Since 1959

Affordable Clean Water Using Advanced Materials

Thalappil Pradeep
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https://pradeepresearch.org

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.

Professor-in-charge

International Centre for Clean Water

Associate Editor

ACS Sustainable Resource Management

Centennial Jubilee Celebration, Indian Chemical Society, Nehru Centre, Mumbai, January 28, 2025

Since 1959

Molecular Acorns to Institutional Oaks

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ICCW
INTERNATIONAL CENTRE FOR CLEAN WATER

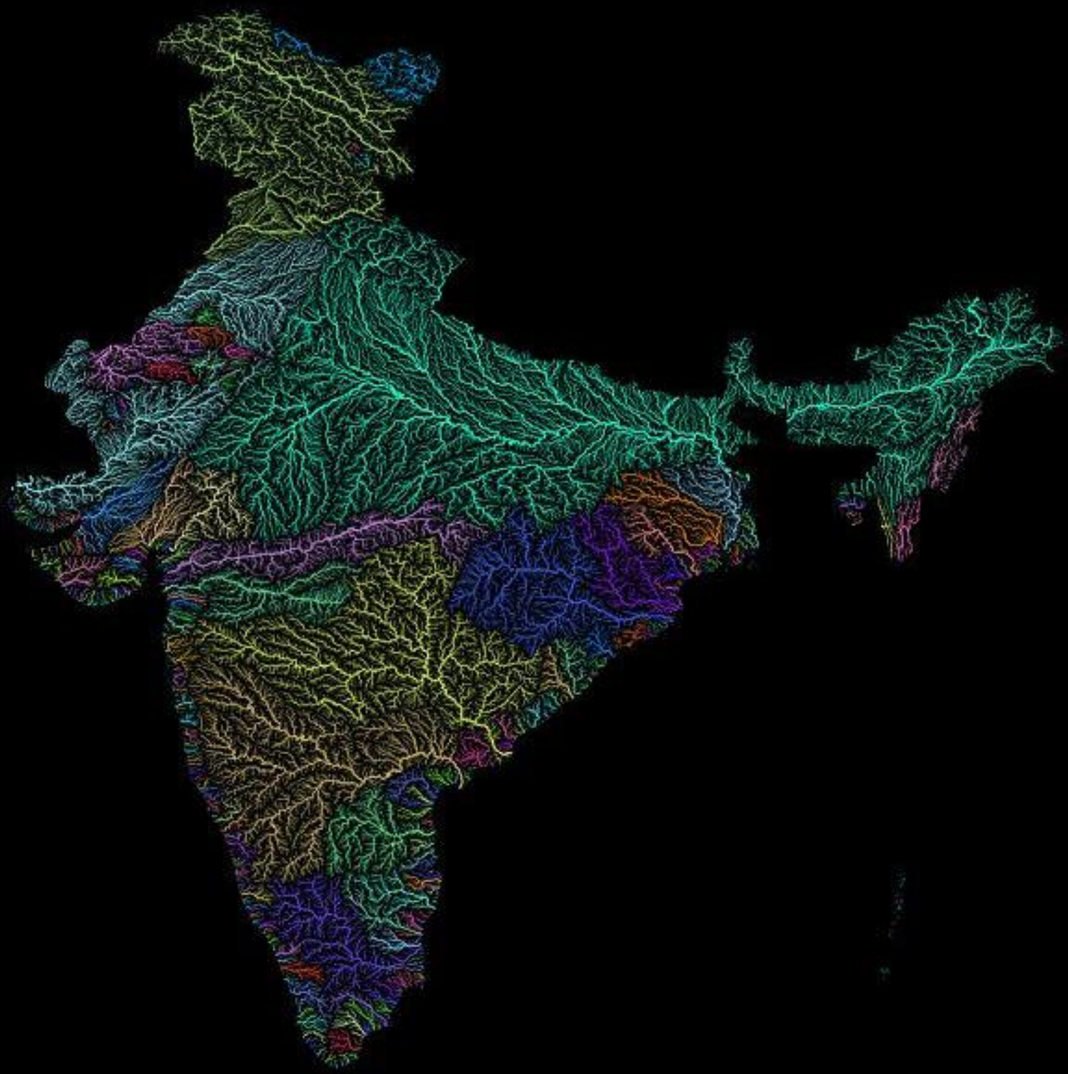
International Centre for Clean Water

Associate Editor
ACS Sustainable Resource Management

pradeep RESEARCH GROUP

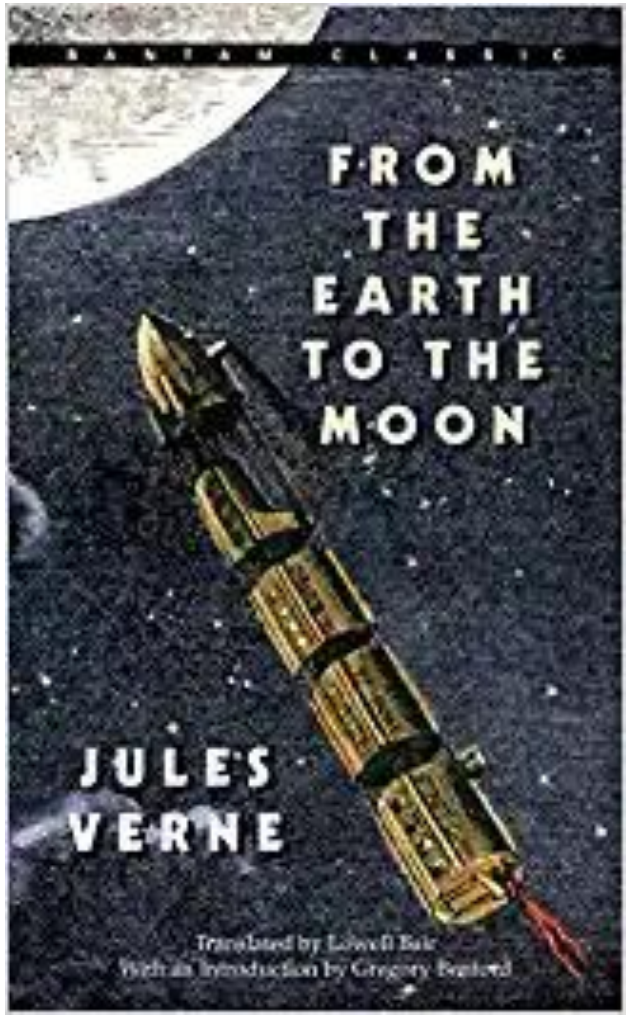
THEMATIC UNIT OF EXCELLENCE


"Pale blue dot" Voyager 1 Feb. 14, 1990
Water is the most important inheritance of our planet



From S. Vishwanath

Our dreams become reality with materials



World's first nanochemistry-based water purifier

RSC | Advancing the Chemical Sciences

Chemistry World

Pesticide filter debuts in India

20 April 2007

Killugudi 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. Jayachandra Reddy, 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,' Thalappil Pradeep who led the team at IIT Chennai told *Chemistry World*. He and his student Sreekumaran 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 nanoparticles[1].

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 ... water supplies.

Use and recycle

Chemistry world

First ever nanotechnology product for clean water

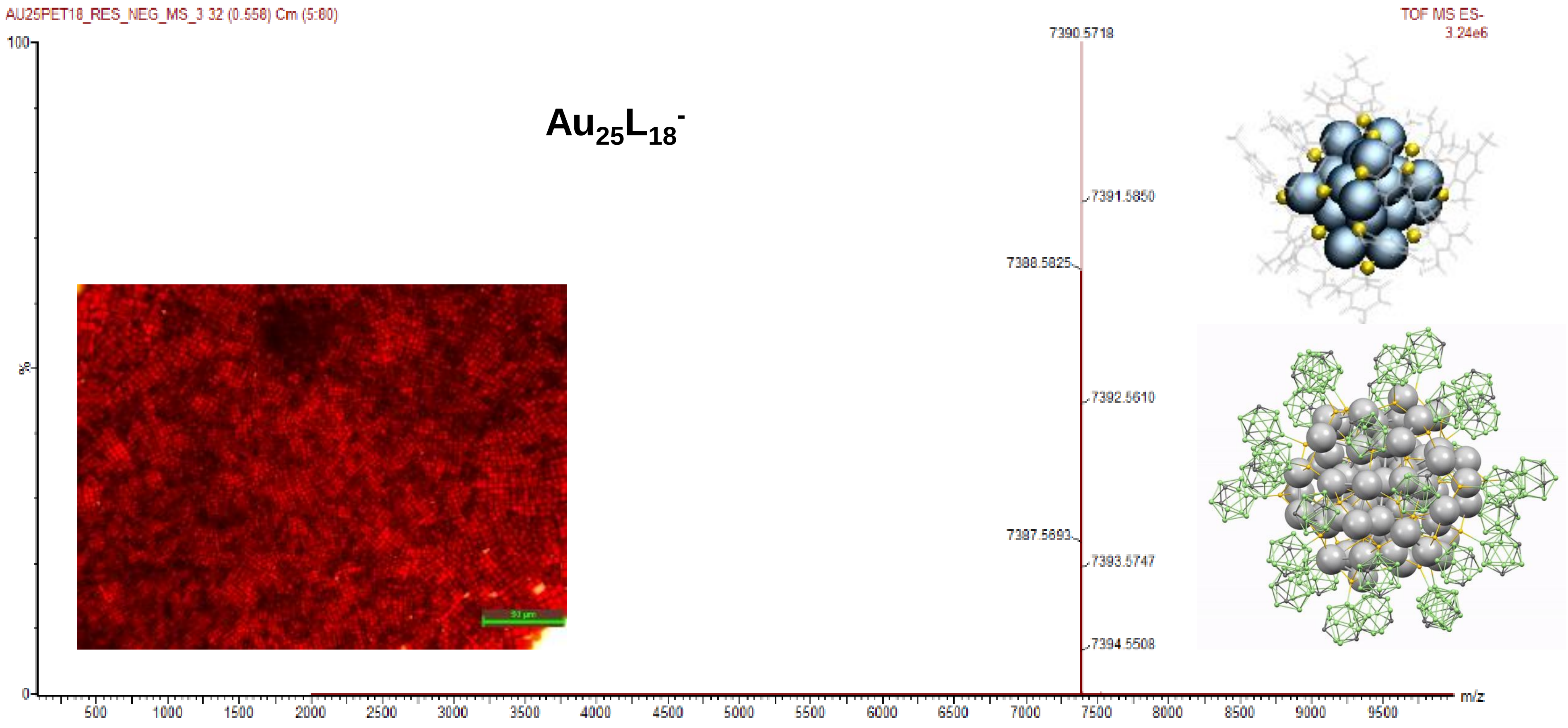
A plant to make supported nanomaterials for water purification; with capacity of 4.5 tons per month, 2007

1. Patents: A method of preparing purified water from water containing pesticides, **Indian patent 200767**
2. Extraction of malatheon and chlorpiryhphos 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

