Since 1959

Affordable Clean Water Using Advanced Materials

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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

Professor-in-charge
ICCW
International Centre for Clean Water

Teachers' Day Lecture, IIT Kharagpur, September 5, 2024

Since 1959

Molecular Acorns to Institutional Oaks

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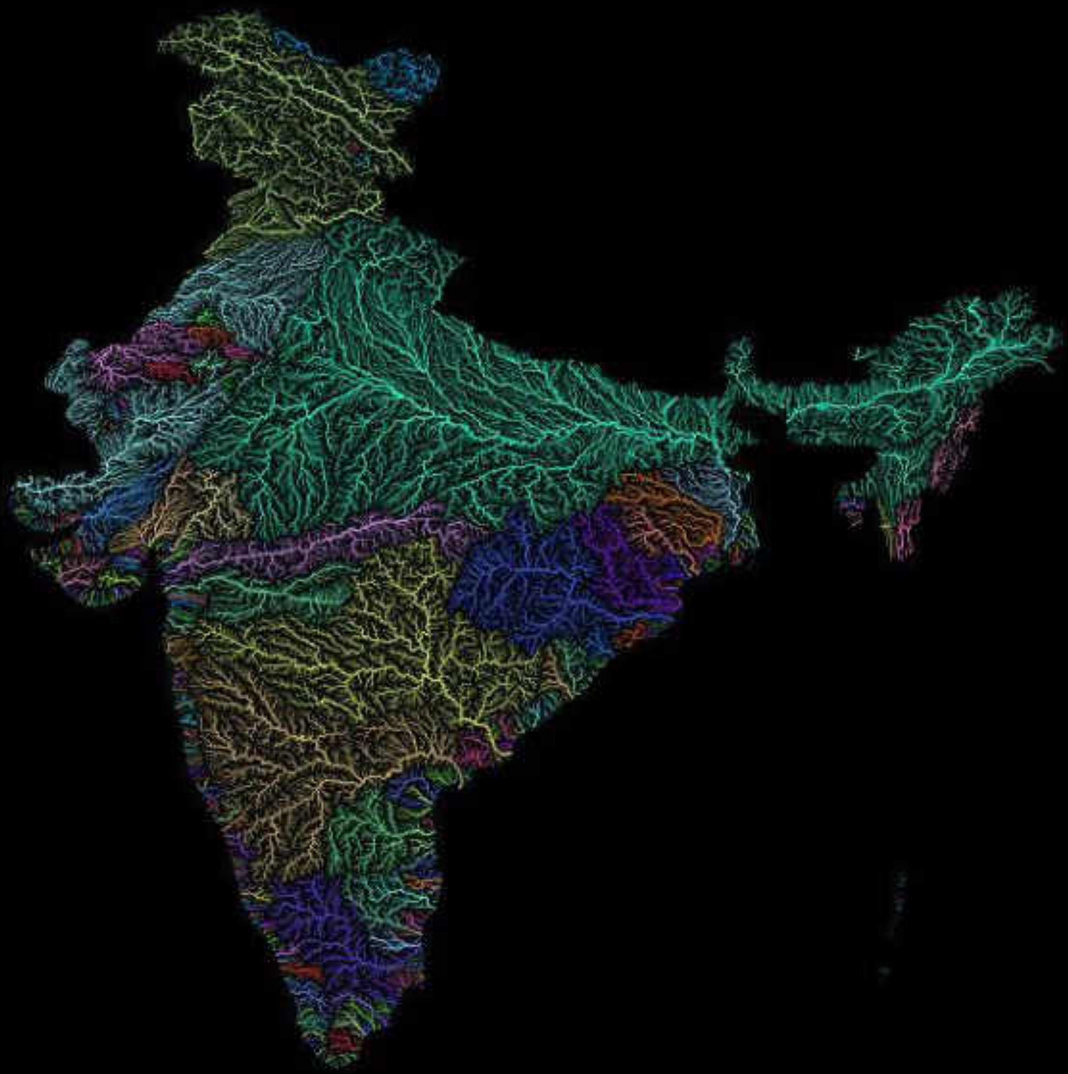
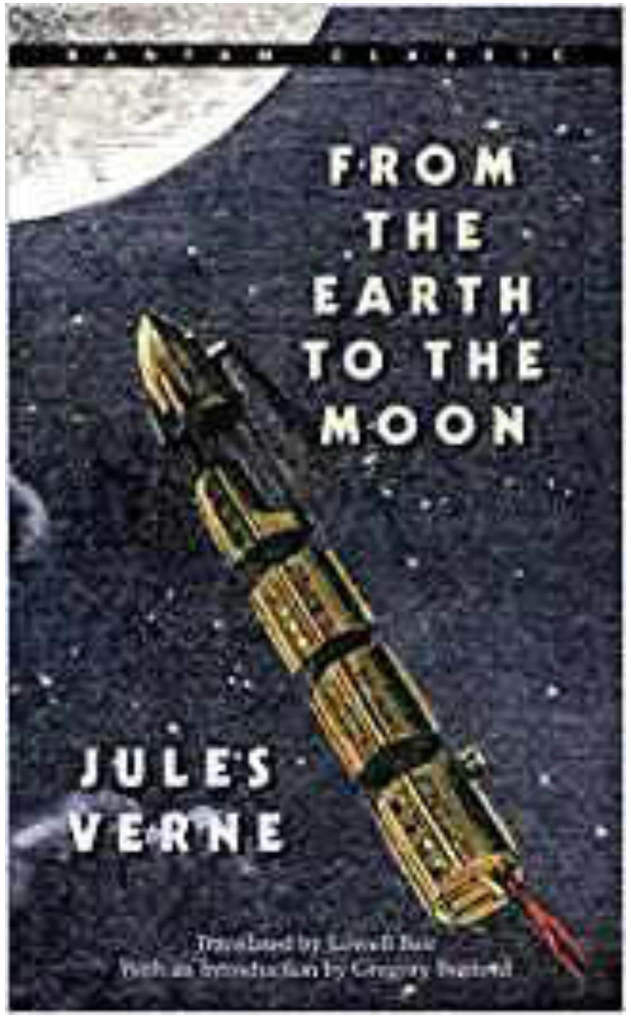
“Pale blue dot” Voyager 1 Feb. 14, 1990
Water is the most important inheritance of our planet



From S. Vishwanath

Our dreams become reality with materials



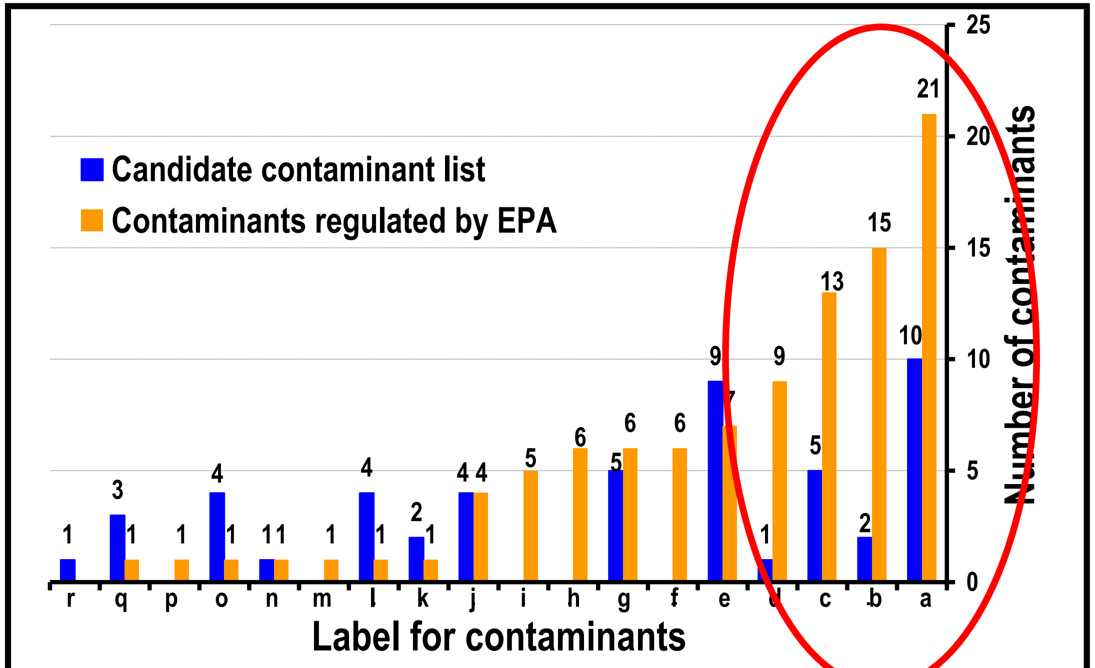
Water purification, history

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	*Silent Spring* 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)

T. Pradeep and Anshup, *Thin Solid Films*, 2009

Future of water purification: An enigma with some pointers



(a): Halogenated organic (b): Metal (c): Organochlorine pesticide (d): Inorganic salt (e): Biological contaminant (f): Nuclear (g): Benzo derivative (h): Carbamate pesticide (i): Pesticides (others) (j): Unclassified (k): Triazine derivative pesticide (l): Organophosphorus pesticide (m): Organobromine pesticide (n): Non-metal (o): Nitrophenol derivative, (p): Dioxin, (q): Benzo and halogenated organic (r): Organometallics

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

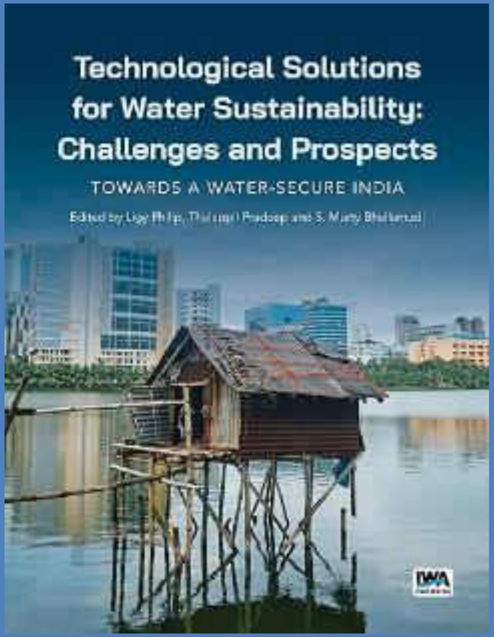
New adsorbents

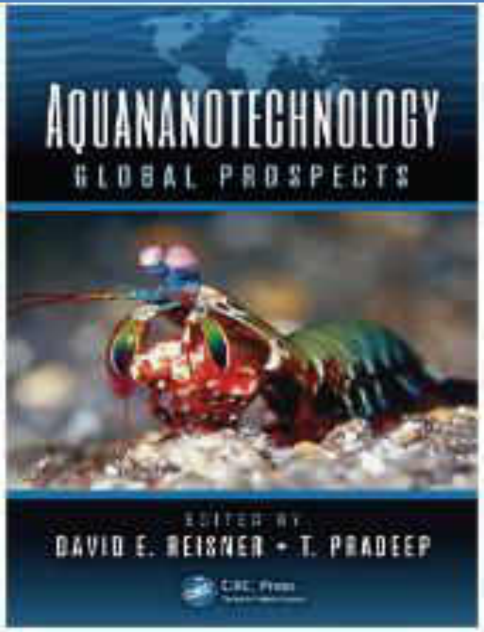
New sensors

New catalysts

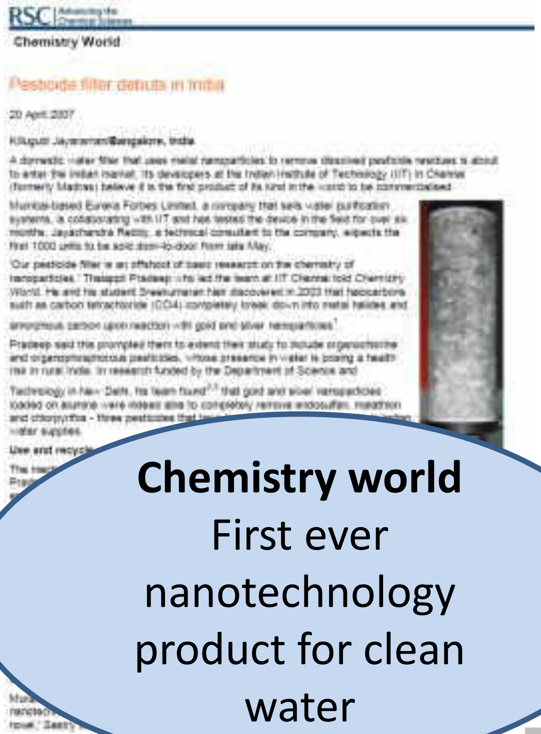
Novel phenomena

New devices





World’s first nanochemistry-based water purifier



Chemistry world
First ever nanotechnology product for clean water

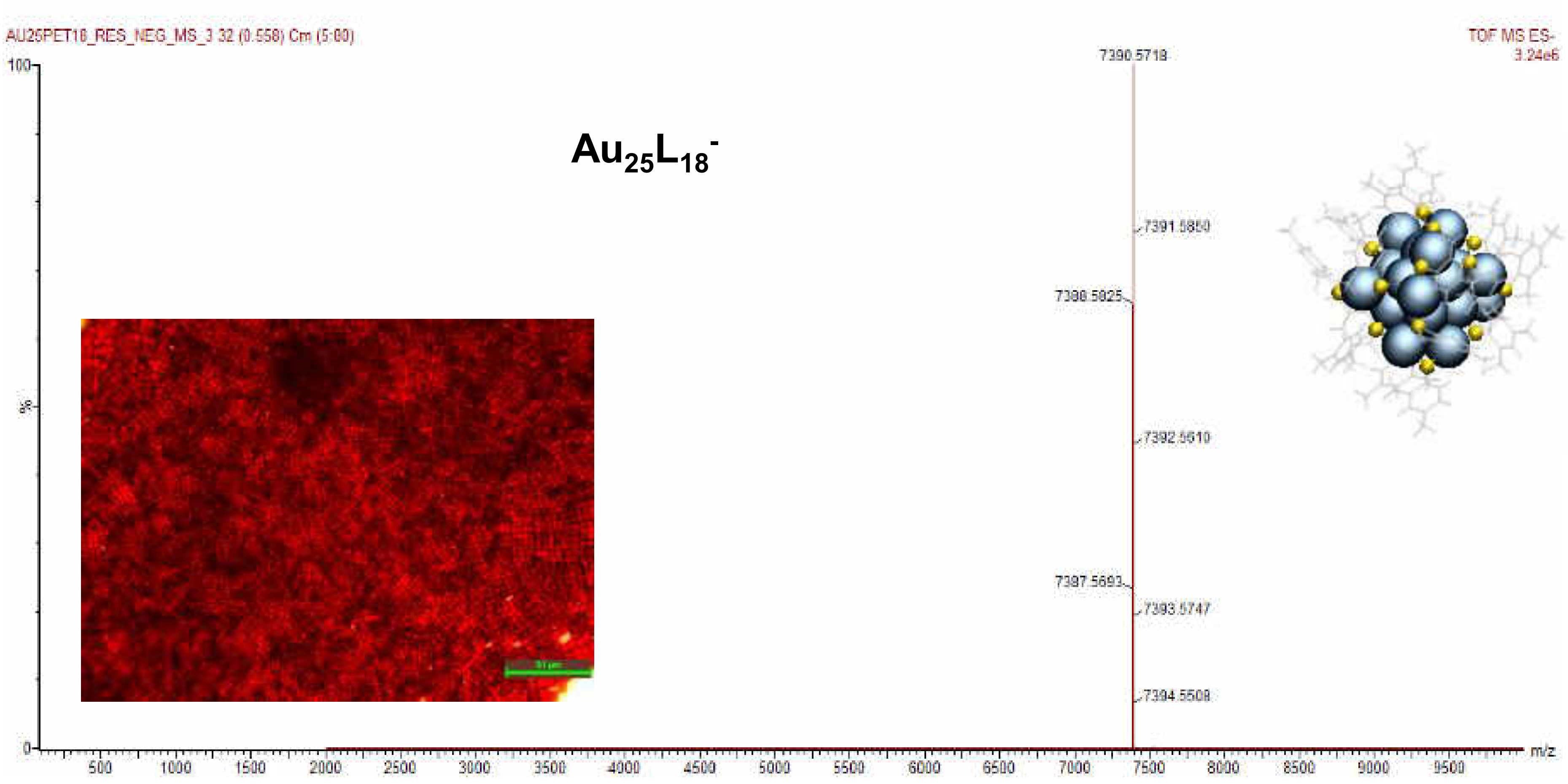
A plant to make supported nanomaterials for water purification; with capacity of 4.5 tons per month, 2007

