



Since 1959



Pro-poor Water Services

Affordable Clean Water Using Advanced Materials

Co-founder

InnoNano Research Pvt. Ltd.
InnoDI Water Technologies Pvt. Ltd.
VayuJAL Technologies Pvt. Ltd.
Aqueasy Innovations Pvt. Ltd.
Hydromaterials Pvt. Ltd.
EyeNetAqua Solutions Pvt. Ltd.
DeepSpectrum Innovations Pvt. Ltd.



Associate Editor

ACS
Sustainable
Resource Management

Thalappil Pradeep

Institute Professor, IIT Madras

pradeep@iitm.ac.in

<https://pradeepresearch.org>

Professor-in-charge



International Centre for Clean Water



First Ultraviolet Water Treatment Technology Workshop in Uganda
Busitema University, January 23, 2025



Since 1959

Molecular Acorns to Institutional Oaks

Institute Professor, IIT Madras

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

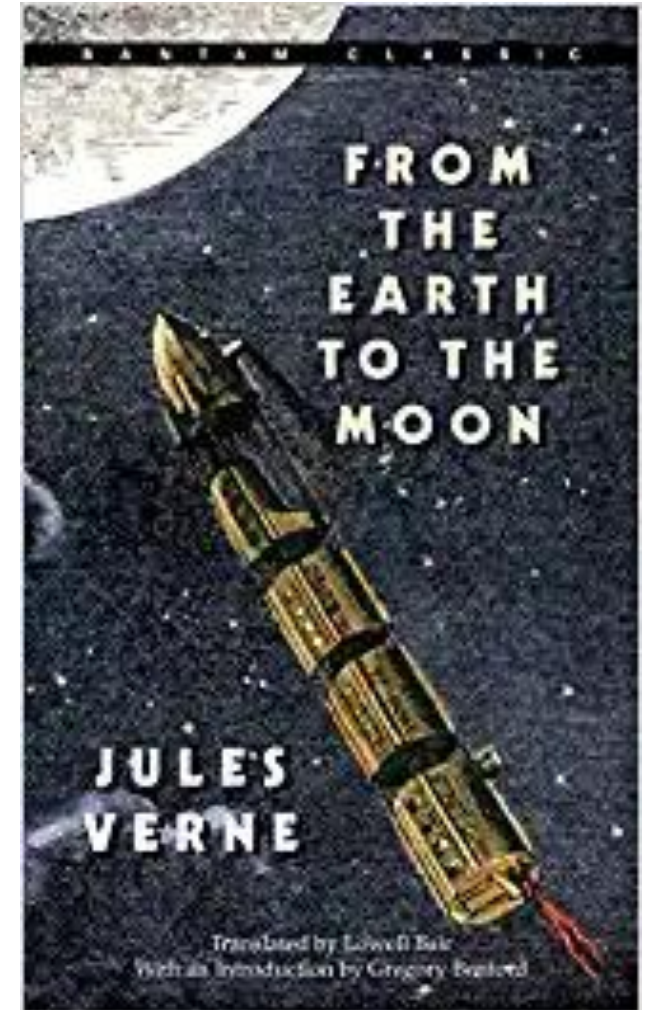
Water is the most important inheritance of our planet



From S. Vishwanath

© Robert Szucs/Grasshopper Geography

Our dreams become reality
with materials

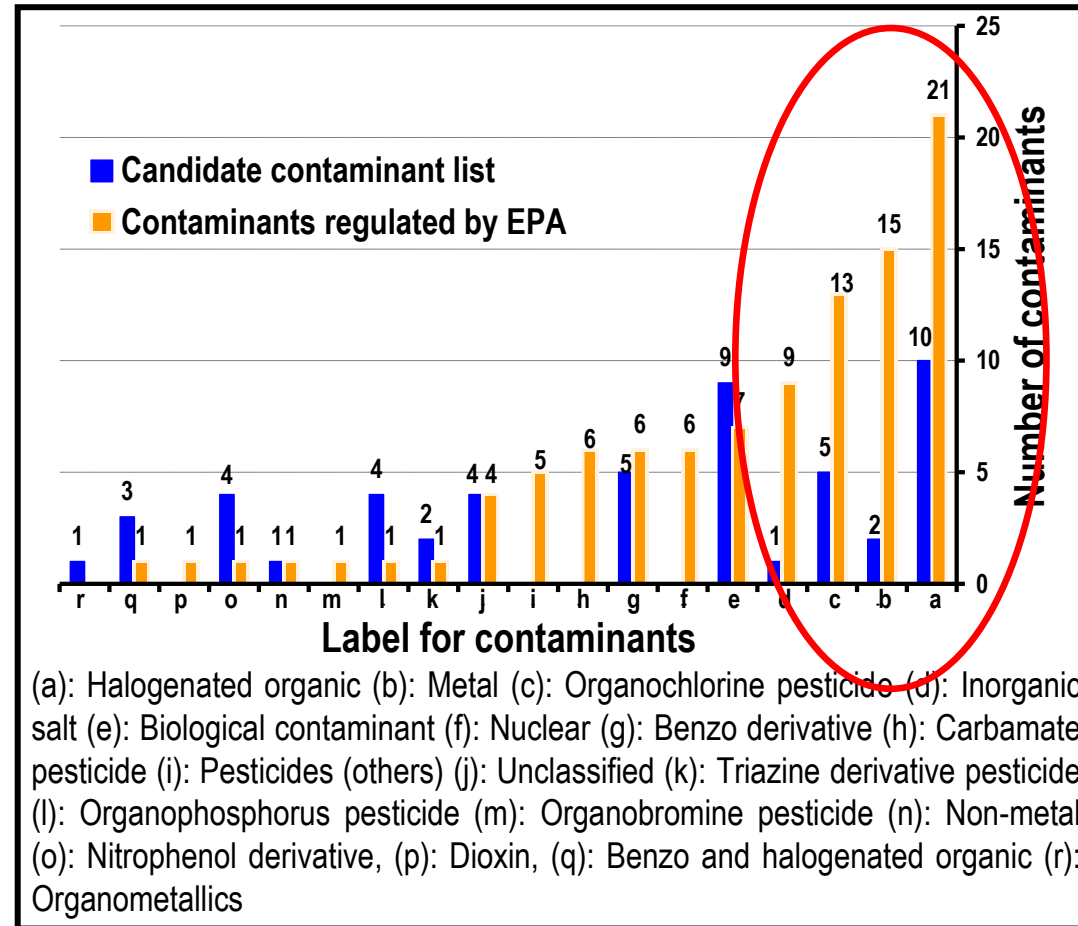


Water purification, history

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

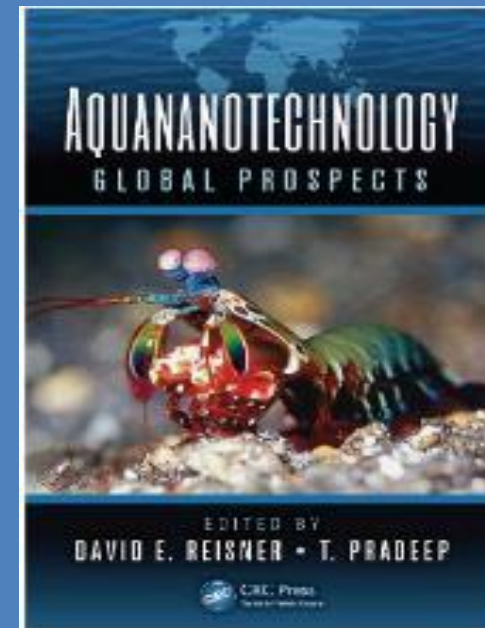
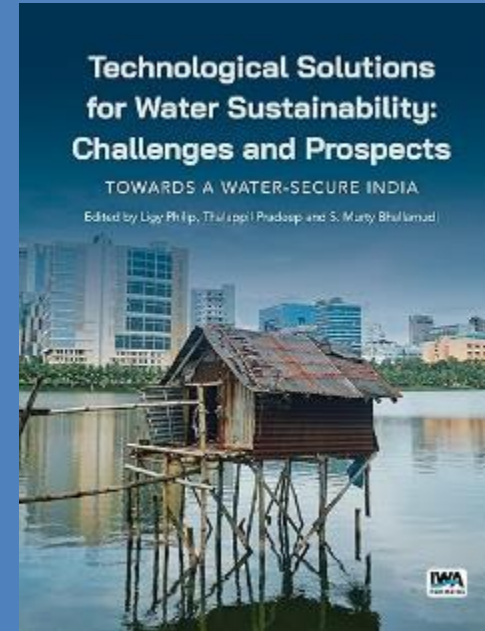
New adsorbents

New sensors

New catalysts

Novel phenomena

New devices



World's first nanochemistry-based water purifier

RSC | Advancing the
Chemical Sciences
Chemistry World

Pesticide filter debuts in India

20 April 2007

Kilugudi Jayaraman@Bangalore, India

A domestic water filter that uses metal nanoparticles to remove dissolved pesticide residues is about to enter the Indian market. Its developers at the Indian Institute of Technology (IIT) in Chennai (formerly Madras) believe it is the first product of its kind in the world to be commercialised.

Mumbai-based Eureka Forbes Limited, a company that sells water purification systems, is collaborating with IIT and has tested the device in the field for over six months. Jayachandran Raveed, a technical consultant to the company, expects the first 1000 units to be sold door-to-door from late May.

'Our pesticide filter is an offshoot of basic research on the chemistry of nanoparticles,' Thirupathi Pradeep who led the team at IIT Chennai told Chemistry World. He and his student Sreekanth Nair discovered in 2003 that halocarbons such as carbon tetrachloride (CCl₄) completely break down into metal halides and amorphous carbon upon reaction with gold and silver nanoparticles¹.

Pradeep said this prompted them to extend their study to include organochlorine and organophosphorous pesticides, whose presence in water is posing a health risk in rural India. In research funded by the Department of Science and Technology in New Delhi, his team found^{2,3} that gold and silver nanoparticles loaded on alumina were indeed able to completely remove endosulfan, malathion and chlorpyrifos - three pesticides that have been found in drinking water supplies.

Use and recycle

The method

Pradeep

Mumbai

nanotech

novel, Gastry

Chemistry world
First ever
nanotechnology
product for clean
water

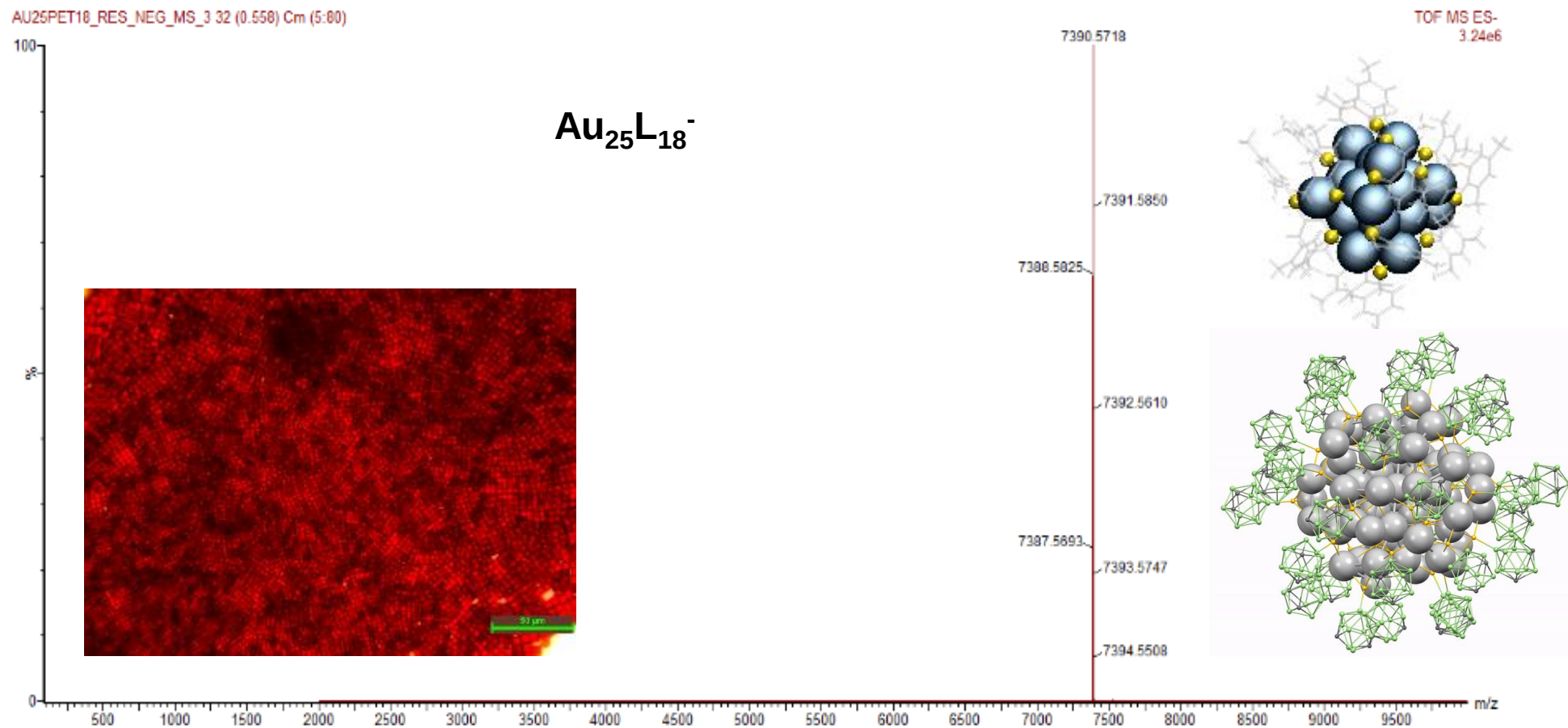


A plant to make supported nanomaterials for water purification; with capacity of 4.5 tons per month, 2007

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

PNAS PNAS PNAS

Biopolymer-reinforced synthetic granular nanocomposites for efficient water purification

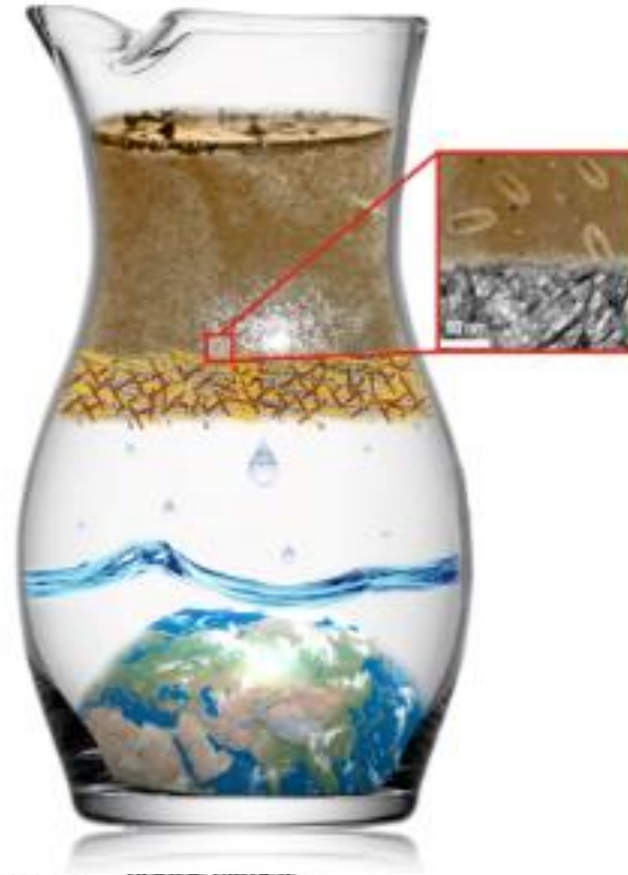
Mohan Udhaya Sankar¹, Sahaja Aigal,
Kamalesh Chaudhari, and Thalappil Prasad

Unit of Nanoscience and Thematic Unit of Excellence

Edited by Eric Hoek, University of California, Los Angeles

Creation of affordable materials for constant clean drinking water is one of the most promising ways to ensure 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, an affordable, all-inclusive drinking water purifier can be developed 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 constant materials can be synthesized in a simple and effective fashion without the use of electrical power. The nanocomposites have sand-like properties, such as higher shear strength and stability. These materials have been used to develop a water purifier to deliver clean drinking water. The ability to prepare nanostructures at ambient temperature has wide relevance for water purification.