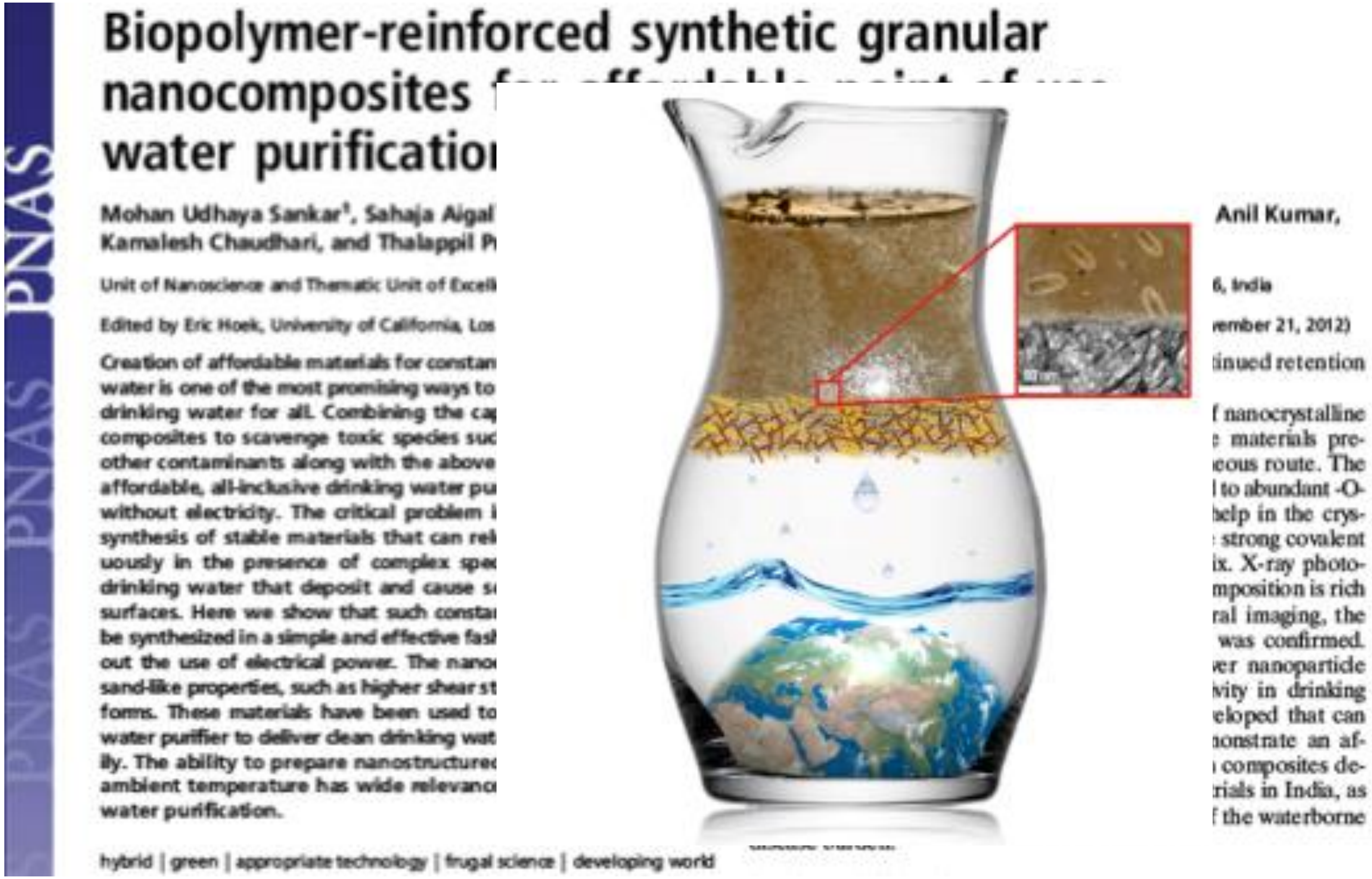


T. Pradeep et. al. *Acc. Chem. Res.* 2018; 2019.

Clean water for everyone

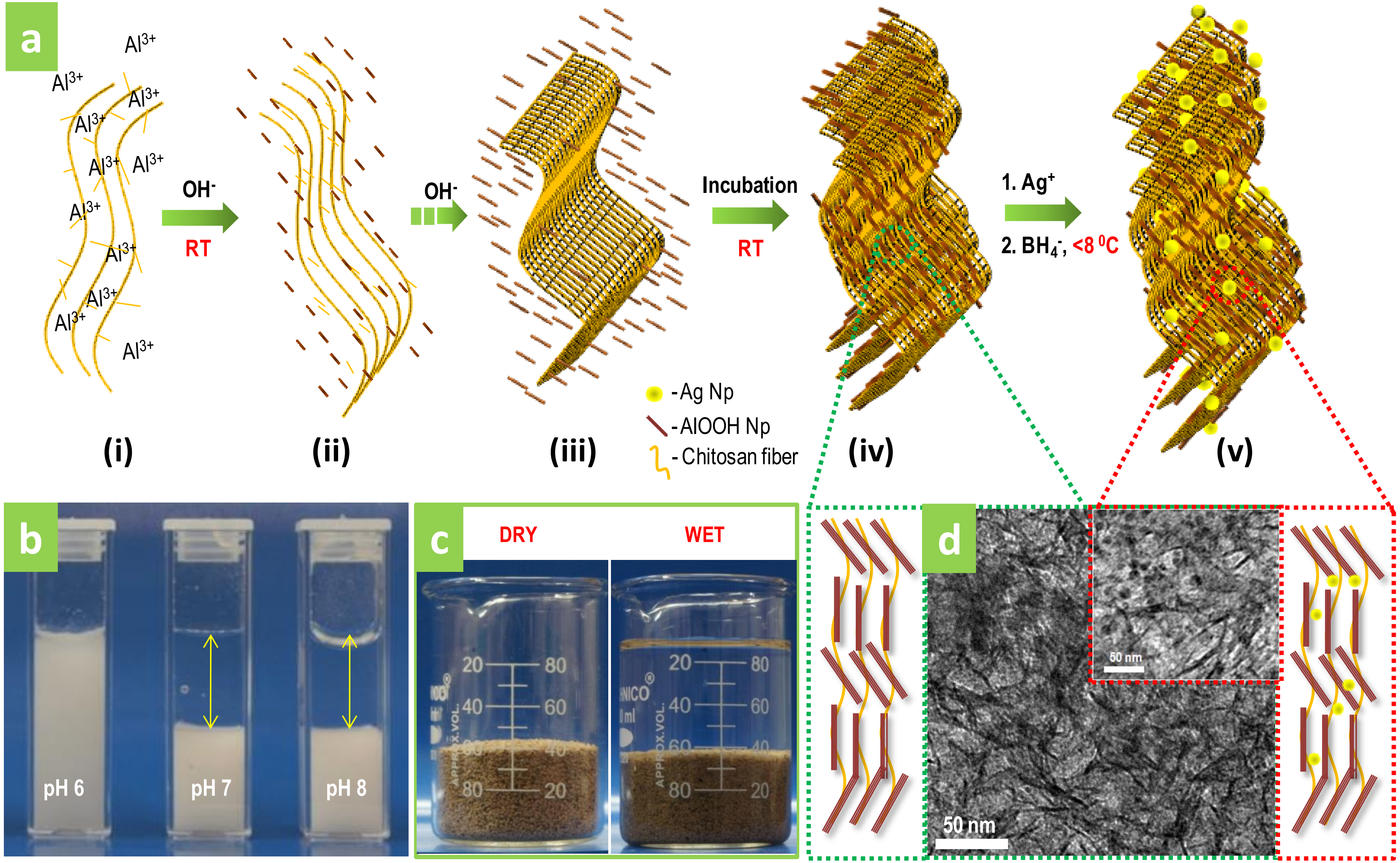
ACS Sustainable Chemistry & Engineering Editorial,
December 2016

Water positive materials



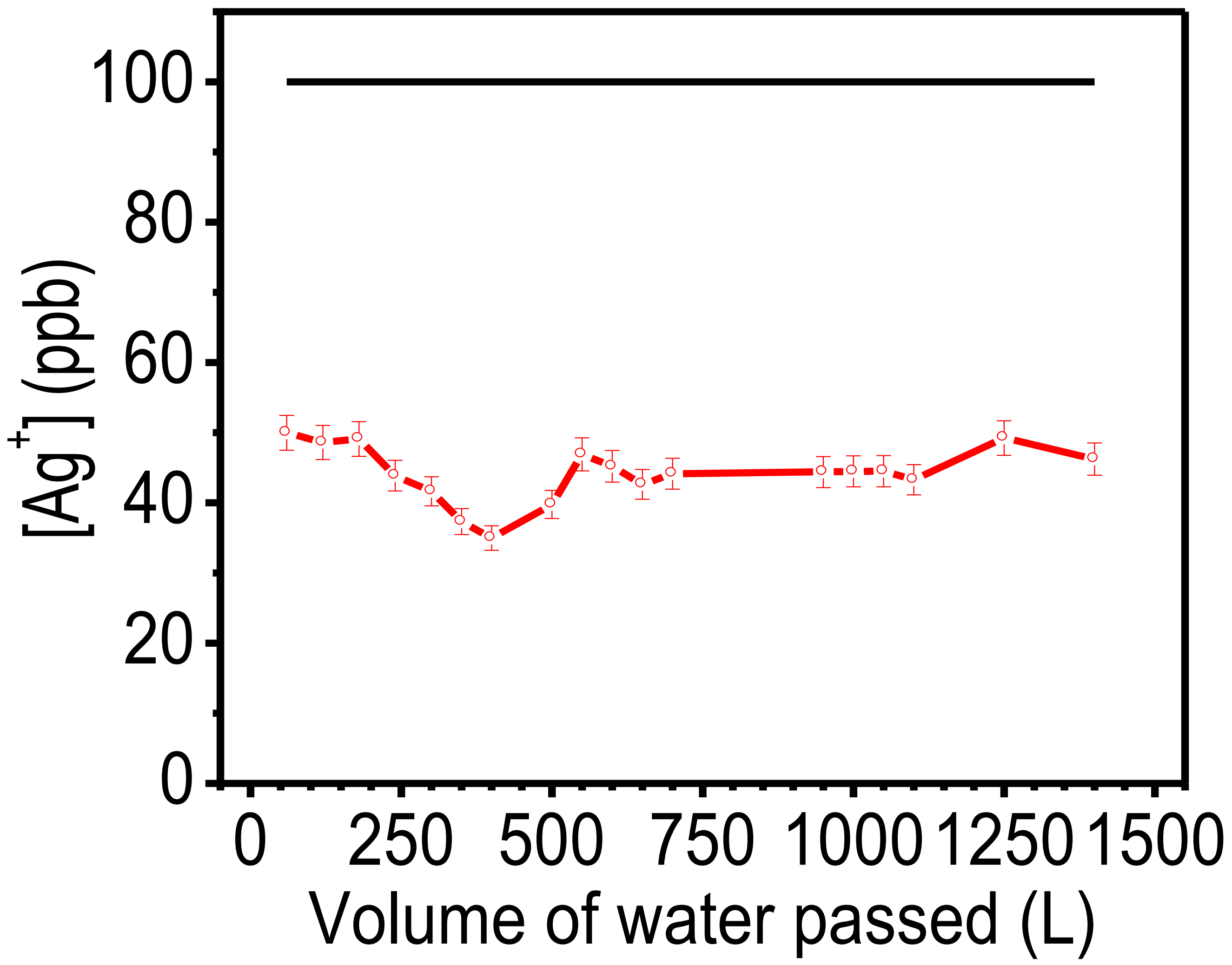
M. Udhaya Sankar, et. al. *Proc. Natl. Acad. Sci.,* 110 (2013) 8459-8464.

How to make?

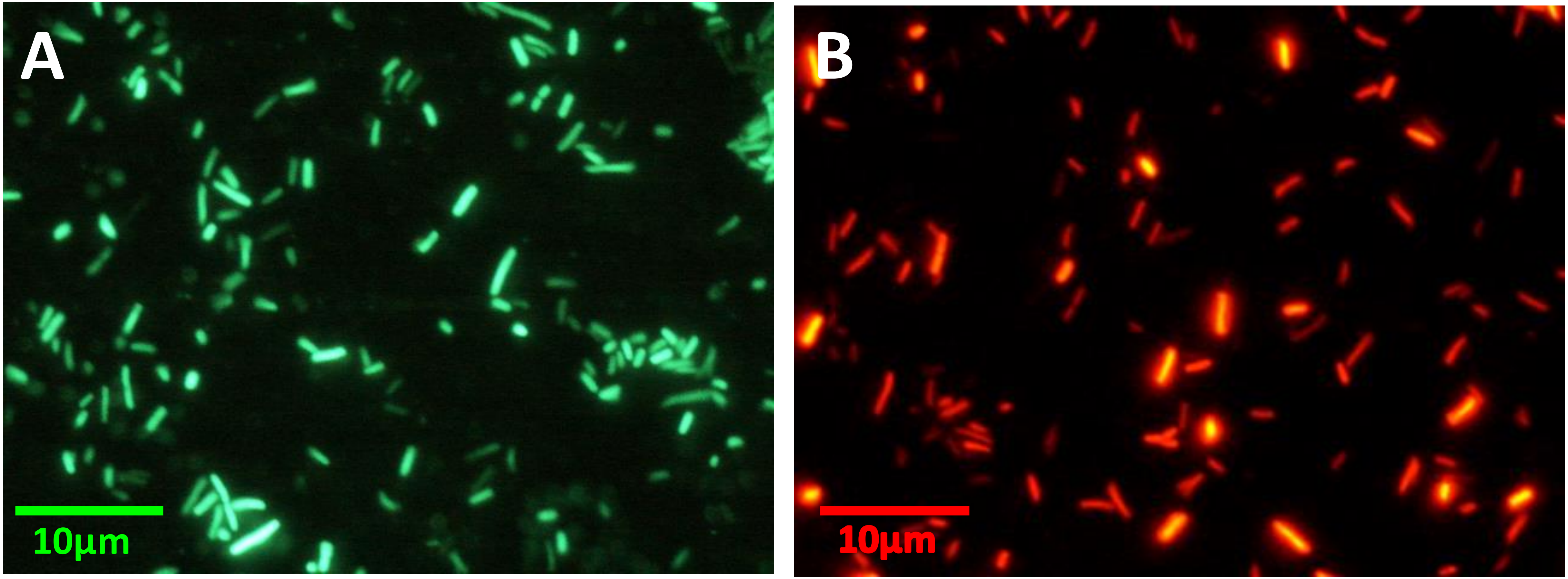


a
Al3+
OH-
RT
OH-
Incubation
RT
1. Ag+
2. BH4-, <8 0C
- Ag Np
- AlOOH Np
- Chitosan fiber
(i)
(ii)
(iii)
(iv)
(v)
b
pH 6
pH 7
pH 8
c
DRY
WET
d
50 nm
50 nm