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

PNAS

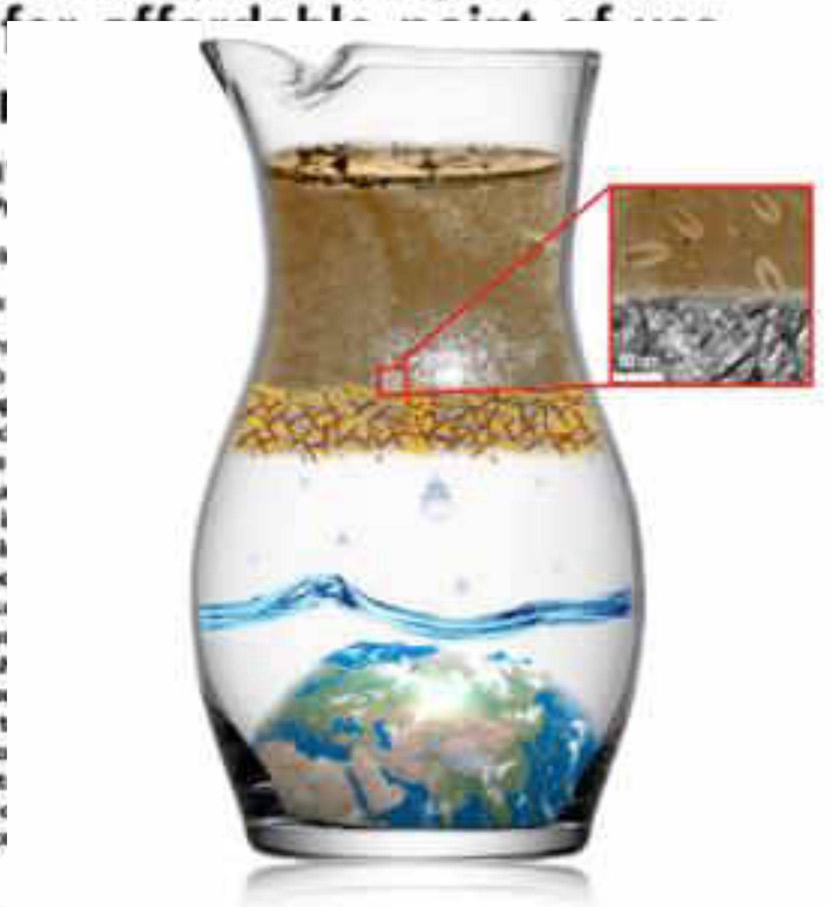
Biopolymer-reinforced synthetic granular nanocomposites f… water purificatio…

Mohan Udhaya Sankar[1], Sahaja Aigal… Anil Kumar,
Kamalesh Chaudhari, and Thalappil P…

Unit of Nanoscience and Thematic Unit of Excell… 6, India

Edited by Eric Hoek, University of California, Lo… ember 21, 2012)

Creation of affordable materials for constan… water is one of the most promising ways to… drinking water for all. Combining the ca… composites to scavenge toxic species suc… other contaminants along with the above… affordable, all-inclusive drinking water pu… without electricity. The critical problem i… synthesis of stable materials that can rel… uously in the presence of complex spe… drinking water that deposit and cause s… surfaces. Here we show that such consta… be synthesized in a simple and effective fas… out the use of electrical power. The nano… sand-like properties, such as higher shear st… forms. These materials have been used to… water purifier to deliver clean drinking wat… ily. The ability to prepare nanostructure… ambient temperature has wide relevanc… water purification.



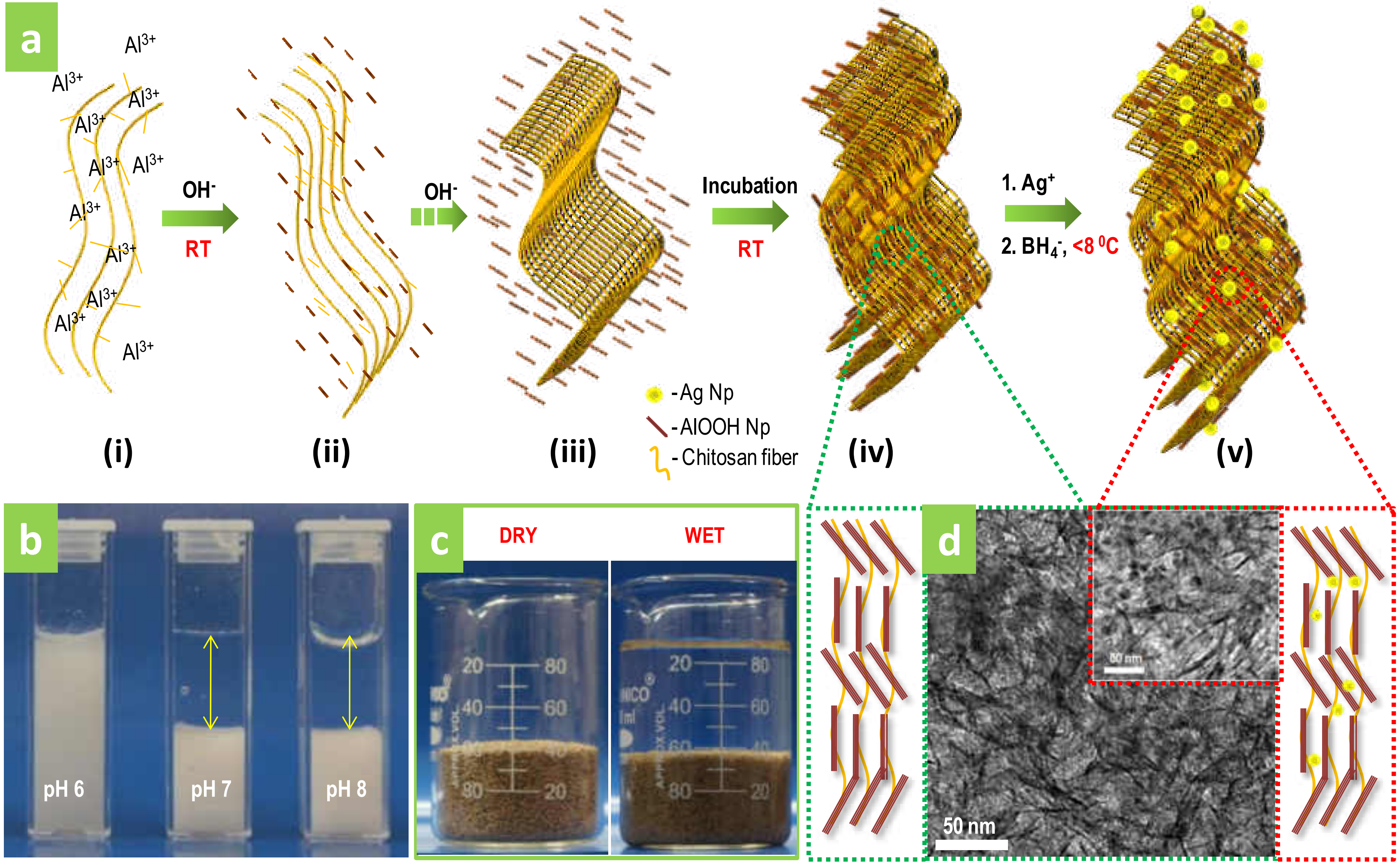
…tinued retention

…f nanocrystalline …e materials pre- …eous route. The …l to abundant -O- …help in the crys- …strong covalent …ix. X-ray photo- …mposition is rich …ral imaging, the … was confirmed. …ver nanoparticle …vity in drinking …eloped that can …monstrate an af- …composites de- …rials in India, as …f the waterborne

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

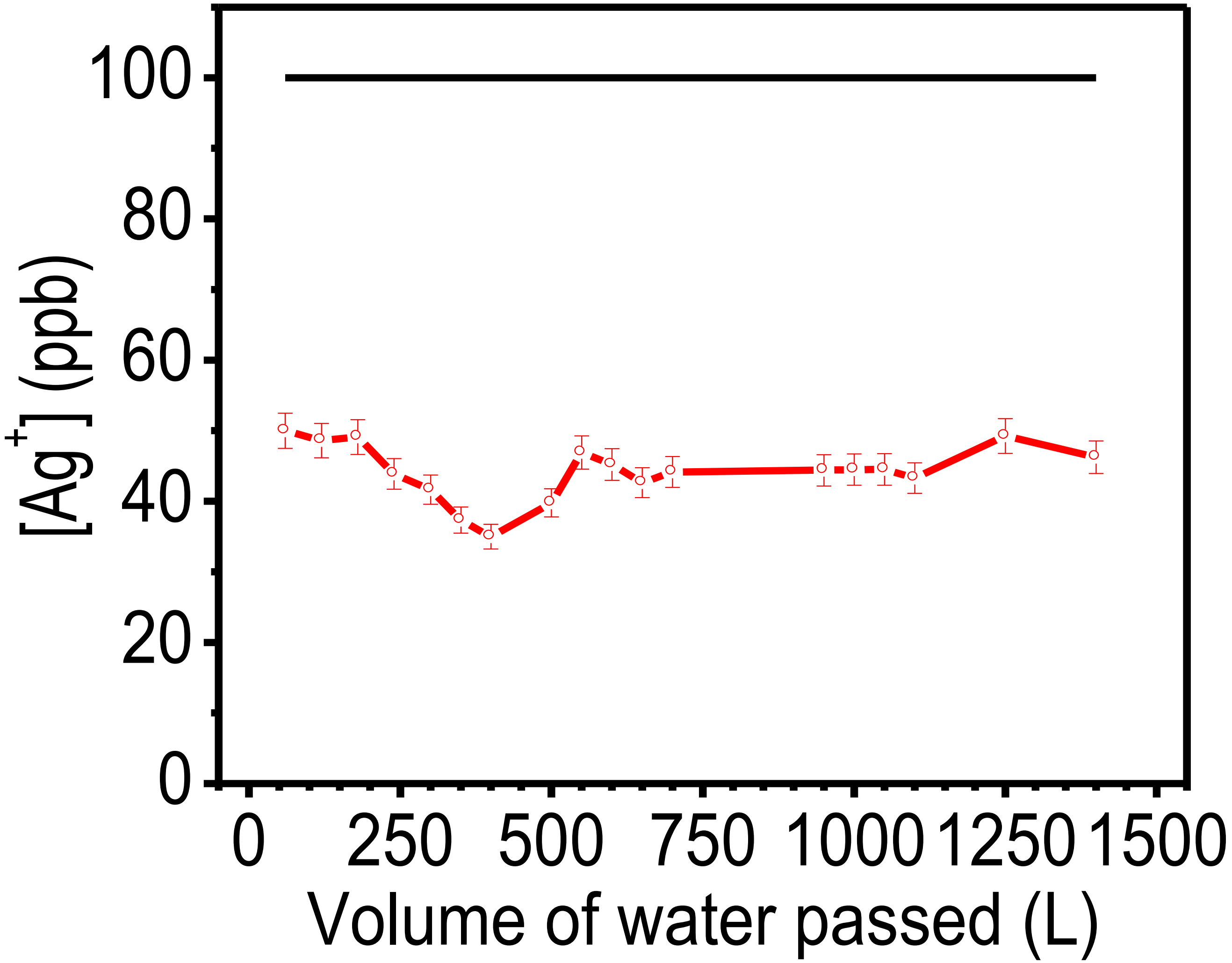
M. Udhaya Sankar, et. al. *Proc. Natl. Acad. Sci.,* 110 (2013) 8459-8464.

How to make?

