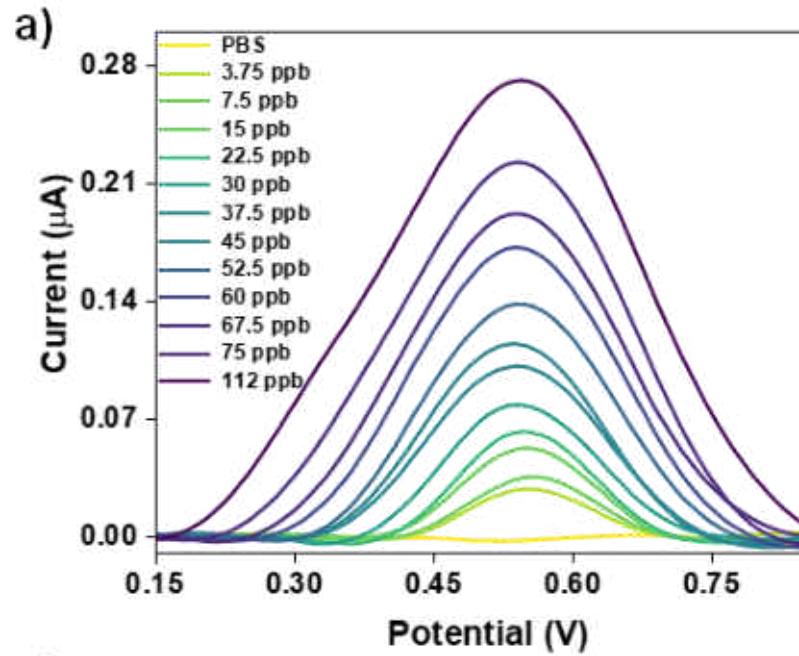
1,2-bis(diphenylphosphino)ethane (DPPE)