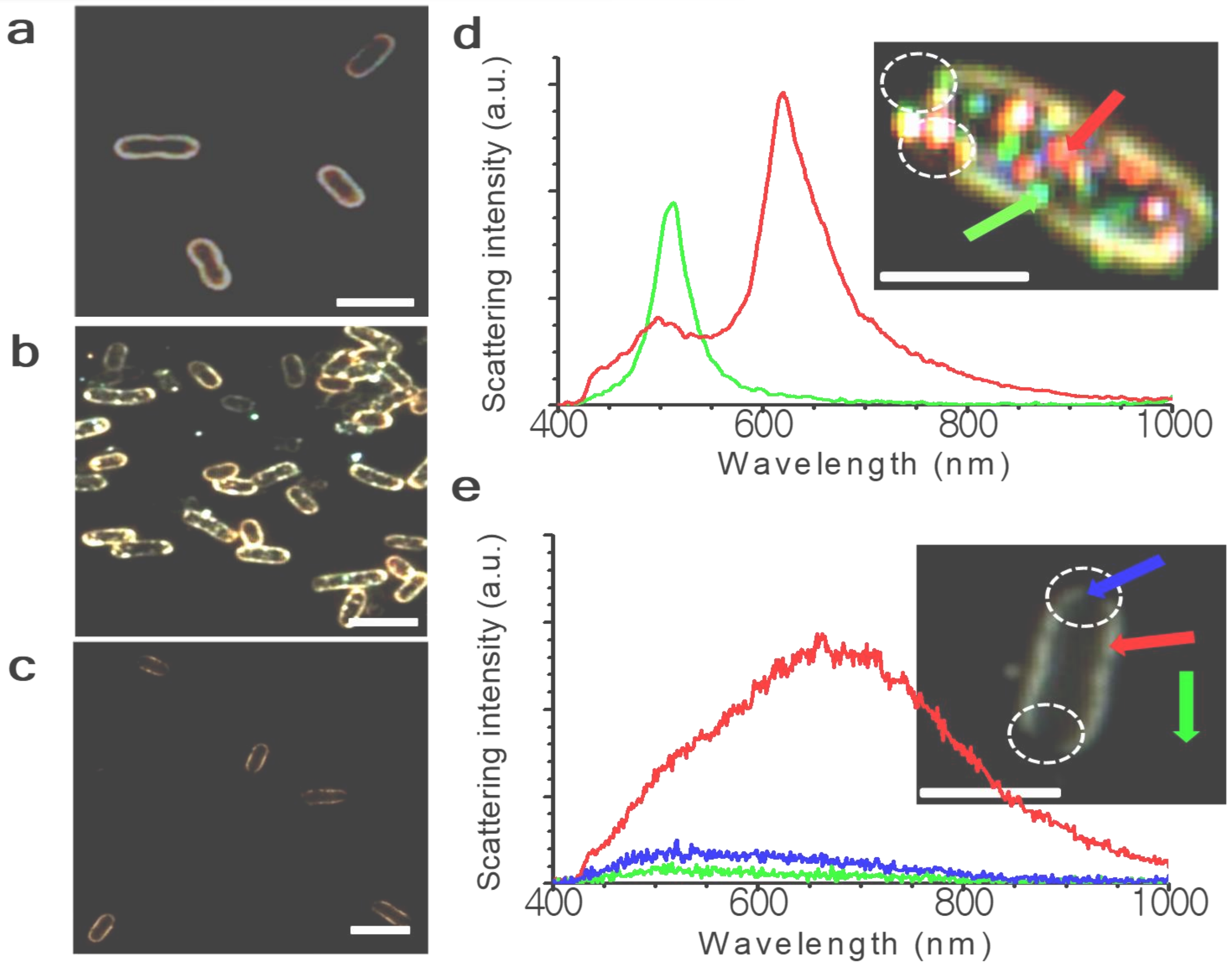
What is special?