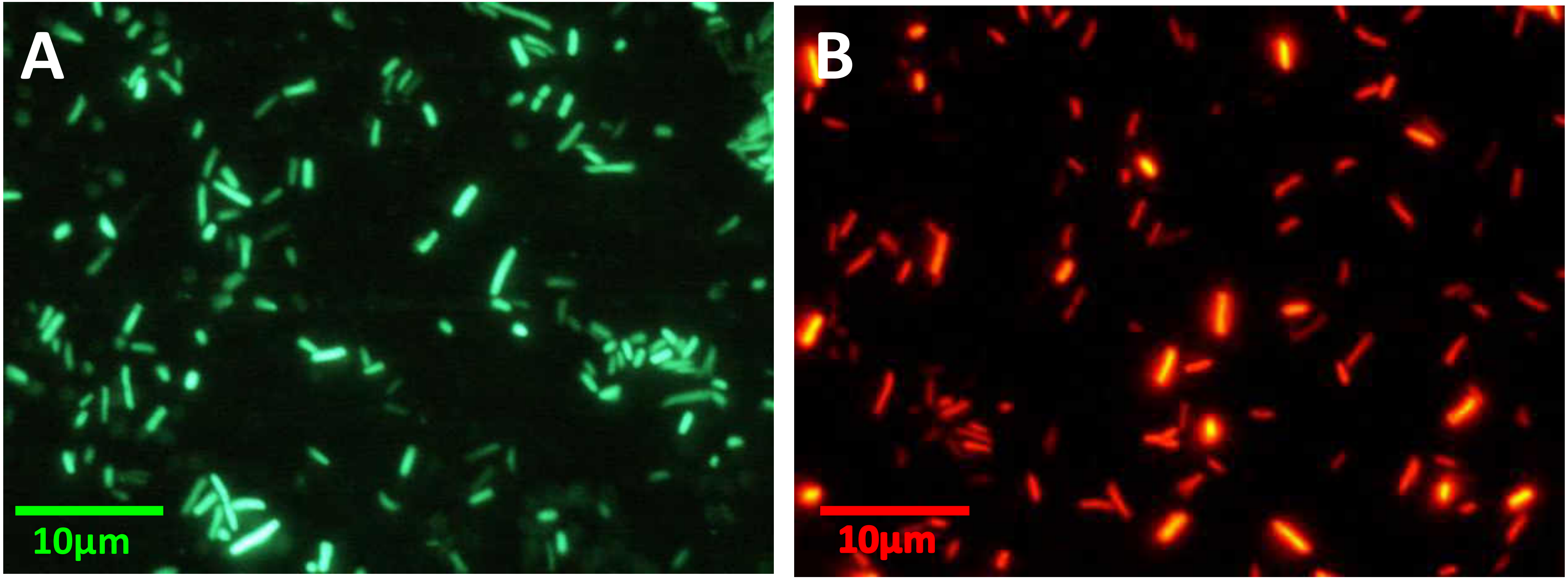


a
Al^{3+}
OH-
RT
OH-
Incubation
RT
1. Ag^+
2. BH_4^-, <8 ^0C
-Ag Np
-AlOOH Np
-Chitosan fiber
(i)
(ii)
(iii)
(iv)
(v)
b
pH 6
pH 7
pH 8
c
DRY
WET
d
50 nm

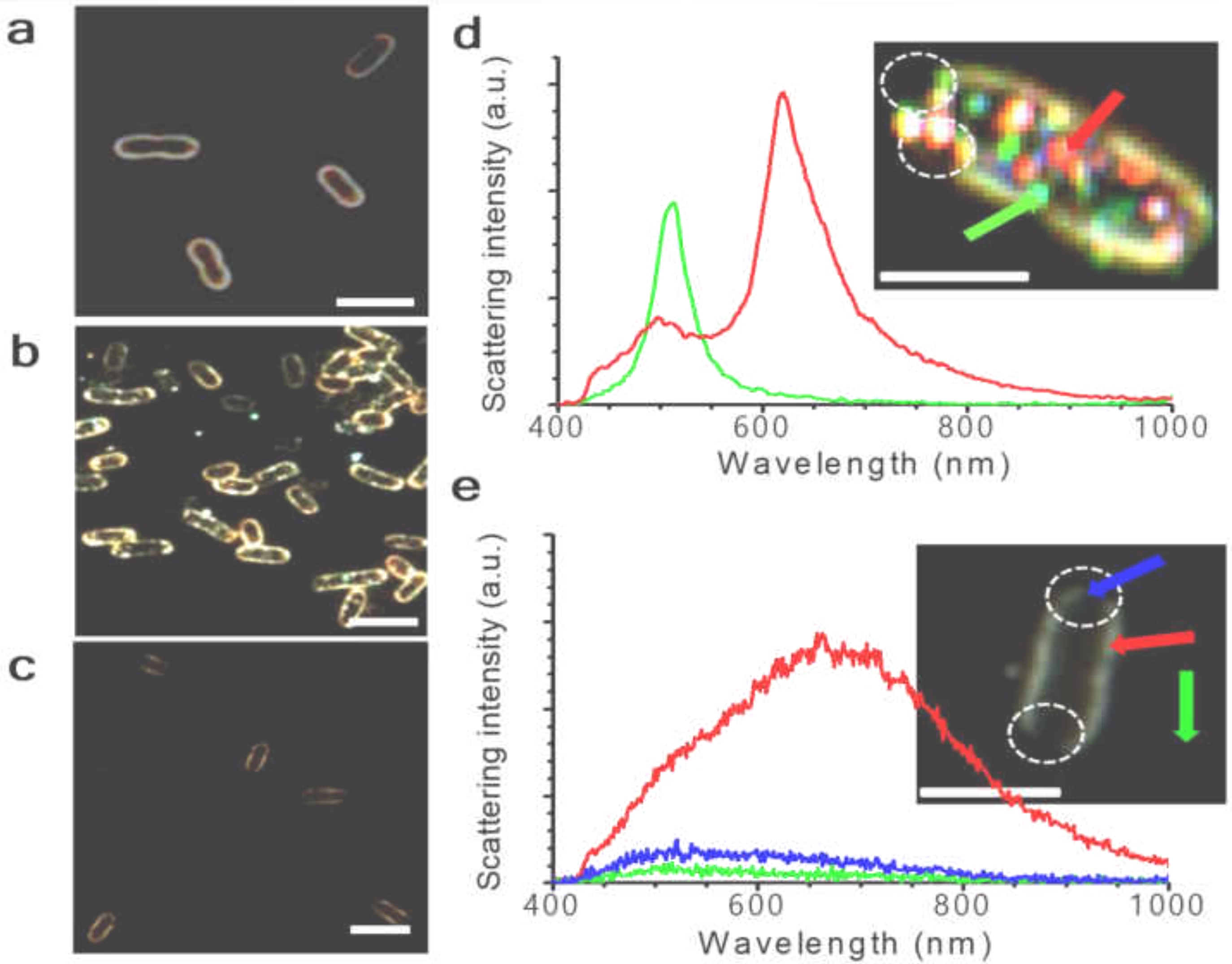
What is special?