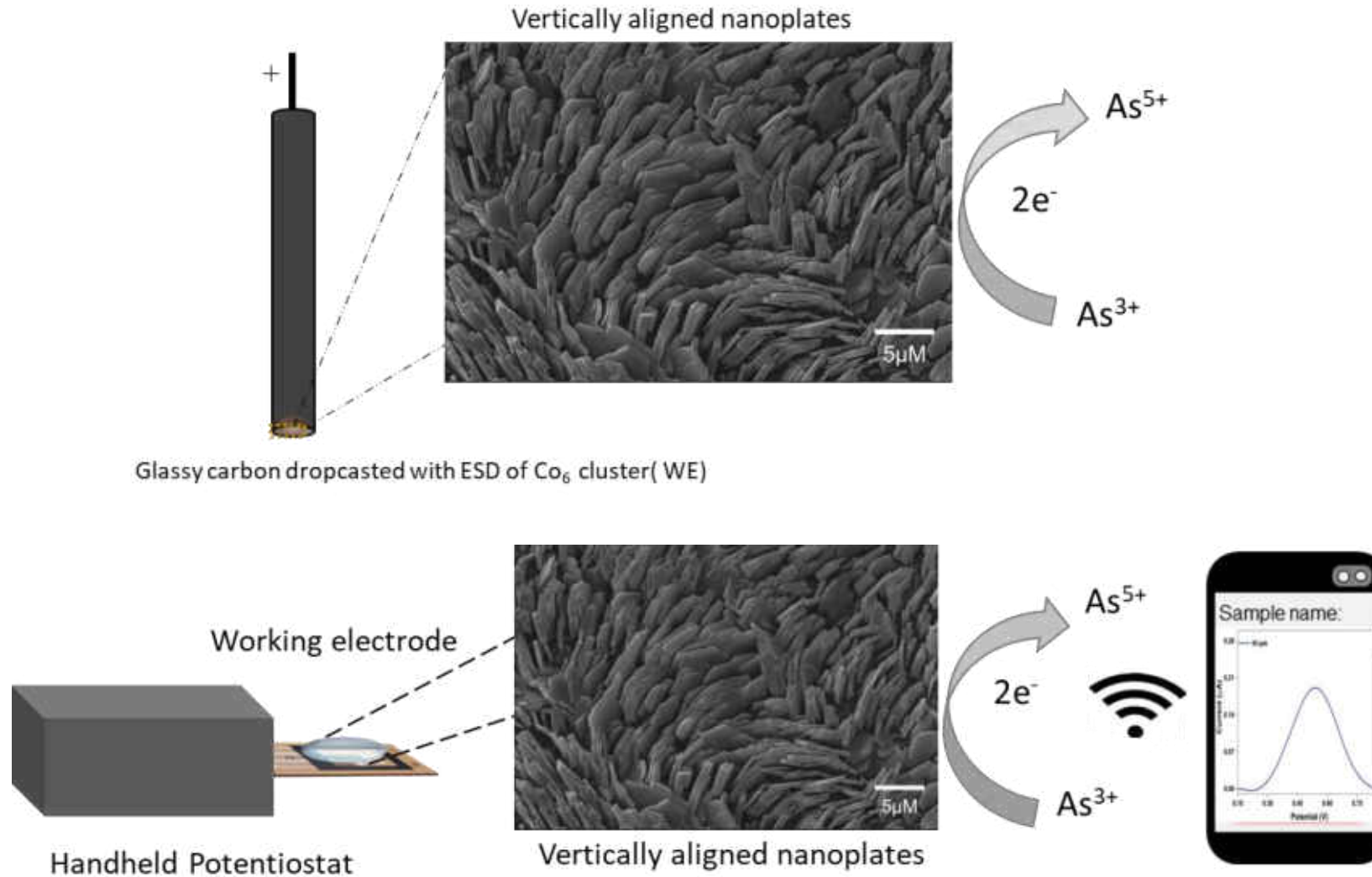
Electrospray deposition



Sensing



Working electrode



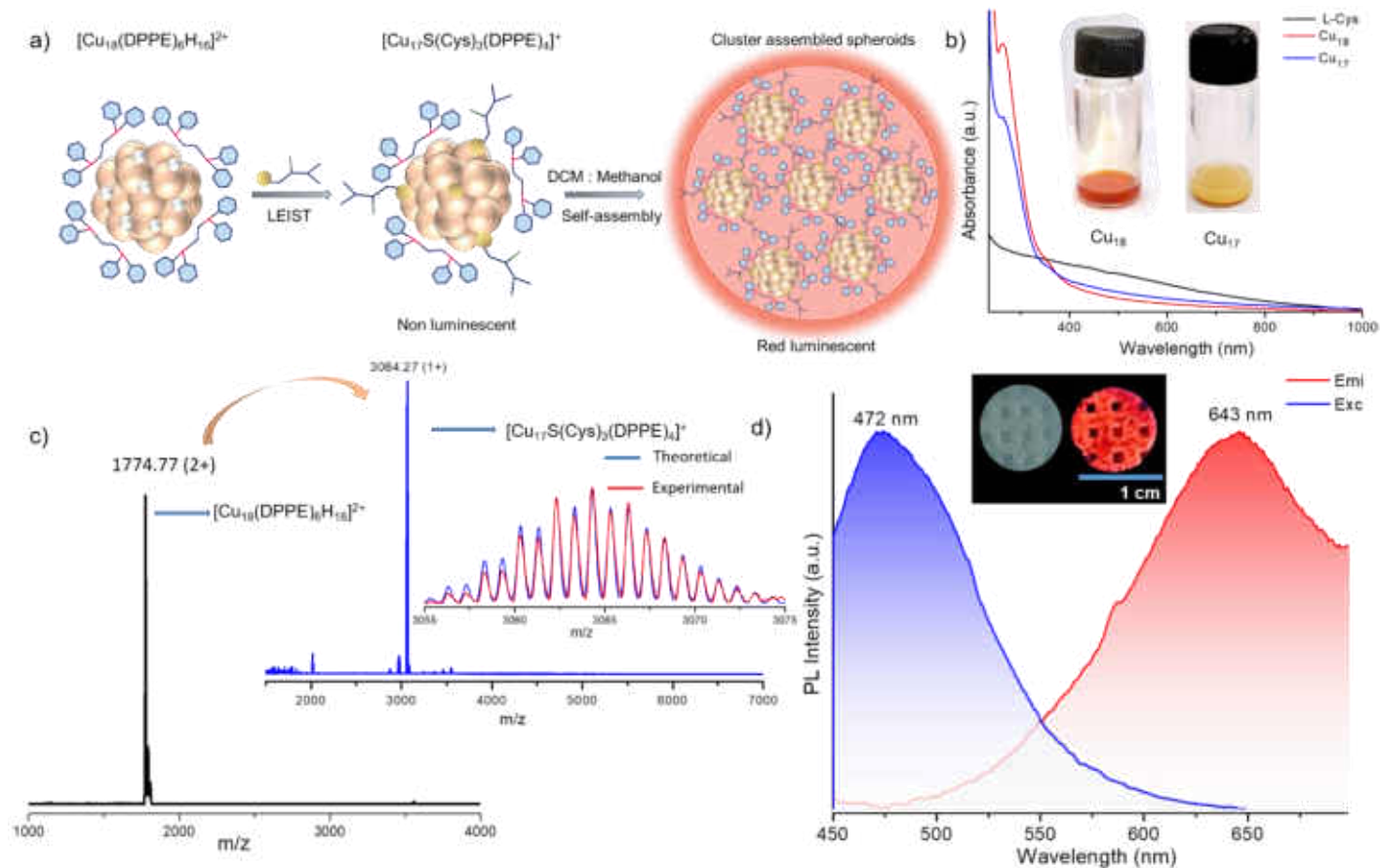
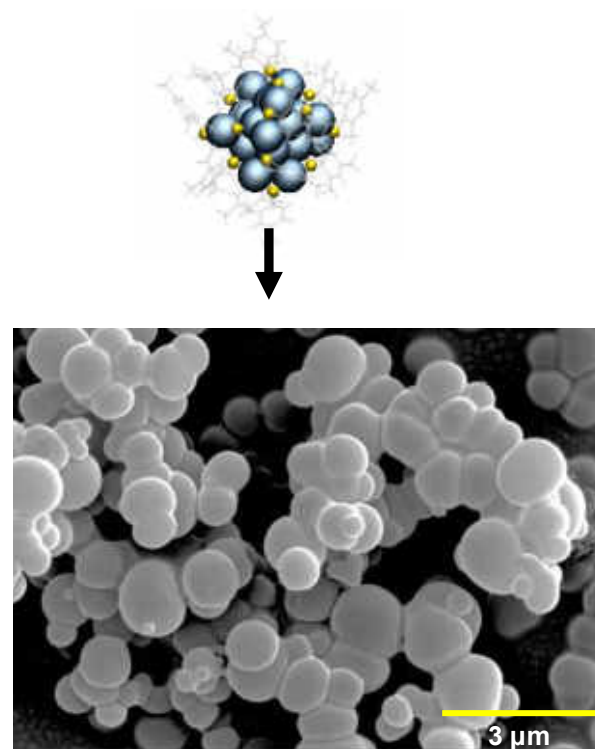
Anagha Jose et al. *ACS Materials Lett.*, 5 (2023) 893–899.