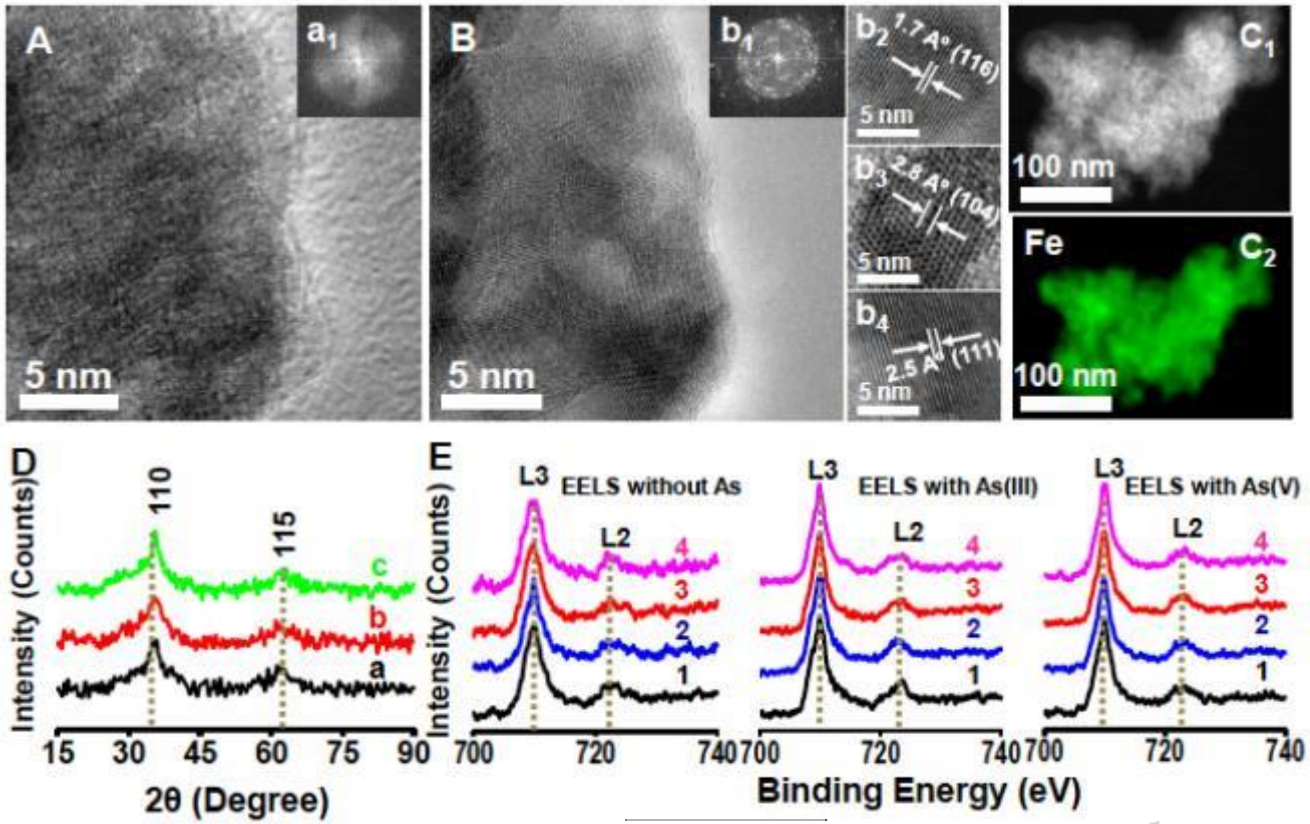
Live/dead staining experiments



No nanotoxicity



Variety of materials



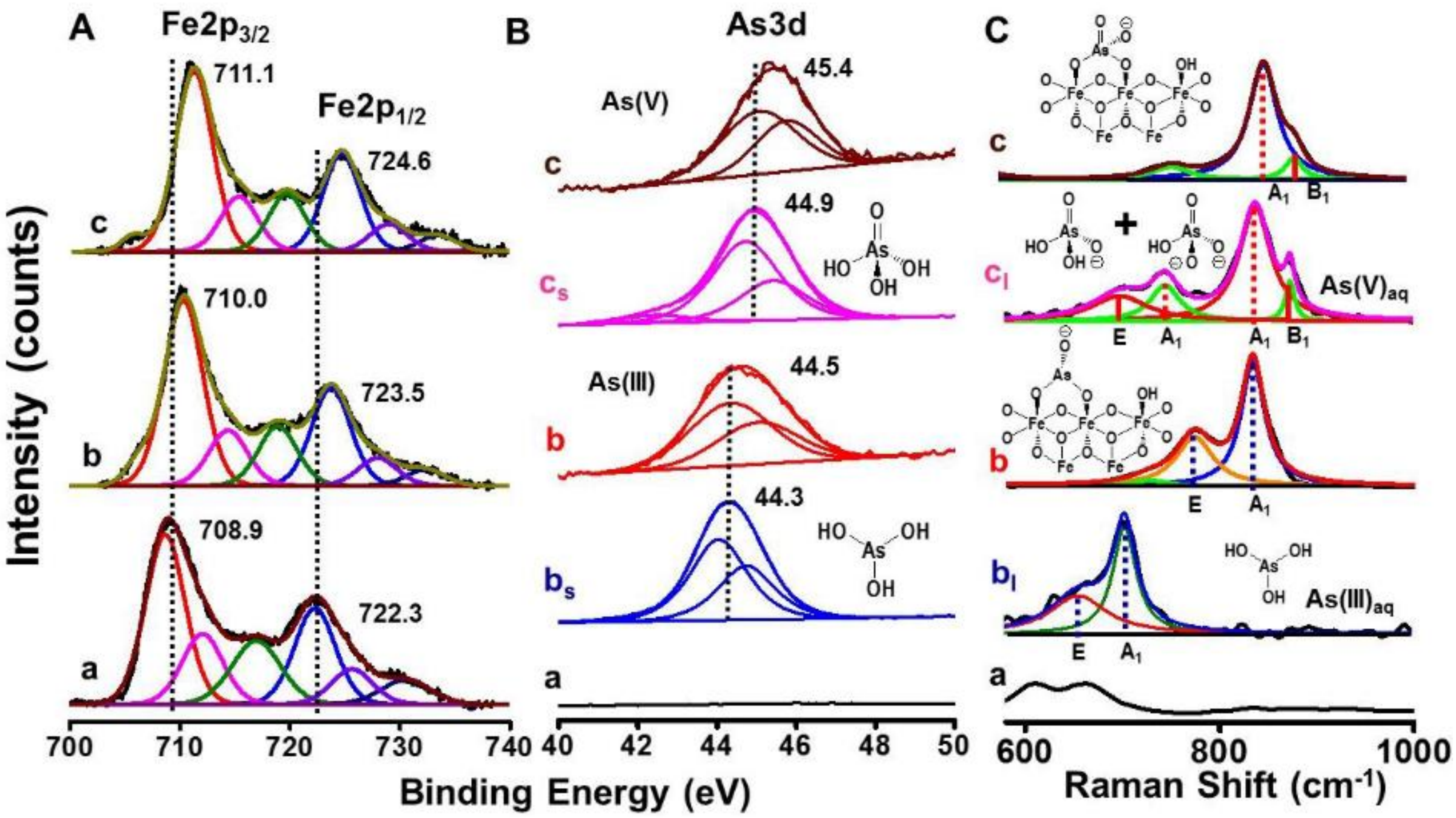

Author Proof
www.advmat.de
ADVANCED MATERIALS
Communication

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

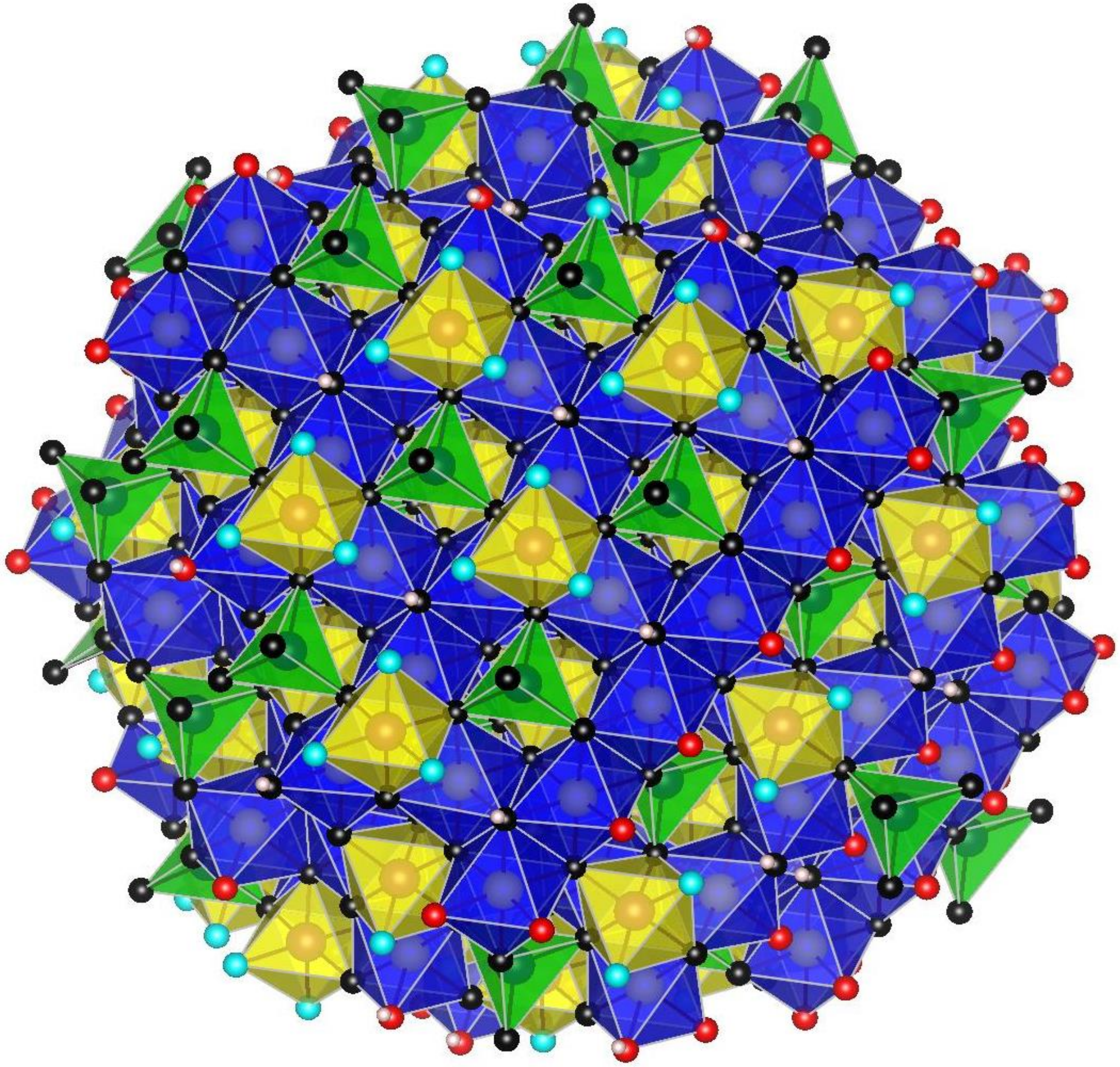
By Avula Anil Kumar, Anirban Som, Paolo Longo, Chennu Sudhakar, Radha Gobinda Bhuin, Soujit Sen Gupta, Anshup, Mohan Udhaya Sankar, Amrita Chaudhary, Ramesh Kumar, and T. Pradeep*

A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

Mechanism – molecular tools

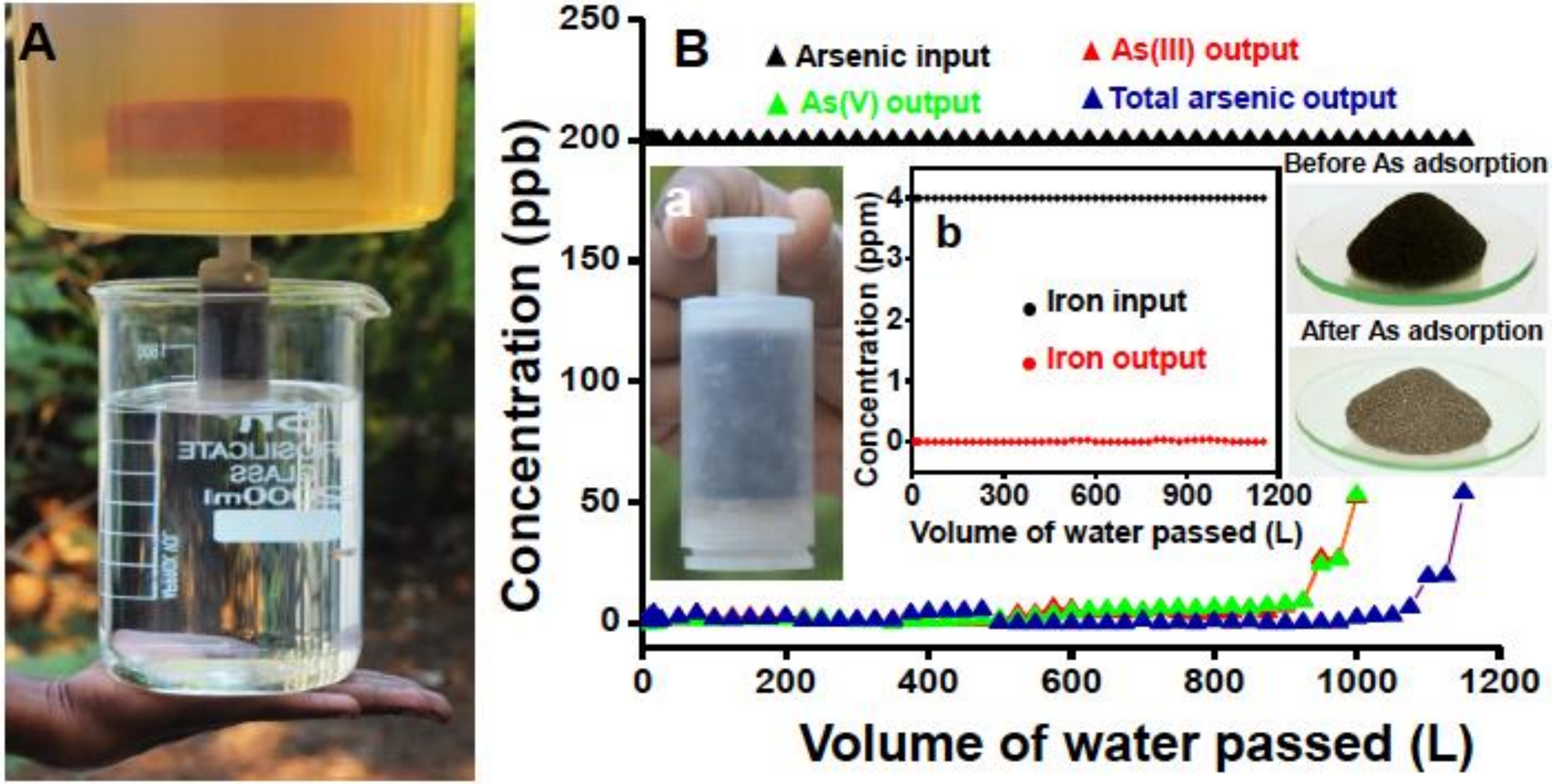


Modeling surfaces



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

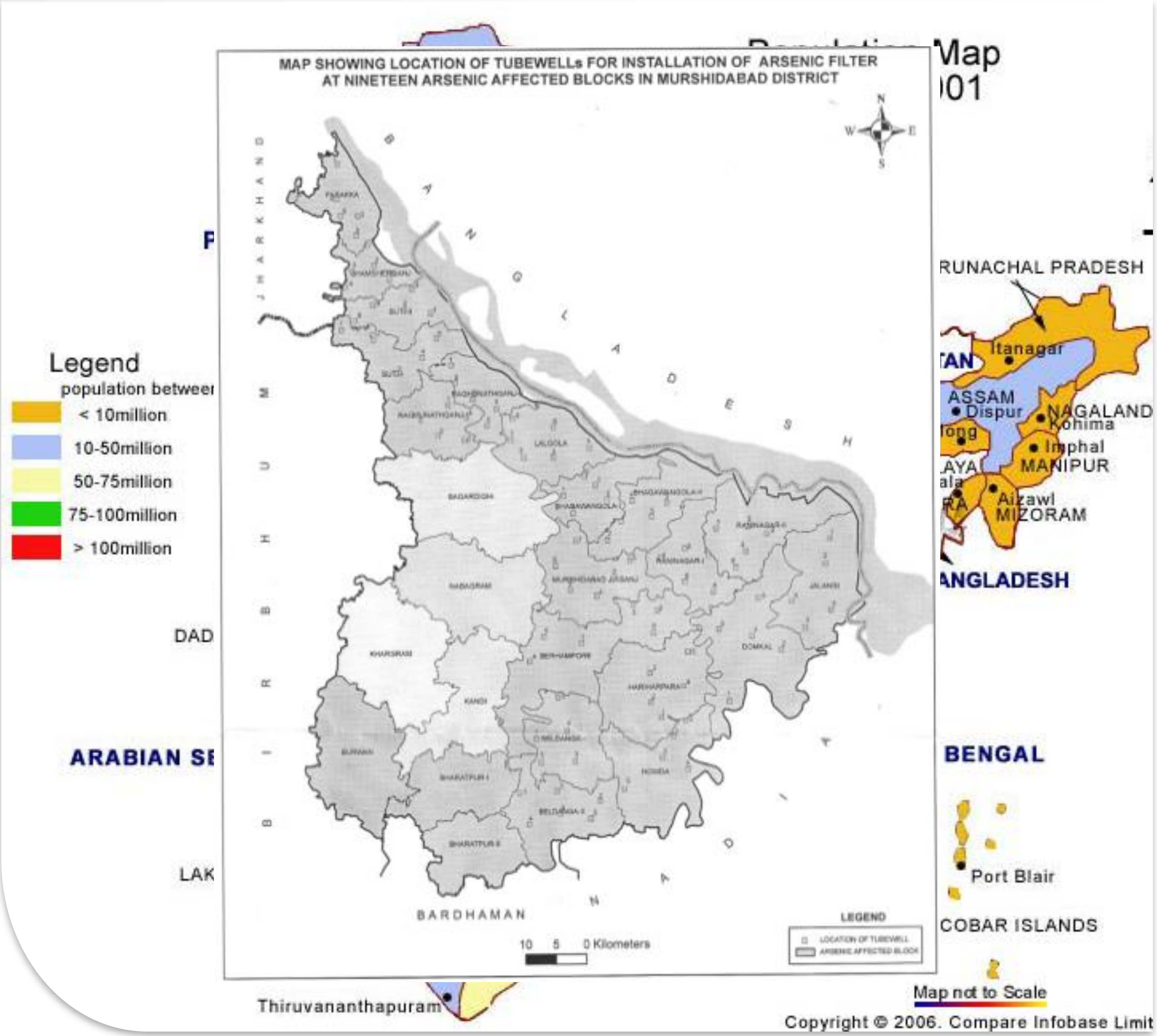
Lab studies



A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

Initial pilot studies

Larger pilot studies



Changing the dynamics in the field

- Existing unit for iron and arsenic removal – 20 m^3/h
- Uses activated alumina and iron oxide (old generation of adsorbents)

- Existing unit for iron and arsenic removal – 18 m^3/h
- Uses iron oxyhydroxide (new generation of adsorbents)
- Input arsenic concentration: 168 ppb
- Output arsenic concentration: 2 ppb