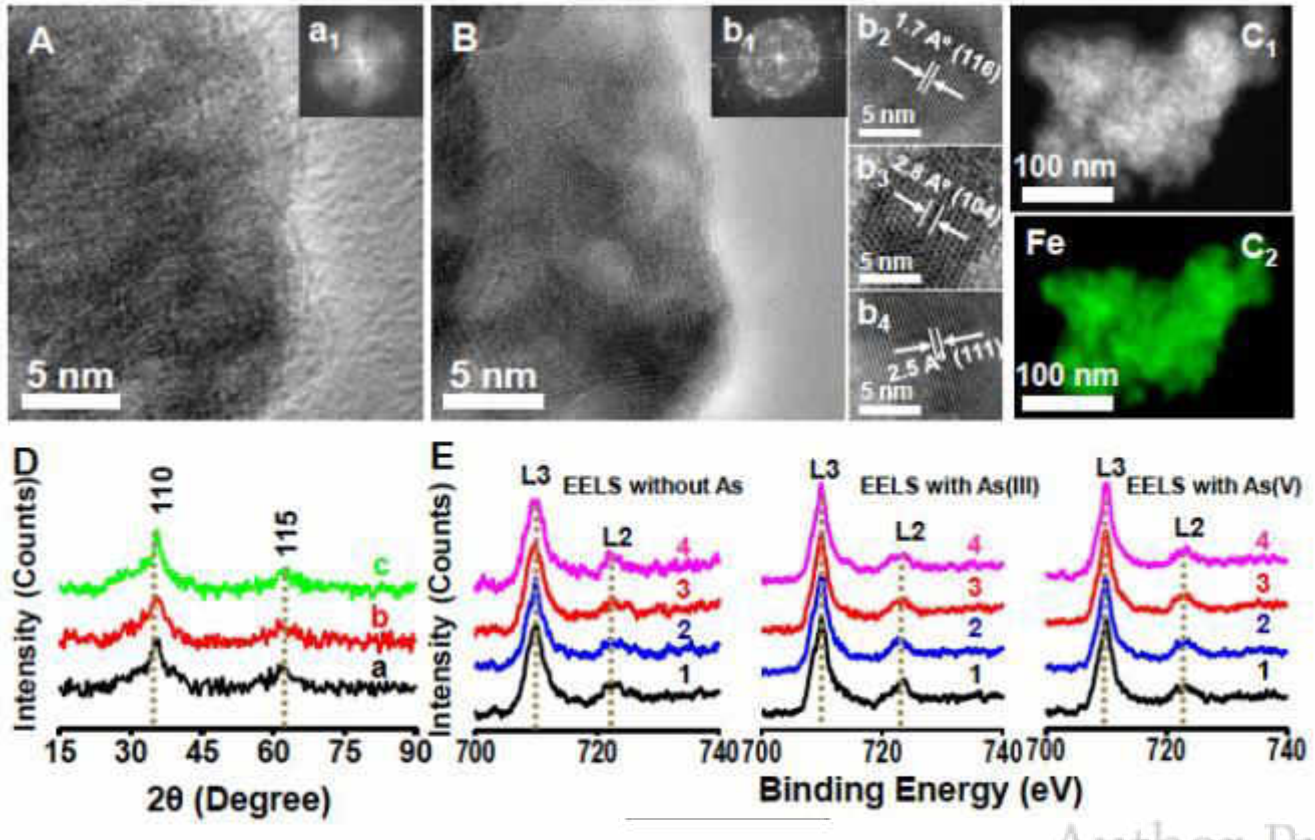
Live/dead staining experiments

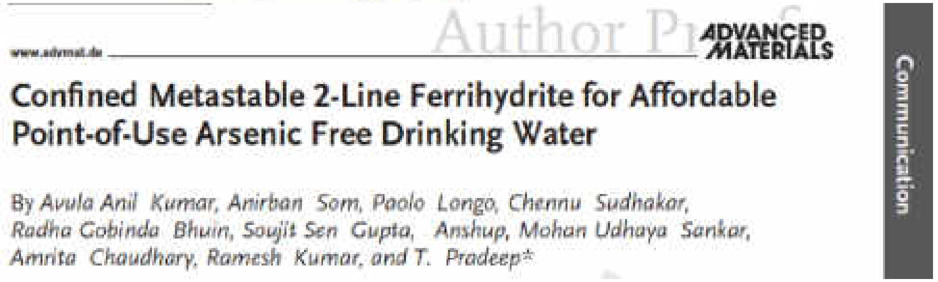


No nanotoxicity



Variety of materials




www.advmat.de

Author Proof

ADVANCED MATERIALS

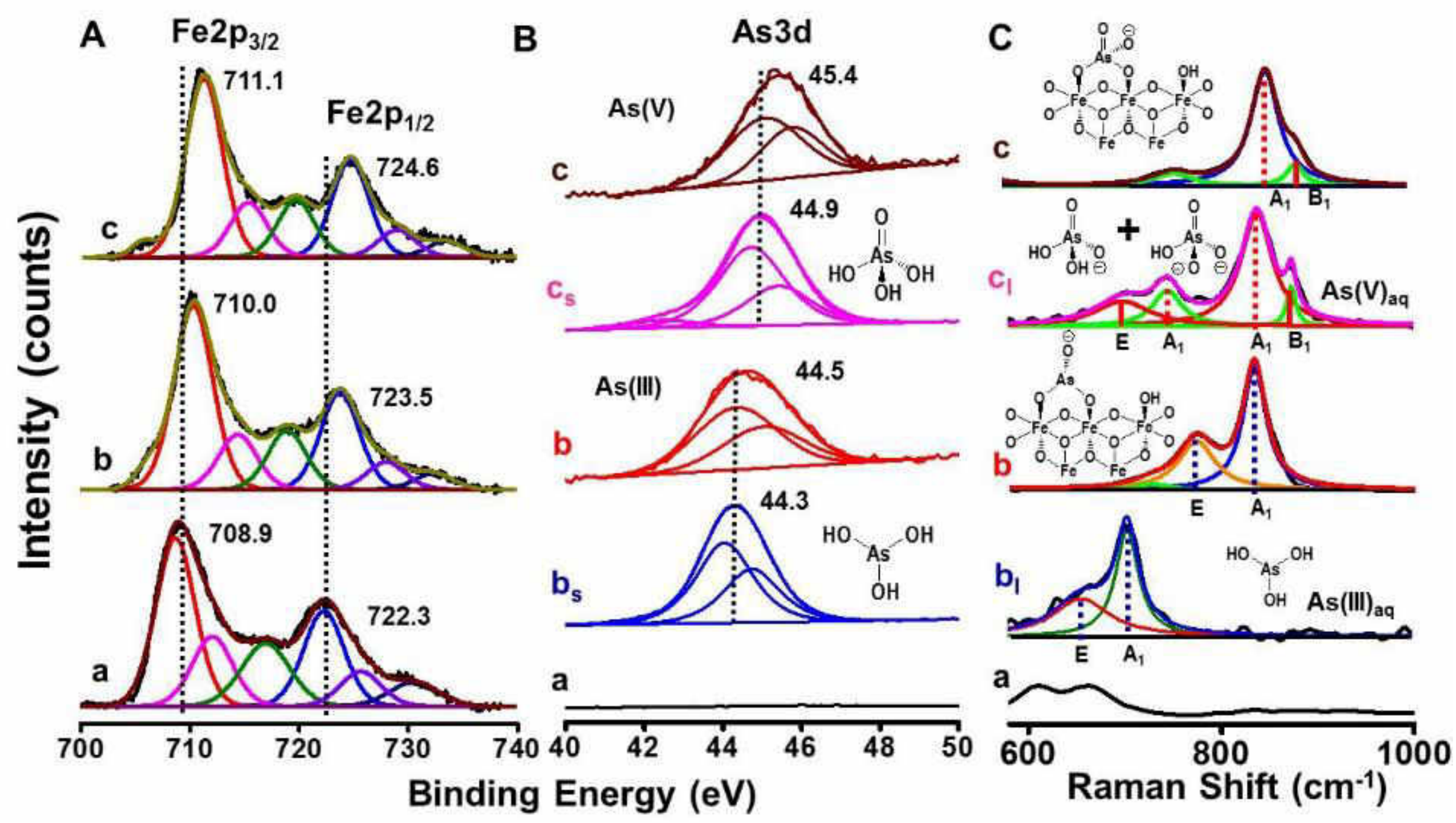
Communication

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

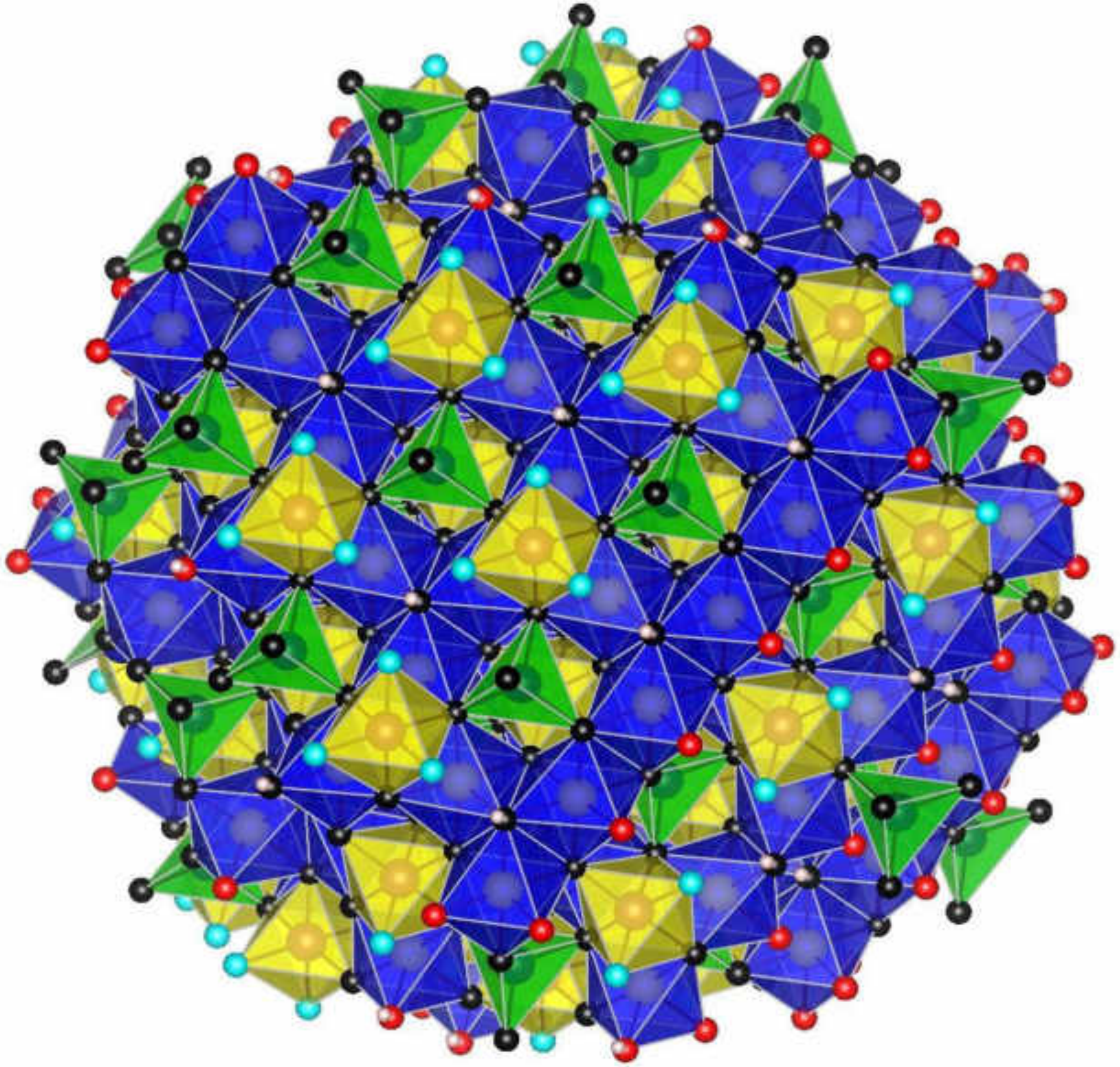
By Avula Anil Kumar, Anirban Som, Paolo Longo, Chennu Sudhakar, Radha Gobinda Bhuin, Soujit Sen Gupta, Anshup, Mohan Udhaya Sankar, Amrita Chaudhary, Ramesh Kumar, and T. Pradeep*

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

Mechanism – molecular tools

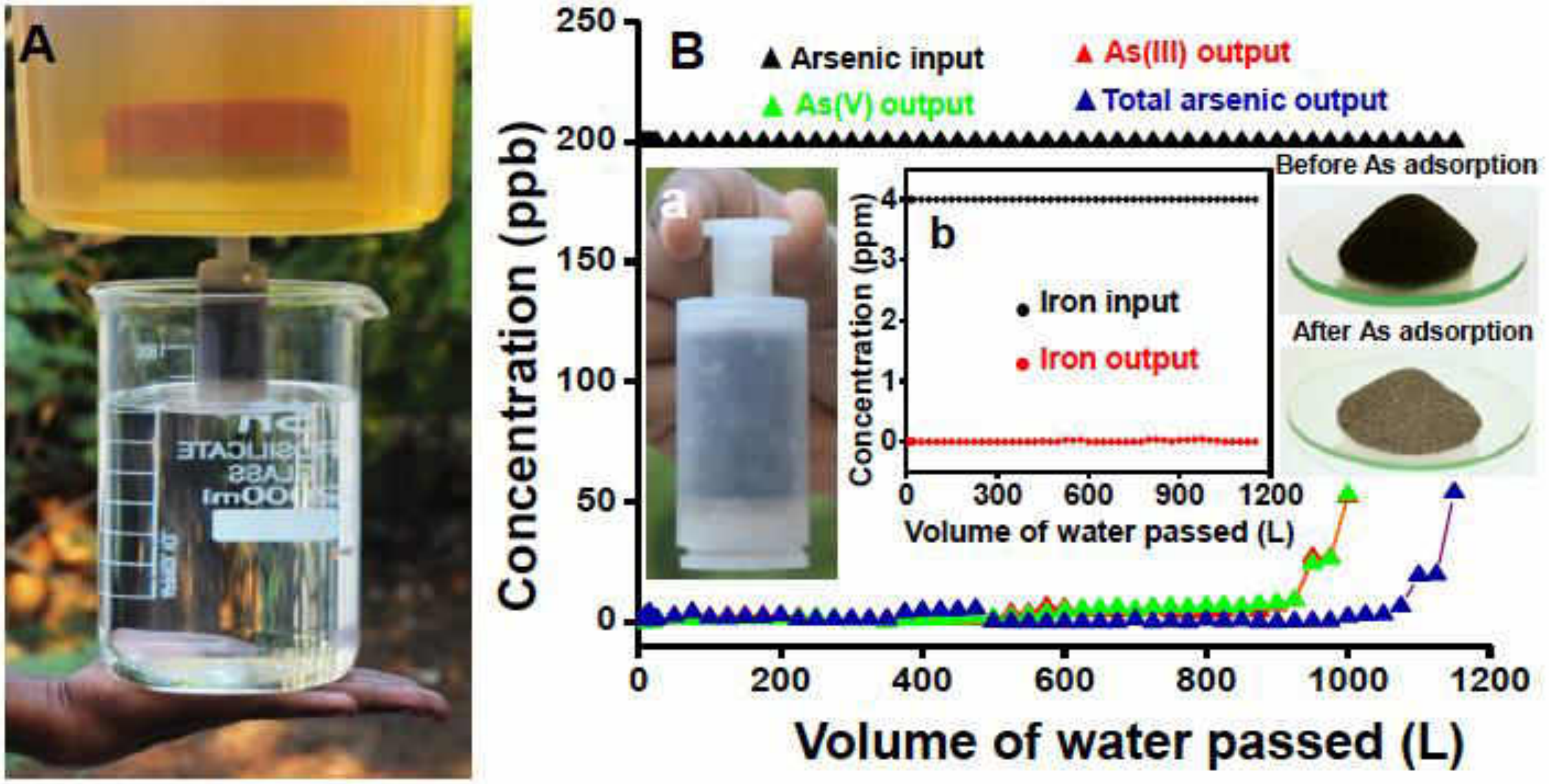


Modeling surfaces



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

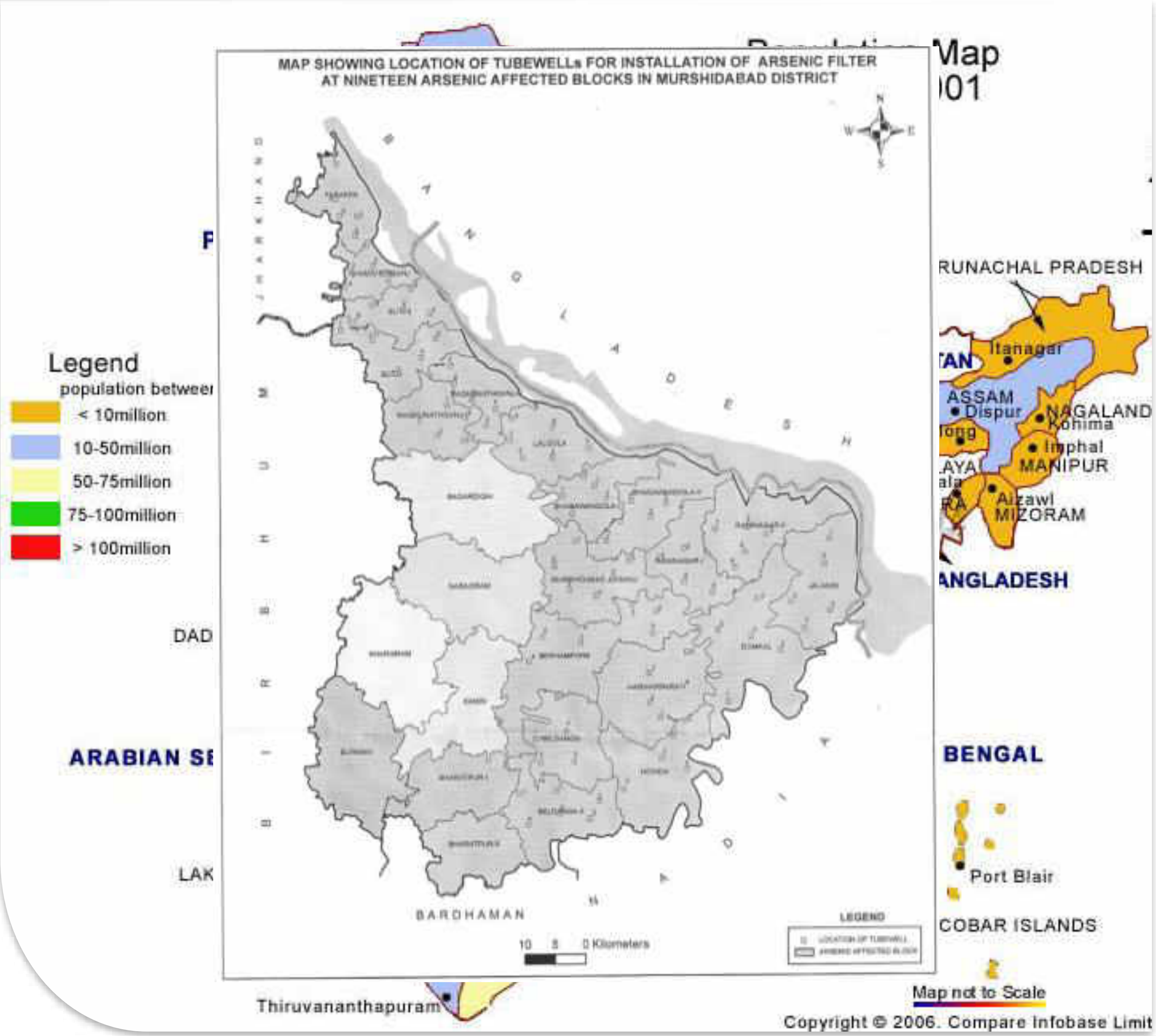
Lab studies



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

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

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

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

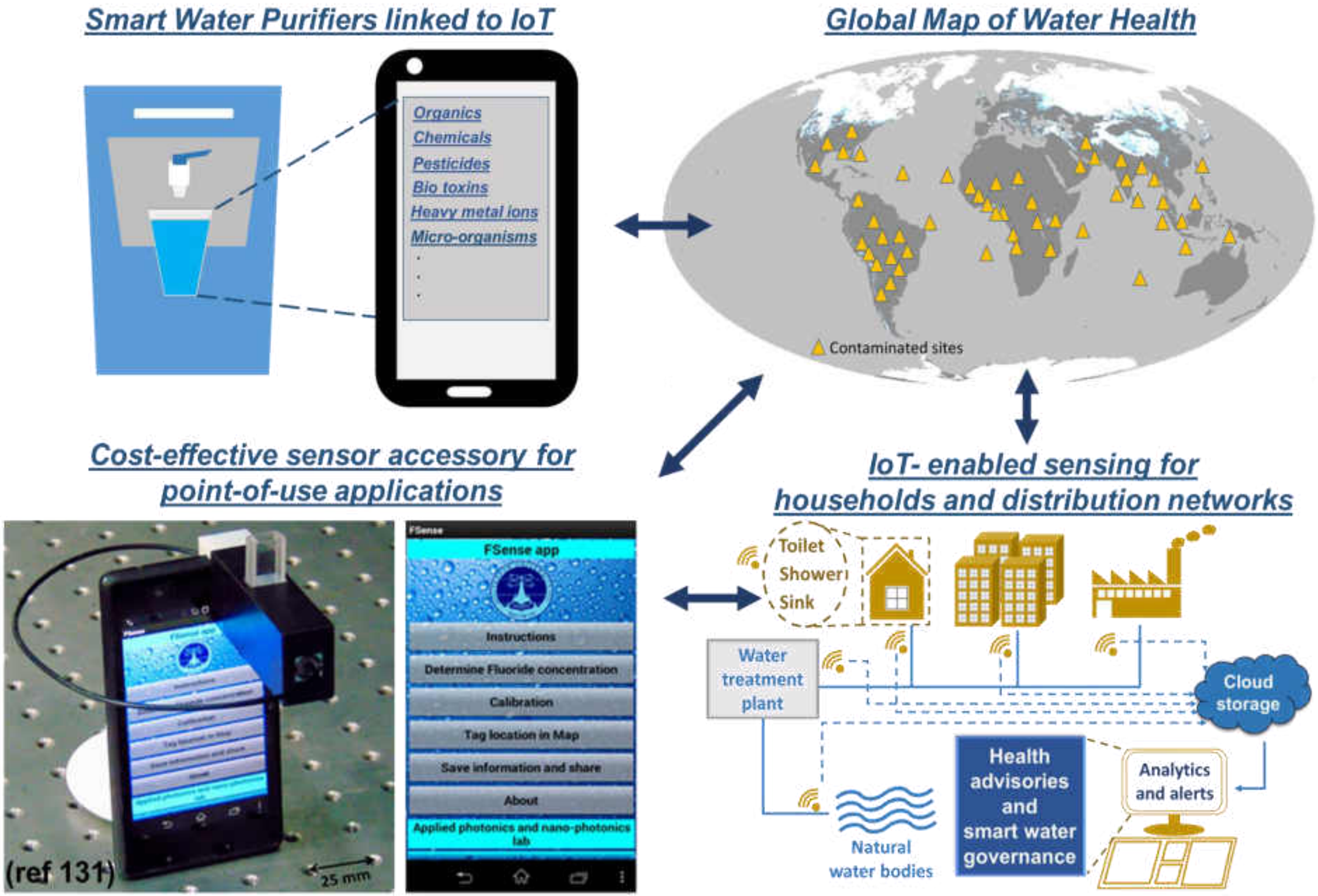
Capacity: 0.1-1 MLD

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 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