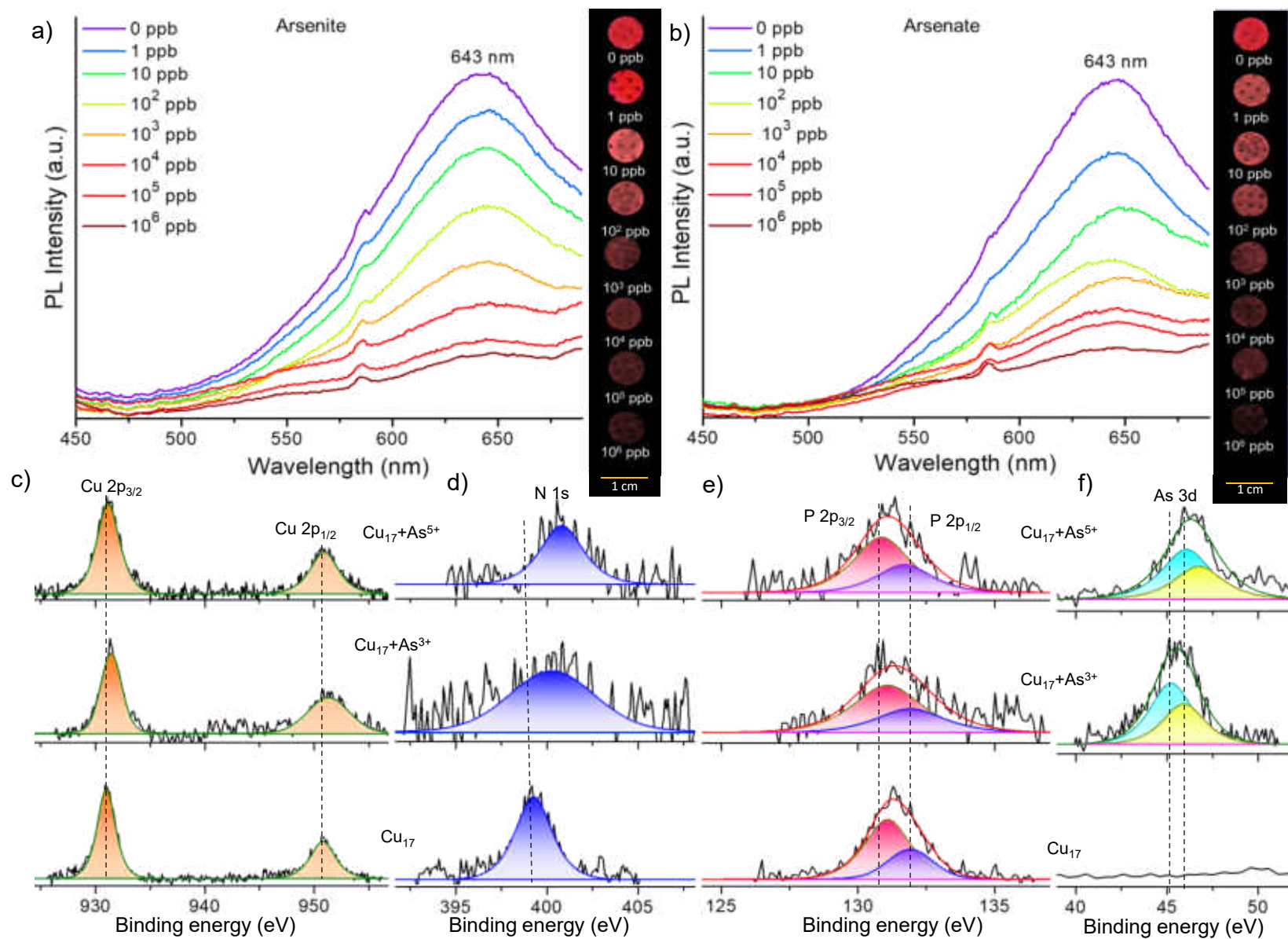
Cysteine-Protected Antibacterial Spheroids of Atomically Precise Copper Clusters for Direct and Affordable Arsenic Detection from Drinking Water