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



Anil Kumar,

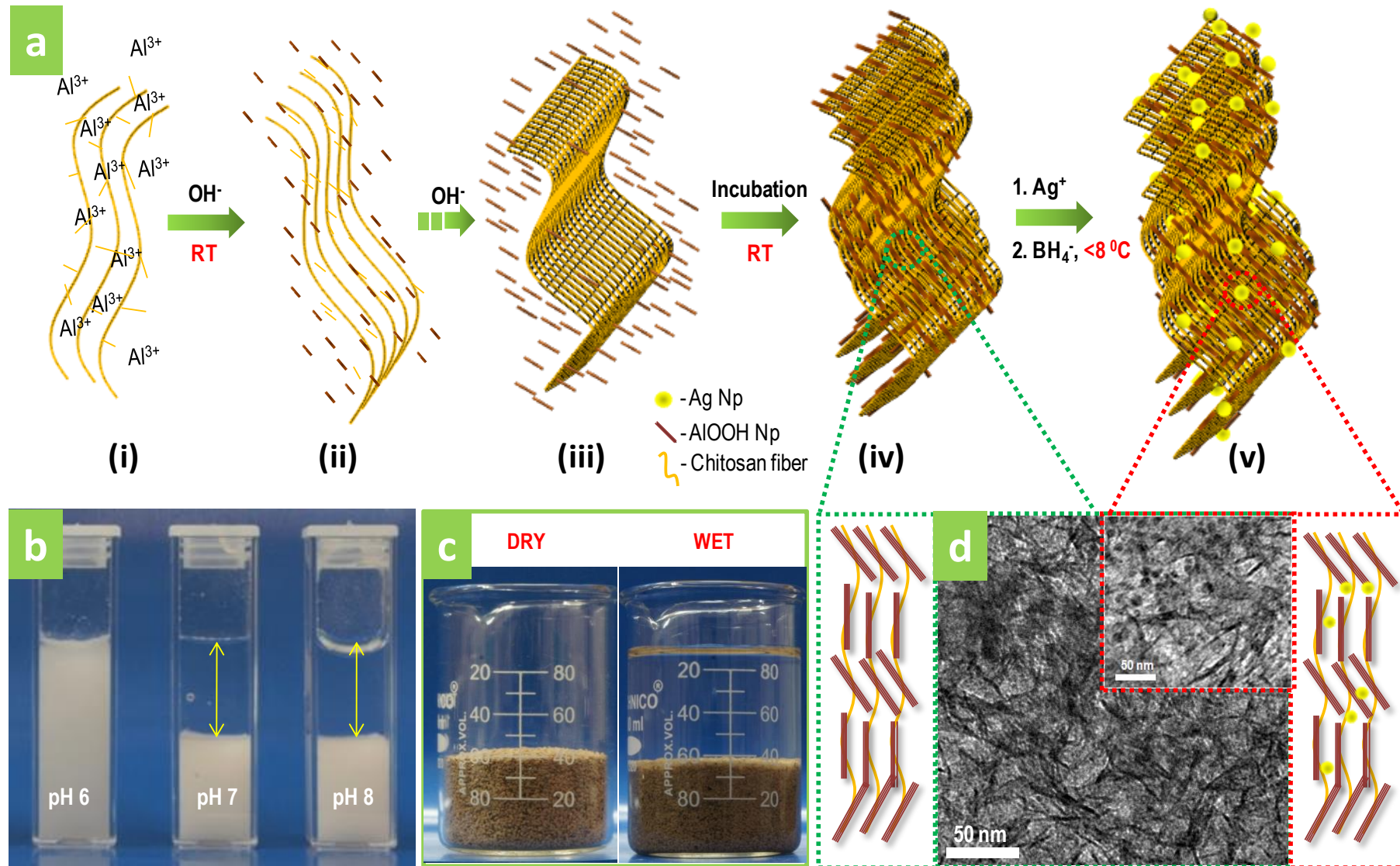
6, India

September 21, 2012

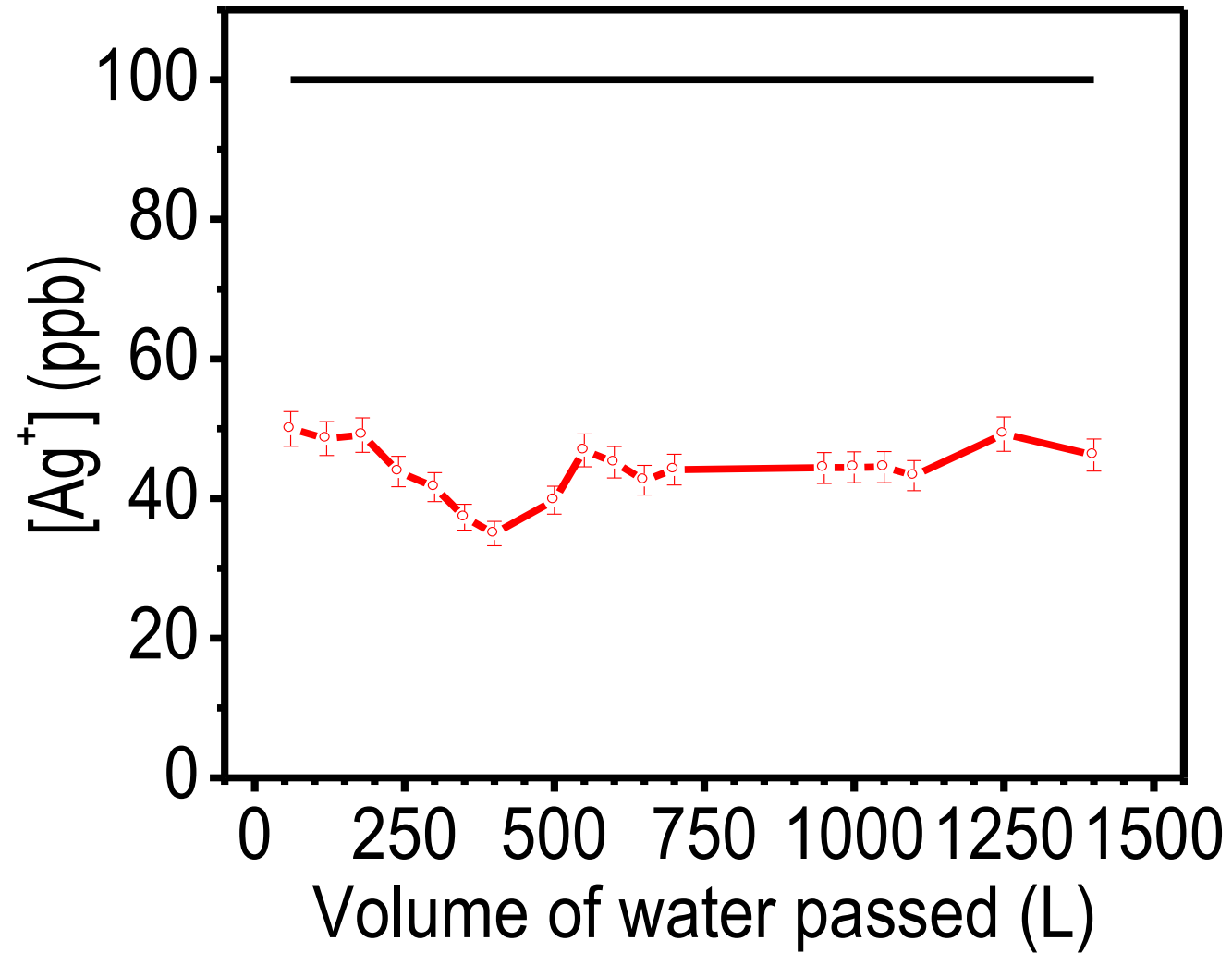
continued retention

nanocrystalline materials prepared by the above route. The high abundance of -OH groups in the crystal structure help in the crystal growth. X-ray photoelectron spectroscopy (XPS) confirmed the presence of strong covalent bonds. X-ray photoelectron spectroscopy (XPS) confirmed the presence of strong covalent bonds. X-ray photoelectron spectroscopy (XPS) confirmed the presence of strong covalent bonds.

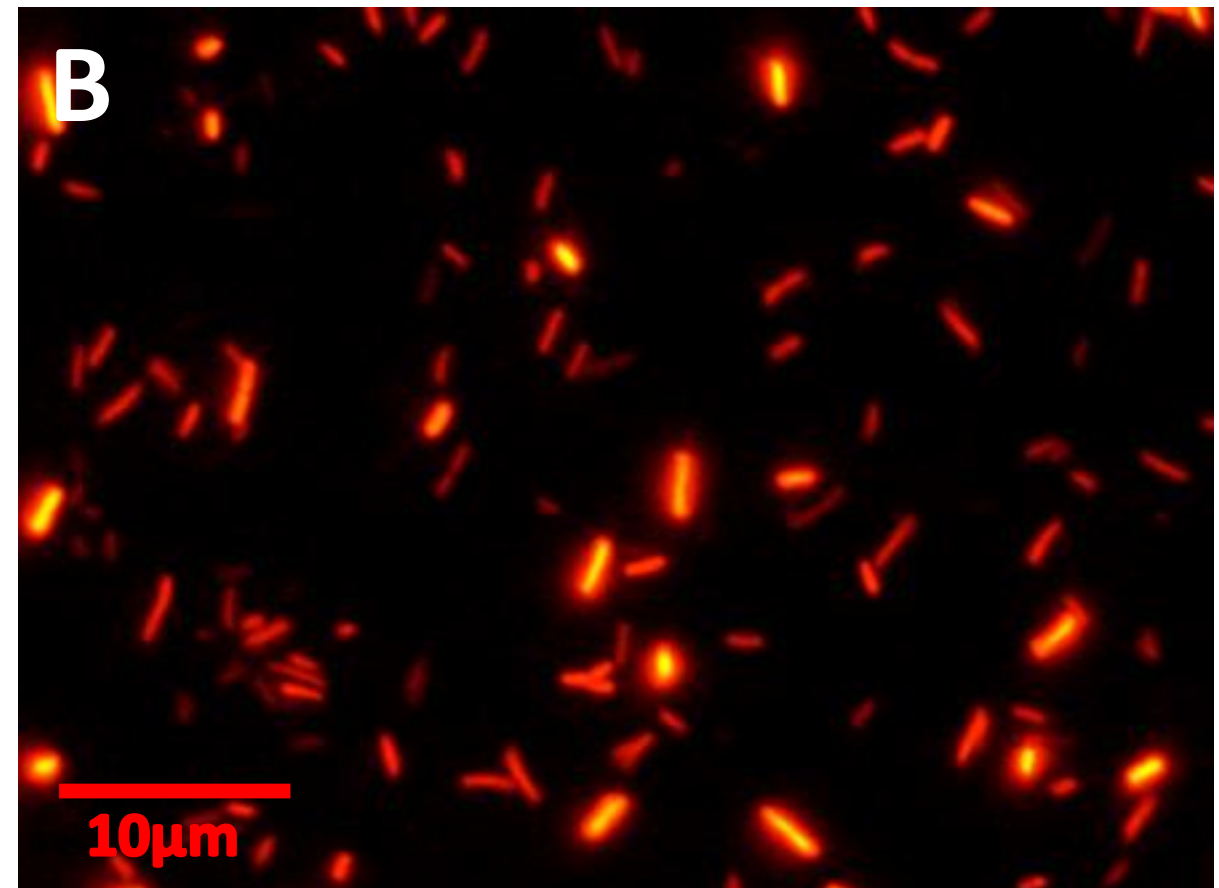
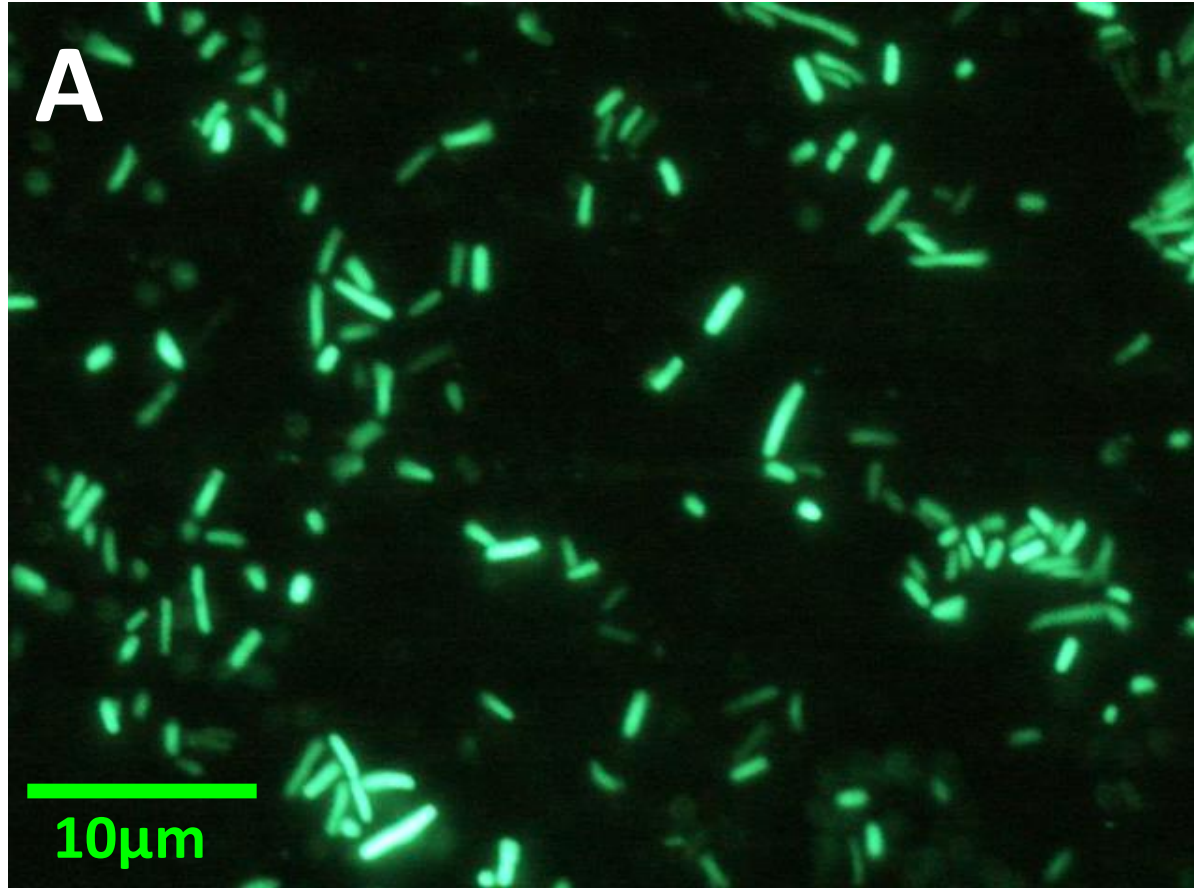
How to make?



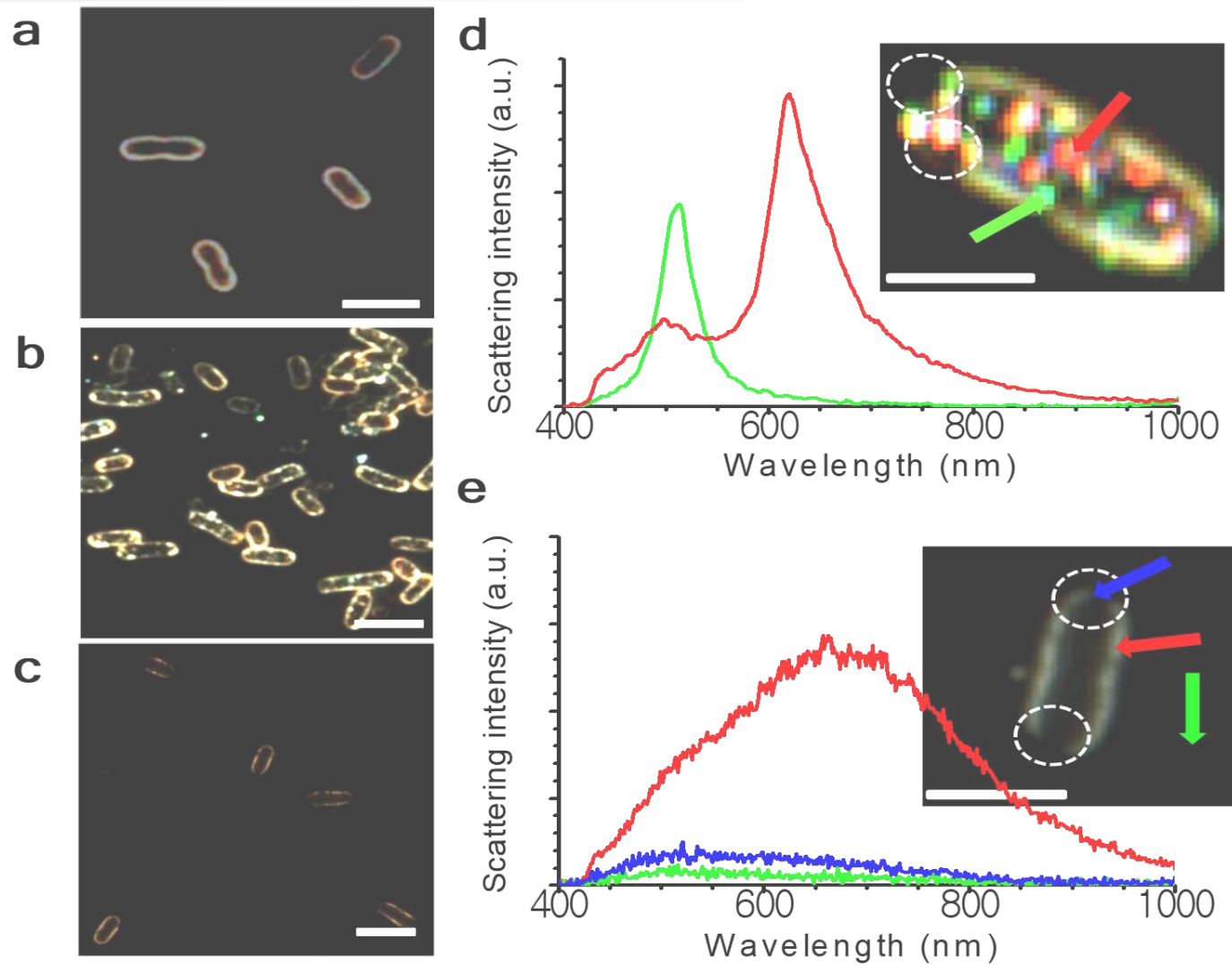
What is special?