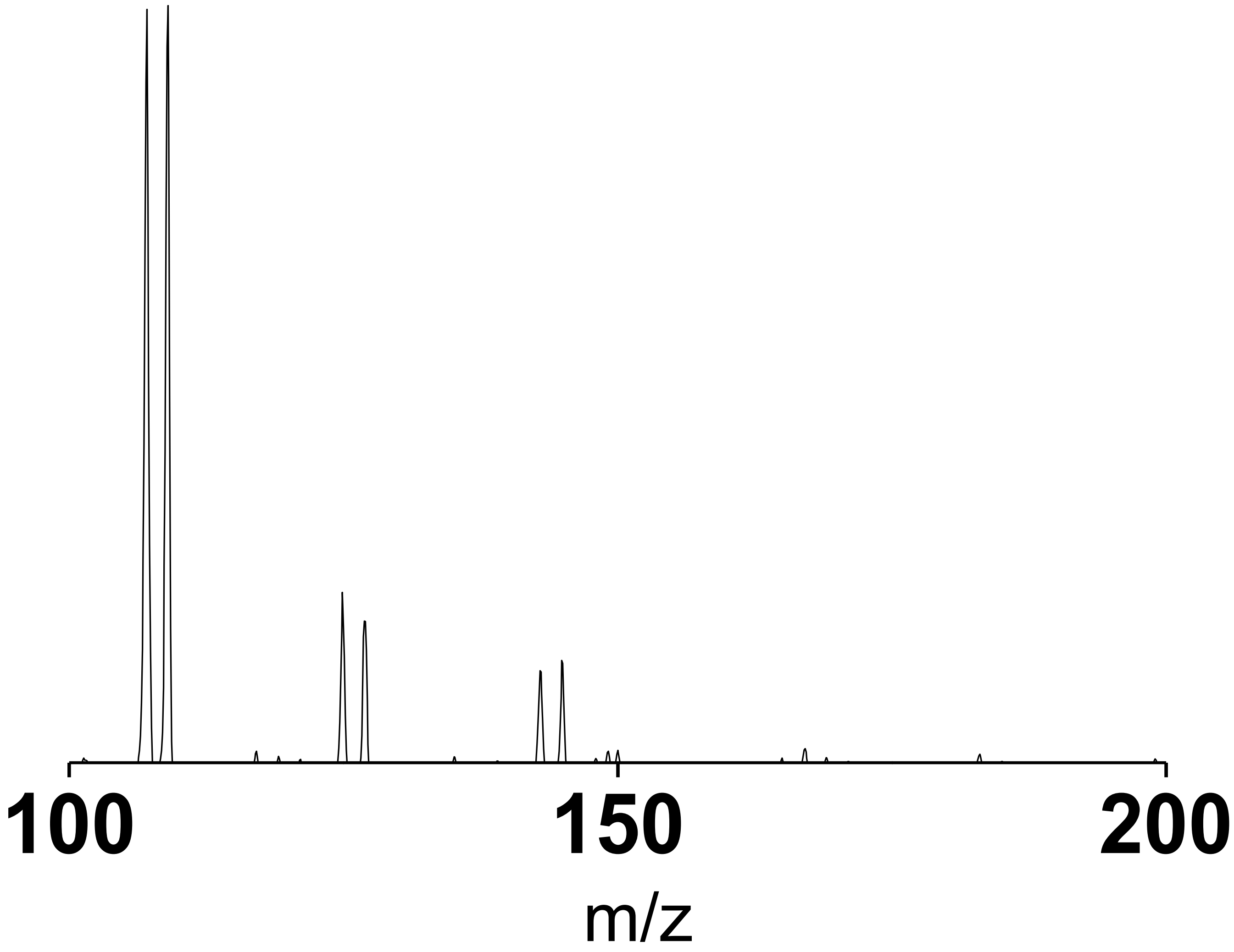
- Adsorbents conform to toxicity characteristic leaching procedure
- Elemental waste goes back to local environment
- Safe disposal of arsenic (or any other) laden waste
- Additional protection could be considered, if necessary
- Exploring viable uses

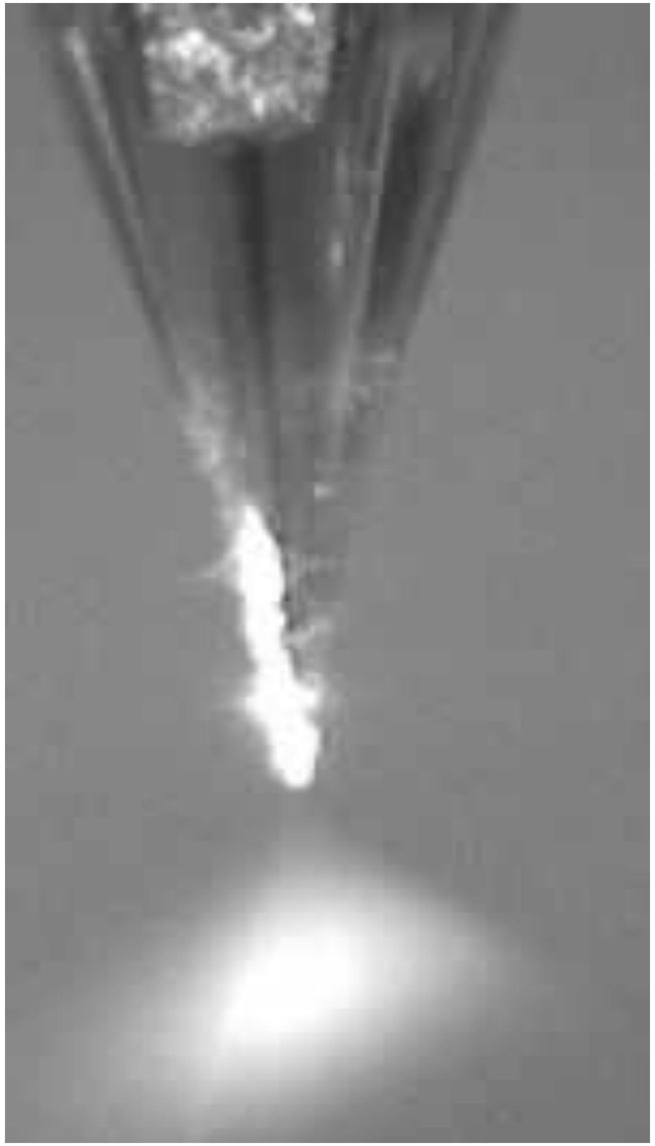
Now they are across the country

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

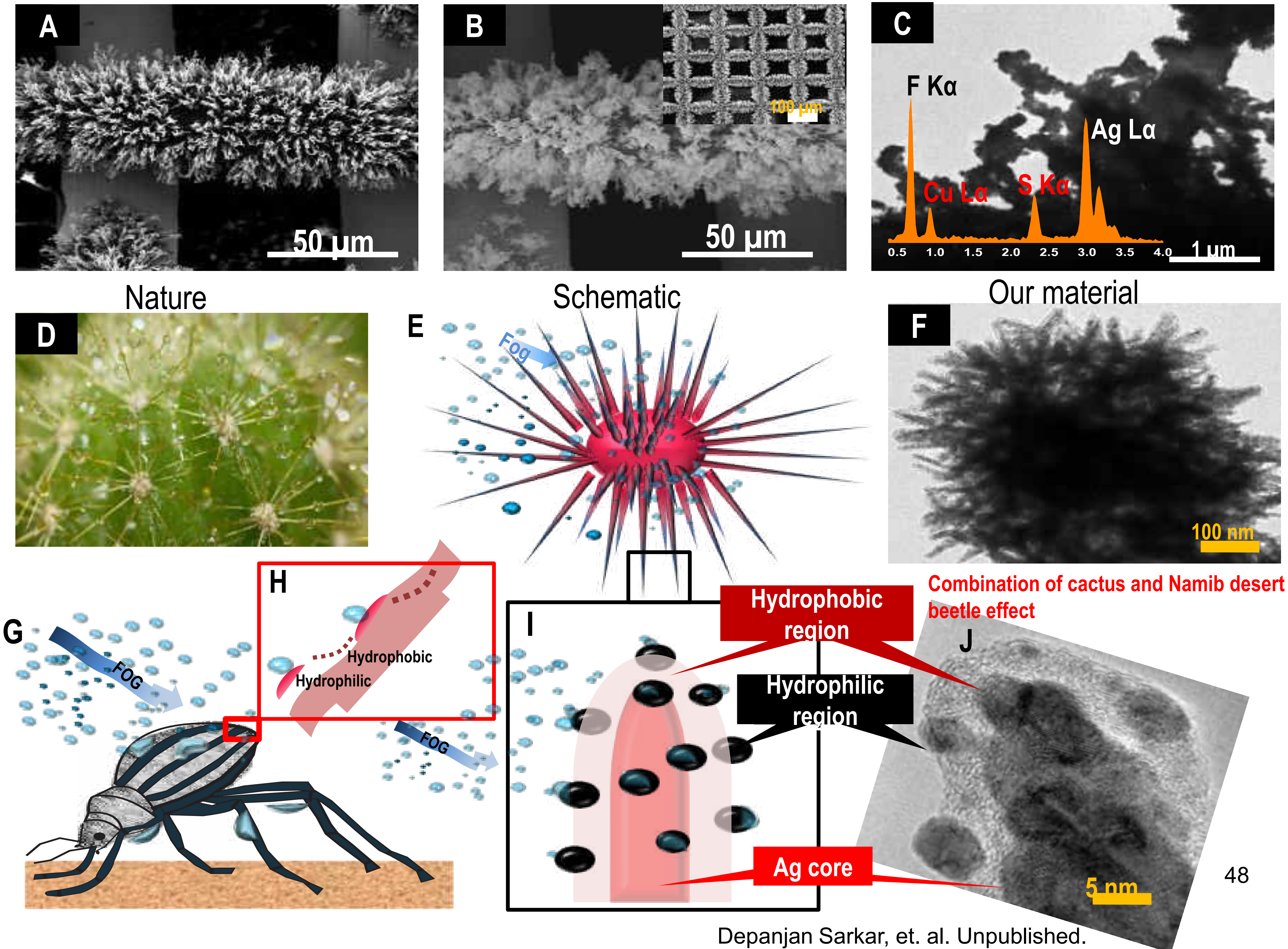
Atmospheric water harvesting



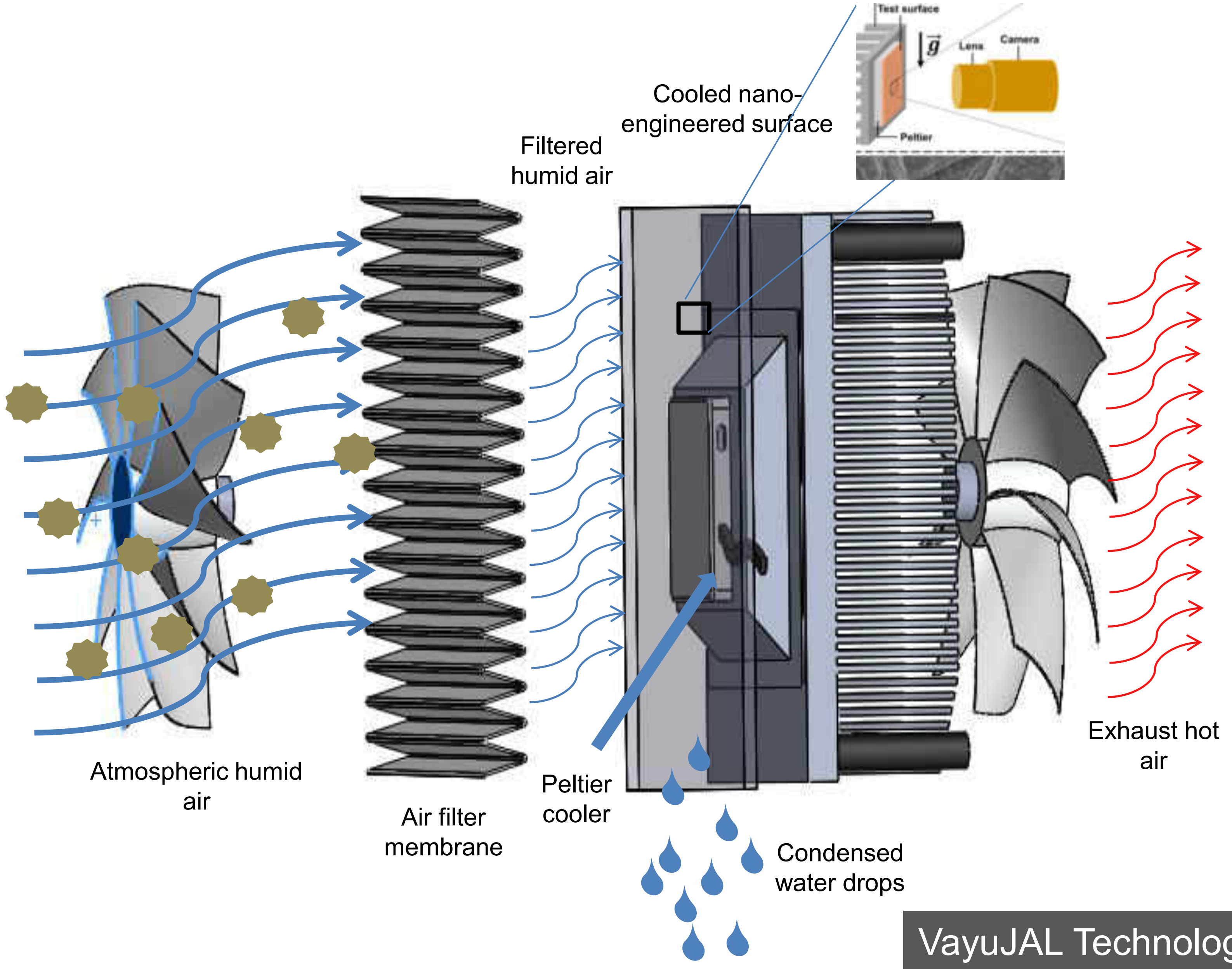


New harvesters

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

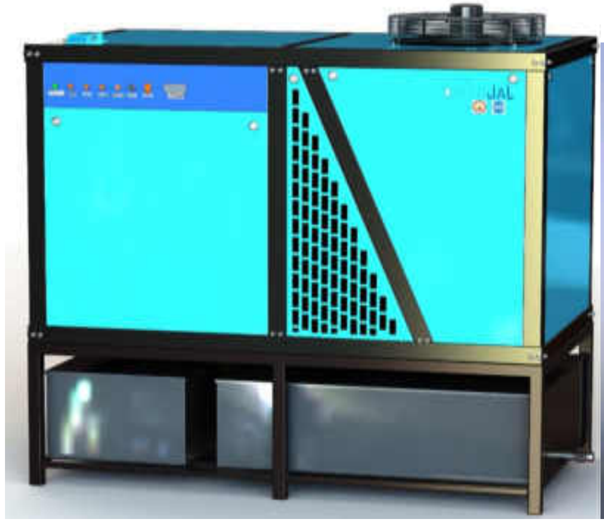


Depanjan Sarkar, et. al. Unpublished.