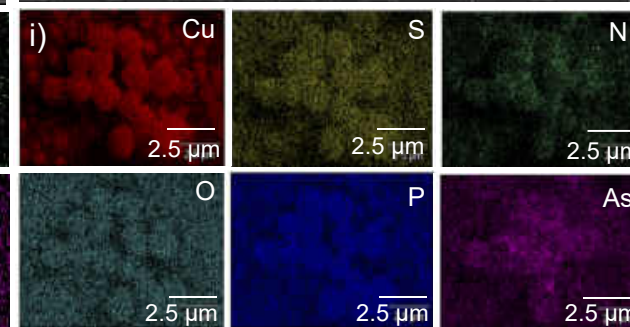
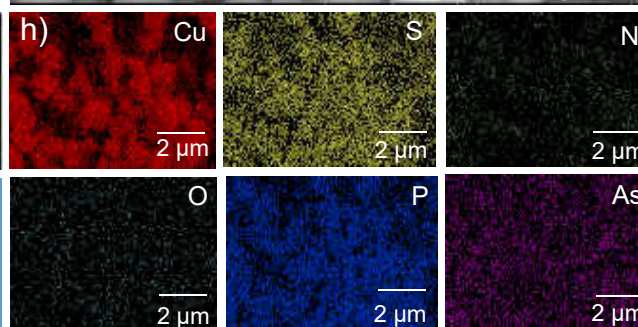
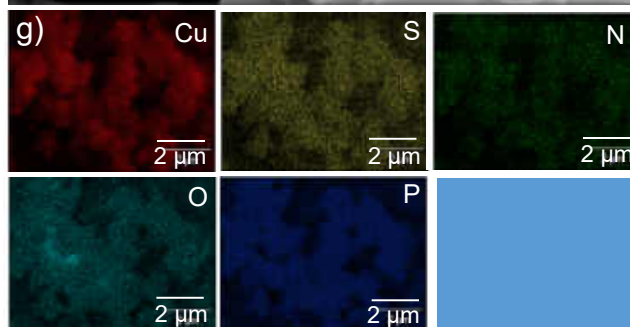
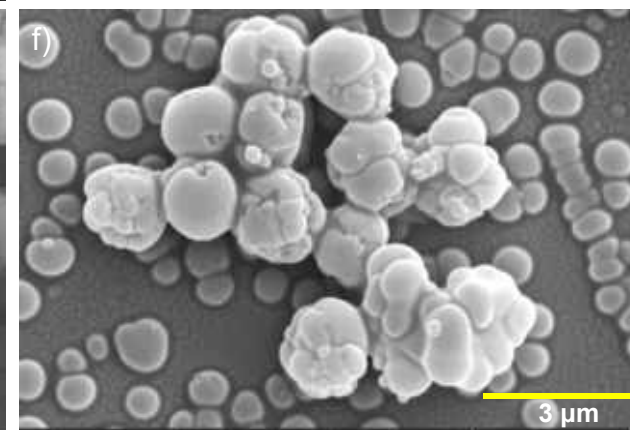
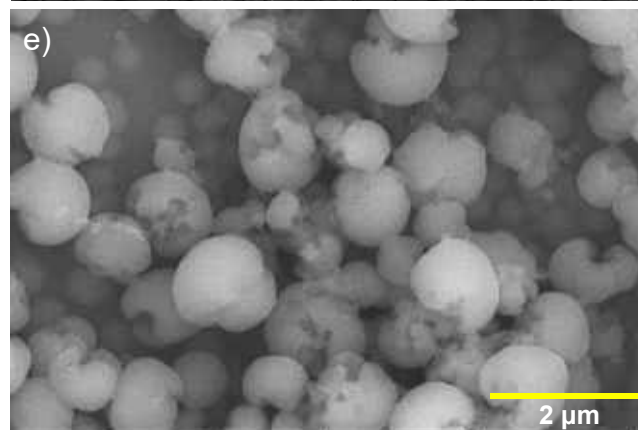
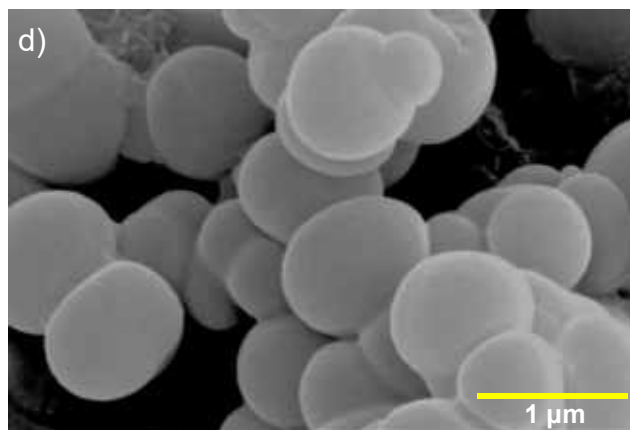
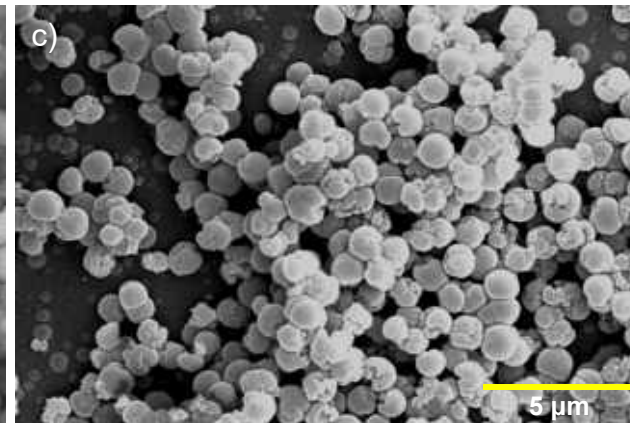
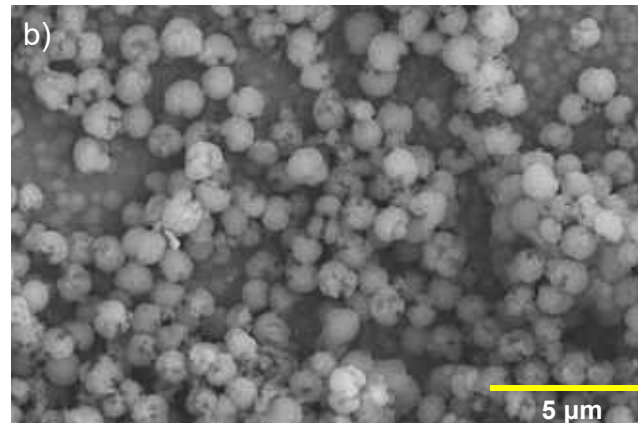
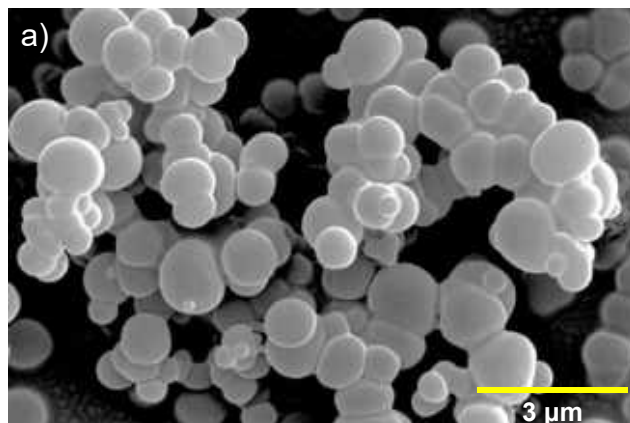
Jenifer Shantha Kumar, Arijit Jana, Jayathraa Raman, Hema Madhuri Veera, Amoghavarsha Ramachandra Kini, Jayoti Roy, Saurav Kanti Jana, Tiju Thomas, and Thalappil Pradeep*