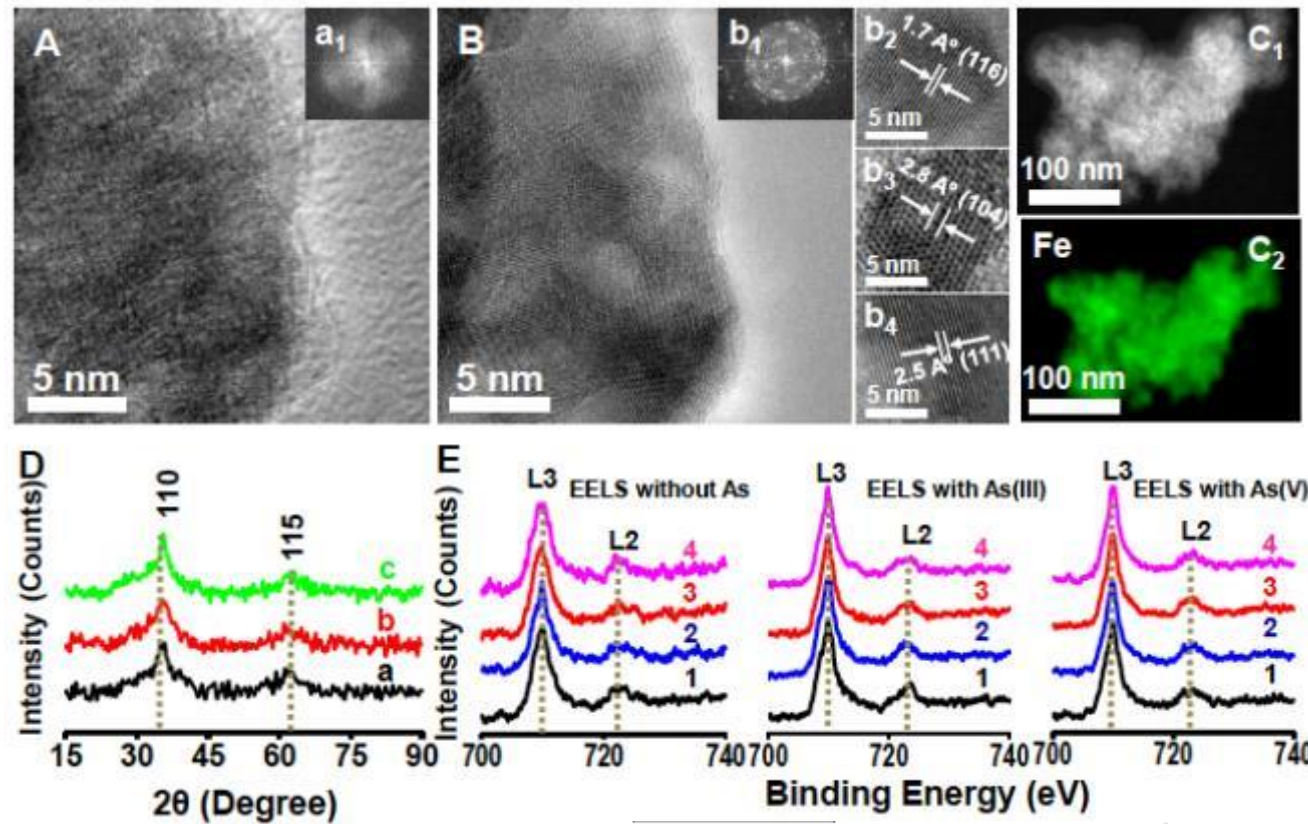
Live/dead staining experiments



No nanotoxicity



Variety of materials



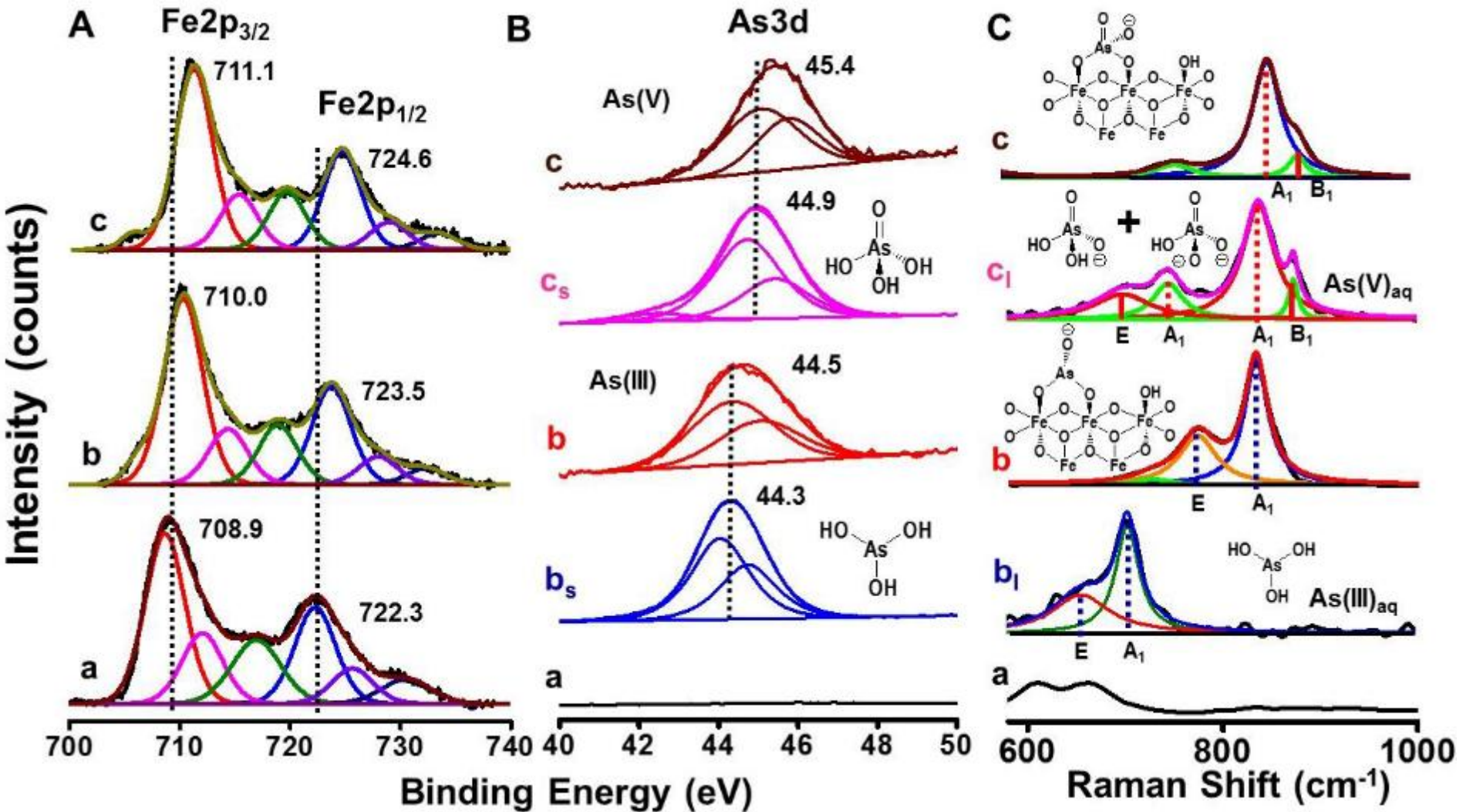
www.advmat.de

Author Pr ADVANCED MATERIALS

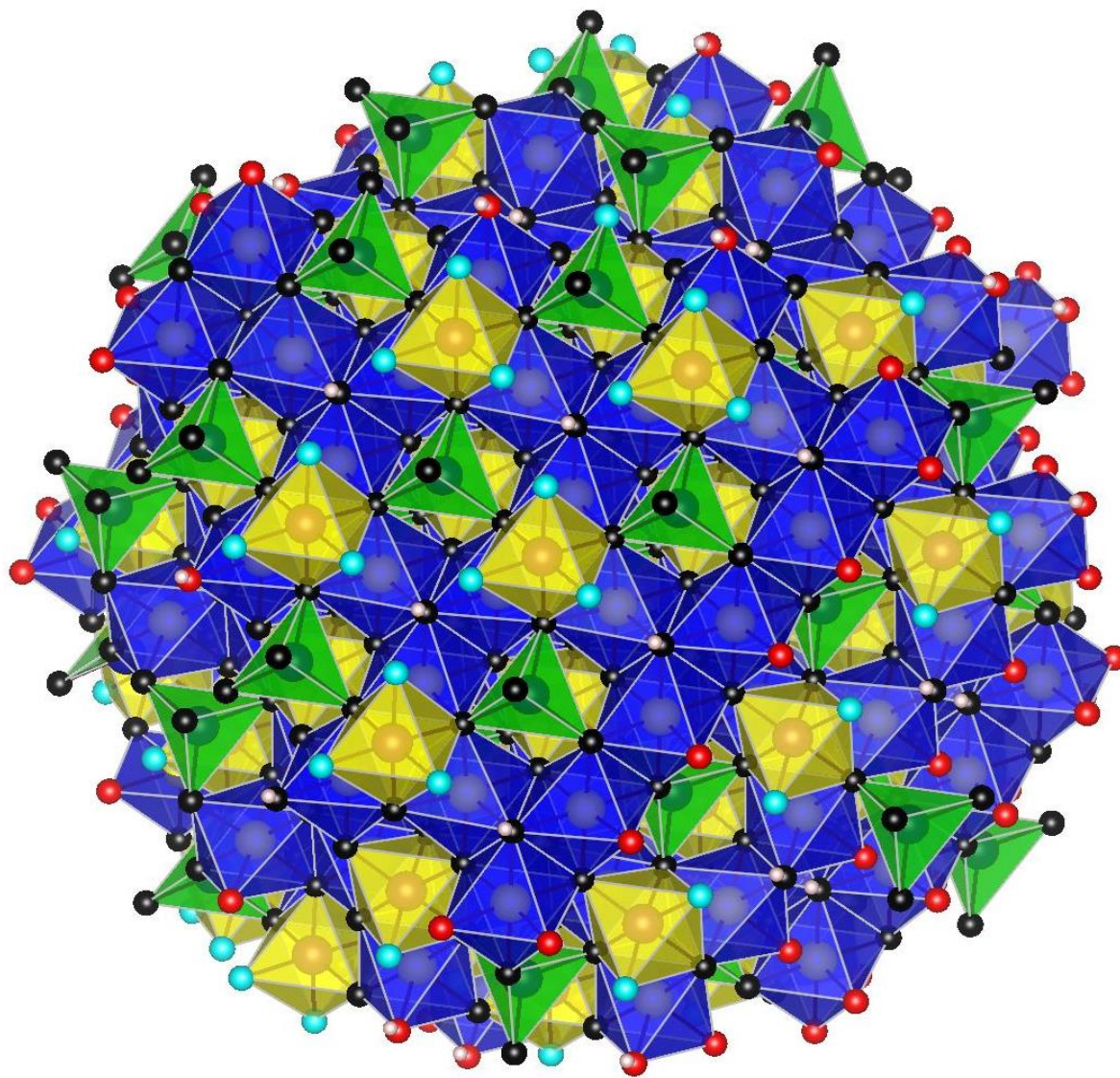
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

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

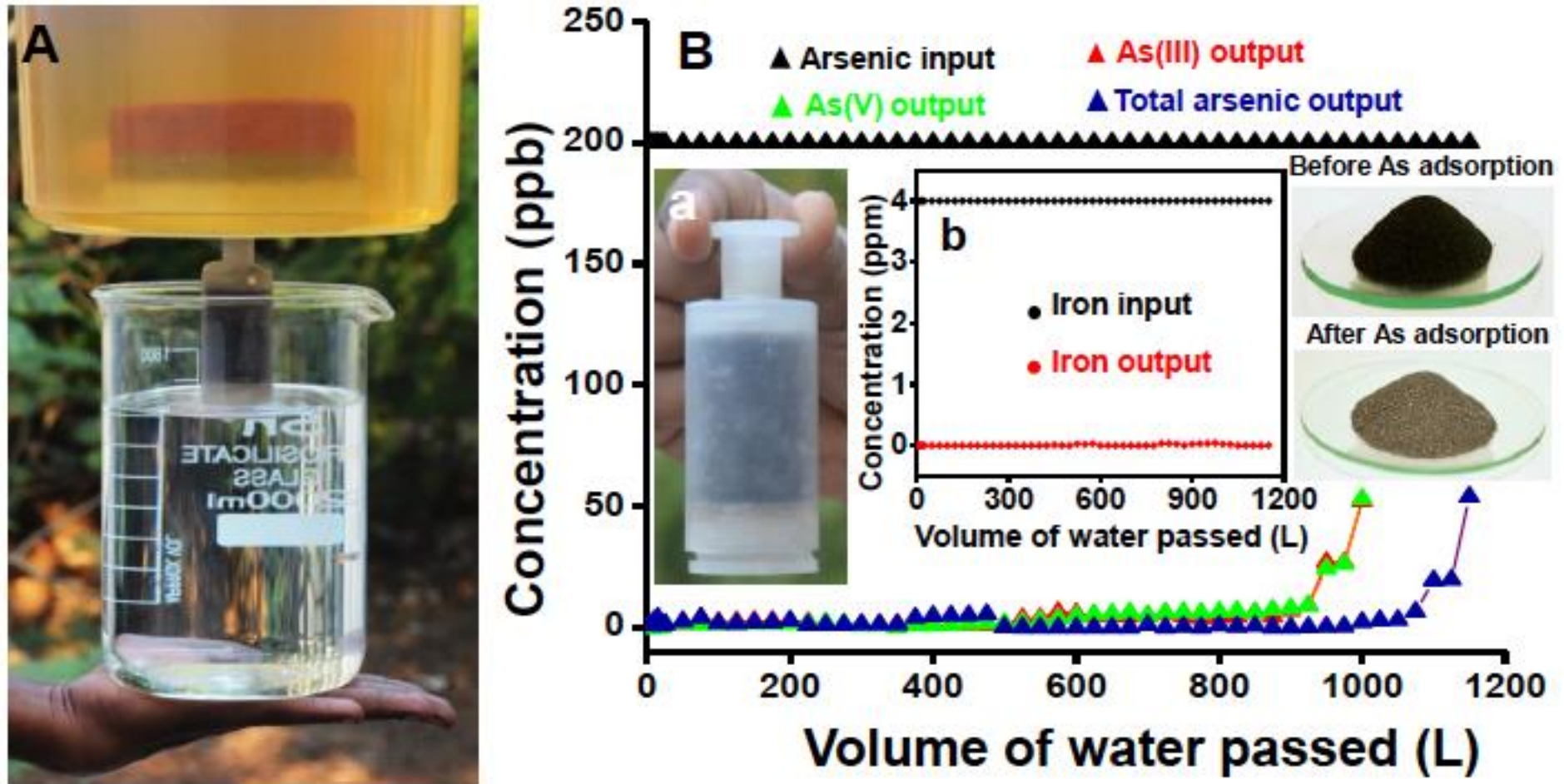


Modeling surfaces



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

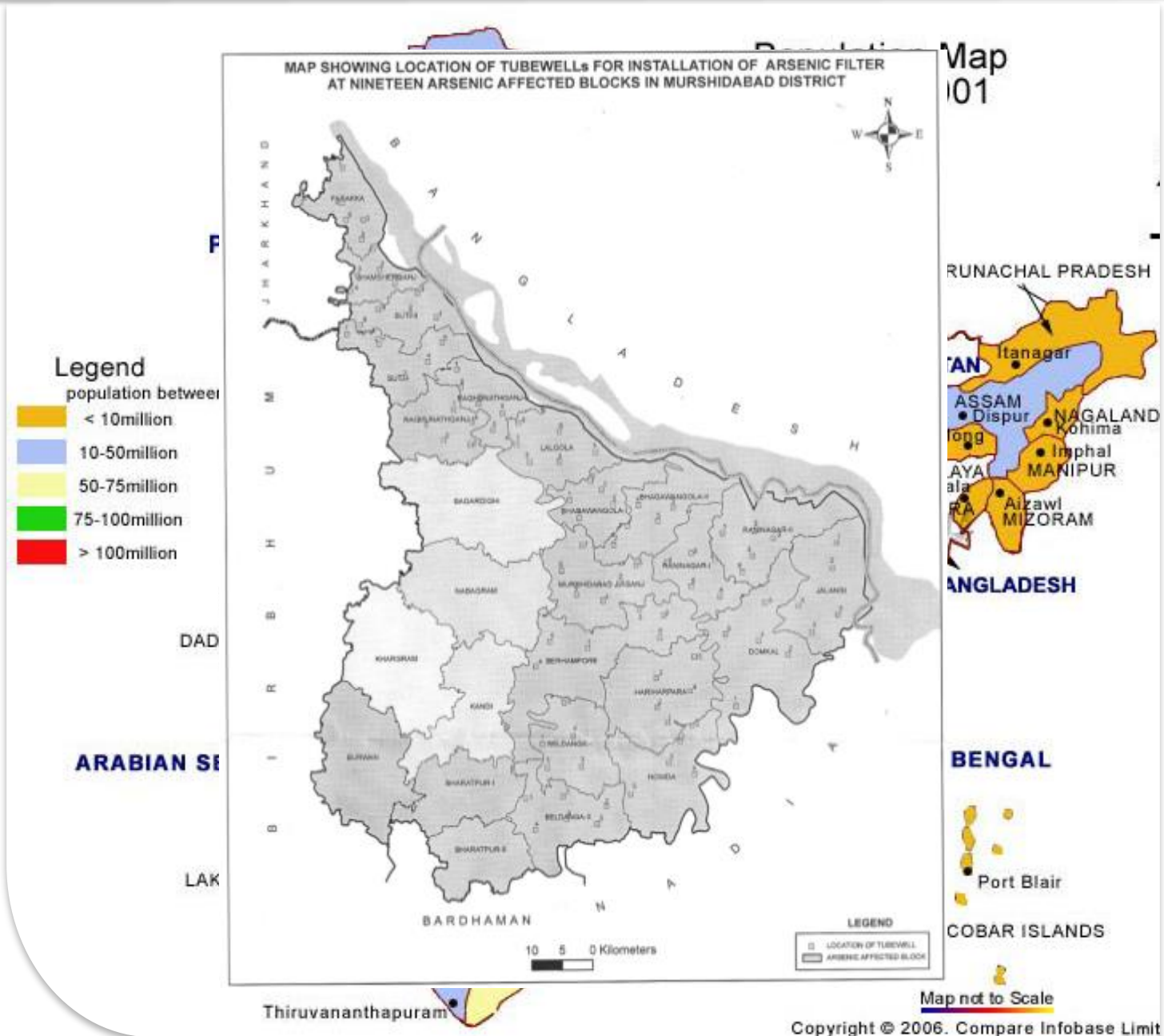
Lab studies



Initial pilot studies



Larger pilot studies



Changing the dynamics in the field



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



- 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



সুপ্রসাদ
- 03471-250221
ফোন-03471-
লস-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

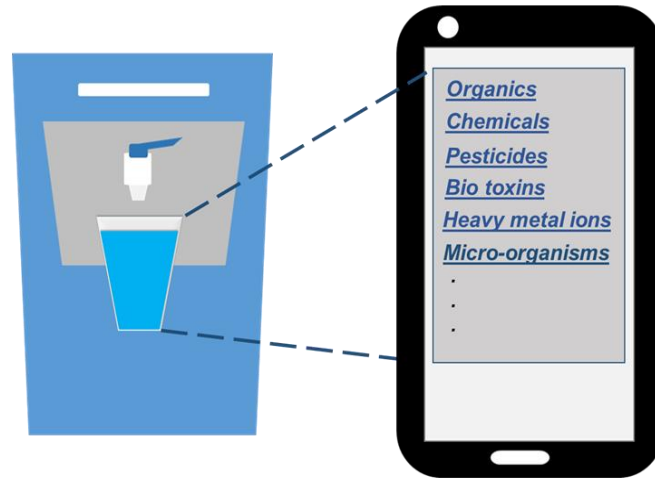
Over 180 units in use across India

Clean water at 2.1 paise per litre!

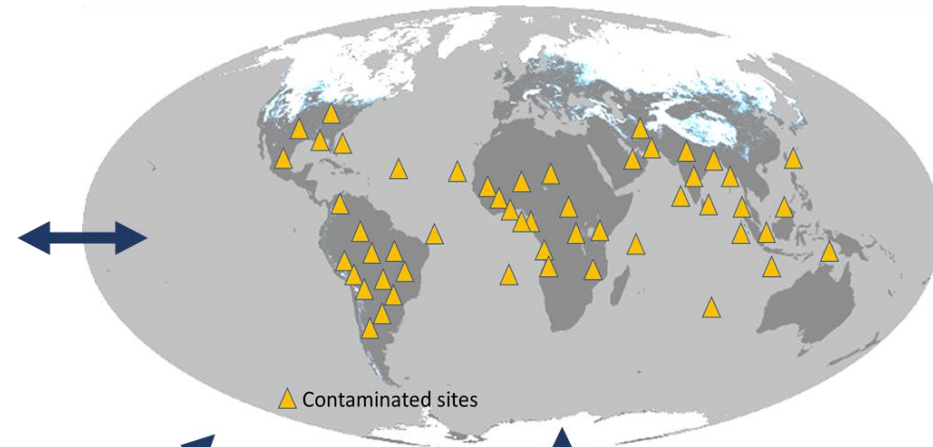
Calculation for the Tariff to be collected for treated water (Revision if Required)			
	Design population	1,071	Plant capacity/70 LPCD
Sr.No.	Item/Description	Cost / Quantity	Remarks
1	Cost of Replacement of Iron removal media	56400	After minimum two years if Iron concentration is more than 5 ppm. But 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