VayuJAL Technologies Pvt. Ltd.
Ramesh Kumar Soni and Ankit Nagar

Products in the field

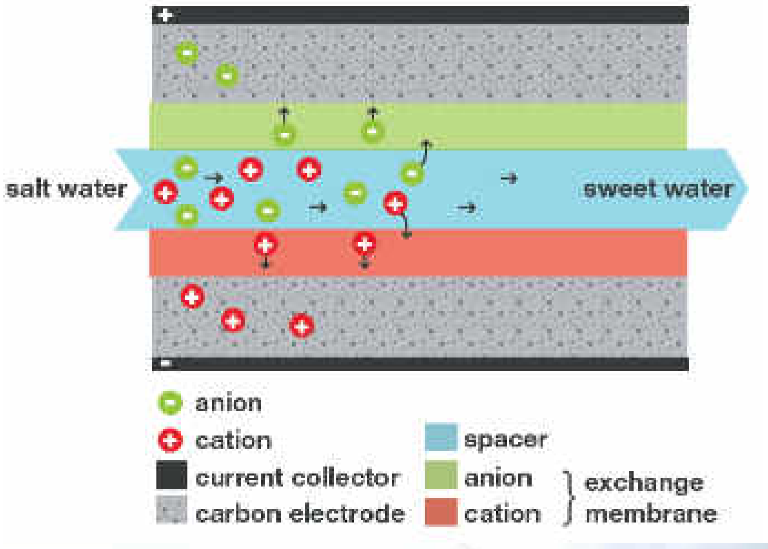



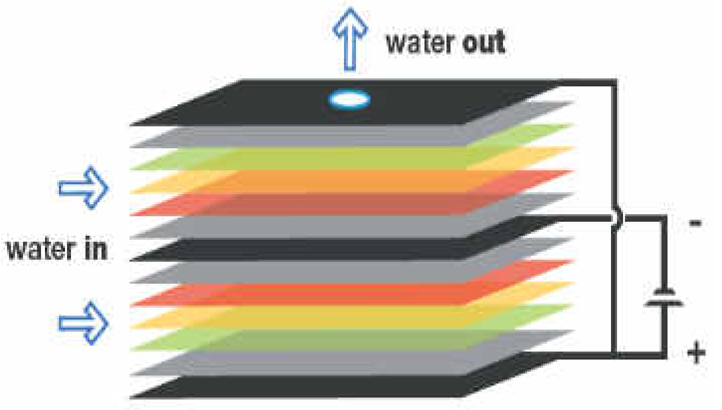
35 LPD 120 LPD 400 LPD 1000 LPD 2000 LPD

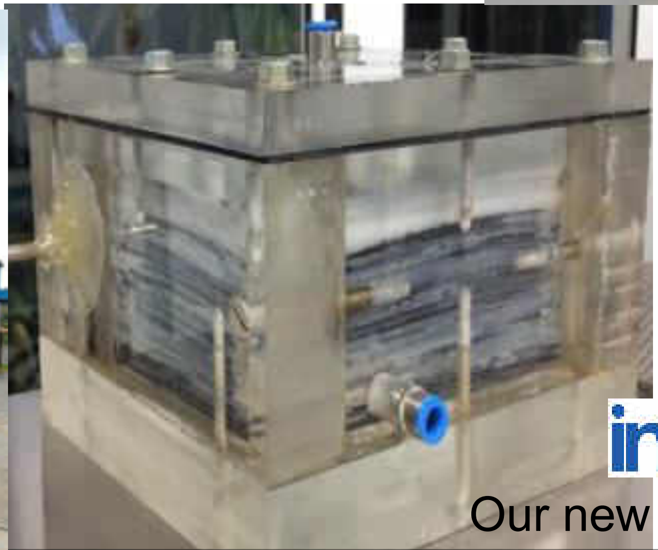
(LPD: Litres per day)


July 2023

Capacitive Desalination (CDI)



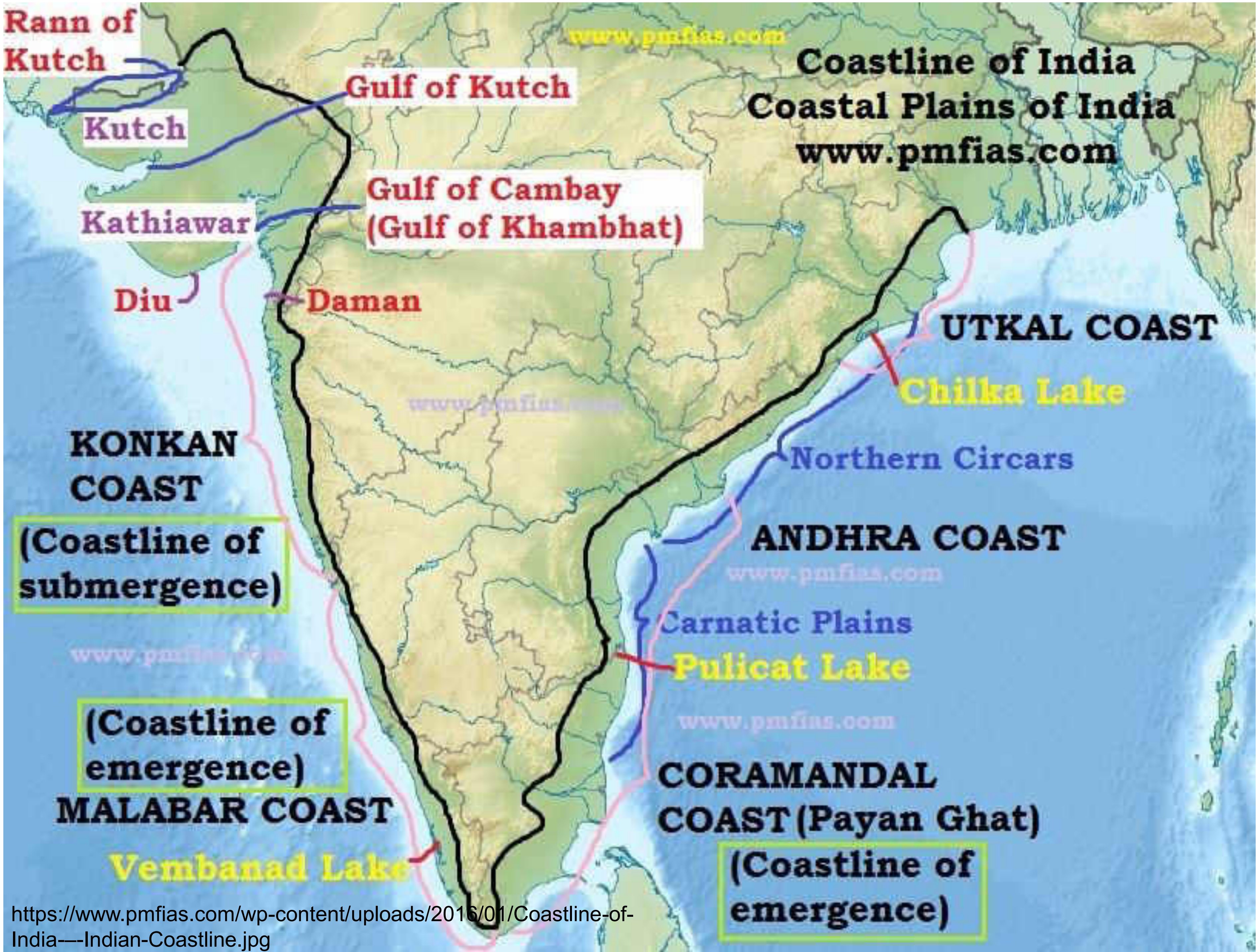




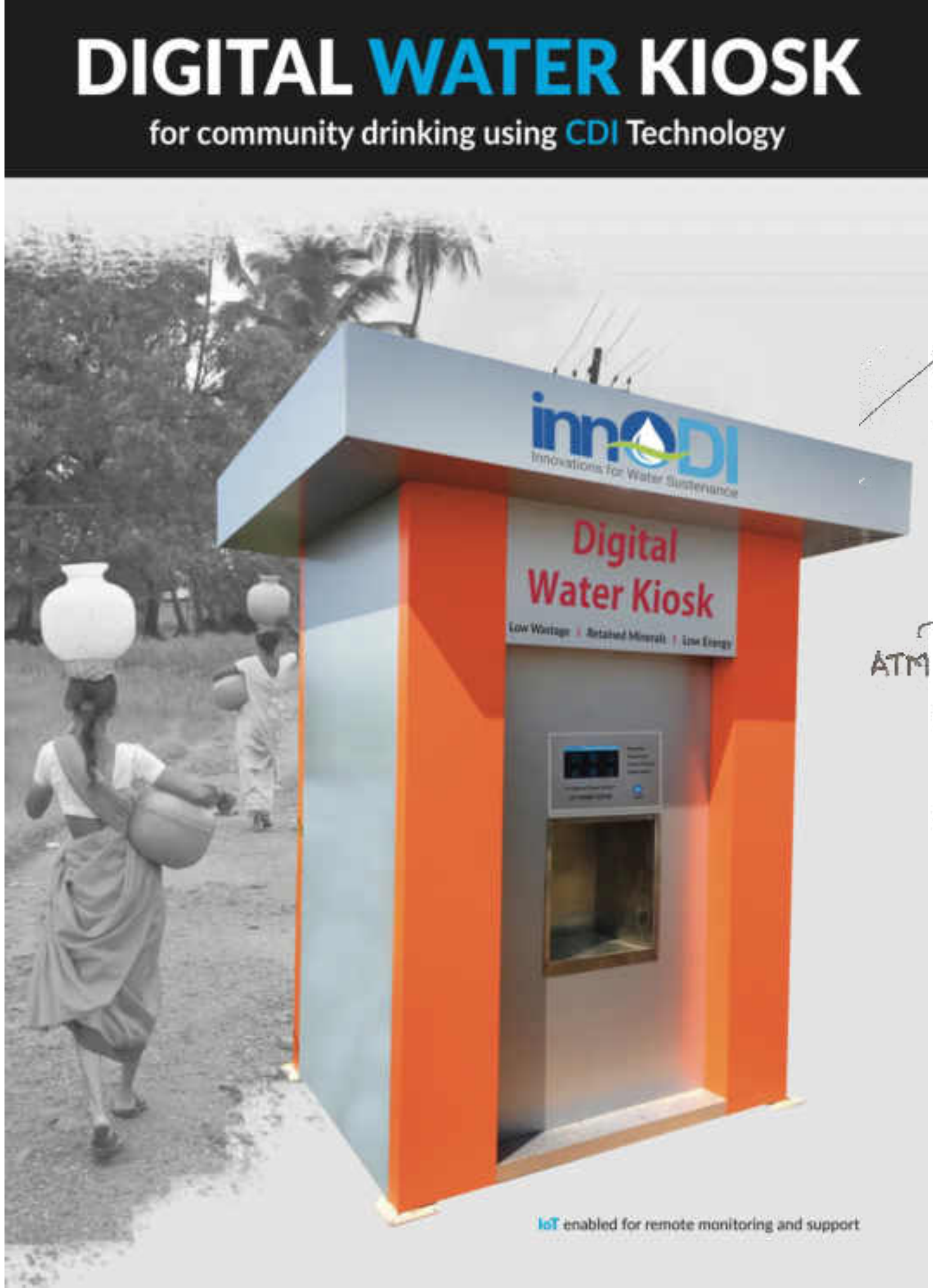
innoDI

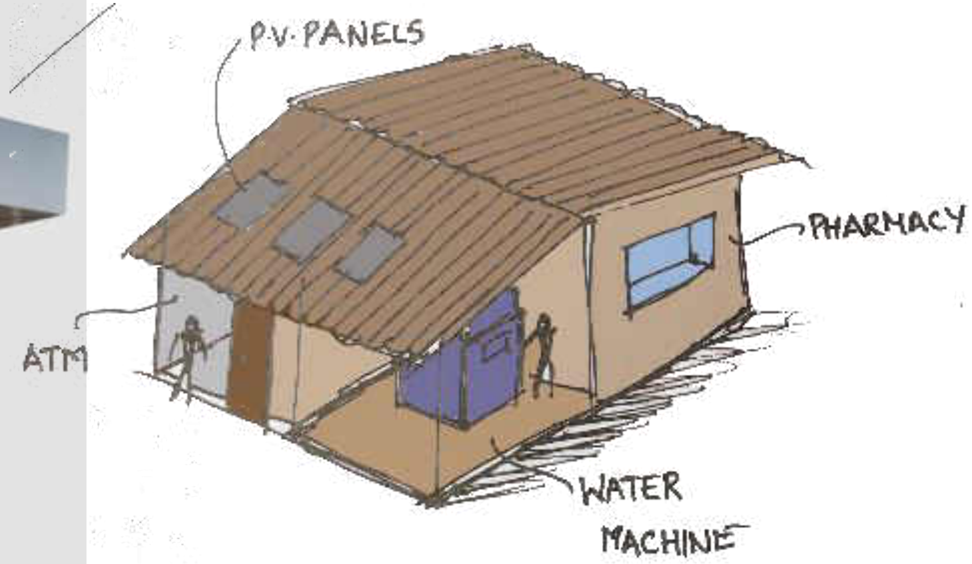
Our new company

Soujit Sengupta, Rabiul Islam and others



https://www.pmfias.com/wp-content/uploads/2016/01/Coastline-of-India---Indian-Coastline.jpg