Cite This: <https://doi.org/10.1021/acs.estlett.4c00264>

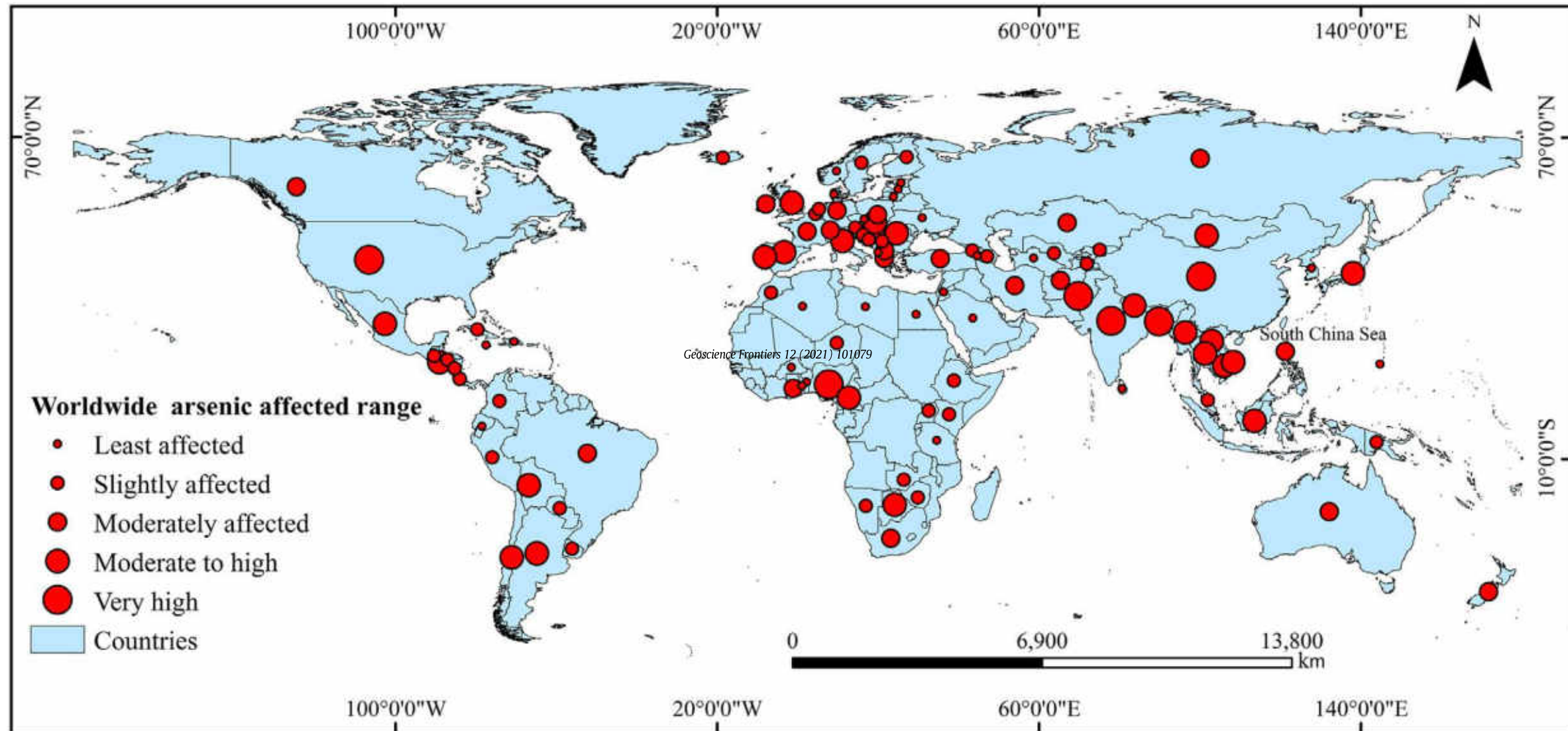
Read Online





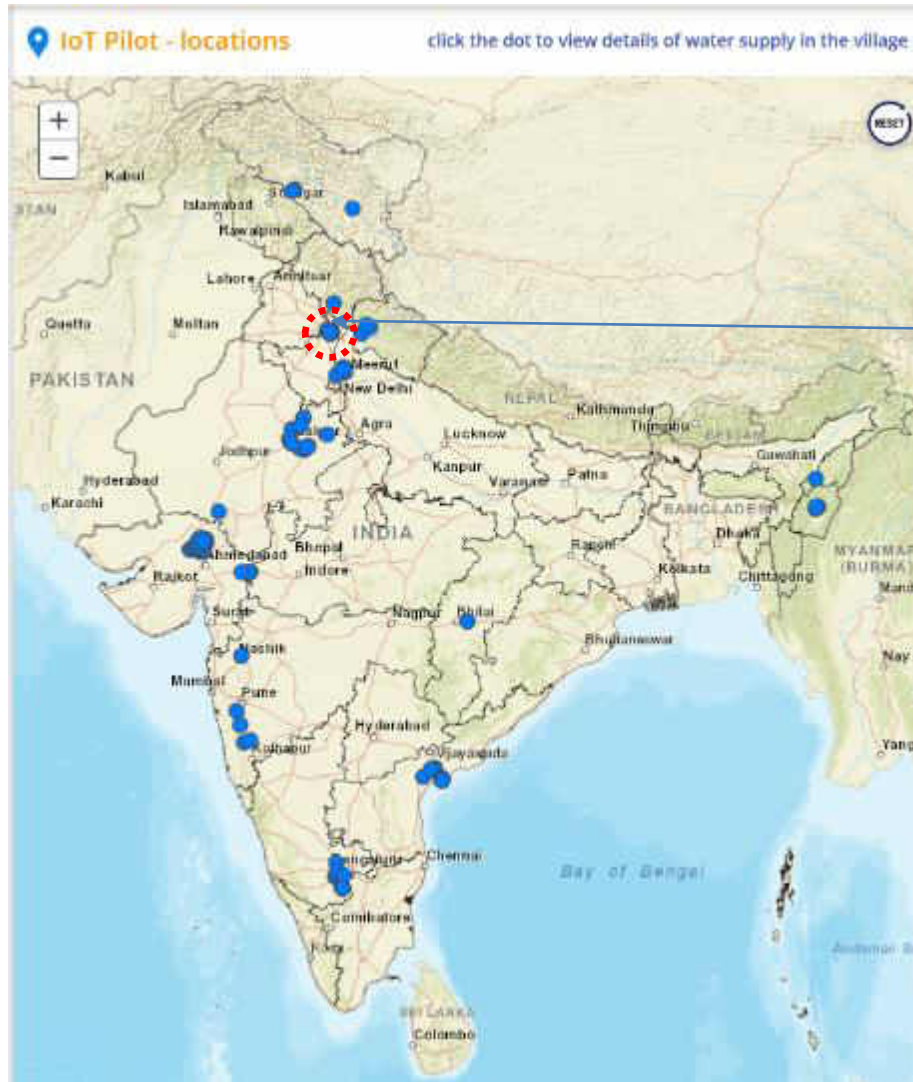


Arsenic poisoning across the world