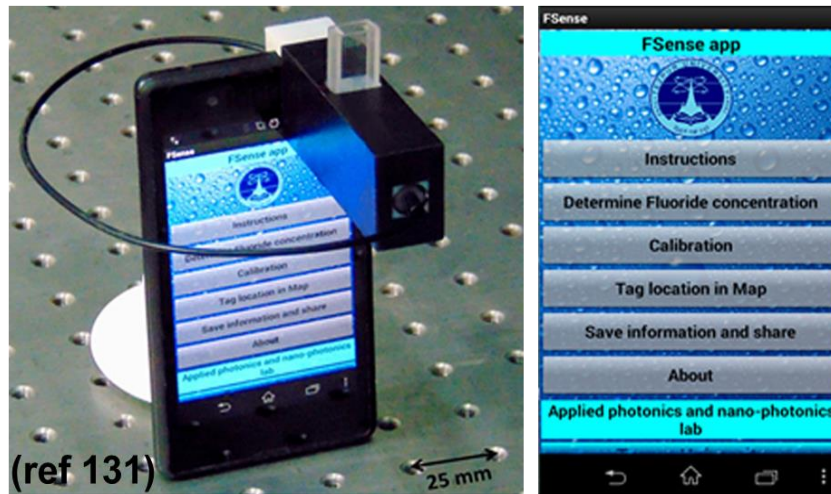
Smart Water Purifiers linked to IoT



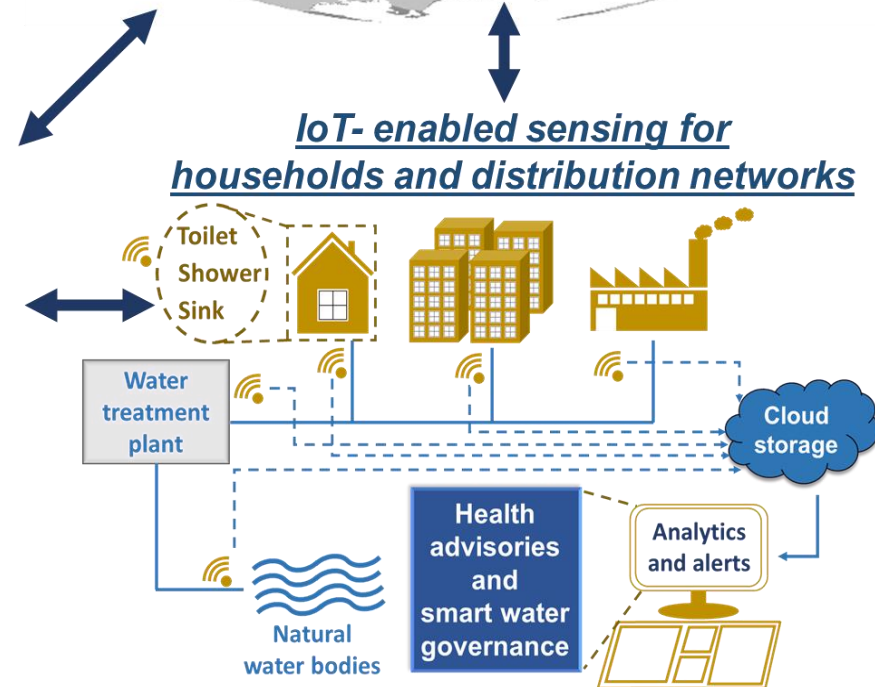
Global Map of Water Health



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



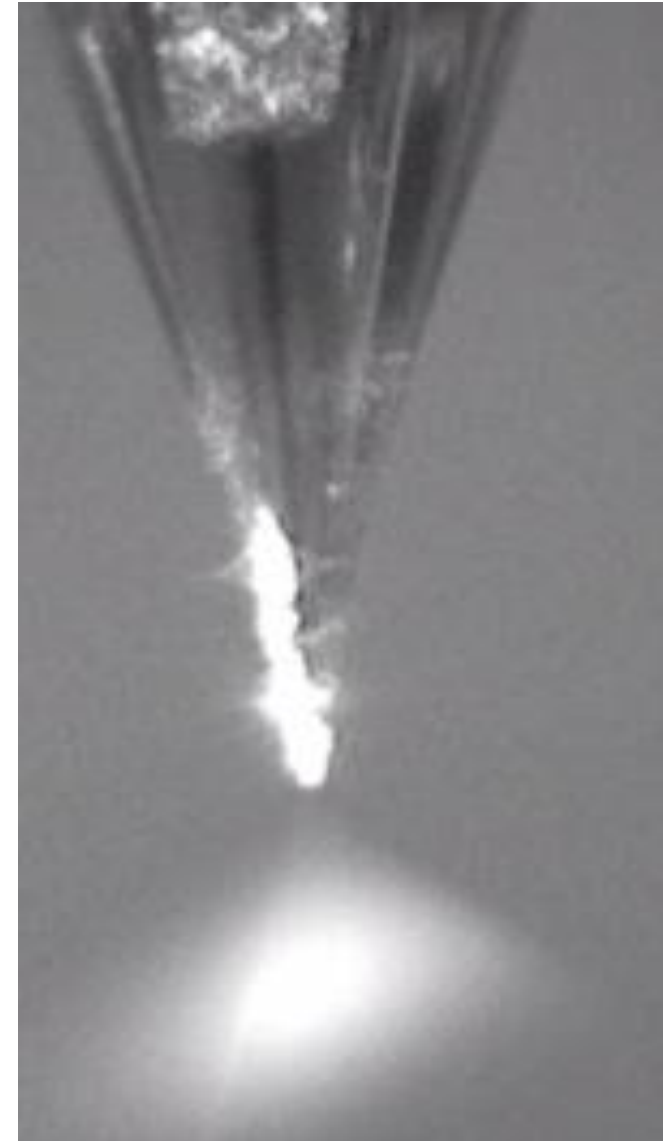
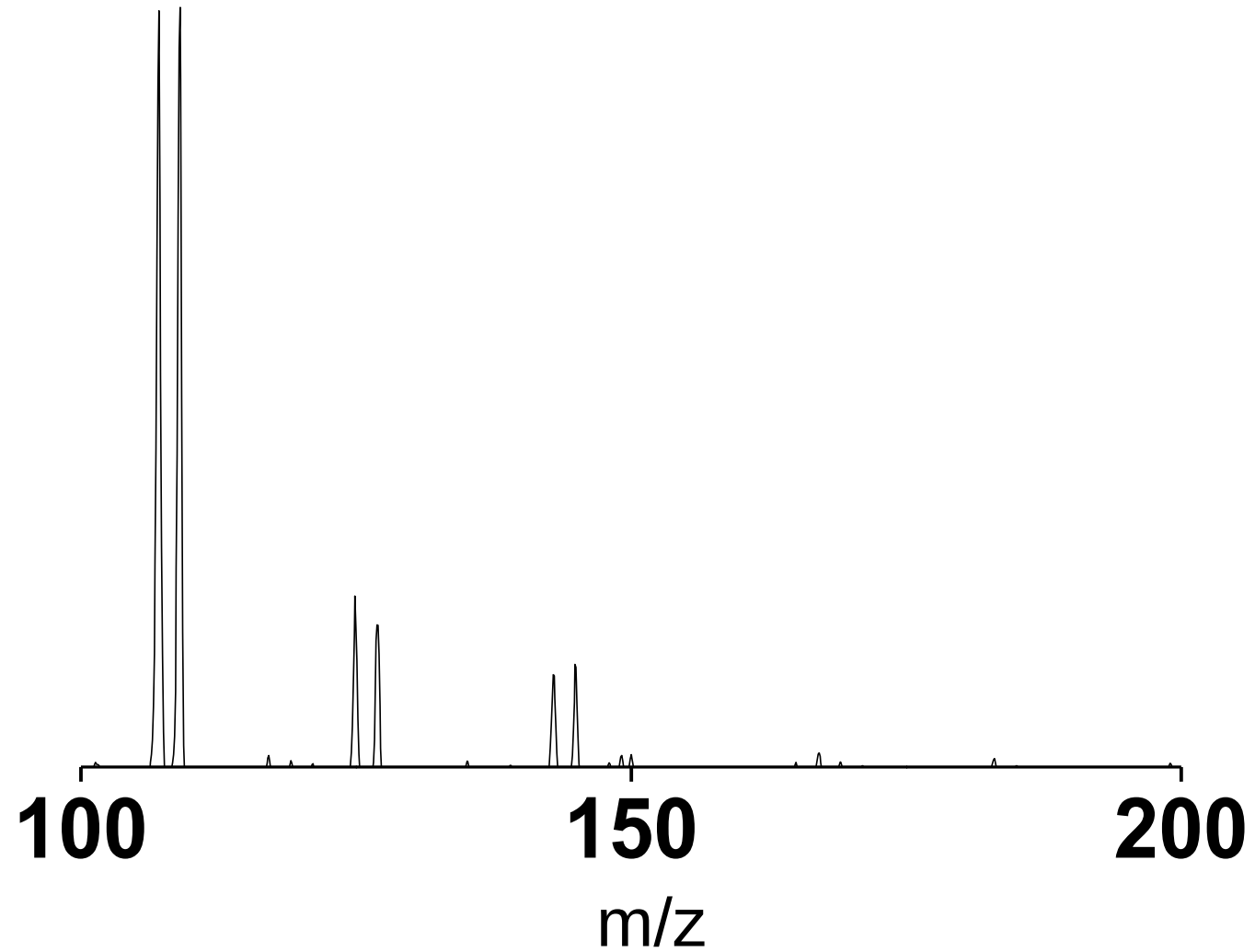
Components of IoT architecture implemented by DWSS, GoP



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



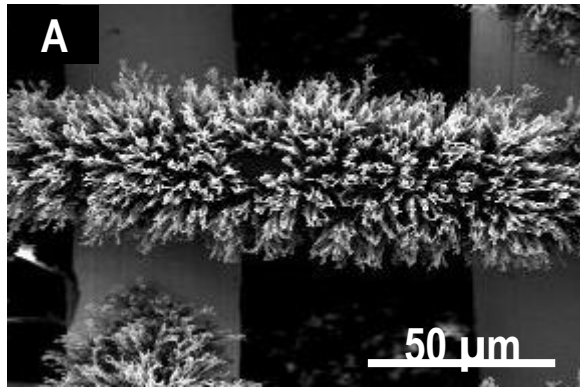
Atmospheric water harvesting



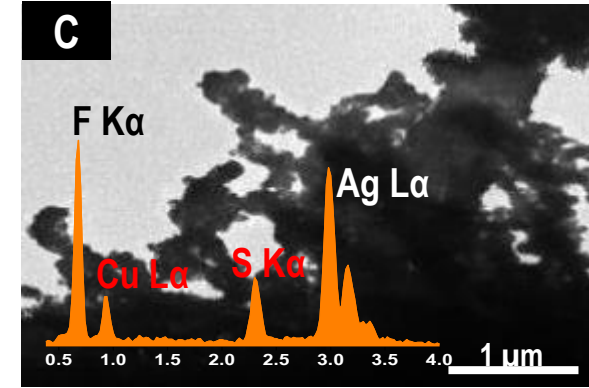
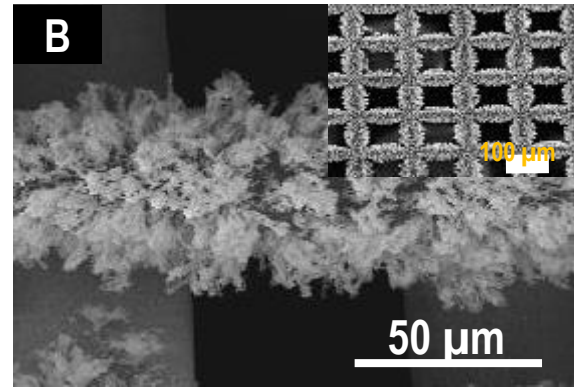
New harvesters



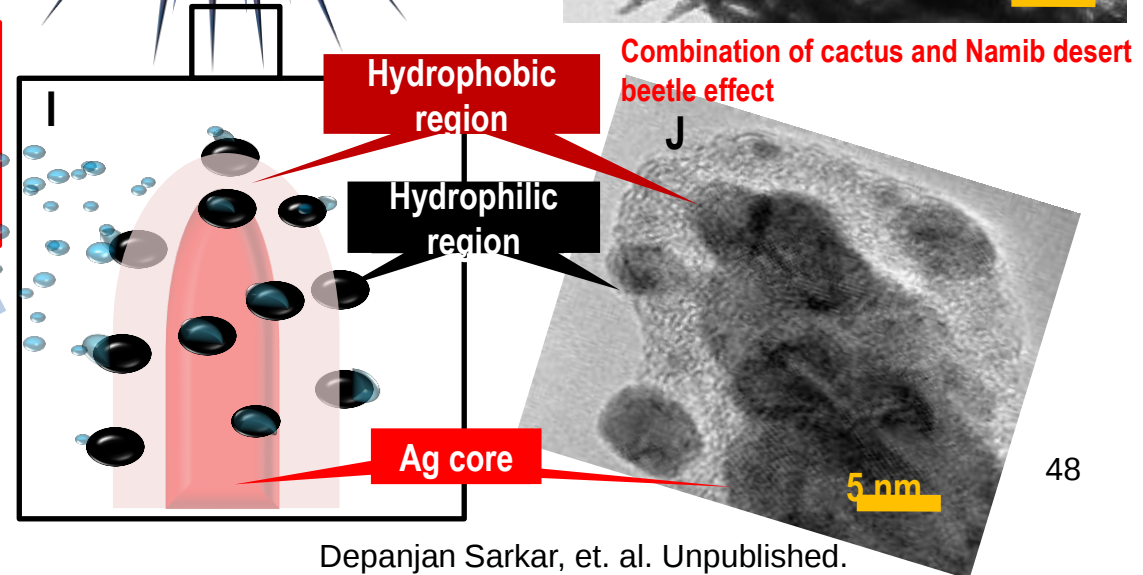
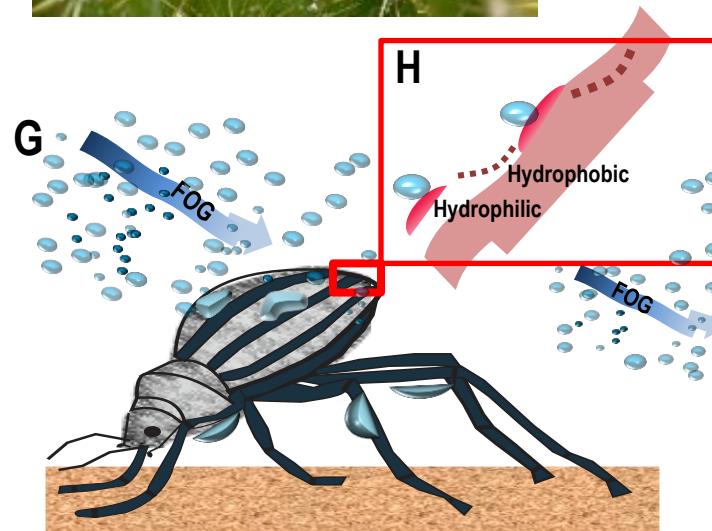
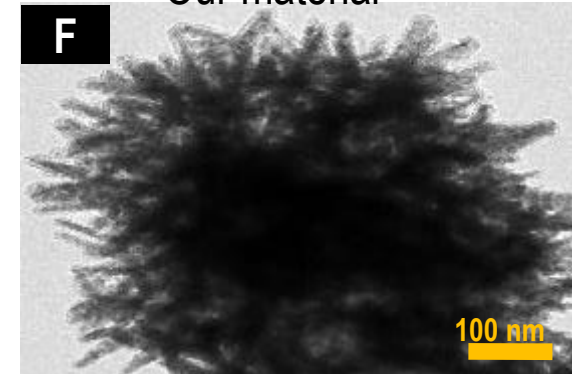
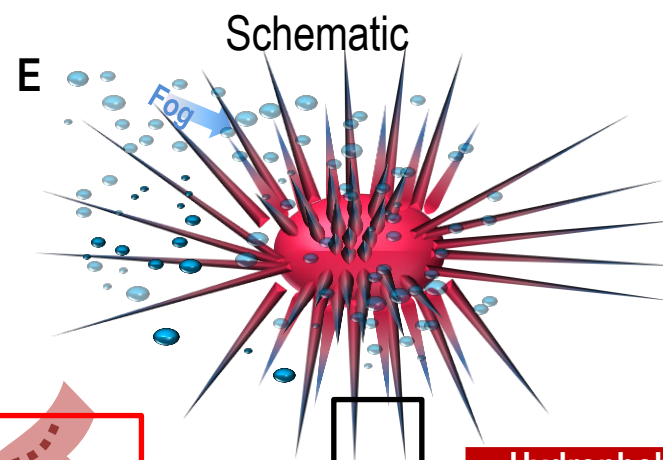
Depanjan Sarkar, et. al. *Advanced Materials*, 28 (11), 2016.

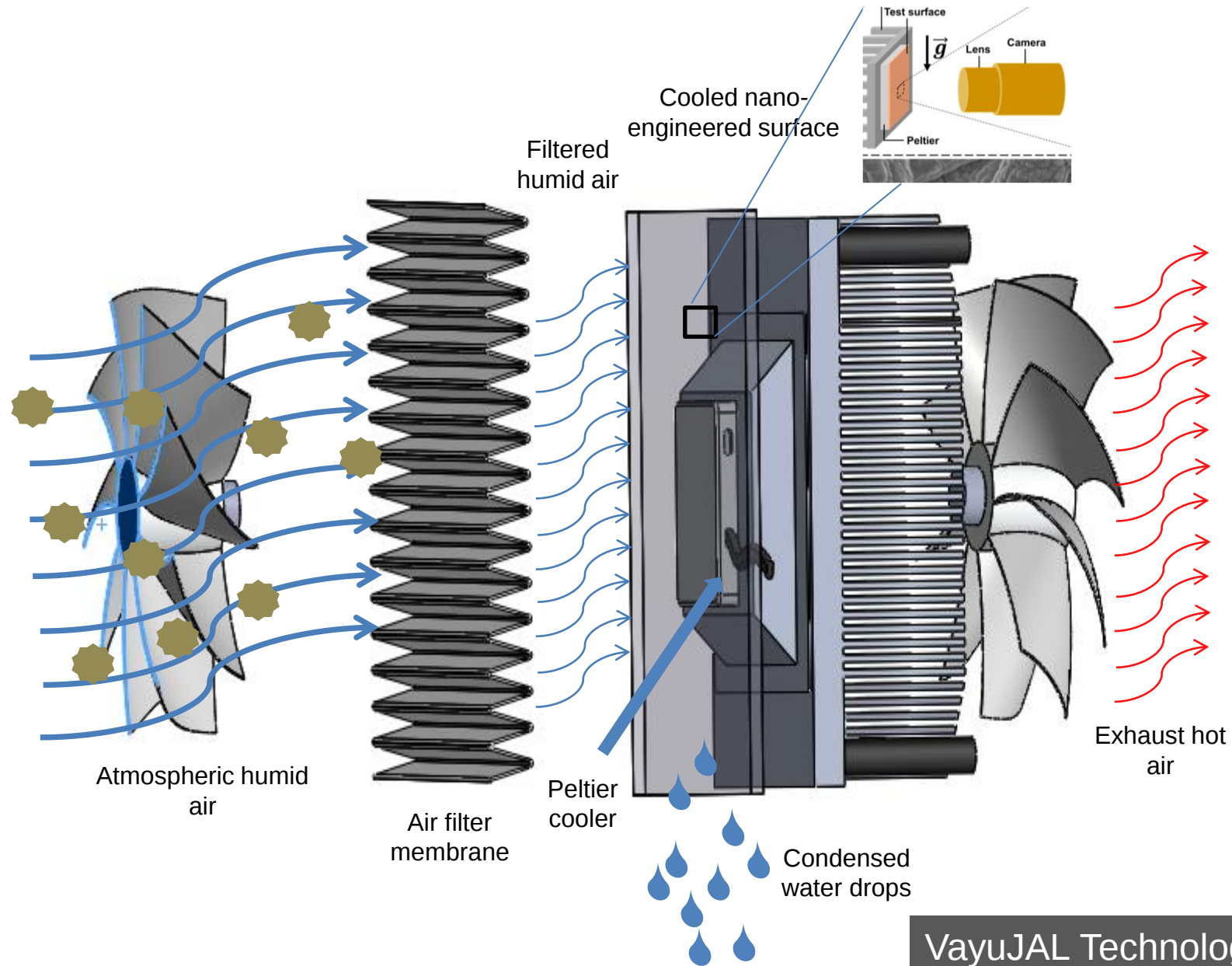


Nature



Our material





VayuJAL Technologies Pvt. Ltd.