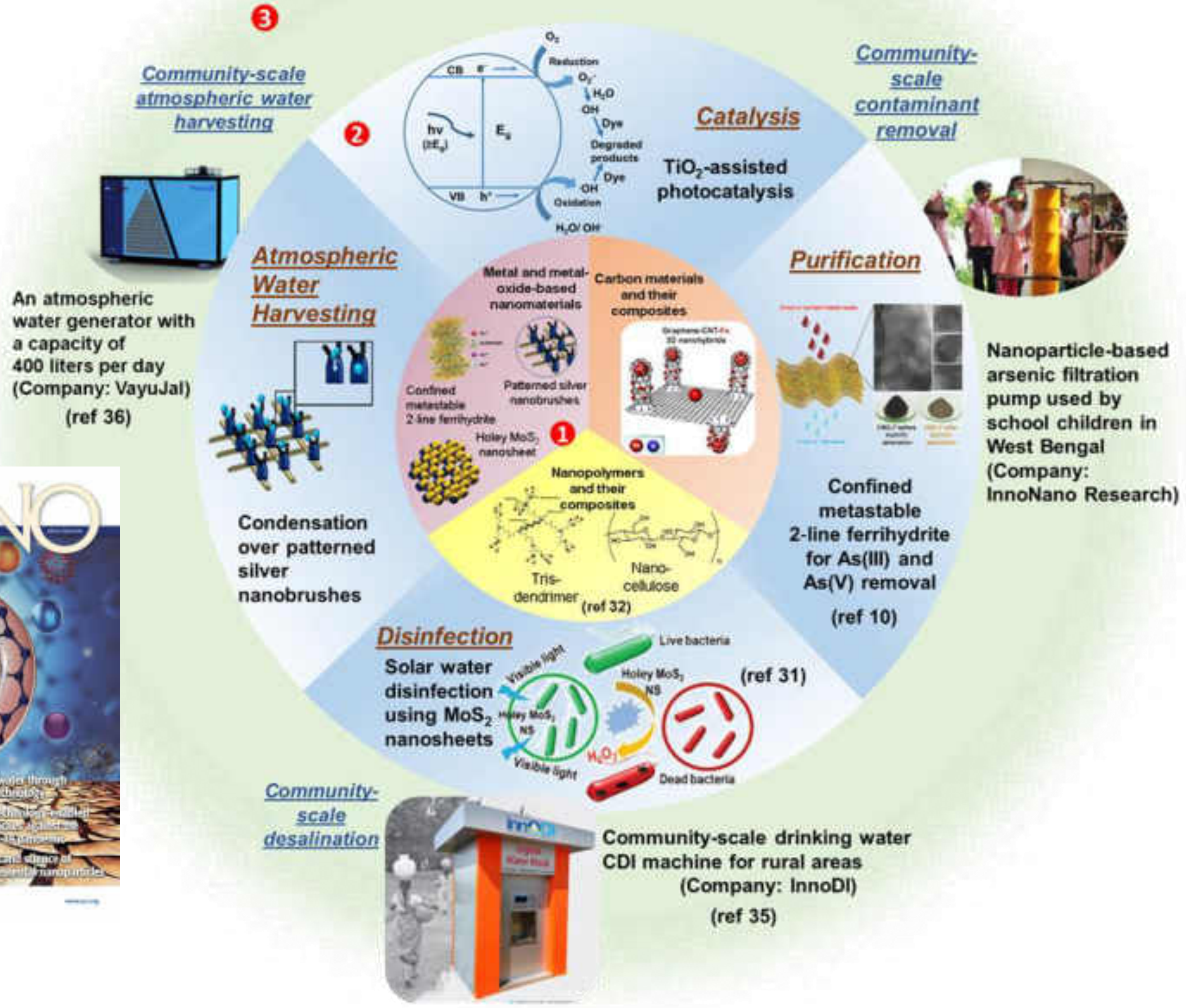


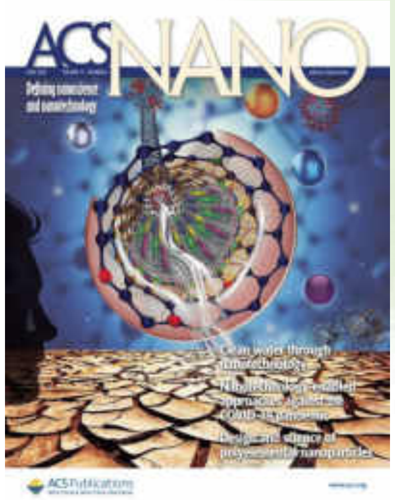


Products under implementation

Vijay Sampath and Tullio Servida

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)**

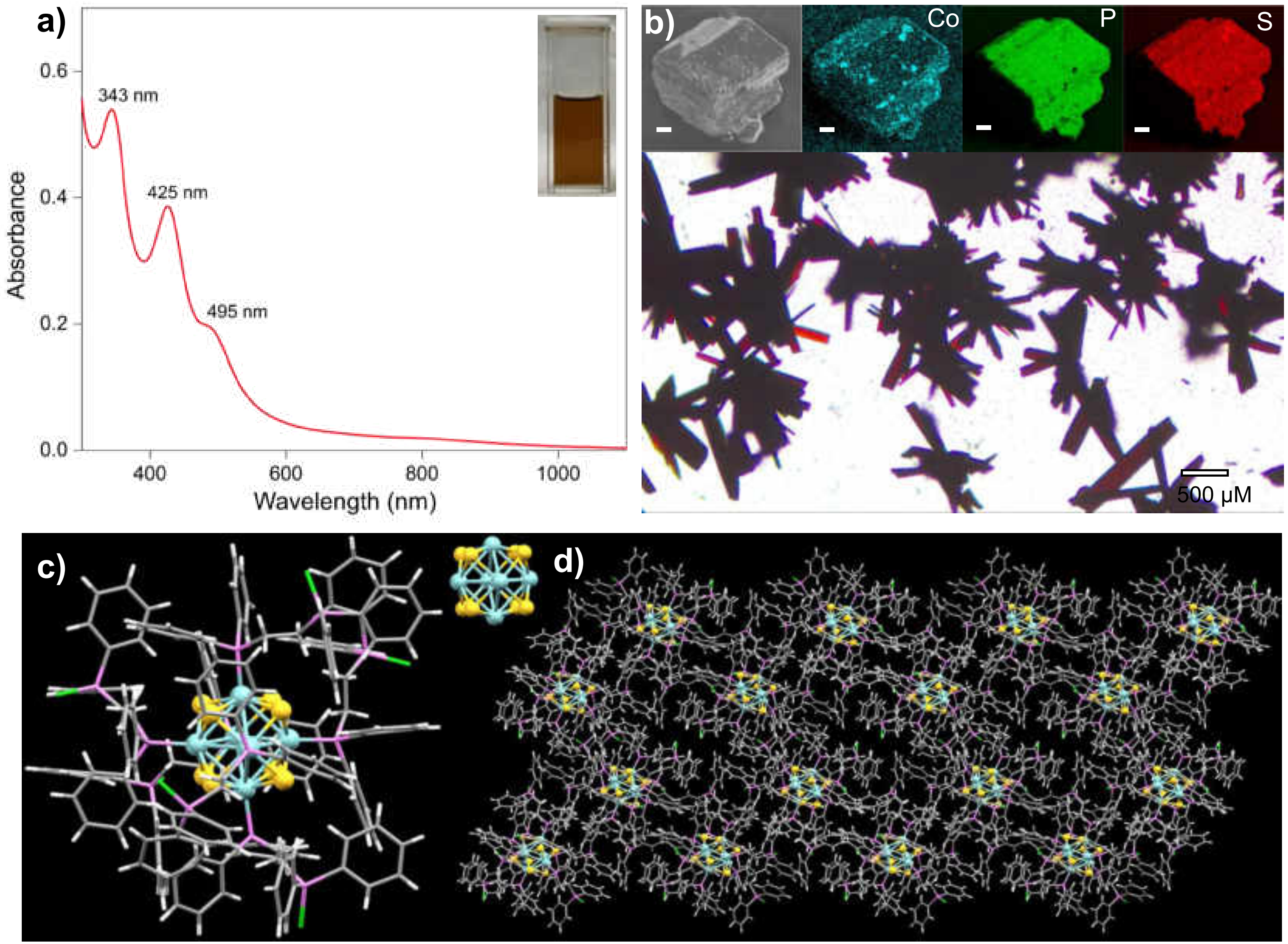
Ultra compact Low Cost Spectral Sensor Module
~ Billions units (? 2027)

Water quality measurement – In the pipeline

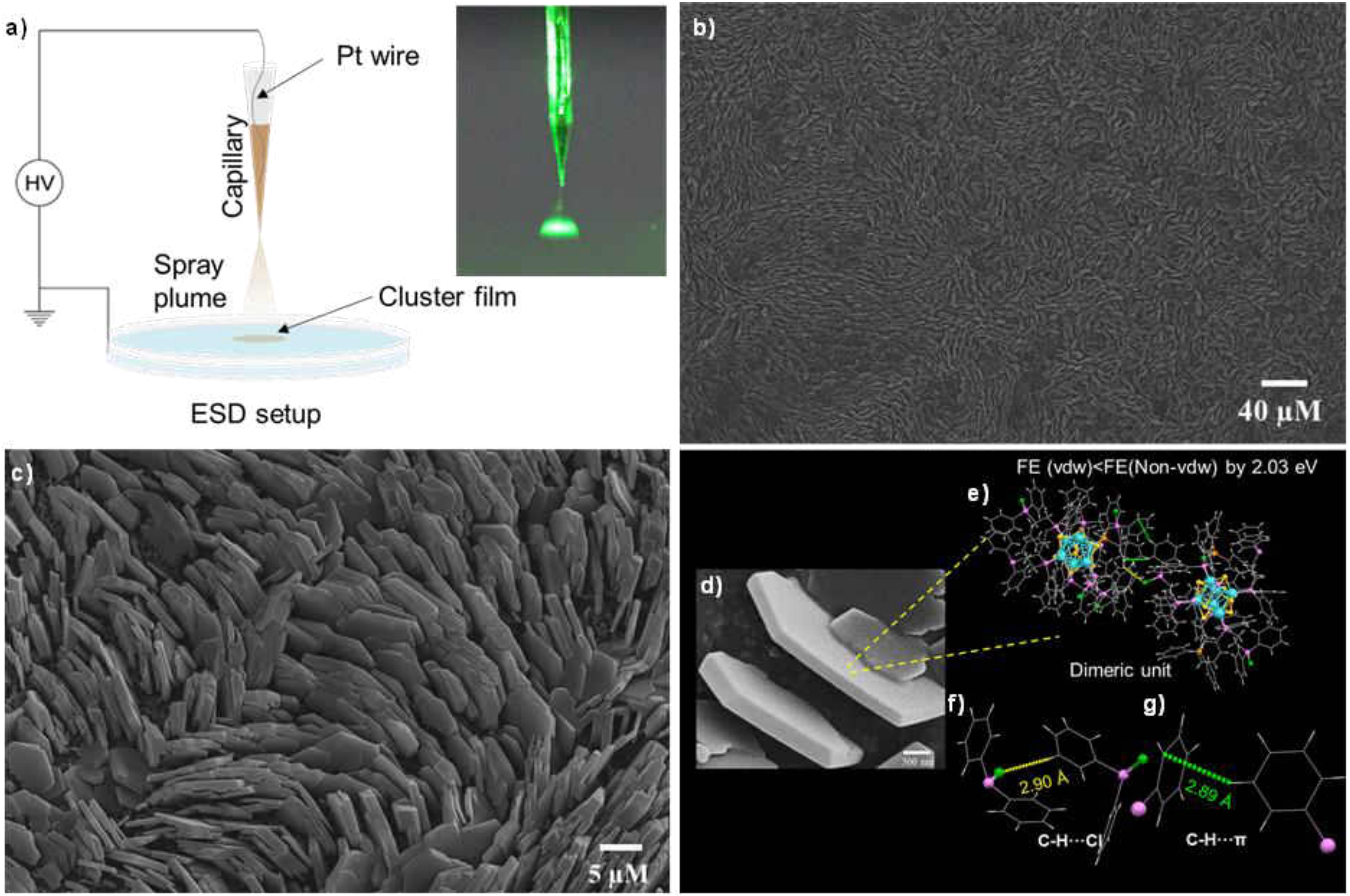
nanoλ

New electrodes - Aligned nanoplates of Co_6S_8

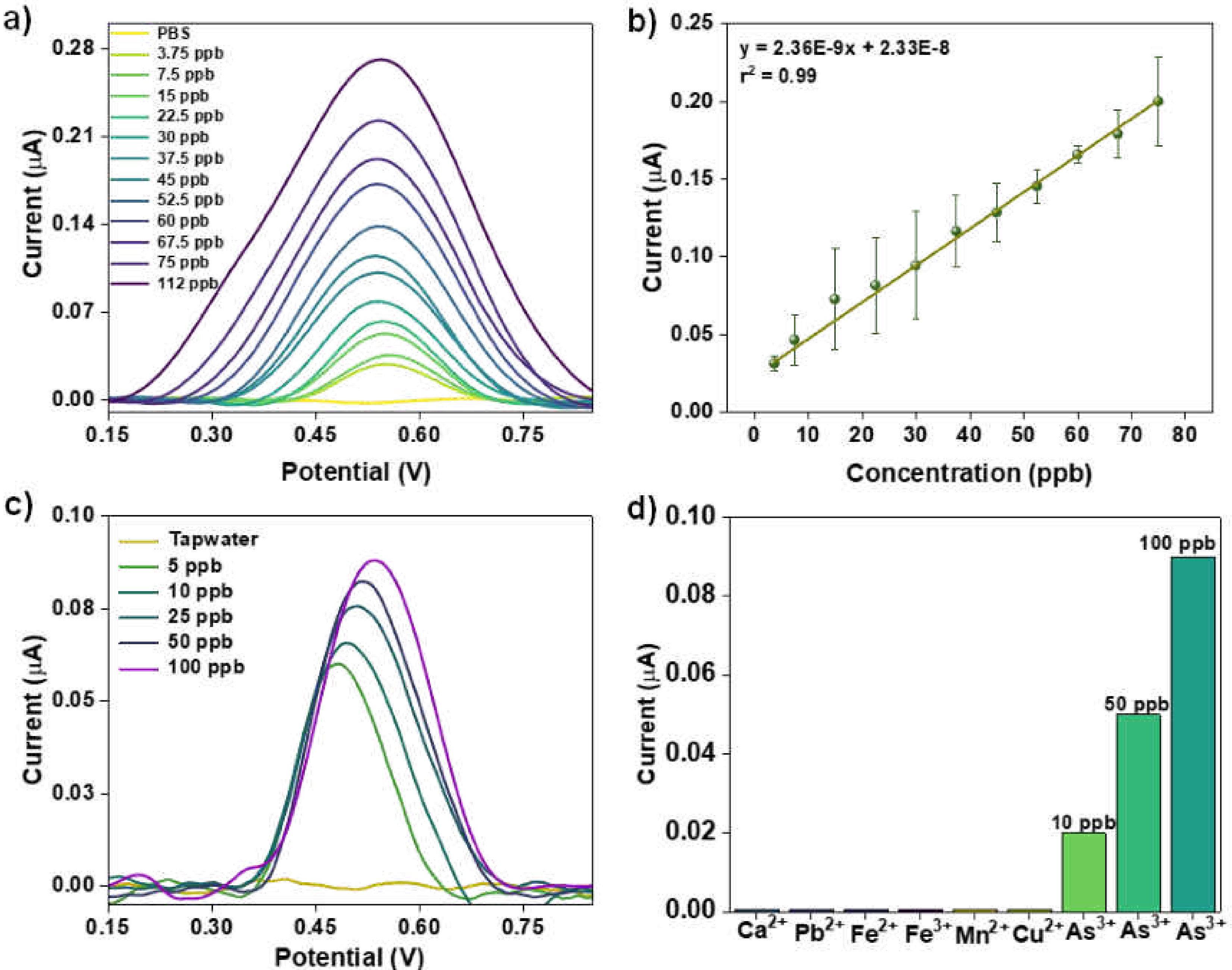
1,2-bis(diphenylphosphino)ethane (DPPE)