Implementation - From 25 KLD to 1 MLD

Large water supply schemes
Capacity: above 1 MLD

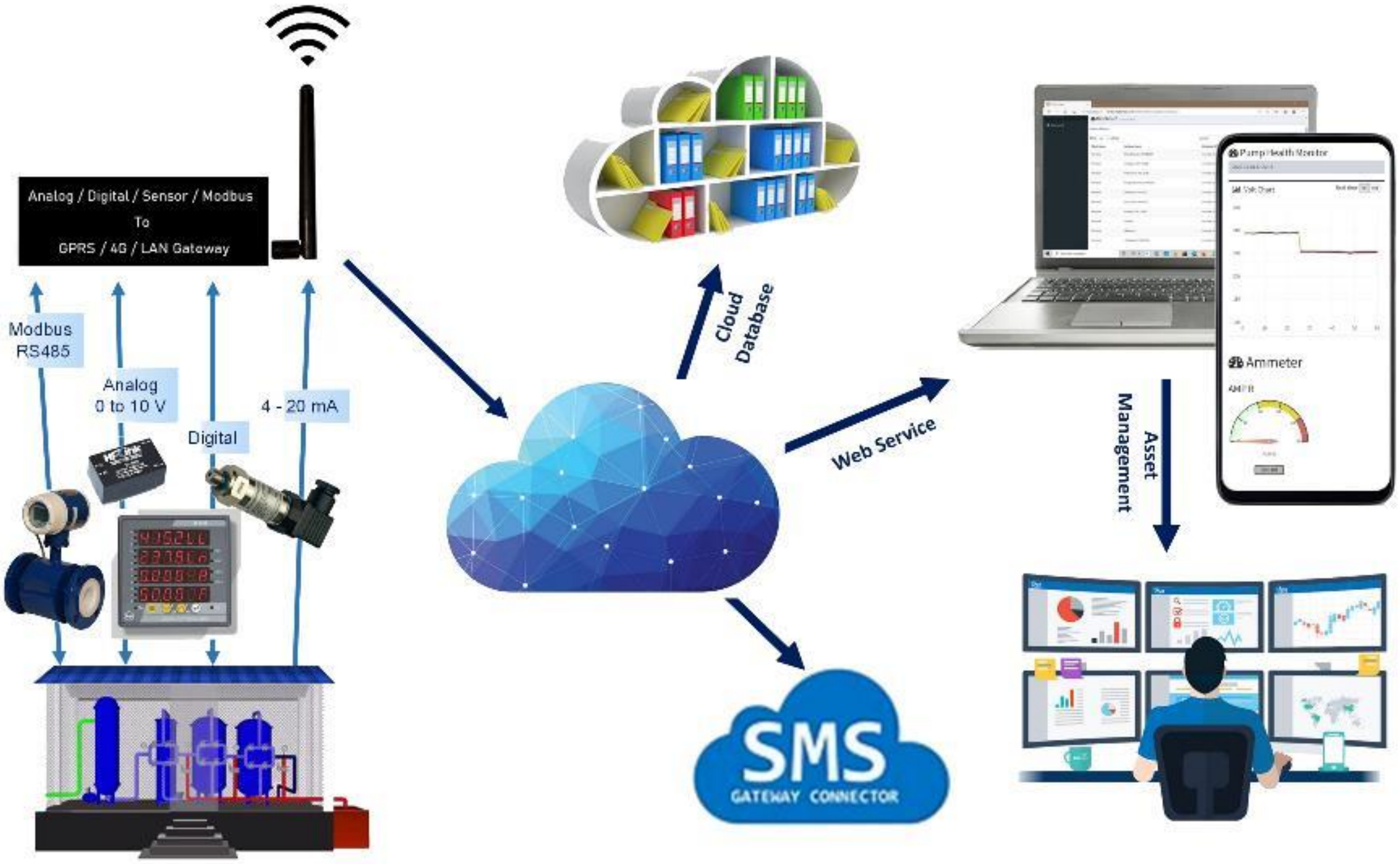
5 schemes in use across India

Retrofitted Water Purification Plant
Capacity: 0.1-1 MLD

Over 180 units in use across India

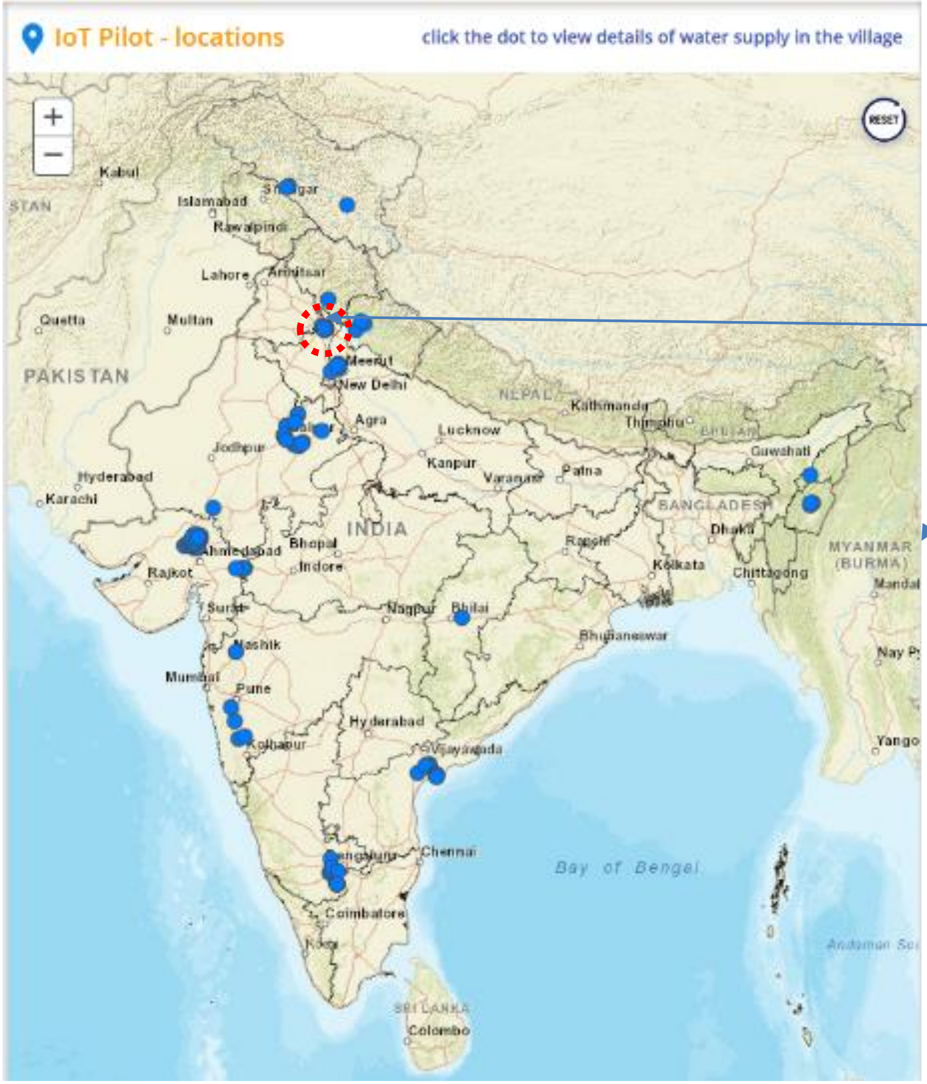
Now they are across the country

Components of IoT architecture implemented by DWSS, GoP



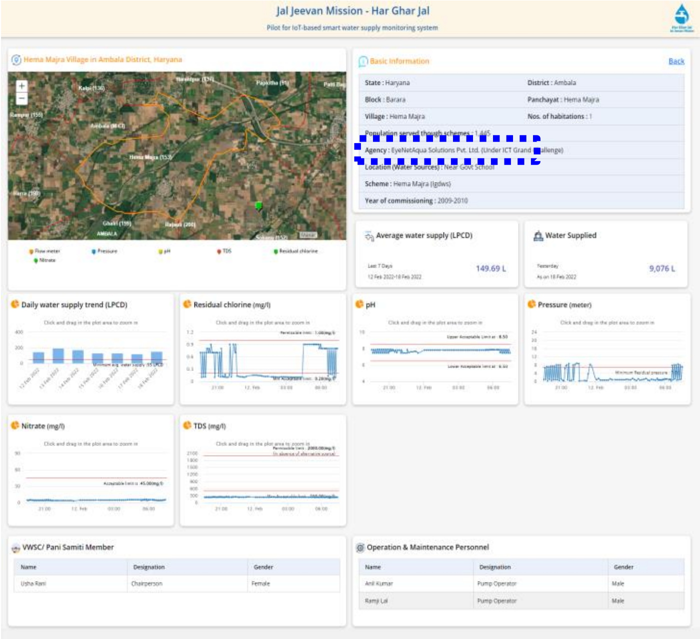
Typical IoT architecture comprises various sensors and meters, communication gateway, Cloud Server, SMS gateway, Webservices and mobile phone application for operator

India’s water is being monitored



IITM/IISc

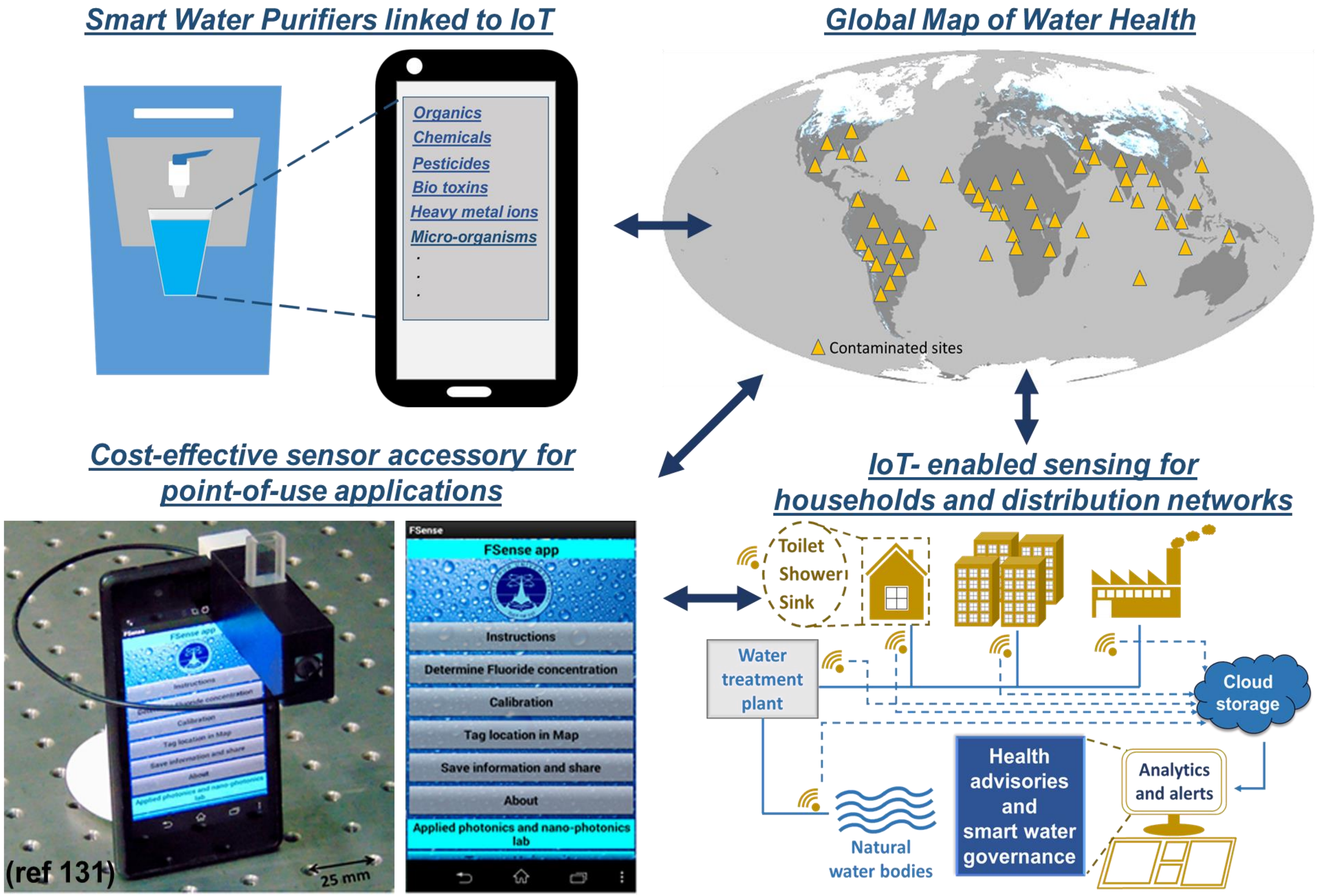
Installations made by four companies



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 litr 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
		40.80	per head per month for 70 LPCD water