Ramesh Kumar Soni and Ankit Nagar

Products in the field



35 LPD



120 LPD



400 LPD



1000 LPD



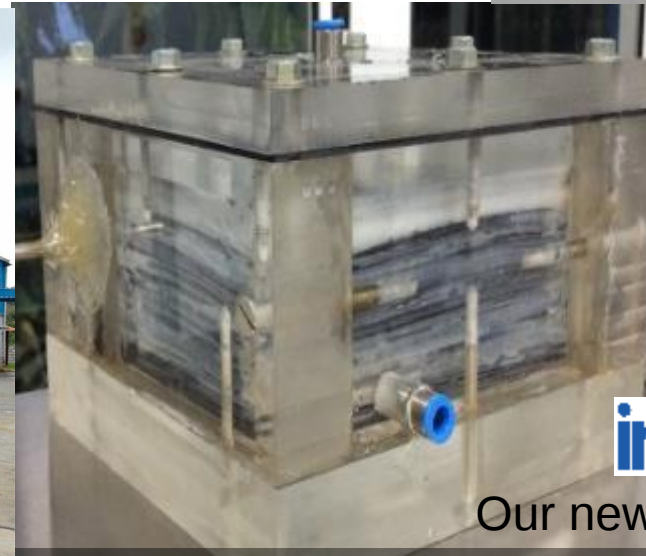
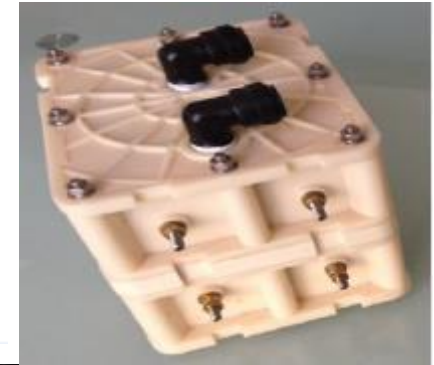
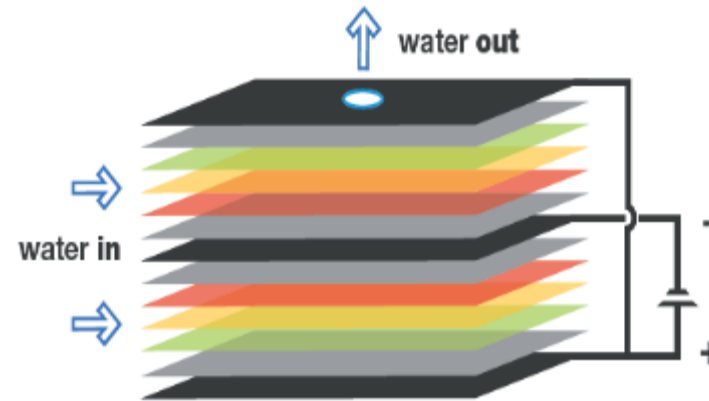
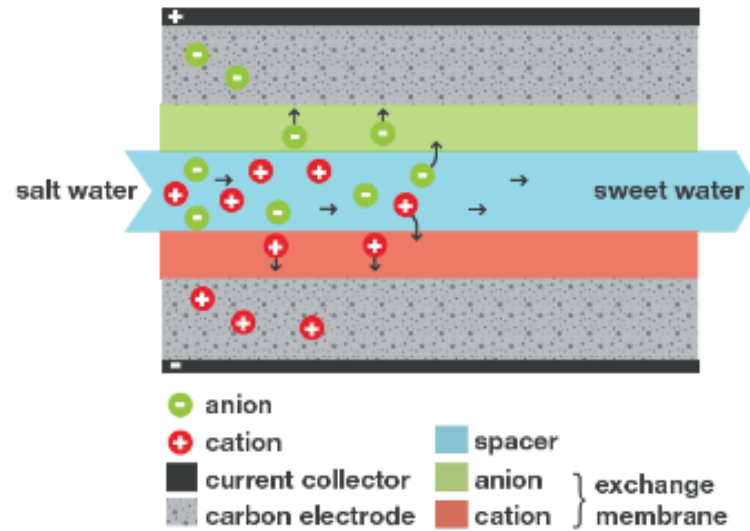
2000 LPD

(LPD: Litres per day)



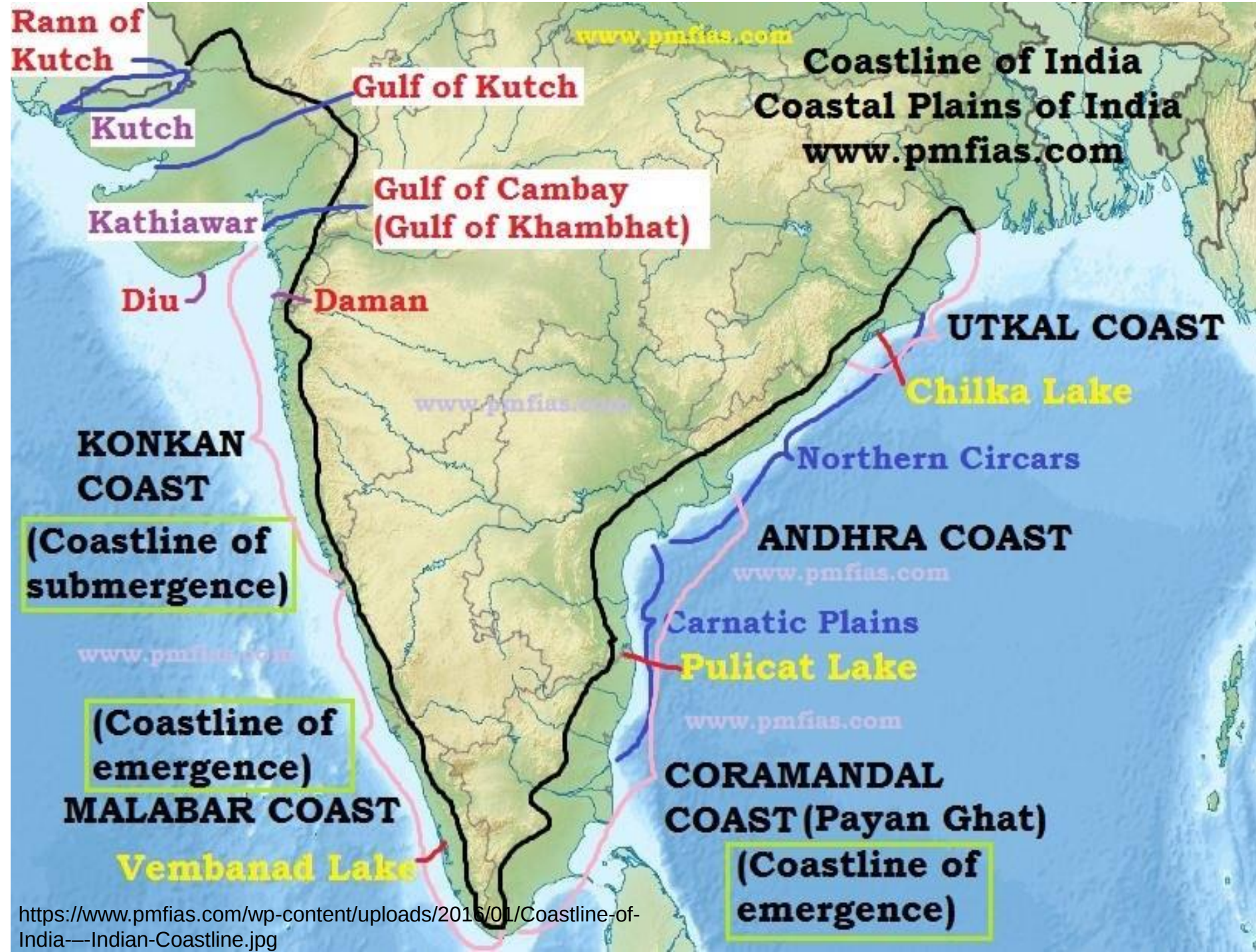
July 2023

Capacitive Desalination (CDI)



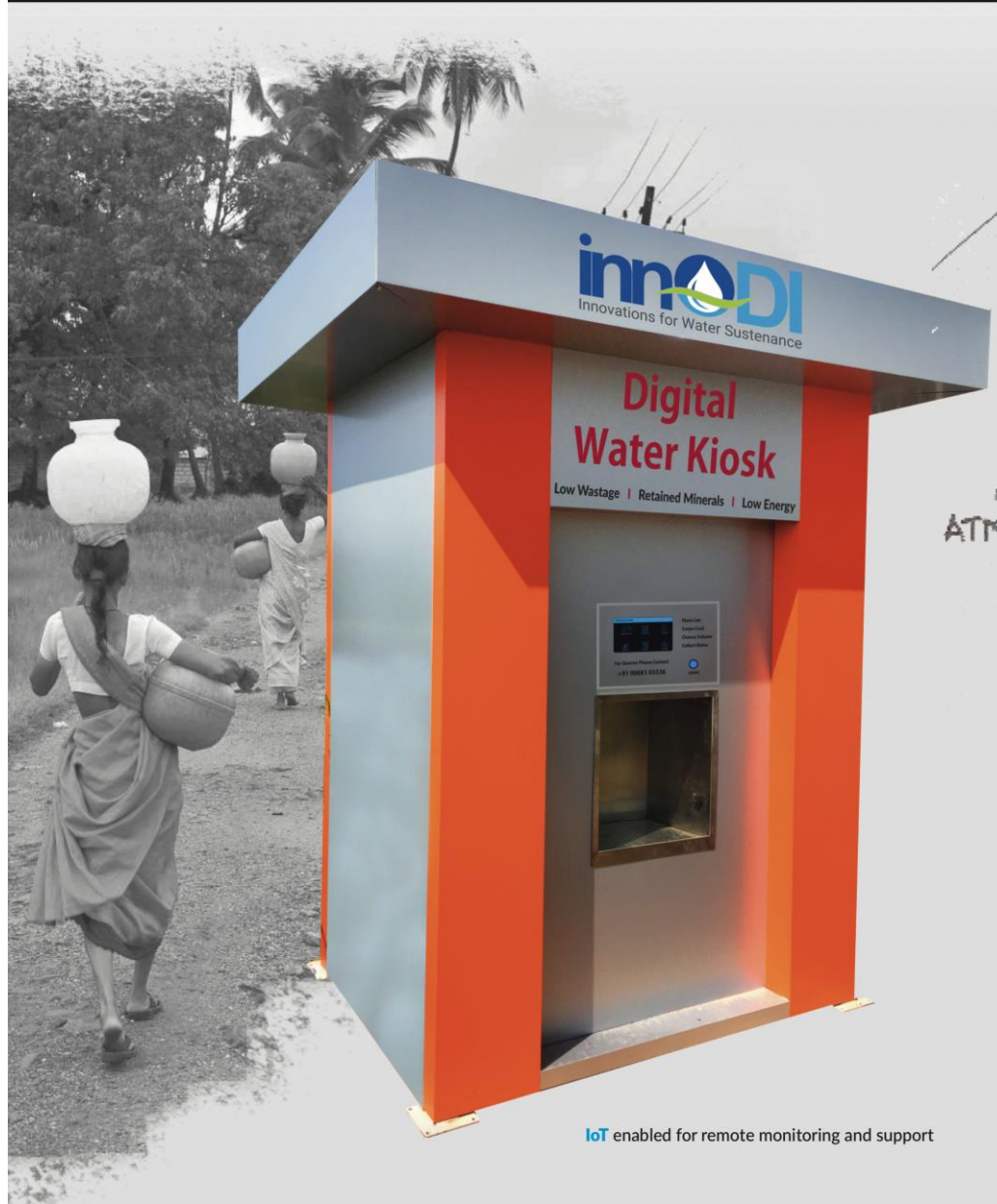
Our new company

Soujit Sengupta, Rabiul Islam and others

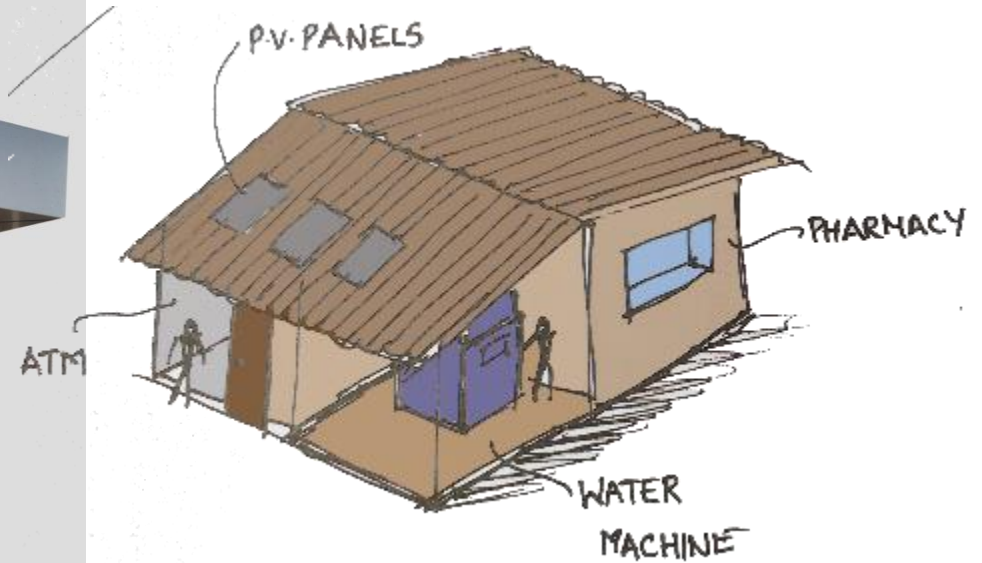


DIGITAL WATER KIOSK

for community drinking using CDI Technology



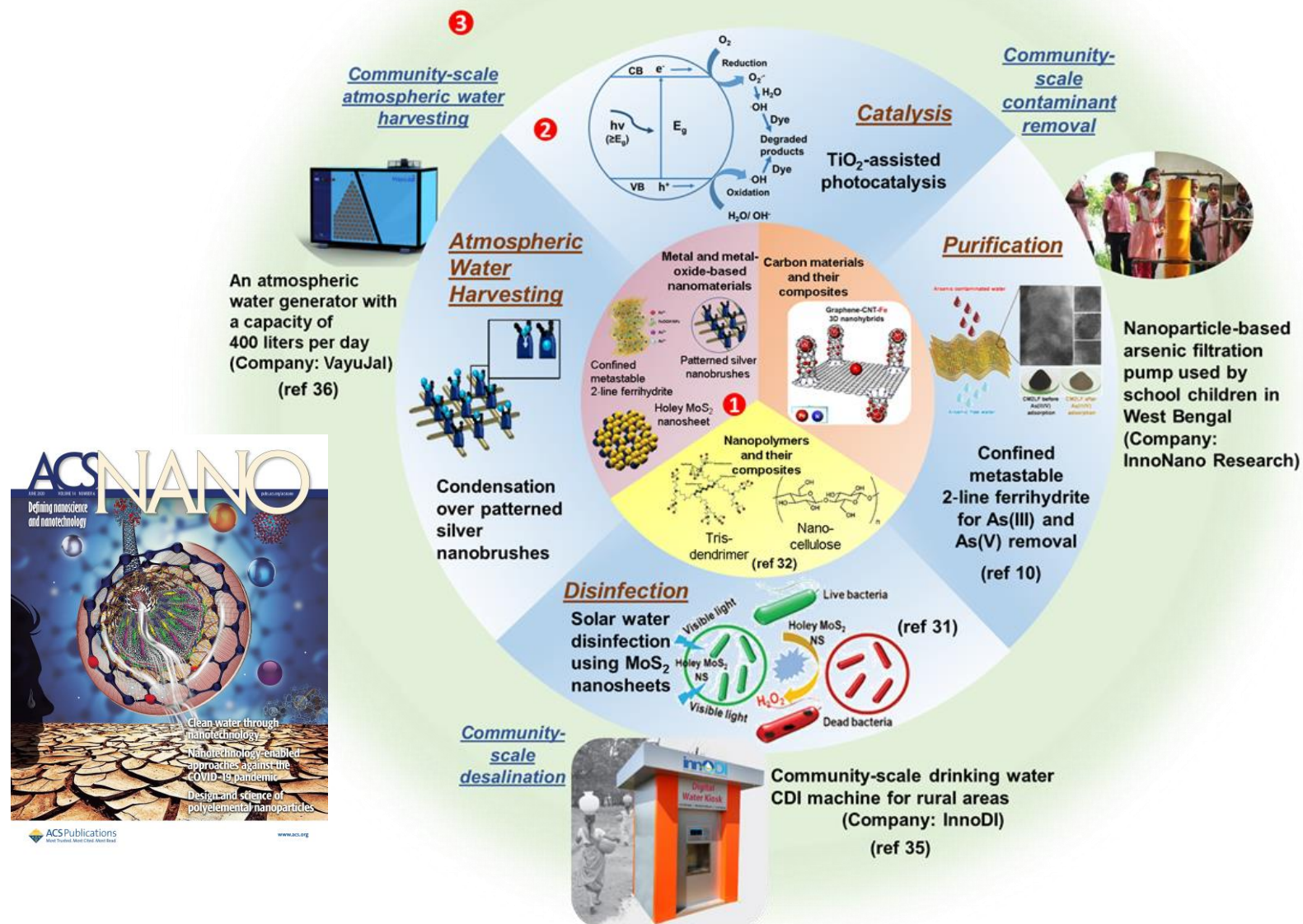
IoT enabled for remote monitoring and support