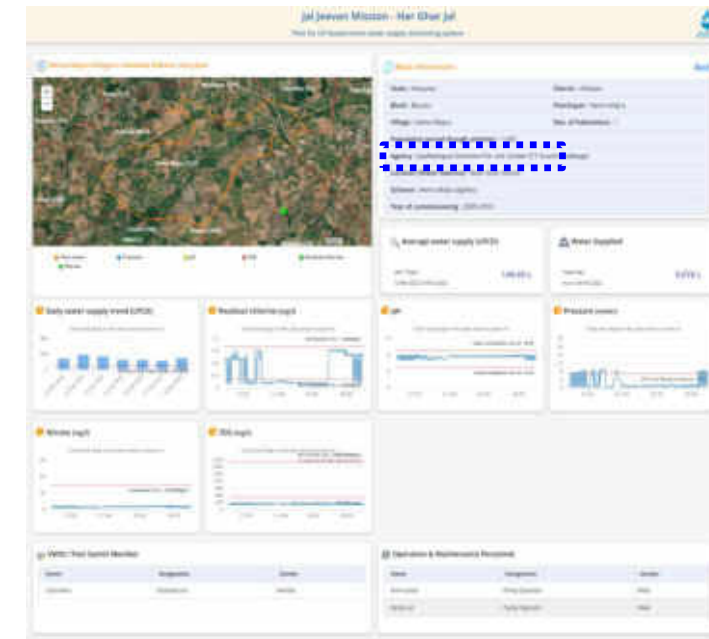


India's water is being monitored



IITM/IISc

Installations made by four companies

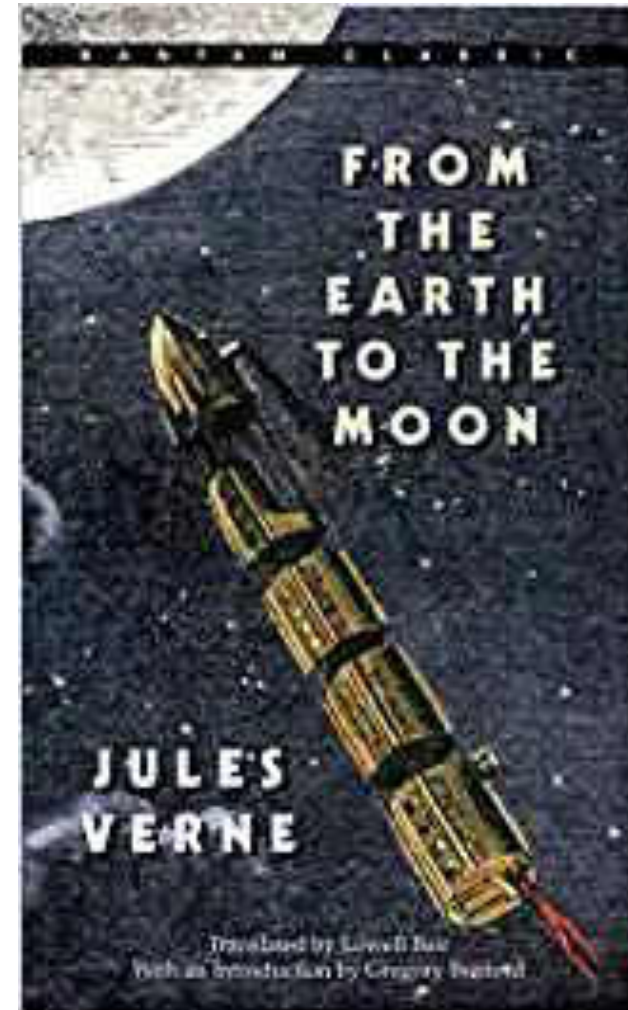
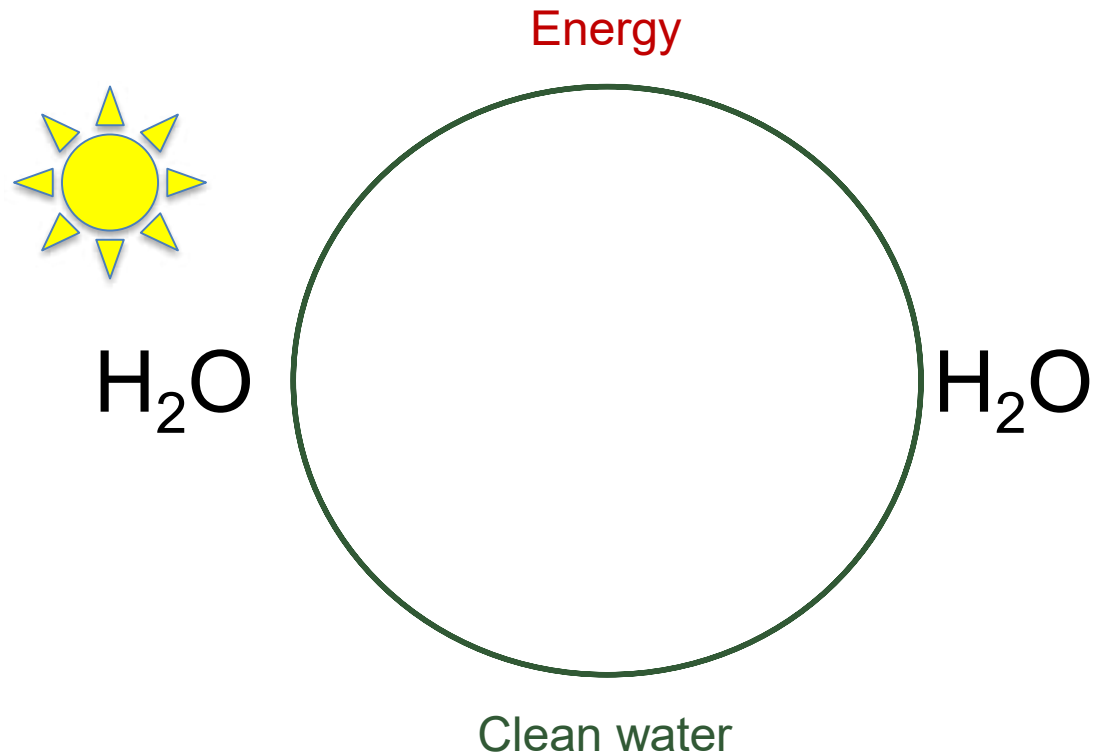