Smart water purifiers and big data

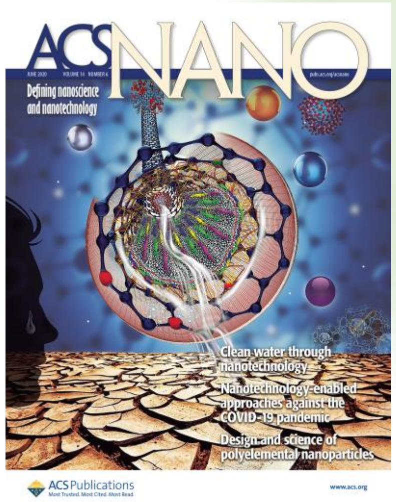


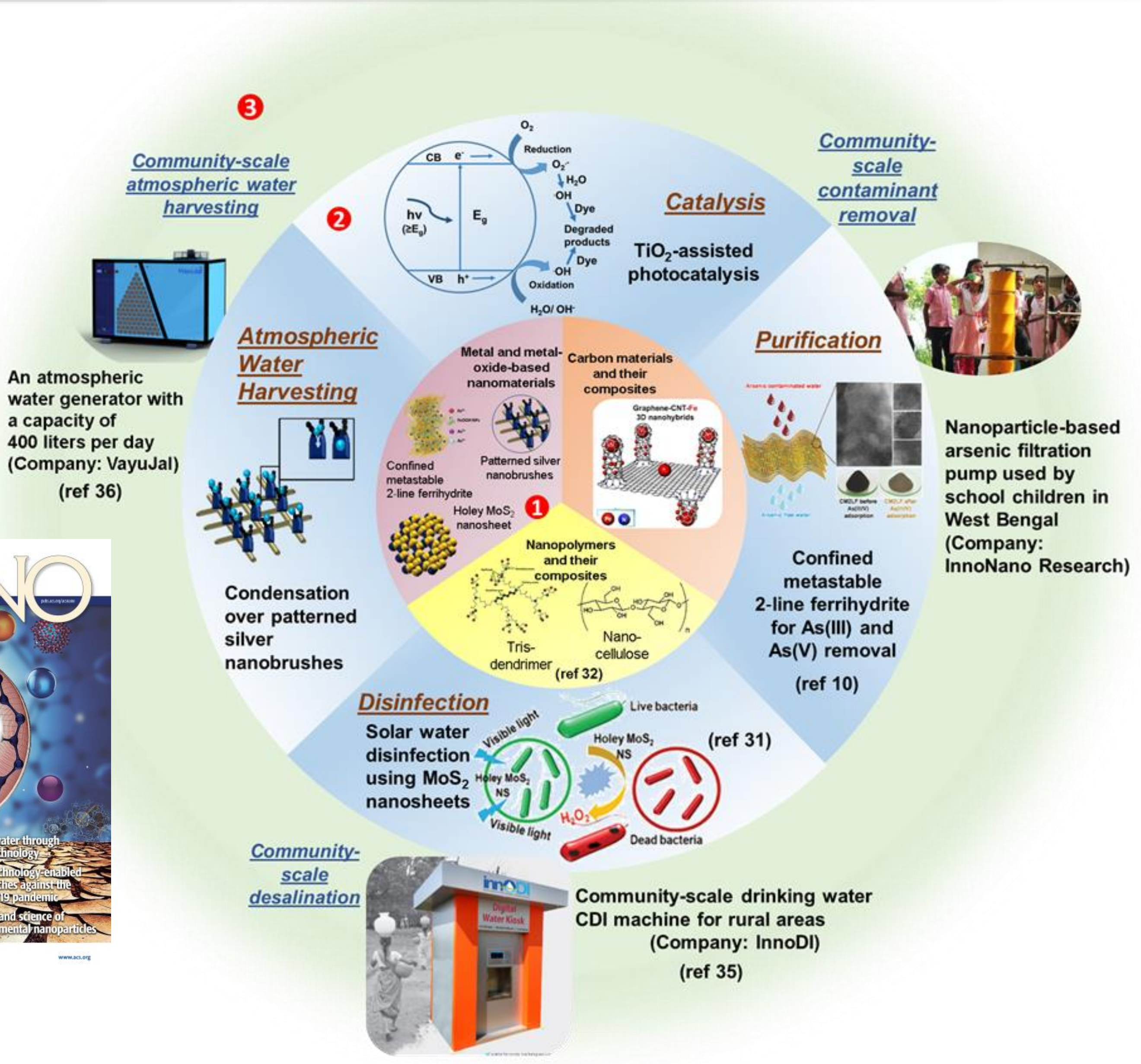
Ankit Nagar and T. Pradeep 14(2020). *ACS Nano*, 6420-6435

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

Evolution of materials to products



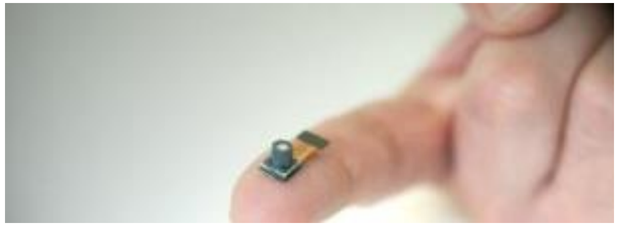


Ankit Nagar and T. Pradeep, *ACS Nano* 14 (2020) 6420-6435.

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)

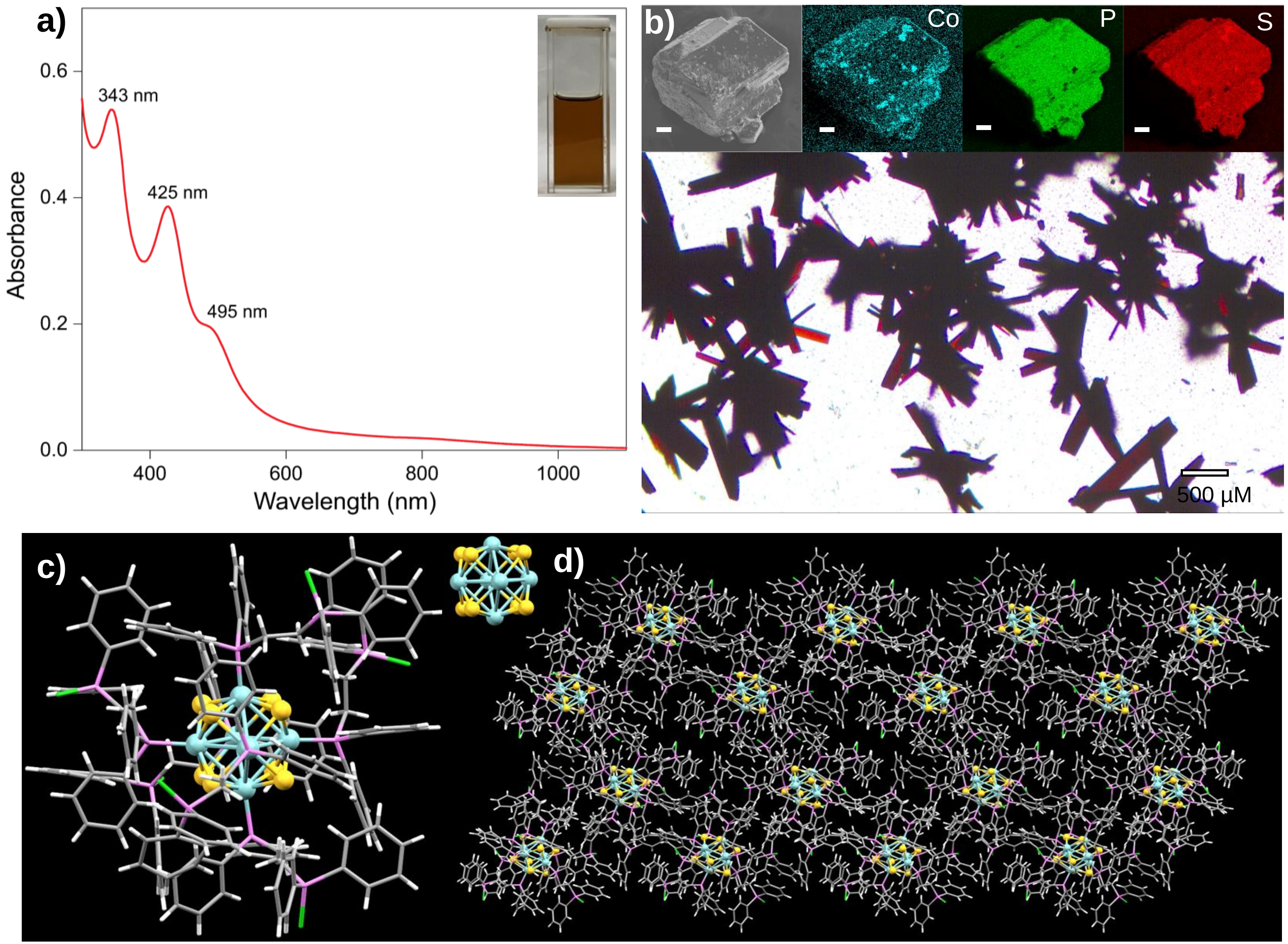


Water quality measurement – In the pipeline

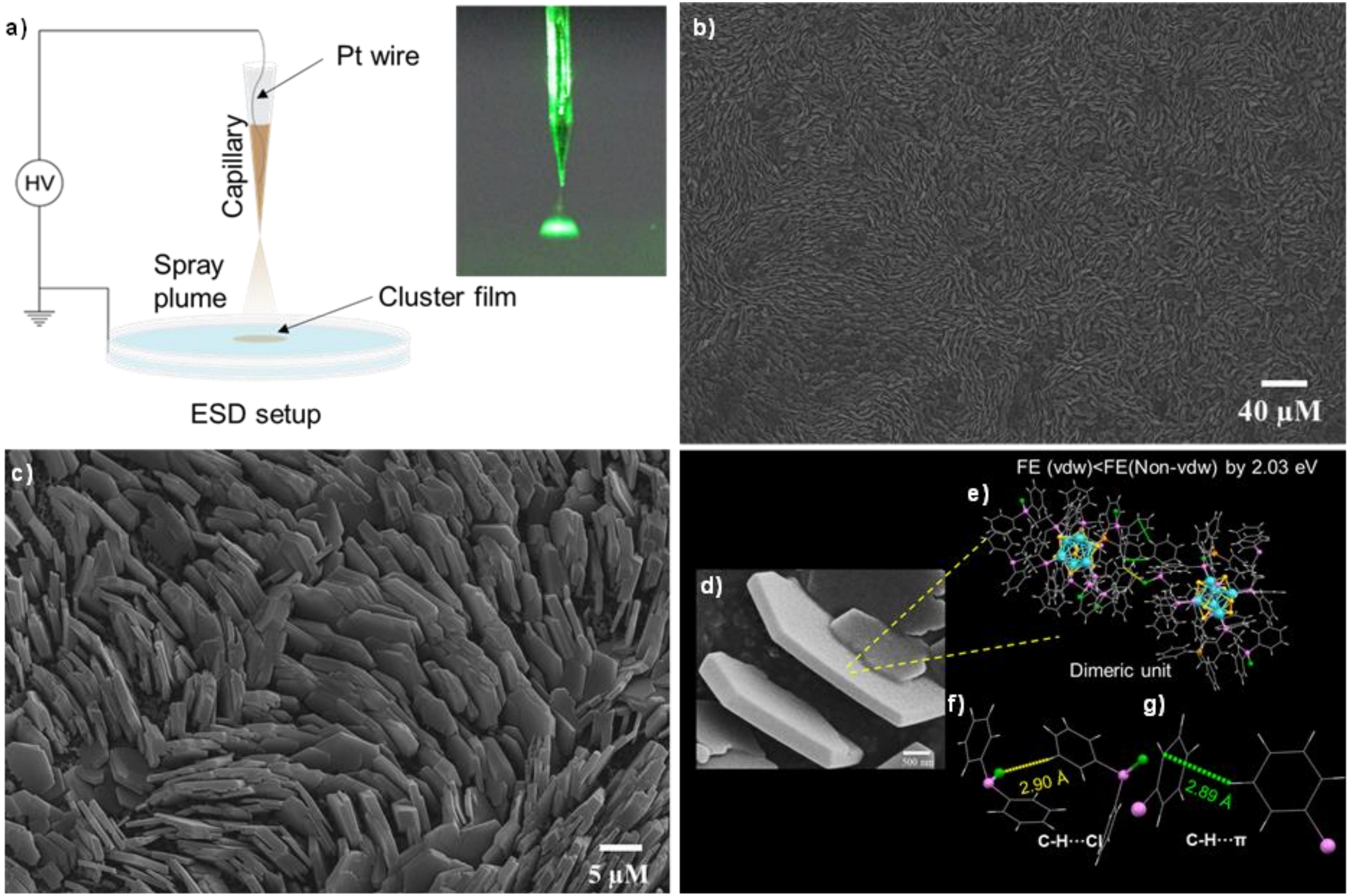
nanoλ

New electrodes - Aligned nanoplates of Co_6S_8

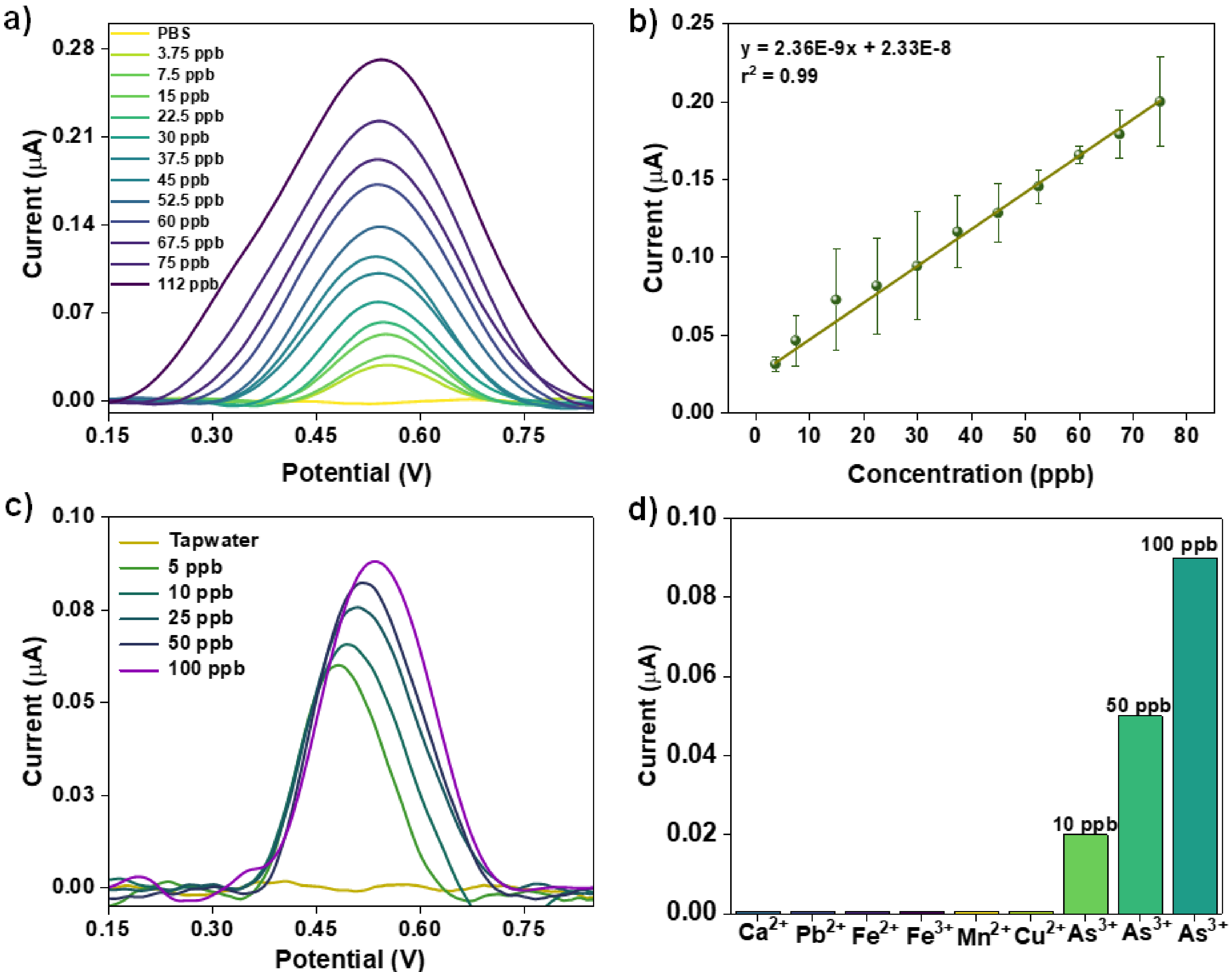
1,2-bis(diphenylphosphino)ethane (DPPE)