Products under implementation

Vijay Sampath and Tullio Servida

Evolution of materials to products



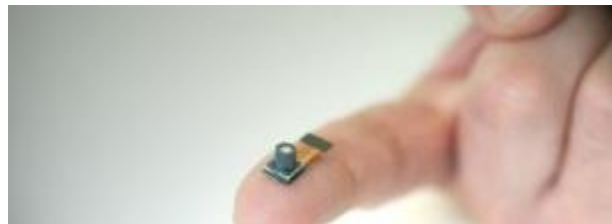
Sensors and new opportunities



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



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

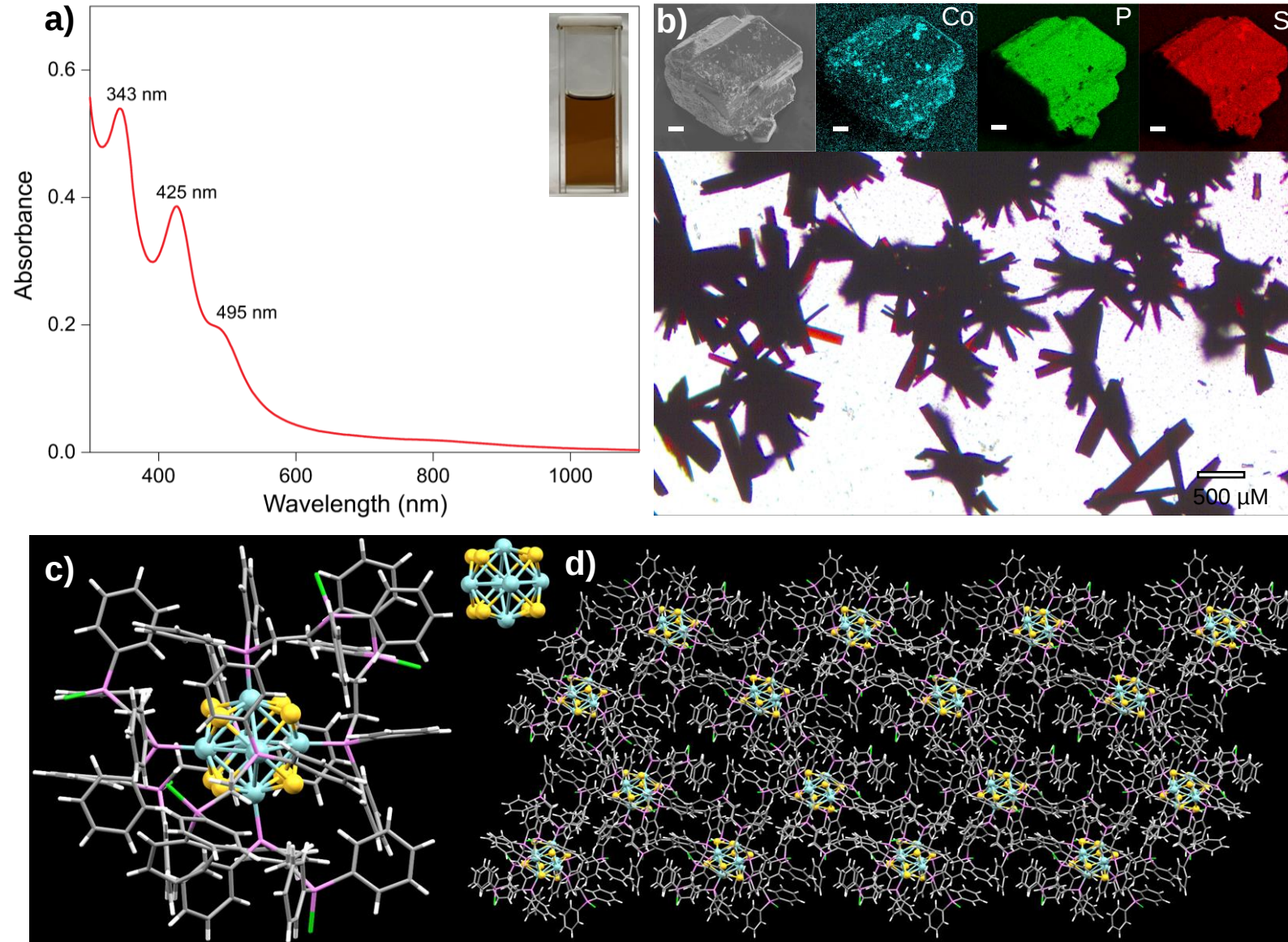


Water quality measurement – In the pipeline

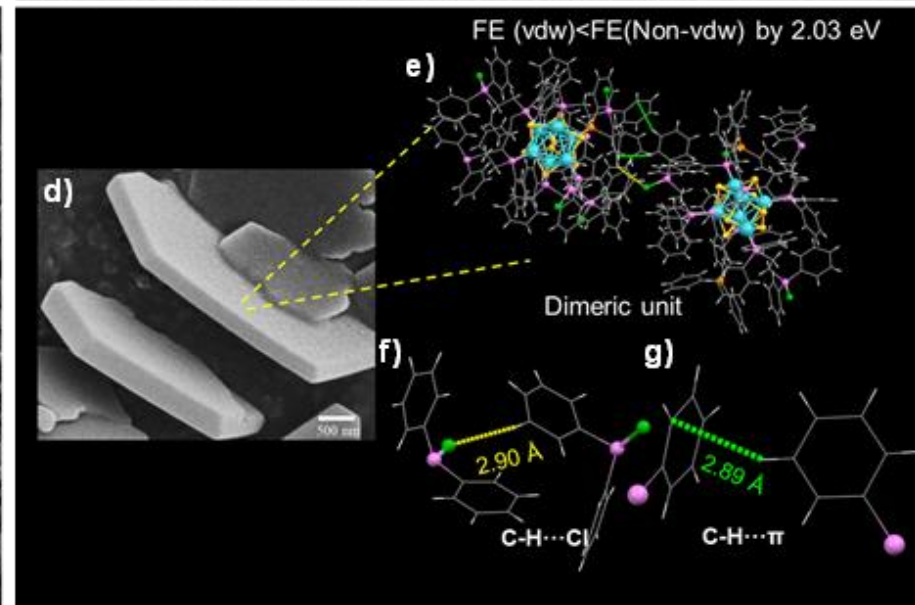
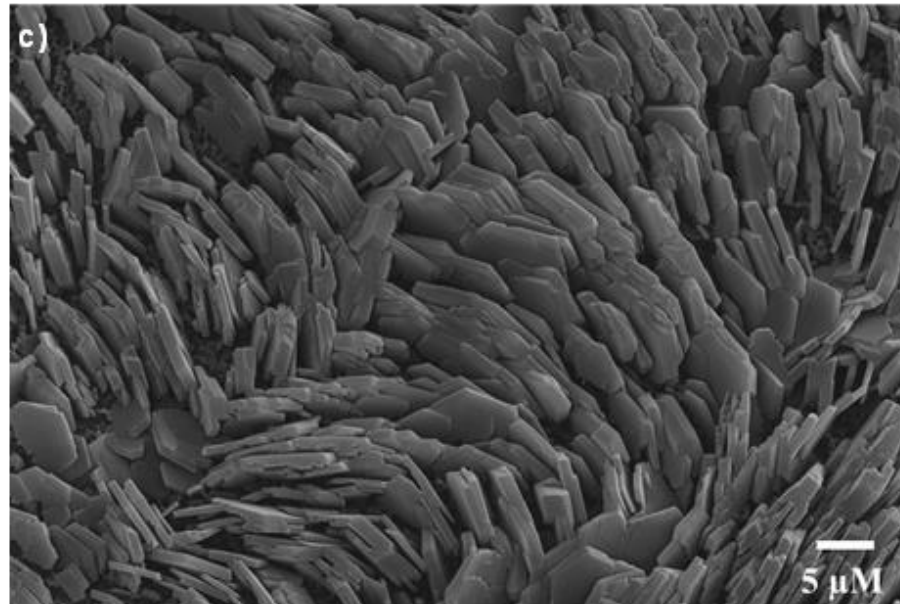
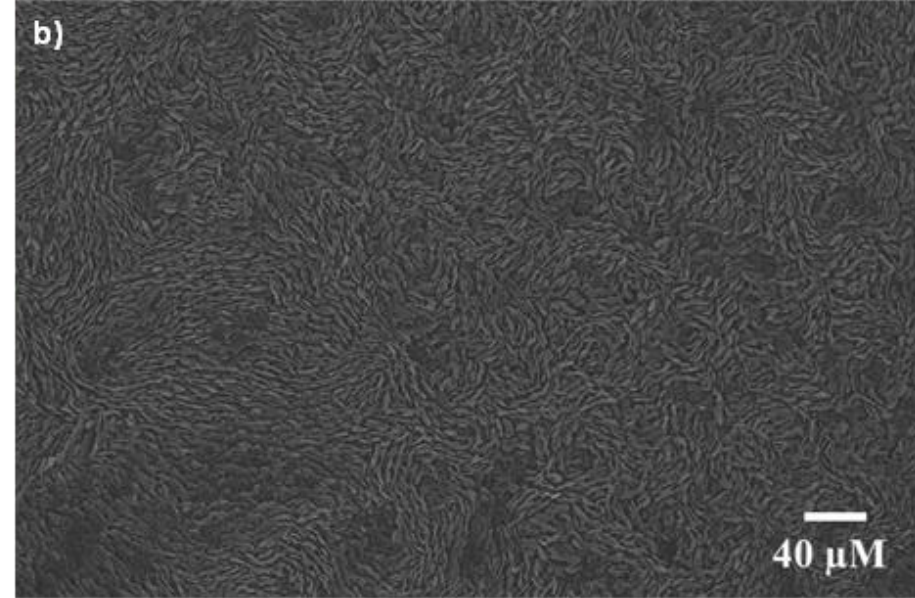
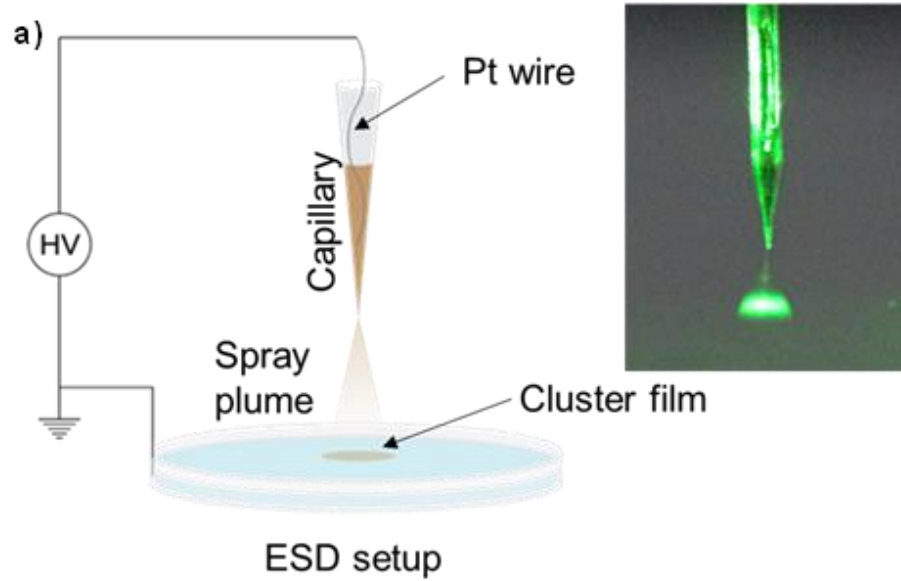
nanolambda

New electrodes - Aligned nanoplates of Co_6S_8

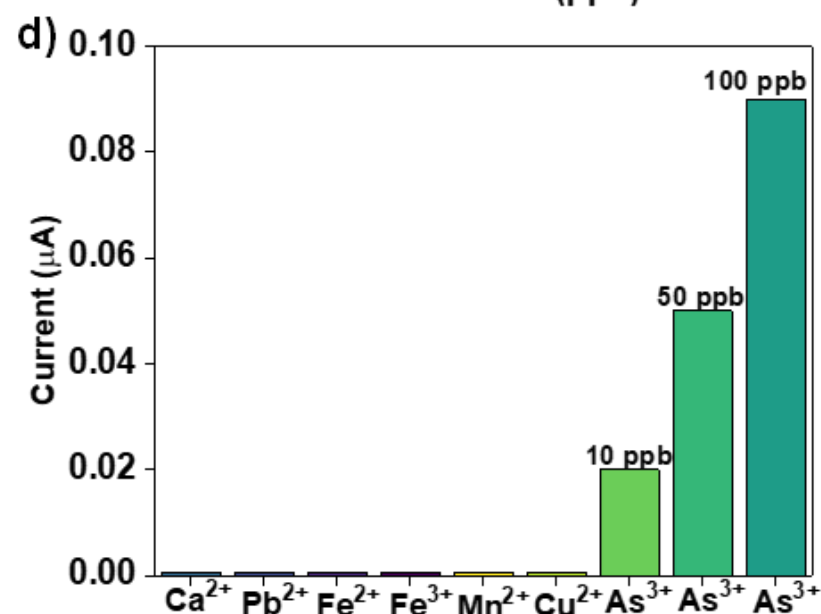
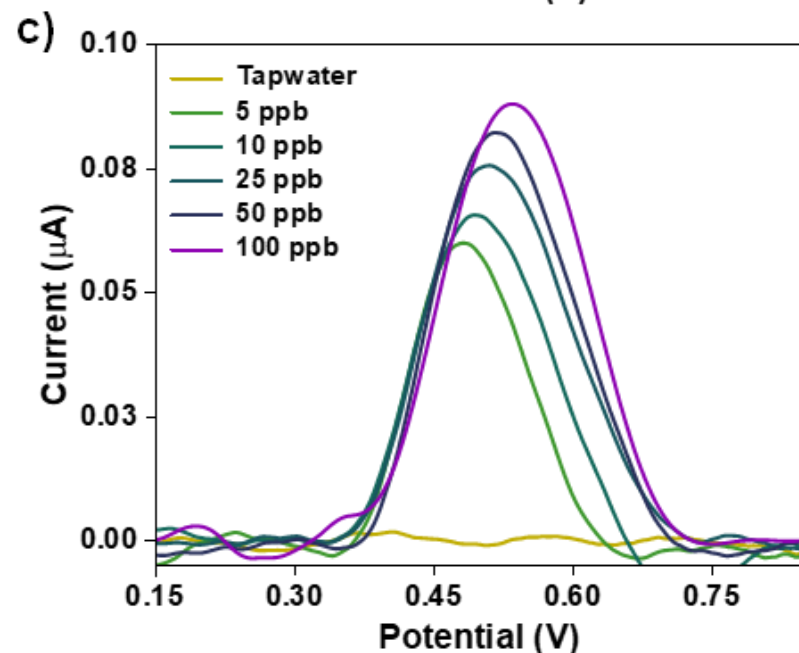
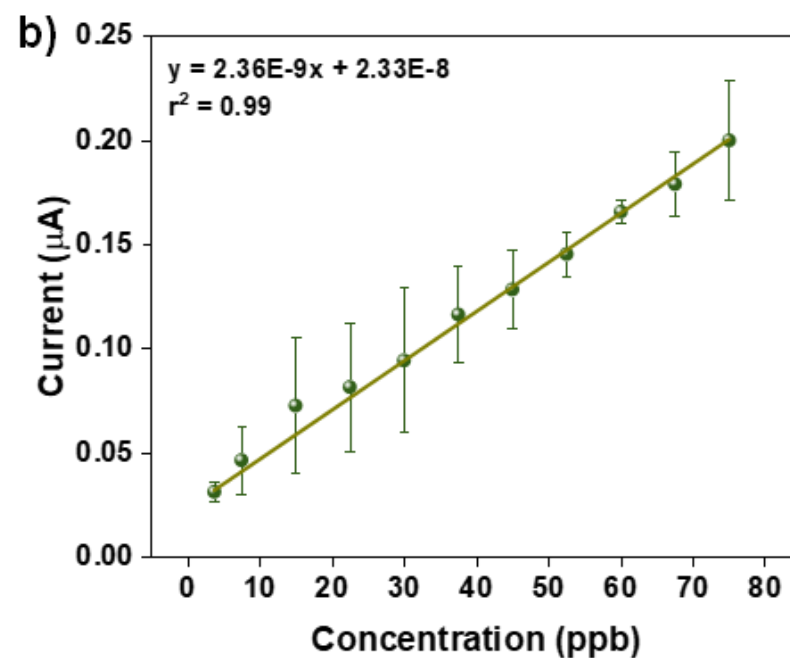
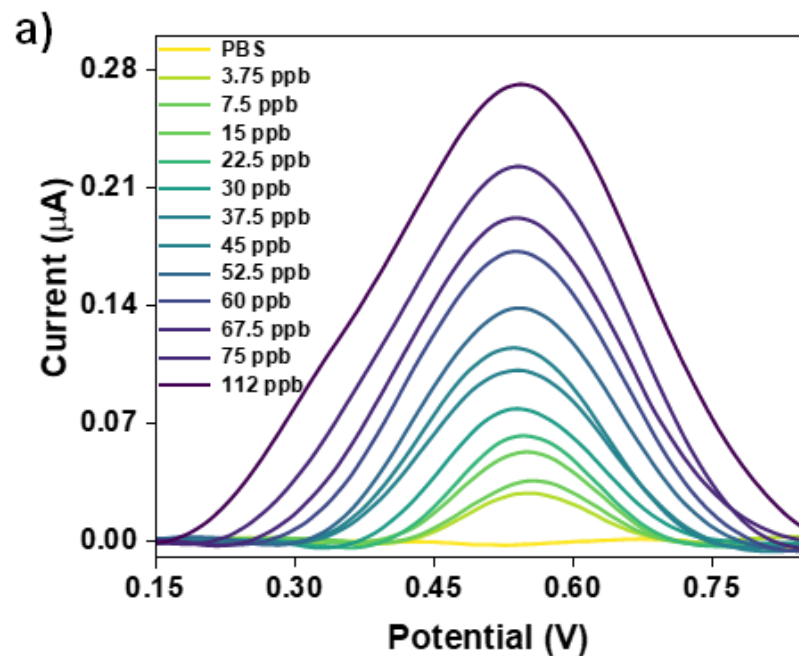
1,2-bis(diphenylphosphino)ethane (DPPE)