<https://www.youtube.com/watch?v=fiJyptbXBtM>

Our dreams become reality with materials

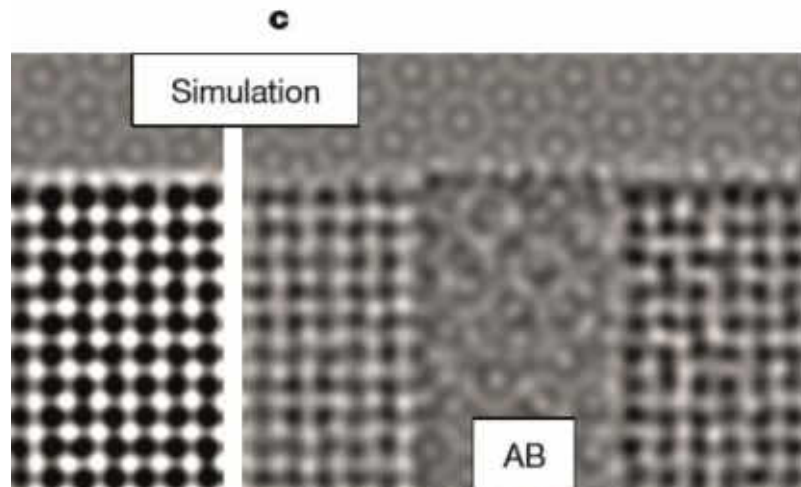
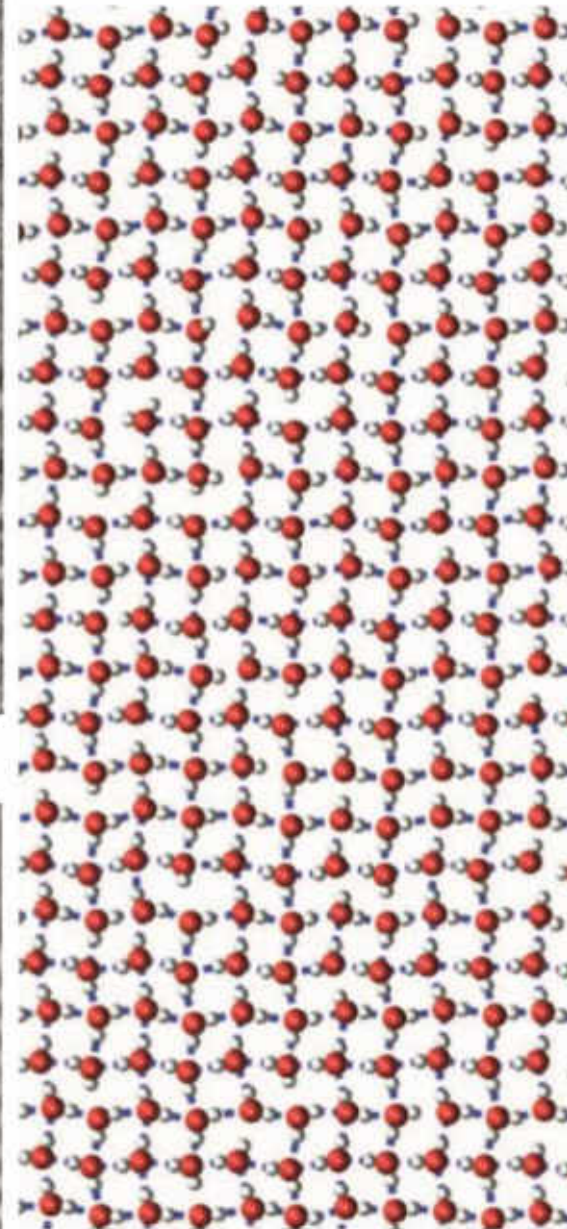
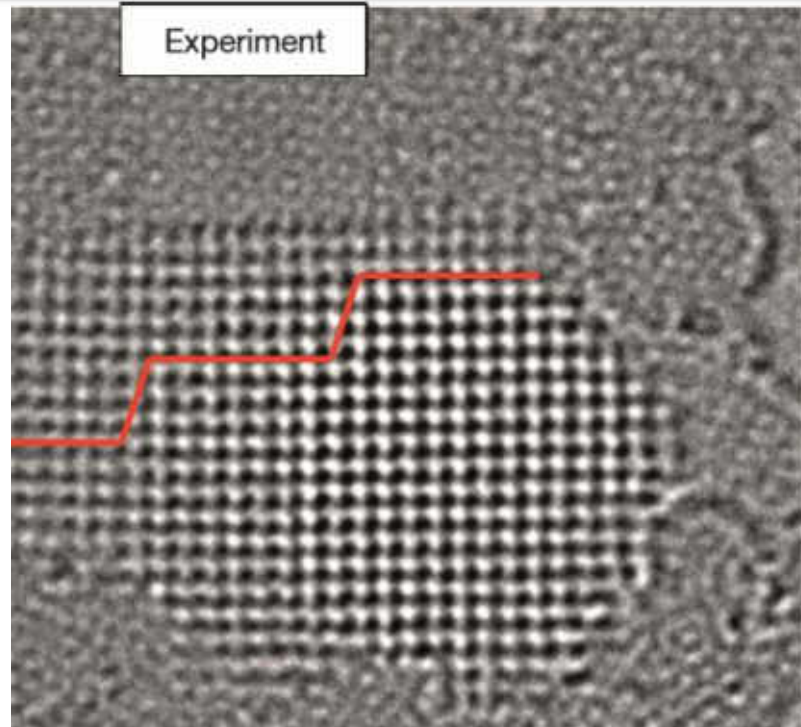


Affordable, inclusive, sustainable and contextual excellence



International Centre for Clean Water

Observing water



Algara-Siller, G.; Lehtinen, O.; Wang, F. C.; Nair, R. R.; Kaiser, U.; Wu, H. A.; Geim, A. K.; Grigorieva, I. V., Square ice in graphene nanocapillaries. *Nature* **2015**, 519 (7544), 443-445.



An ocean of
opportunities

Water presents a unique
opportunity to find a purpose in life.



Earthrise, taken on December 24, 1968, by Apollo astronaut William Anders.
From Wikipedia