Electrospray deposition

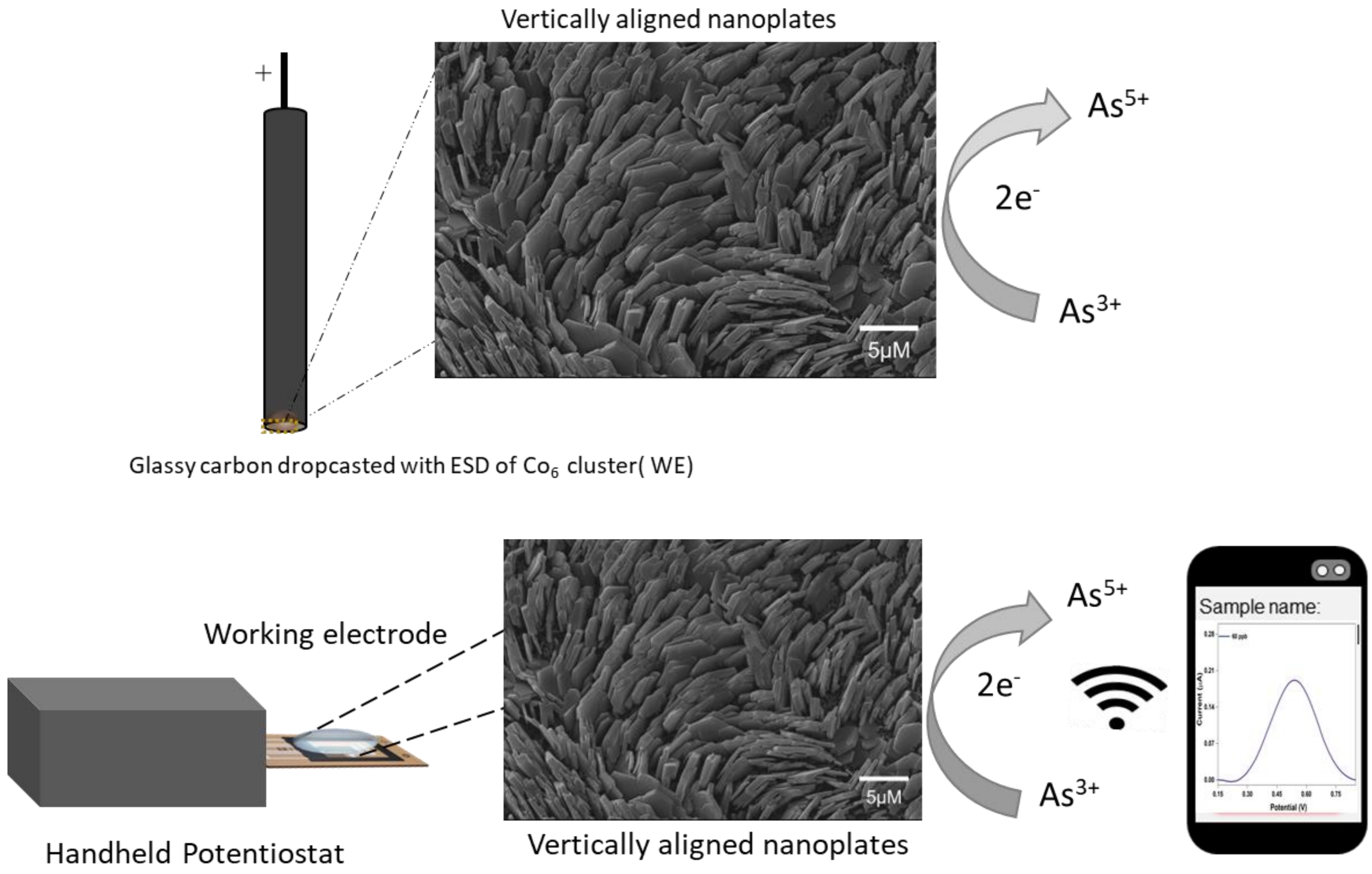


Sensing



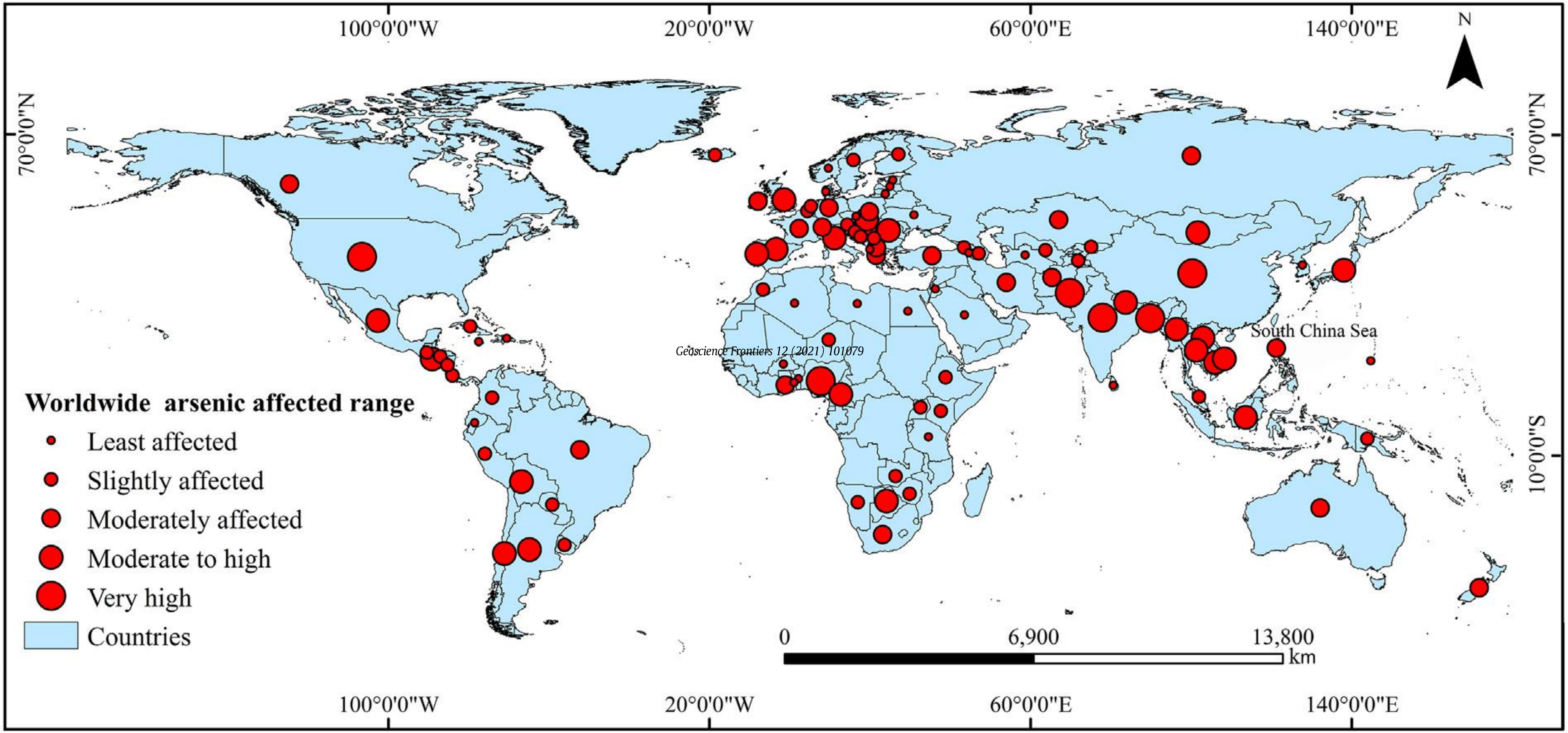
a)
PBS
3.75 ppb
7.5 ppb
15 ppb
22.5 ppb
30 ppb
37.5 ppb
45 ppb
52.5 ppb
60 ppb
67.5 ppb
75 ppb
112 ppb
Current (μA)
Potential (V)
b)
y = 2.36E-9x + 2.33E-8
r² = 0.99
Current (μA)
Concentration (ppb)
c)
Tapwater
5 ppb
10 ppb
25 ppb
50 ppb
100 ppb
Current (μA)
Potential (V)
d)
Current (μA)
100 ppb
50 ppb
10 ppb
Ca2+ Pb2+ Fe2+ Fe3+ Mn2+ Cu2+ As3+ As3+ As3+

Working electrode



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

Arsenic poisoning across the world



E. Shaji, M. Santosh, K. V. Sarath, Pranav Prakash, V. Deepch and B. V. Divya, Geoscience Frontiers, 12 (2021) 101079.

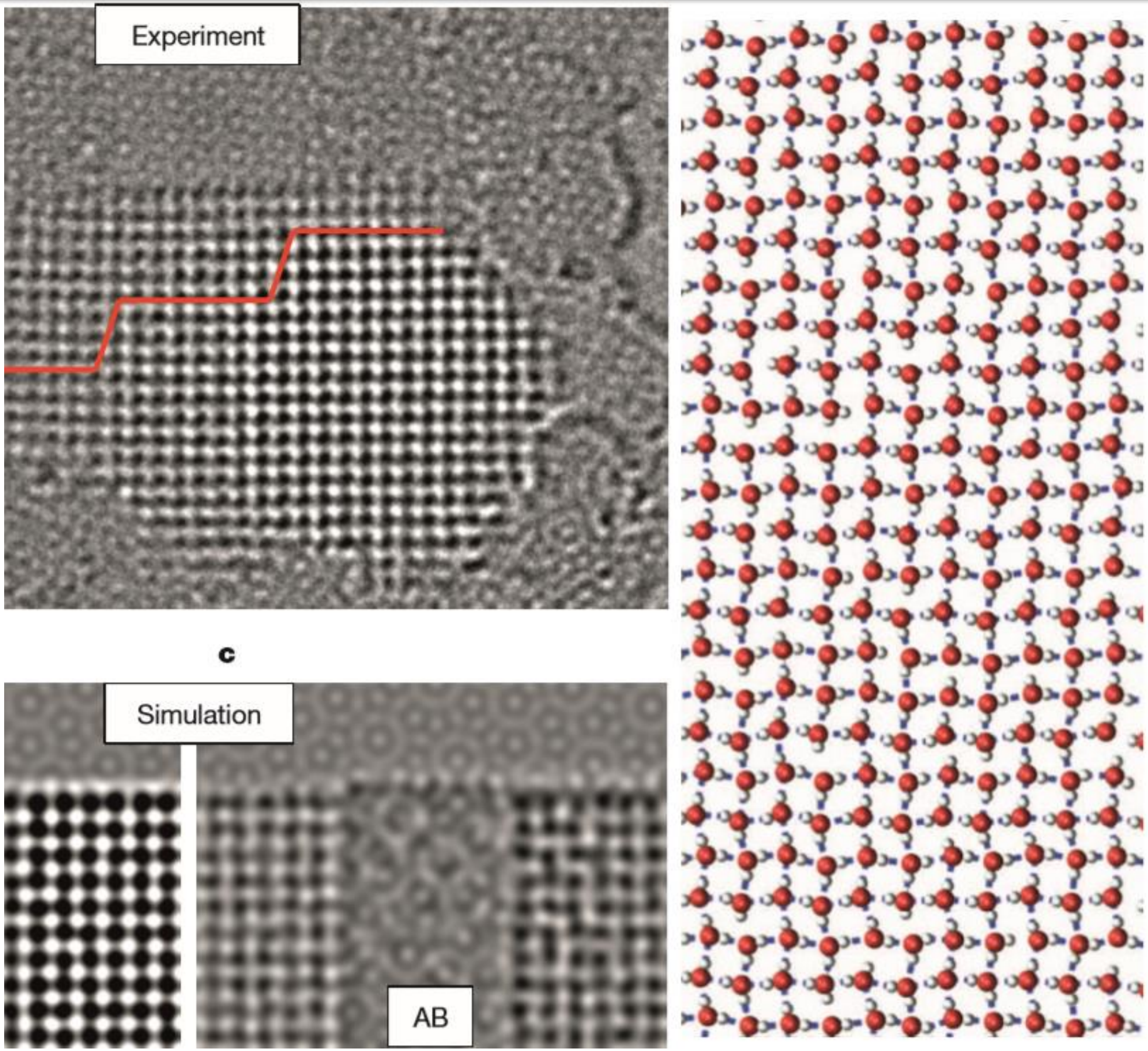
International Centre for Clean Water


IIT Madras Research Park
A
B
C

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


Water Quality
Drinkable
Non-Drinkable
Total coliform
Total chlorine
Free chlorine
Hardness
Alkalinity
pH
TDS
Turbidity
ORP
Conductivity
E coli
Click here for more information