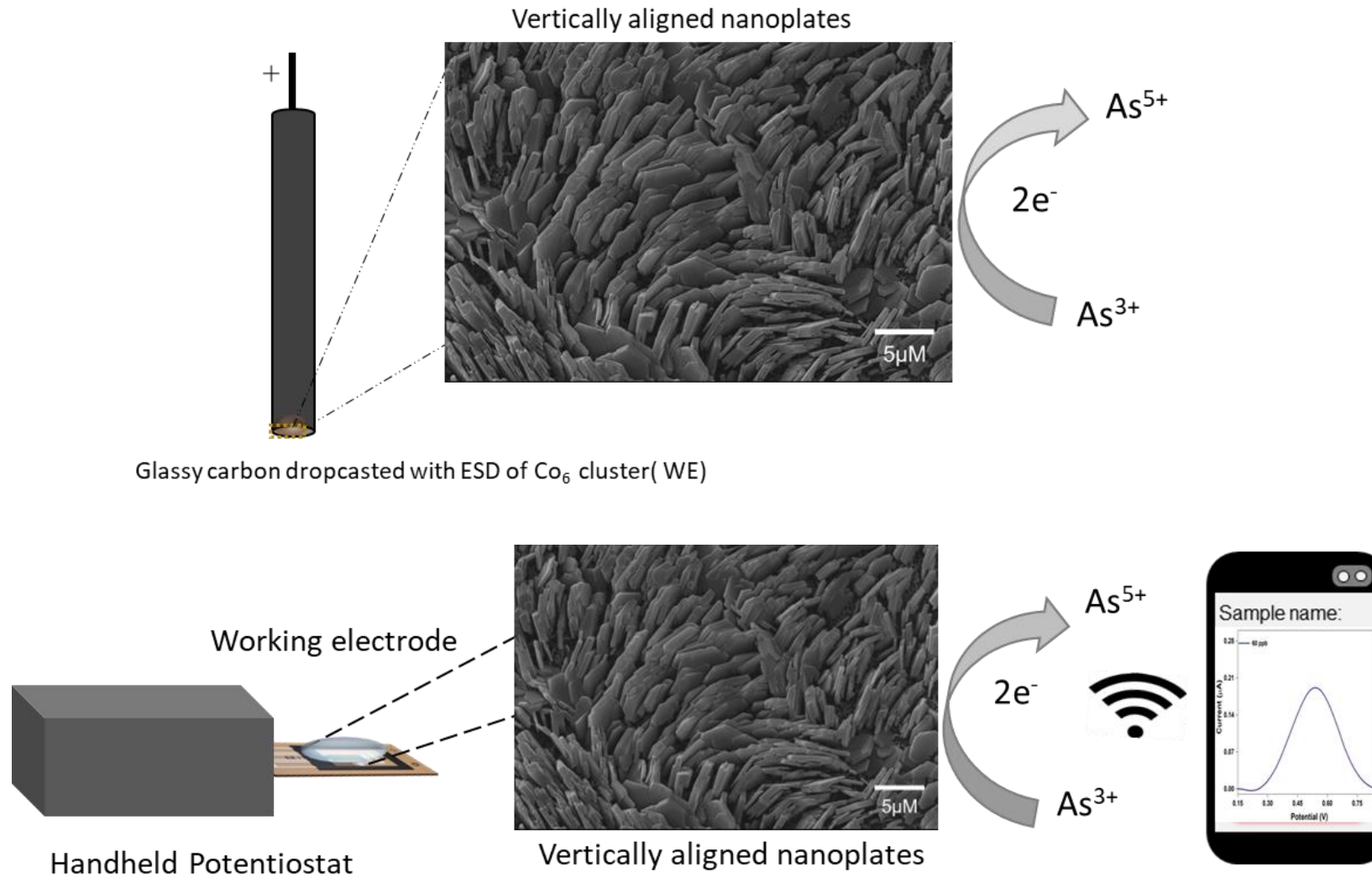
Electrospray deposition



Sensing



Working electrode



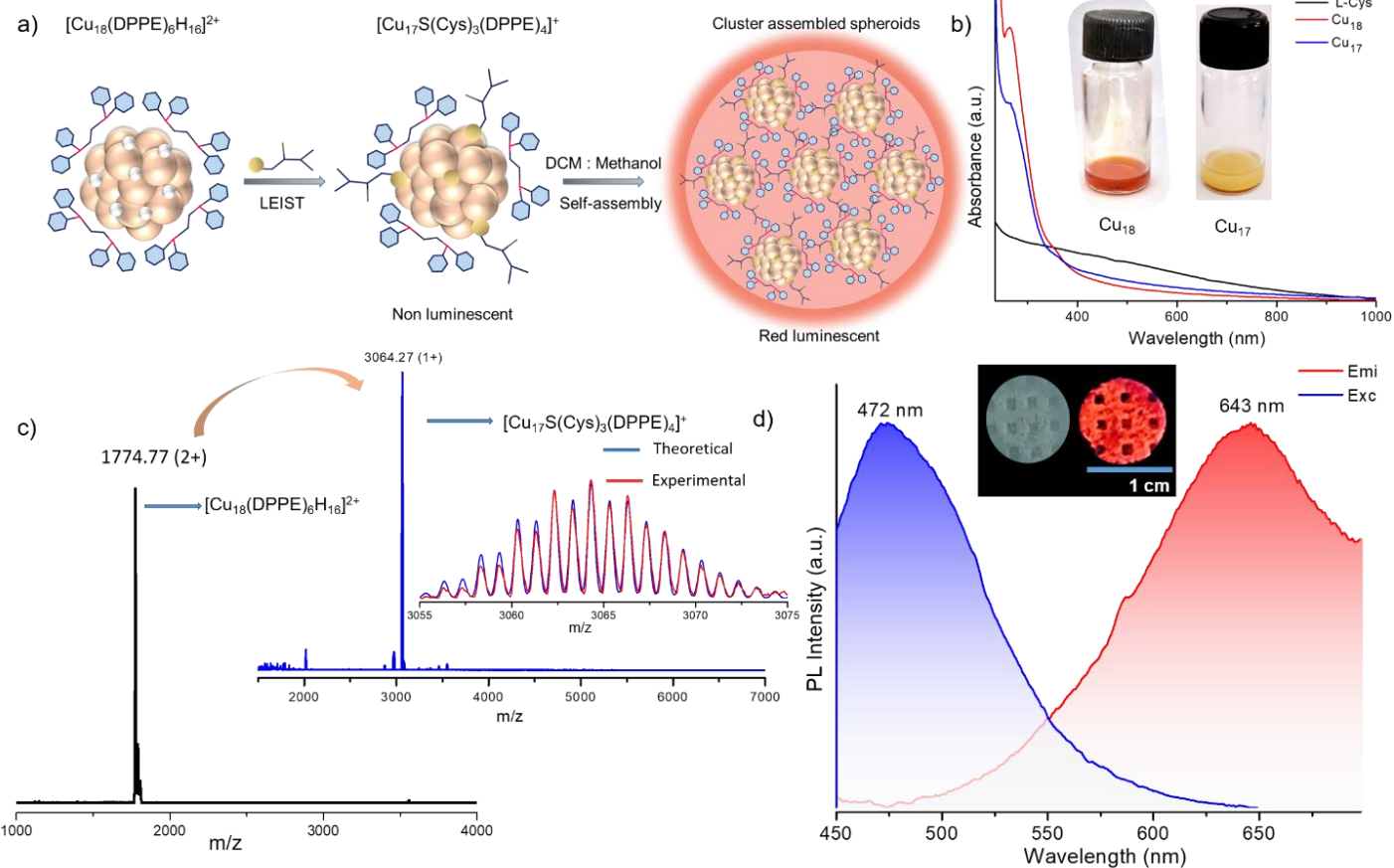
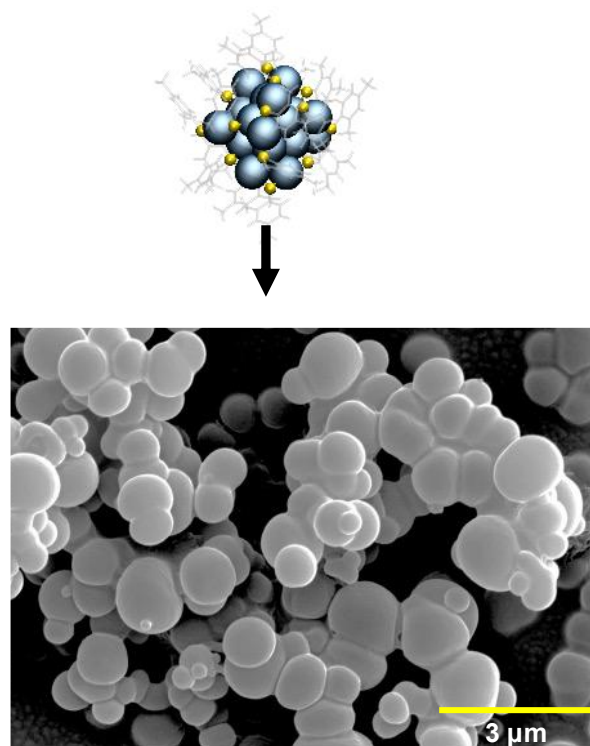
Anagha Jose et al. *ACS Materials Lett.*, 5 (2023) 893–899.

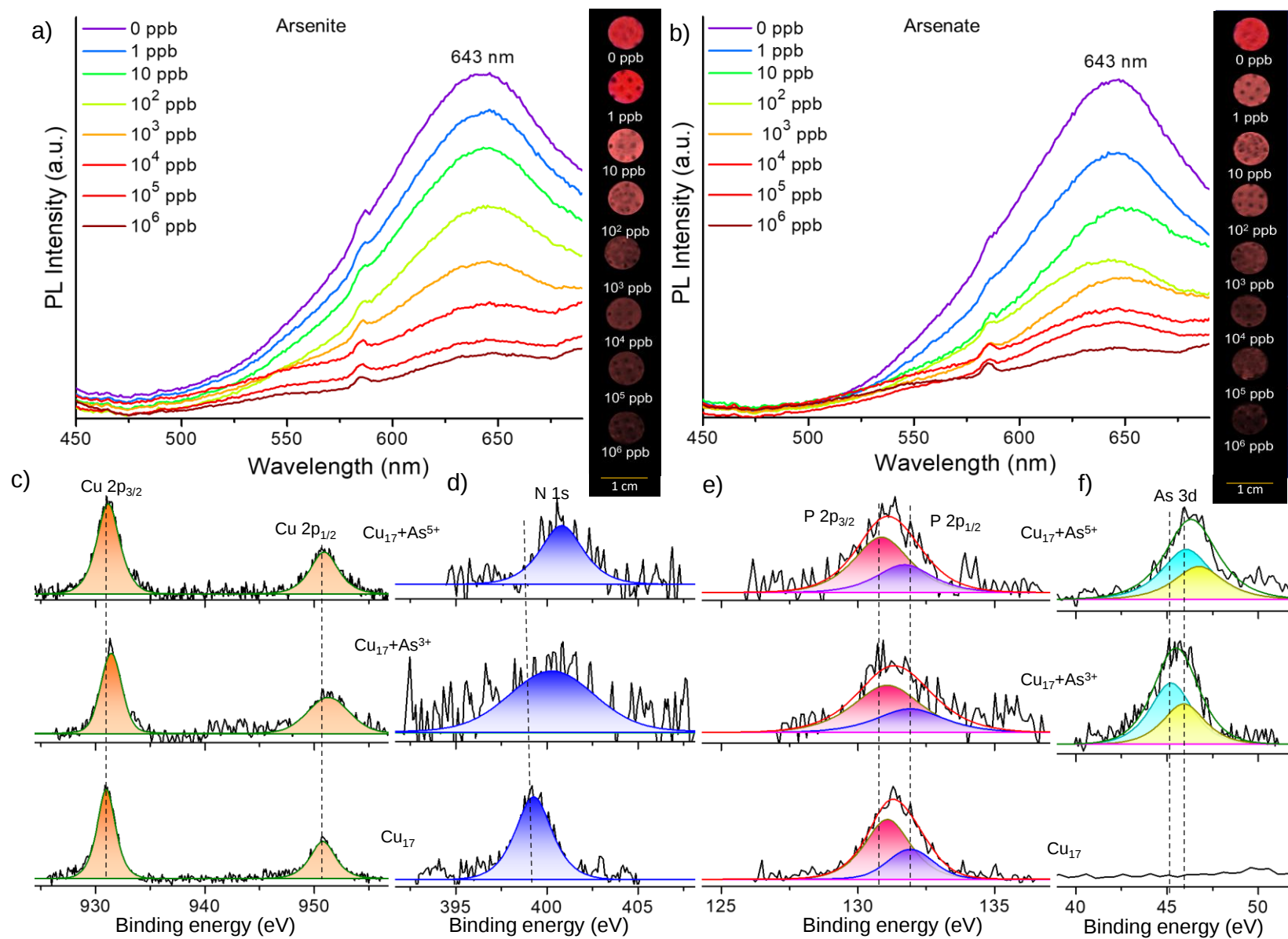
Cysteine-Protected Antibacterial Spheroids of Atomically Precise Copper Clusters for Direct and Affordable Arsenic Detection from Drinking Water

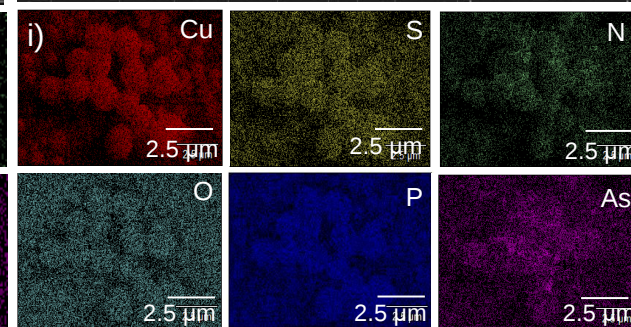
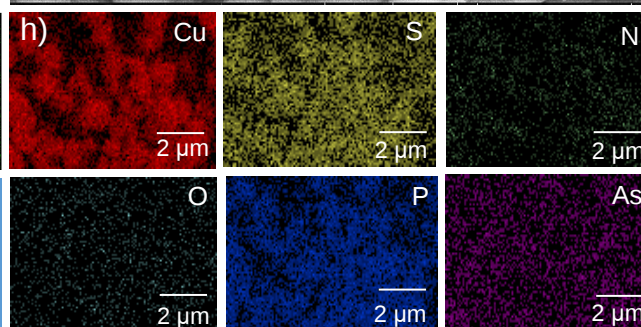
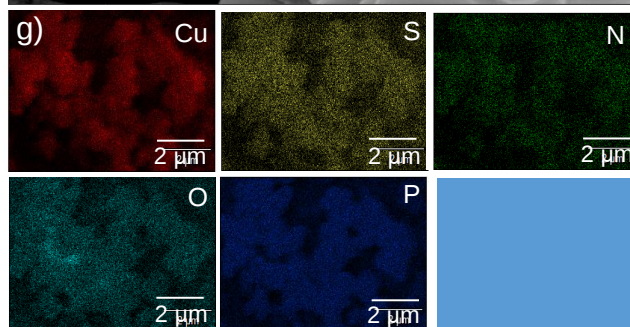
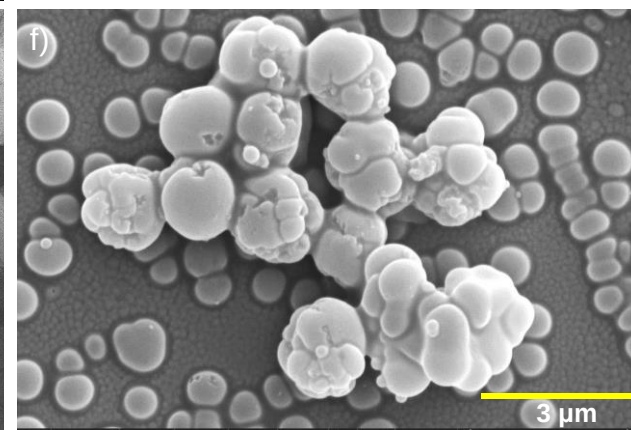
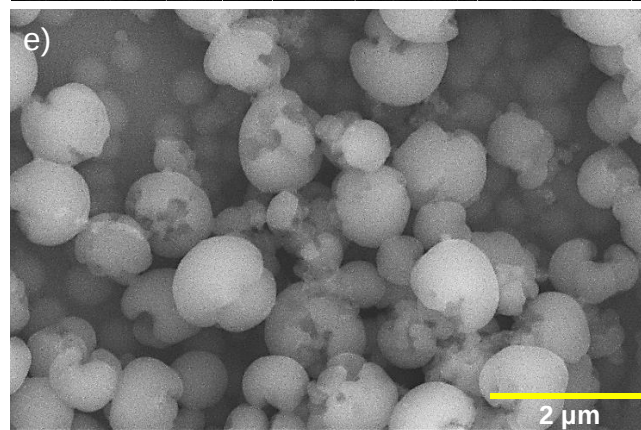
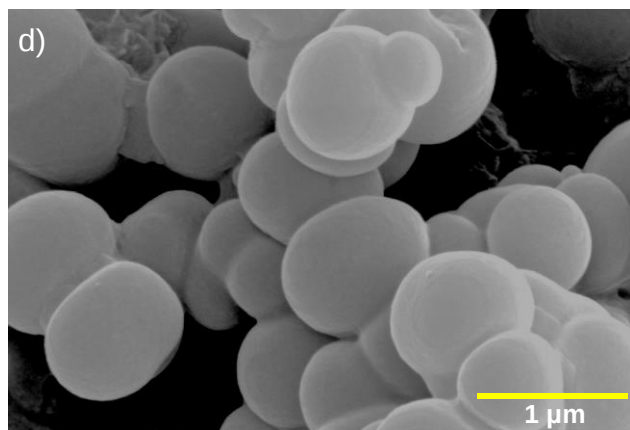
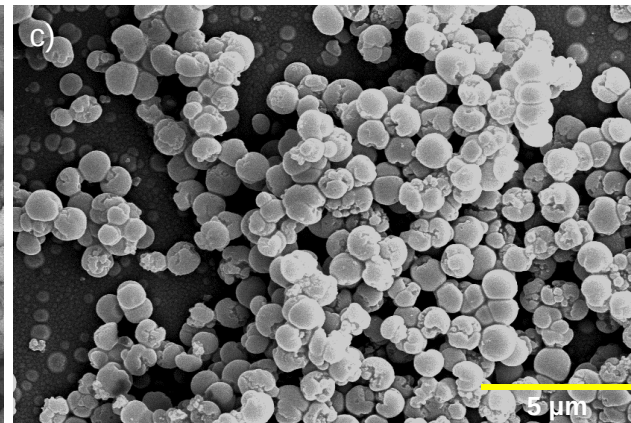
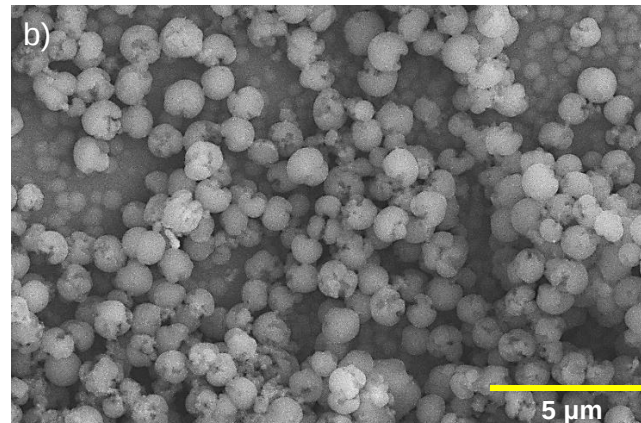
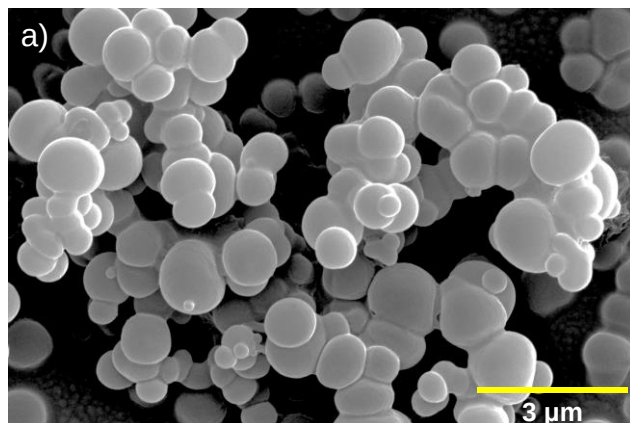
Jenifer Shantha Kumar, Arijit Jana, Jayathraa Raman, Hema Madhuri Veera, Amoghavarsha Ramachandra Kini, Jayoti Roy, Saurav Kanti Jana, Tiju Thomas, and Thalappil Pradeep*