A scale of 1000

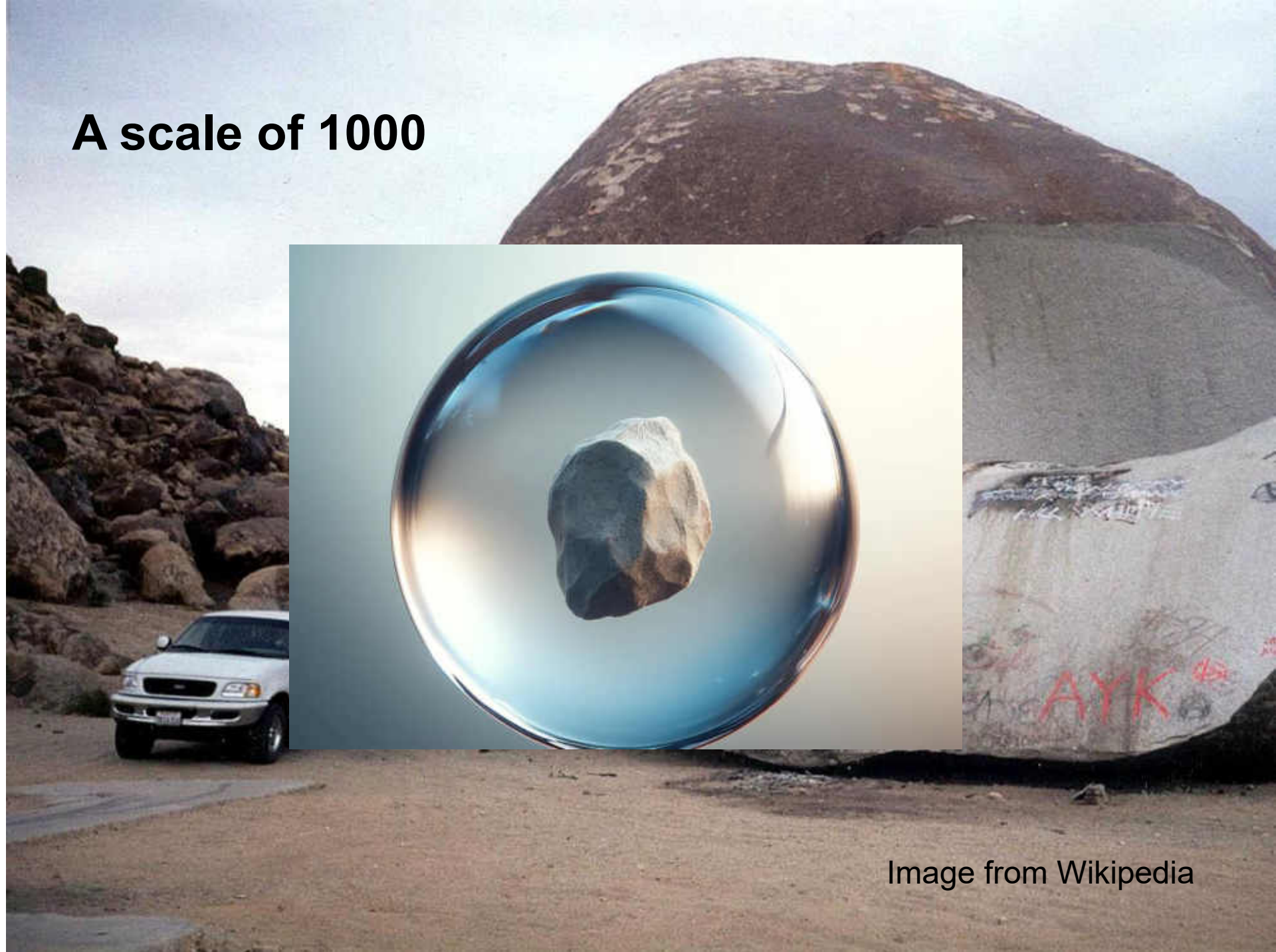


Image from Wikipedia

Science

RESEARCH

NANOPARTICLES

Spontaneous weathering of natural minerals in charged water microdroplets forms nanomaterials

B. K. Spoorthe¹, Kavyashree Debnath², Pallab Bhattacharya¹, Anil Nag¹,
Umesh V. Vaghmare¹, Thirugopal Pradeep^{1,3,4}

In this work, we show that particles of common minerals break down spontaneously to form nanoparticles in charged water microdroplets within milliseconds. We transfer these micron-sized natural minerals like quartz and ruby into 5- to 10-nanometer particles when integrated into aqueous microdroplets generated via electrospray. We deposited the droplets on a substrate, which allowed nanoparticle characterization. We determined through simulations that quartz undergoes proton-induced slip, especially when reduced in size and exposed to an electric field. This leads to particle scission and the formation of silicate fragments, which we confirmed with mass spectrometry. This rapid weathering process may be important for soil formation, given the prevalence of charged aerosols in the atmosphere.

Natural particles of minerals exist naturally in soil, and some of them are essential for life (1). Microdroplets have been a of interest over the past decade, as the confined environment within them is known to cause chemical synthesis at an accelerated rate, as well as other processes such as the formation of nanoparticles (2). We decided to explore whether natural minerals could disintegrate in microdroplets, through a process opposite to chemical synthesis.

For our experiments, we prepared micron-scale particles of natural quartz (SiO_2) and ruby (Cr -substituted Al_2O_3) for use in an electrospray setup (Fig. 1, A and B). We ground commercial millimeter-sized quartz particles well using a

mortar and pestle and used centrifugation to separate the differently sized particles that formed. We carefully excluded all the particles smaller than 1 μm in size and used particles of 5 to 10 μm that were suspended in water for the experiment (Fig. 1C). Even after ultrasonication to detach any adhered particles, we found some smaller particles attached to a few larger ones (Fig. 1C). These adhering particles had dimensions greater than 100 nm (Fig. 1B). We took an optical image of the ground quartz powder and an optical microscopic image of the separated particles that we used for electrospray (Fig. 1D). We electrosprayed a suspension of about 0.1 mg/ml of the separated quartz particles through a capillary

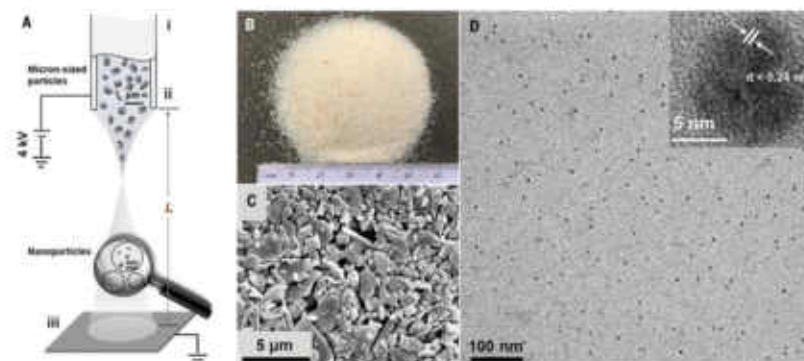
tube that had an inner diameter of 50 μm , at a flow rate of 0.5 ml/hour and observed the exiting plume (Fig. 1A). We collected the product of electrospray 15 cm away from the spray tip, which resulted in a light time on the order of 10 ms, consistent with similar experiments (3, 4). The product that was deposited on a transmission electron microscopy (TEM) grid had only 5- to 10-nm-diameter particles (Fig. 1E) throughout the grid. Under higher magnification, particles of different morphologies were observed. The particles showed the (110) plane of quartz (inset of Fig. 1D). Scission had no effect on the breaking of silica particles. Experimental methods are presented in the supplementary materials, including a video of the electrospray process (movie S1).

To ensure that our initial observations were truly representative of the process, we performed measurements on large quantities of samples. We built a multi-nozzle electrospray unit composed of six nozzles. We electrosprayed 1 liter of the suspension that contained 100 mg of the crushed micron-sized particles discontinuously over a month at the optimal conditions (spray voltage and distance) and a 0.3 ml/hour flow rate, and a deposit

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Funding: Department of Science and Technology, Government of India

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Manswita Mandal for help with the slides