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.


thermoscientific
ThermoFisher
SCIENTIFIC

Science

RESEARCH

NANOPARTICLES

Spontaneous weathering of natural minerals in charged water microdroplets forms nanomaterials

B. K. Spoorthi[1], Koyendrila Debnath[2], Pallab Basuri[1], Ankit Nagar[1], Umesh V. Waghmare[2], Thalappil Pradeep[1,3]*

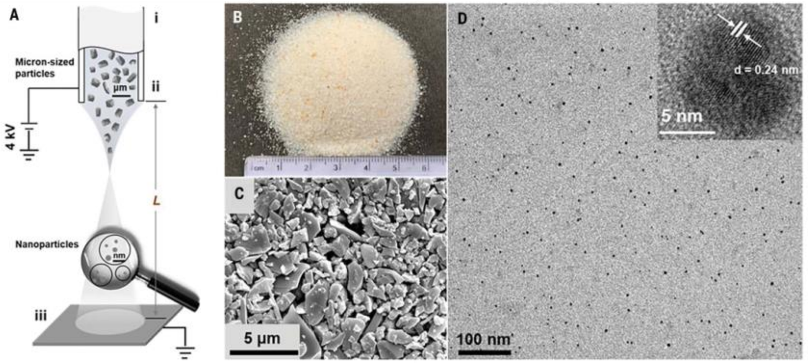
In this work, we show that particles of common minerals break down spontaneously to form nanoparticles in charged water microdroplets within milliseconds. We transformed micron-sized natural minerals like quartz and ruby into 5- to 10-nanometer particles when integrated into aqueous microdroplets generated 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-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 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. S1). 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 mm flow rate of 0.5 ml/hour and observed the resulting plume (Fig. 1A). We collected the product of electrospray 1.5 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 S1).

To ensure that our initial observations were truly representative of the process, we performed measurements on larger quantities of samples. We built a multinozzle 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

[1]Department of Chemistry, Indian Institute of Technology Madras, Chennai 600036, India. [2]Theoretical Sciences Unit, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560064, India. [3]International Centre for Clean Water, IIT Madras Research Park, Chennai 600113, India.
*Corresponding author. Email: pradeep@iitm.ac.in

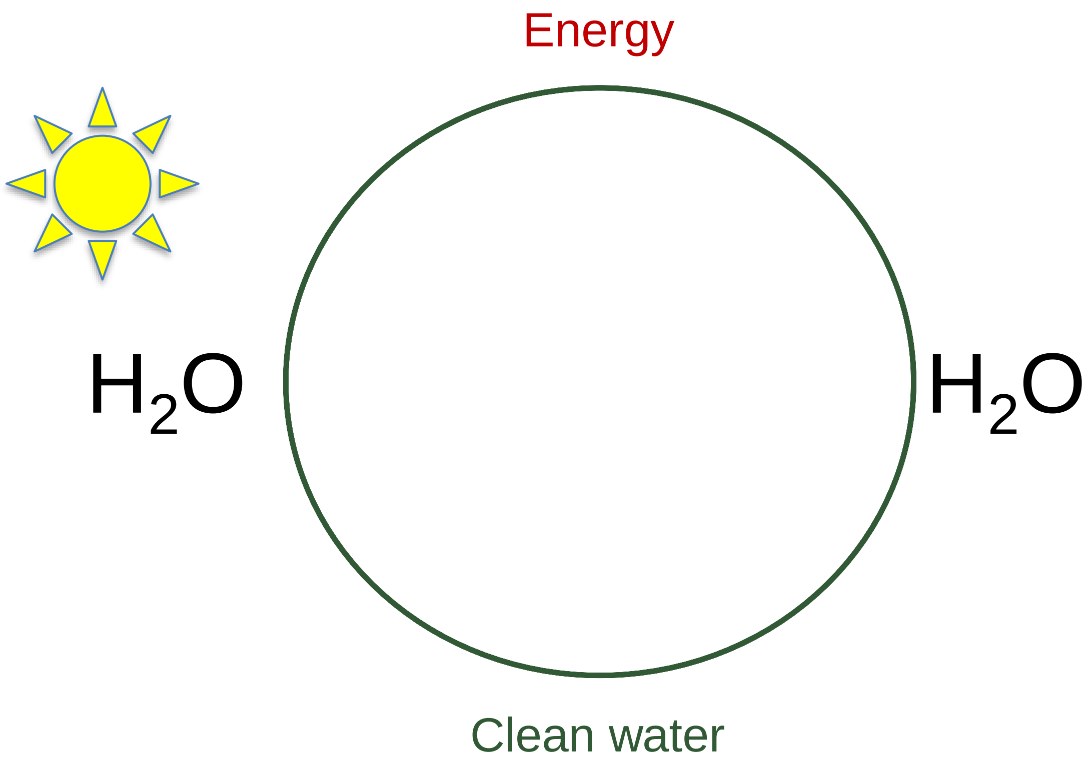


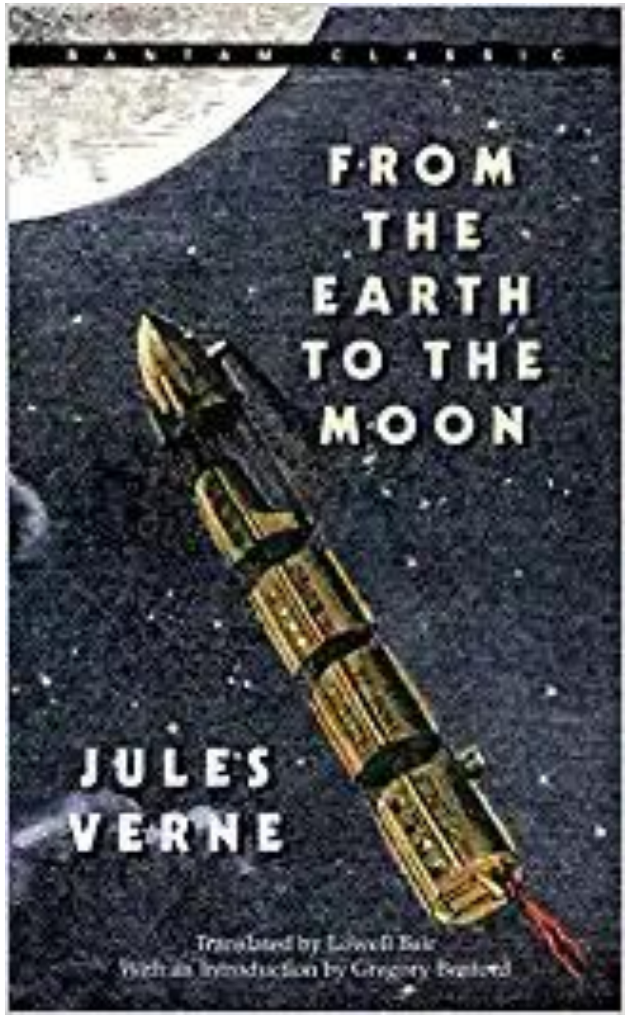
Spoorthi et al., Science 384, 1012–1017 (2024)   31 May 2024

A scale of 1000

Image from Wikipedia

Our dreams become reality with materials





Affordable, inclusive, sustainable and contextual excellence

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

Collaborators






Tatsuya Tsukuda
Keisaku Kimura
Yuichi Negishi
Uzi Landman
Hannu Hakkinen
Rob Whetten
Shiv Khanna
Chandrabhas Narayana


Robin Ras


Nonappa


Tomas Base


Manfred Kappes


Olli Ikkala


Horst Hahn


Biswarup Pathak


K. V. Adarsh


G. U. Kulkarni


Vivek Polshettiwar

The AMRIT Team, 2013

Water team at IIT: A. Sreekumaran Nair, Anshup, M. Udhaya Sankar, Amrita Chaudhary, Renjis T. Tom, T. S. Sreeprasad, Udayabhaskararao Thumu, M. S. Bootharaju, K. R. Krishnadas, Kalamesh Chaudhari, Soujit Sengupta, Depanjan Sarkar, Avijit Baidya, Swathy Jakka Ravindran, Abhijit Nag, S. Vidhya, Biswajit Mondal, Krishnan Swaminathan, Azhardin Gnayee, Sudhakar Chennu, A. Suganya, Rabiul Islam, Sritama Mukherjee, Tanvi Gupte, Jenifer Shantha Kumar, A. Anil Kumar, Ankit Nagar, Ramesh Kumar Soni, Tanmayaa Nayak, Sonali Seth, Shihabudheen M. Maliyekkal, G. Velmurugan, Wakeel Ahmed Dar, Ganapati Natarajan, N. Pugazhenthiran, A. Leelavathi, Sahaja Aigal, S.Gayathri, Bibhuti Bhusan Rath, Ananthu Mahendranath, Harsh Dave, Erik Mobegi, Egor Moses, Hemanta R. Naik, Sourav Kanti Jana, Tanmayaa Nayak, Sonali Seth…

Avula Anil Kumar, Chennu Sudhakar, Sritama Mukherjee, Anshup, and Mohan Udhaya Sankar

Funding: Department of Science and Technology, Government of India

Start-ups and partners:

PhD Theses: Bindhu Varughese, M. R. Resmi, M. Venkataramanan, N. Sandhyarani, R. Selvan, A. Sreekumaran Nair, M. J. Rosemary, Renjis T. Tom, C. Subramaniam, Jobin Cyriac, V. R. Rajeev Kumar, D. M. David Jeba Singh, Akshaya Kumar Samal, E. S. Shibu, M. A. Habeeb Muhammed, P. R. Sajanlal, T. S. Sreeprasad, J. Purushothaman, T. Udayabhaskararao, M. S. Bootharaju, Soumabha Bag, Robin John, Kamalesh Chaudhari, Ammu Mathew, Indranath Chakraborty, Radha Gobinda Bhuin, Ananya Baksi, Amitava Srimony, Anirban Som, Rabin Rajan Methikkalam, K. R. Krishnadas, Soujit Sengupta, Depanjan Sarkar, Atanu Ghosh, Rahul Narayanan, Avijit Baidya, Shridevi Bhat, Papri Chakraborty, Swathy Jakka Ravindran, C. K. Manju, Abhijit Nag, S. Vidhya, Jyoti Sarita Mohanty, Debasmita Ghosh, Jyotirmoy Ghosh, Md. Bodiuzzaman, Biswajit Mondal, Tripti Ahuja, Esma Khatun, Krishnan Swaminathan, K. S. Sugi, Amrita Chakraborty, Sudhakar Chennu, Sritama Mukherjee, Madhuri Jash, Sandeep Bose, Md. Rabiul Islam, Pallab Basuri, Mohd Azhardin Ganayee, Tanvi Gupte, Ankit Nagar, Srikrishnarka Pillalamarri, Arijit Jana, Paulami Bose, Gaurav Viswakarma, Vishal Kumar, Jayoti Roy, A. Anil Kumar, Jenifer Shantha Kumar

MS Theses: Ananthu Mahedranath, Ramesh Kumar Soni

>25 Post-doctoral fellows, >130 masters students and visitors

Indian Institute of Technology Madras

Associate Editor

ACS Sustainable Resource Management

Bhaskar Ramamurthi/V. Kamakoti

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Thematic Unit of Excellence

Manswita Mandal for help with the slides