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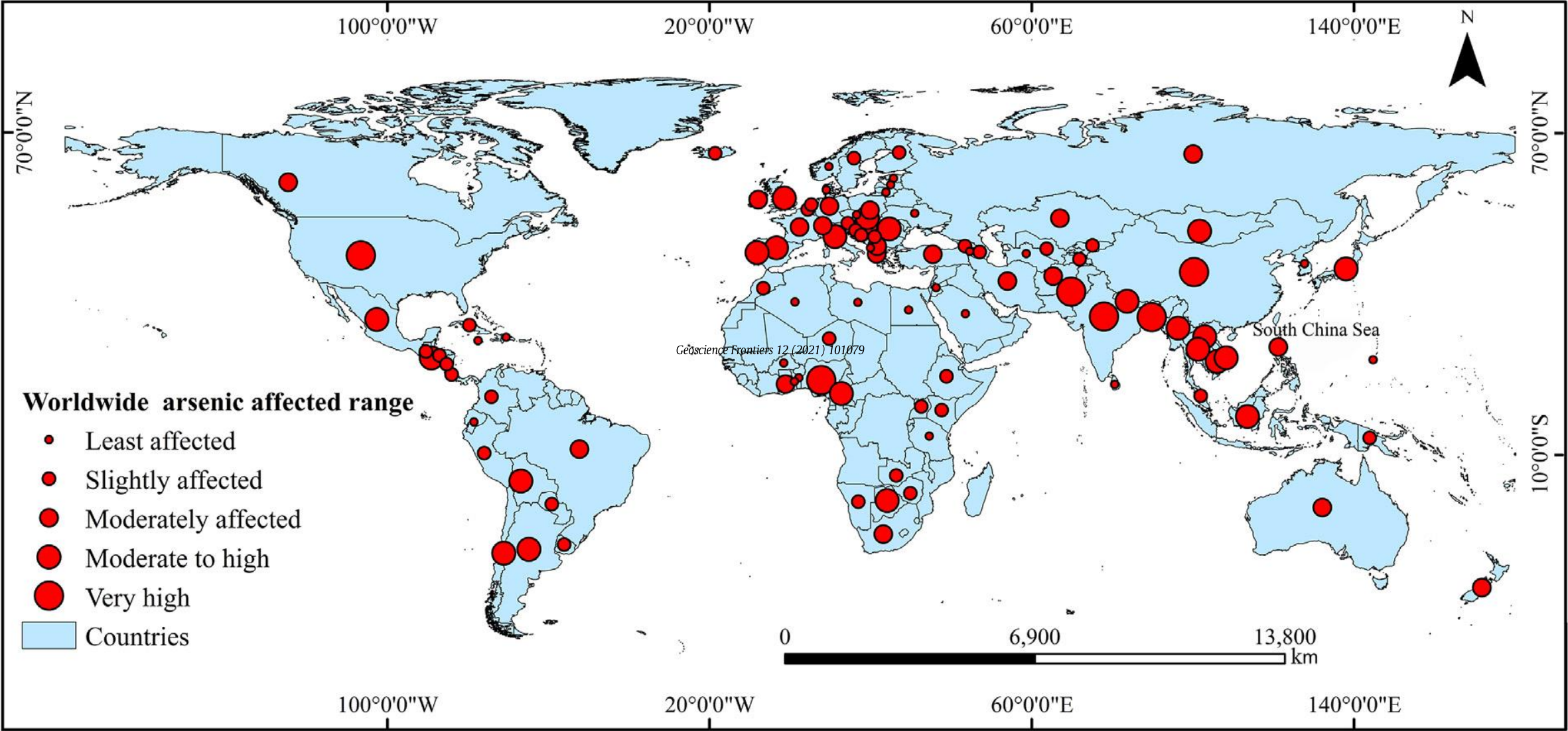
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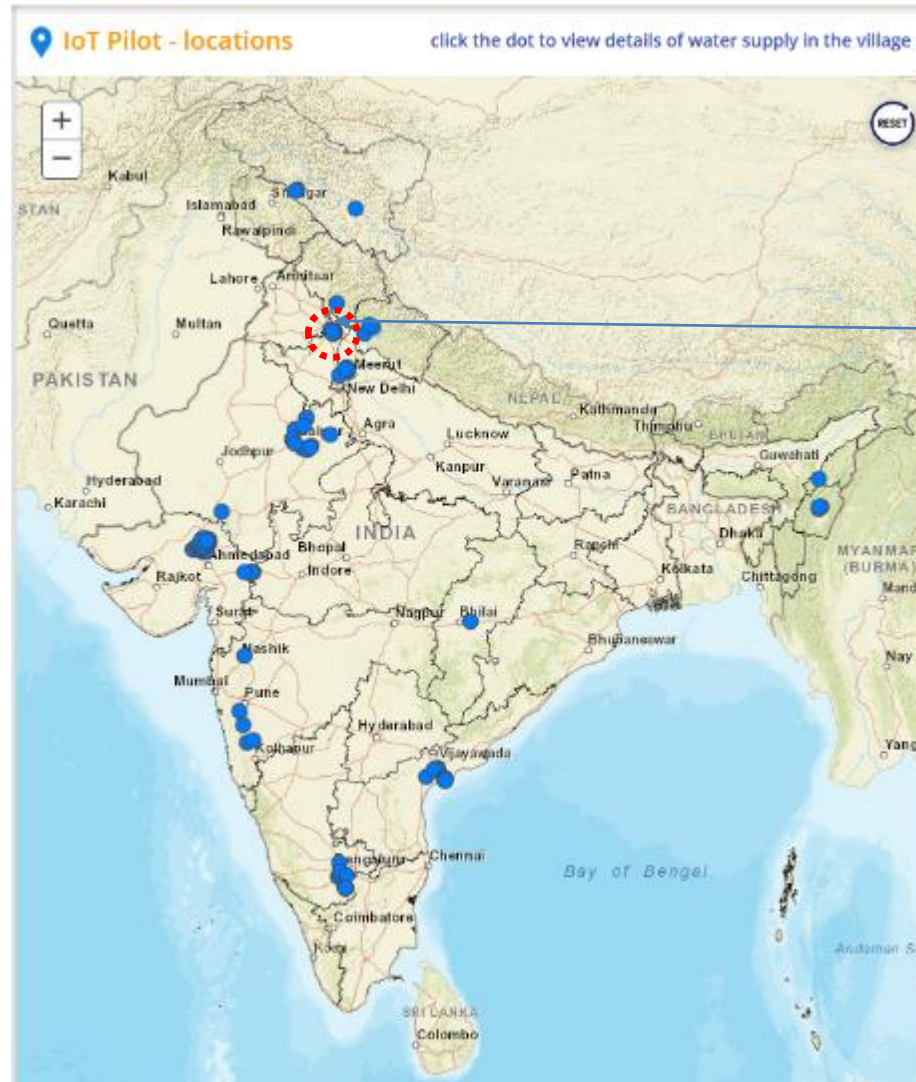


Arsenic poisoning across the world



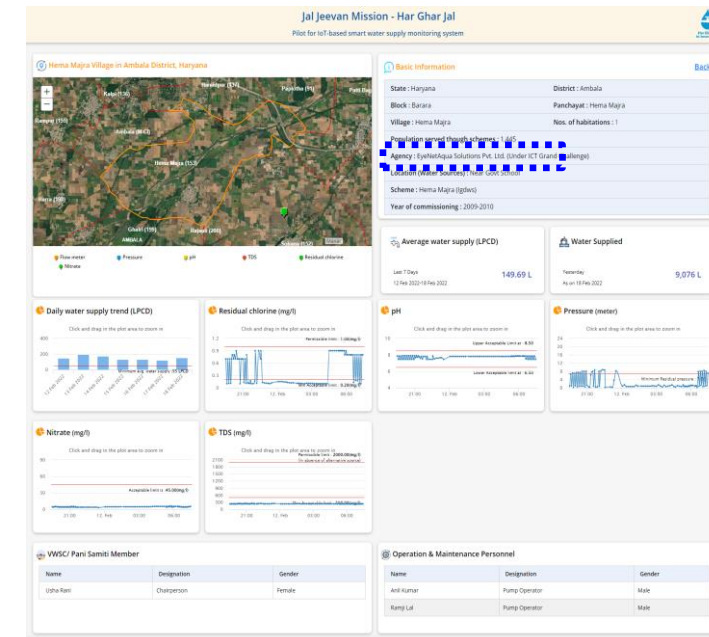


India's water is being monitored



IITM/IISc

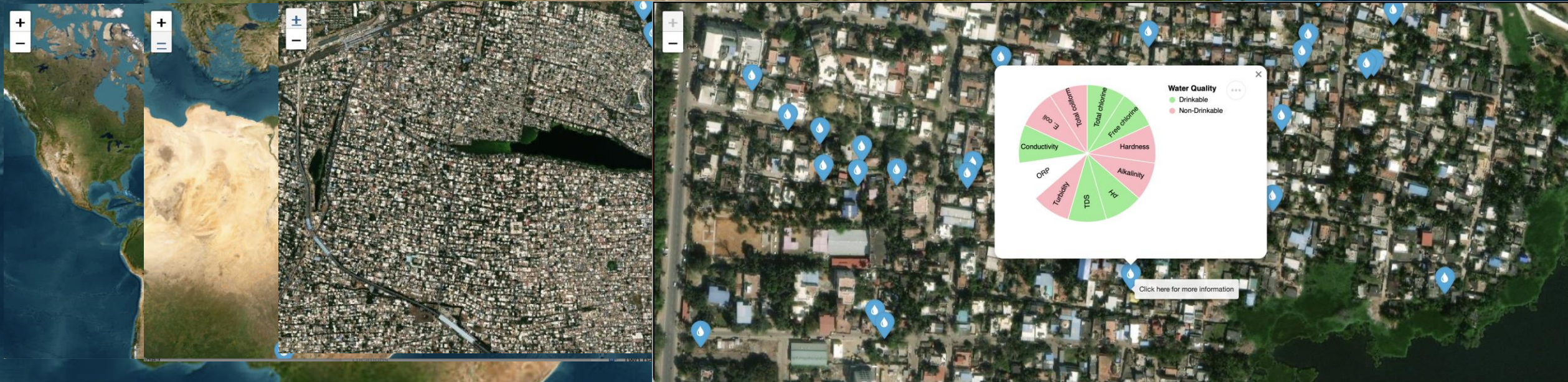
Installations made by four companies



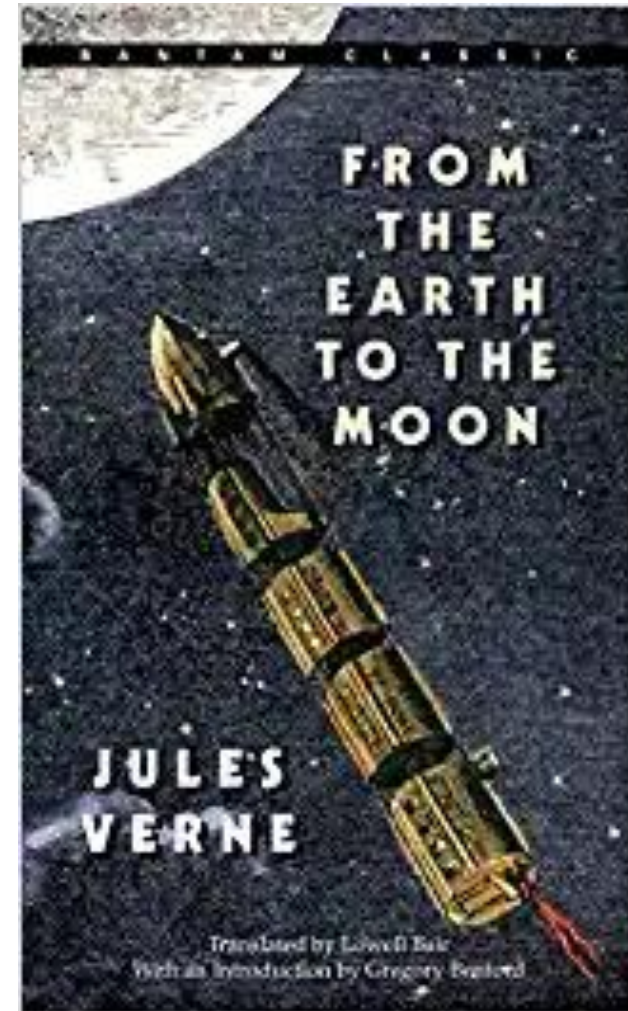
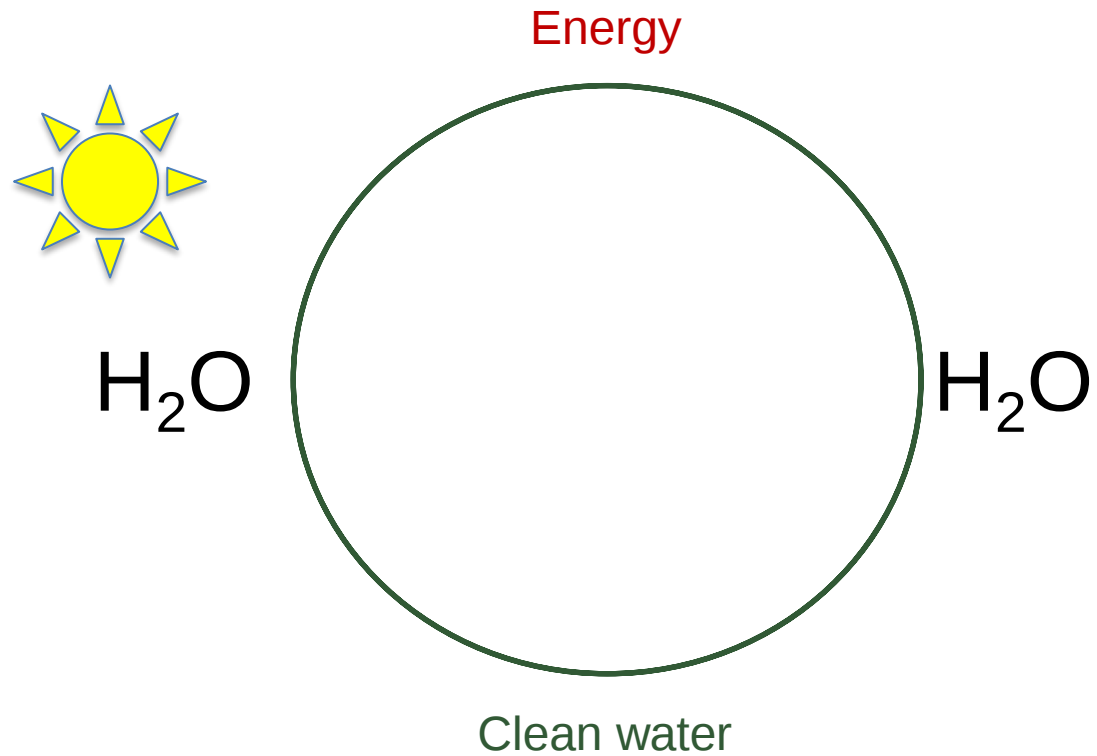




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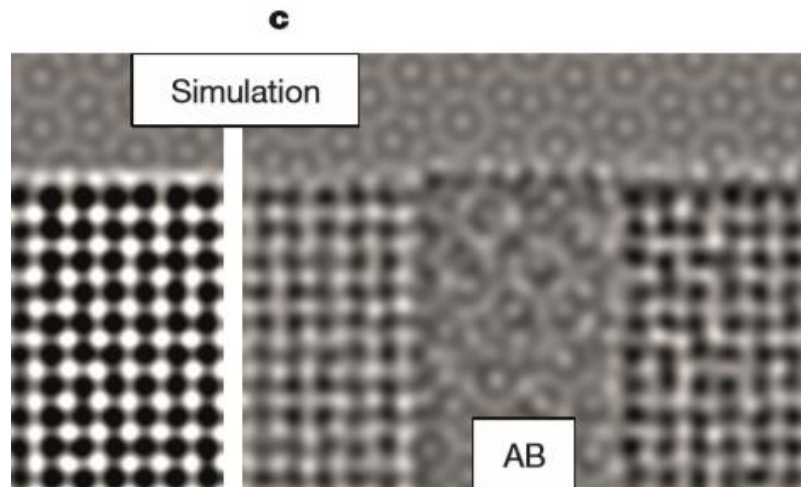
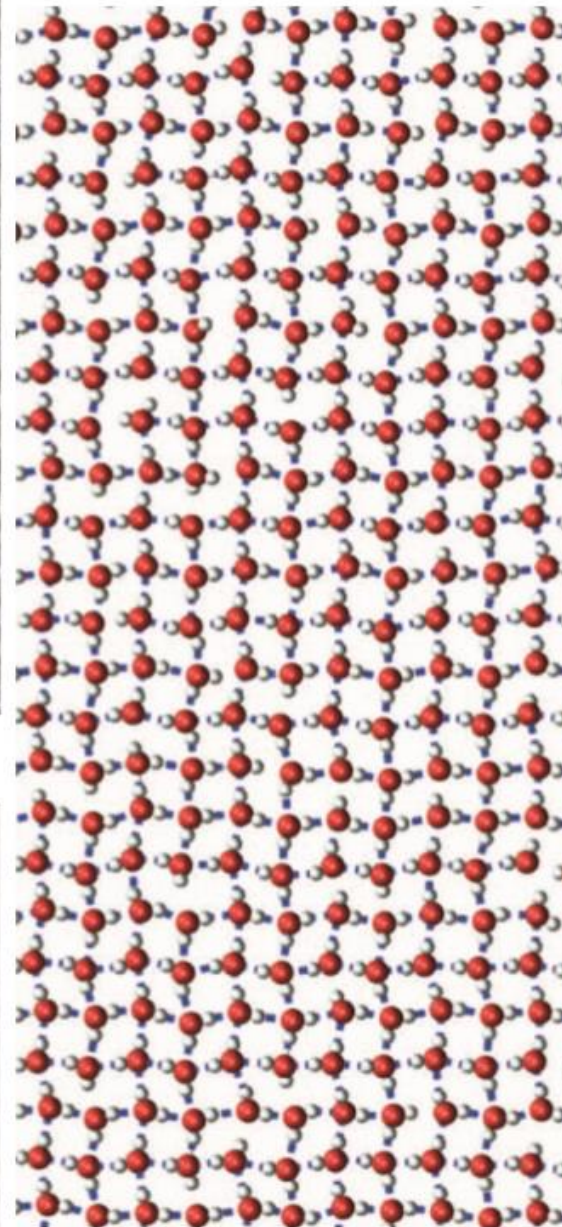
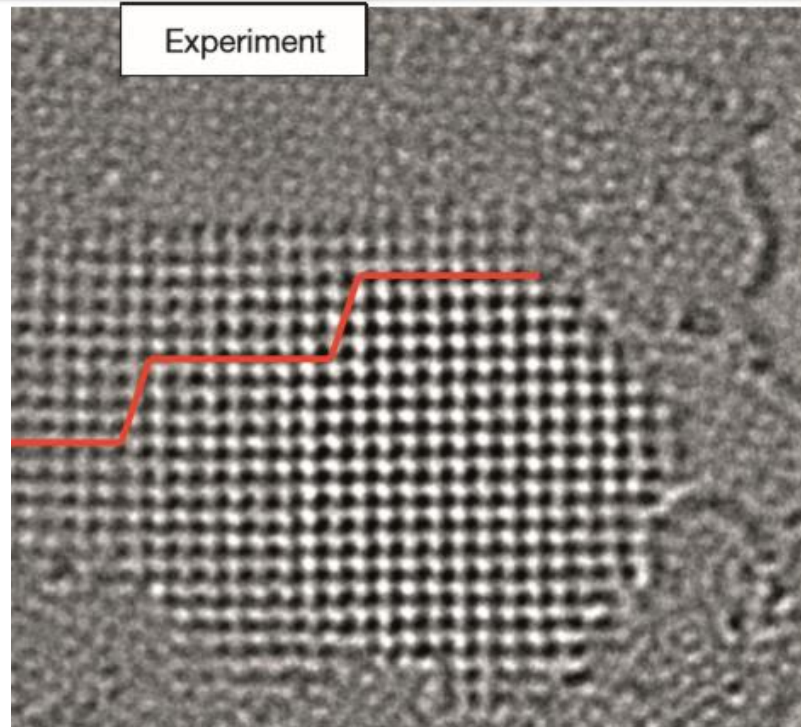


International Centre for Clean Water



IIT Madras Research Park

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.



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Water presents a unique
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Earthrise, taken on December 24, 1968, by Apollo astronaut William Anders.
From Wikipedia

RESEARCH

NANOPARTICLES

Spontaneous weathering of natural minerals in charged water microdroplets forms nanomaterials

B. K. Spoorthi¹, Koyendrilla Debnath², Pallab Basuri¹, Ankit Nagar¹, Umesh V. Waghmare², Thalappil Pradeep^{1,3*}

In this work, we show that particles of common minerals break down spontaneously to form nanoparticles in charged water microdroplets within milliseconds. We transformed 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.

Nanoparticles of minerals exist naturally in soil, and some of them are essential for life (1). Microdroplets have been a topic of interest over the past decade, and 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-sized particles of natural quartz (SiO_2) and ruby (O-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 mm in size and used particles of 5 to 10 mm 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. S8). 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. S2). We electrosprayed a suspension of about 0.1 mg/ml of the separated quartz particles through a capillary

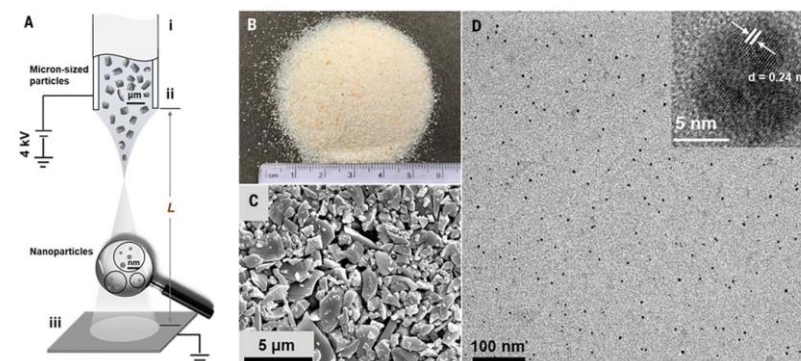
tube that had an inner diameter of 50 nm, flow rate of 0.5 ml/hour and observed the resulting plume (Fig. 1A). We collected the product of electrospray 15 cm away from the spray tip, which resulted in a flight time on the order of 10 ms, consistent with similar experiments (3, 4). The product that was deposited on a transmission electron microscopy (TEM) grid had only 5- to 10-nm-diameter particles (Fig. 1D) throughout the grid. Under higher magnification, particles of different morphologies were observed. The particles showed the (110) plane of quartz (inset of Fig. 1D). Sonication 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 S8).

To ensure that our initial observations were truly representative of the process, we performed measurements on larger 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 optimized conditions (spray voltage and distance) and a 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