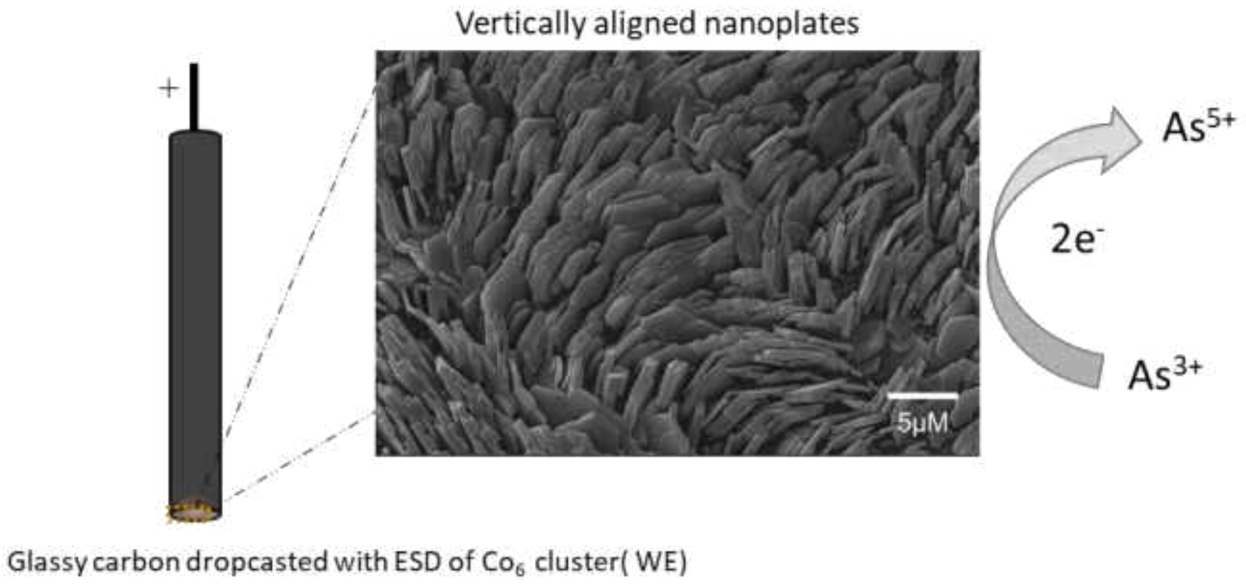
Electrospray deposition

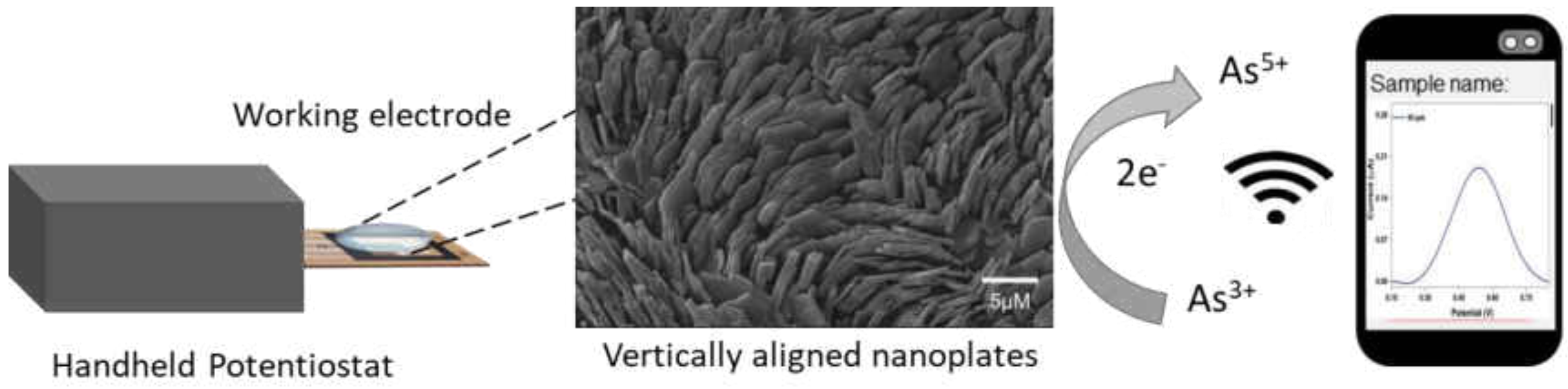


Sensing


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)
100 ppb
50 ppb
10 ppb
Current (μA)
Ca2+ Pb2+ Fe2+ Fe3+ Mn2+ Cu2+ As3+ As3+ As3+

Working electrode





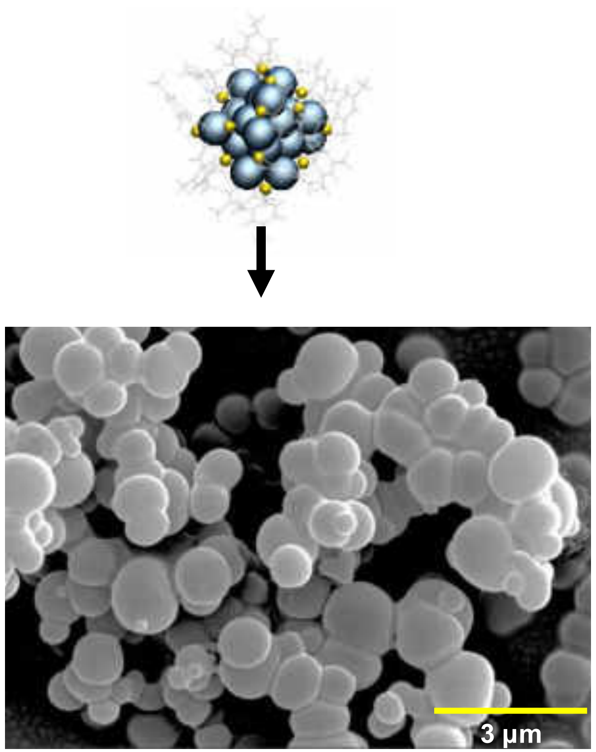
Anagha Jose et al. *ACS Materials Lett.*, 5 (2023) 893–899.

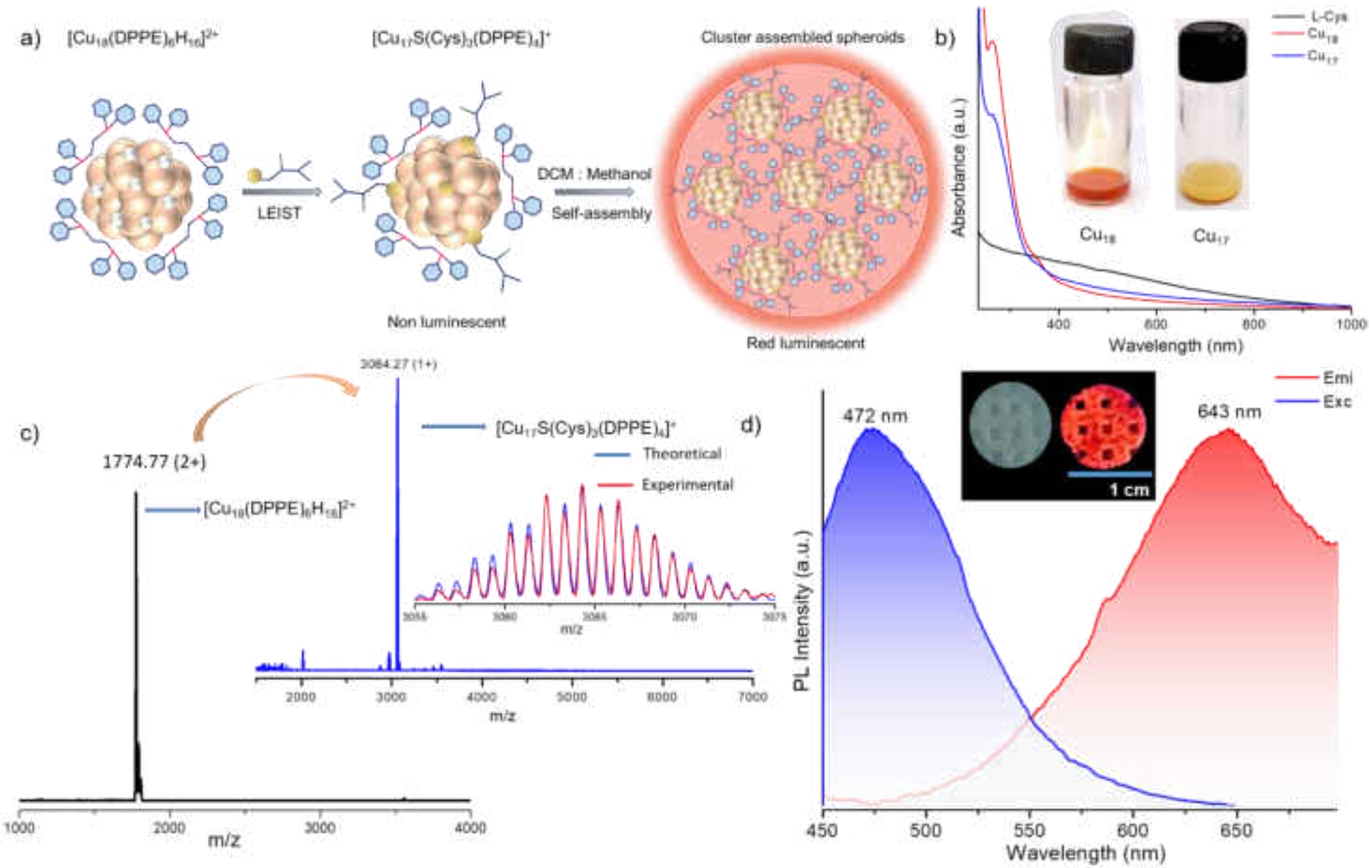
pubs.acs.org/journal/estlcu
Letter

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

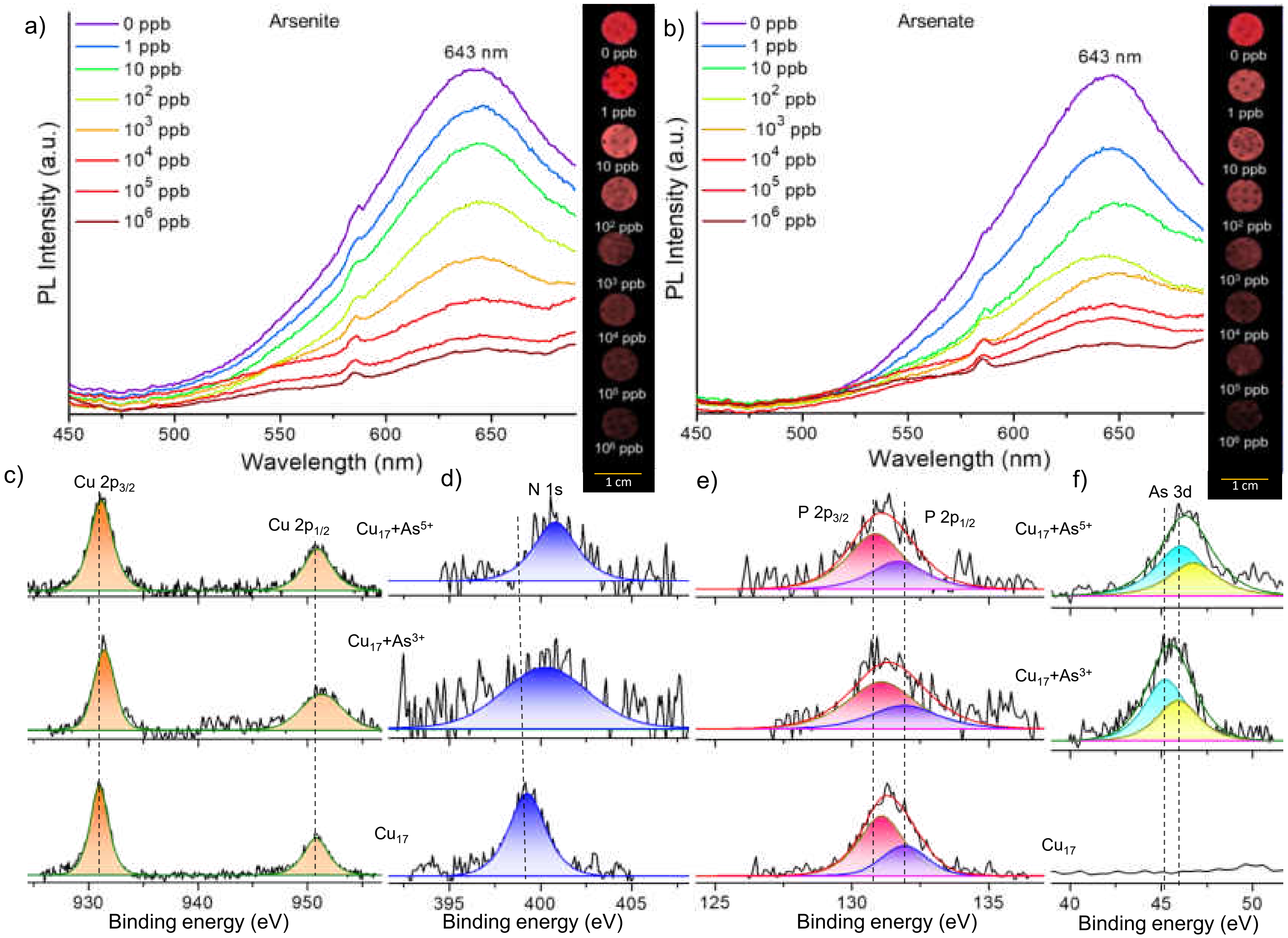
Jenifer Shantha Kumar, Arijit Jana, Jayathraa Raman, Hema Madhuri Veera, Amoghavarsha Ramachandra Kini, Jayoti Roy, Saurav Kanti Jana, Tiju Thomas, and Thalappil Pradeep*

Cite This: https://doi.org/10.1021/acs.estlett.4c00264 Read Online

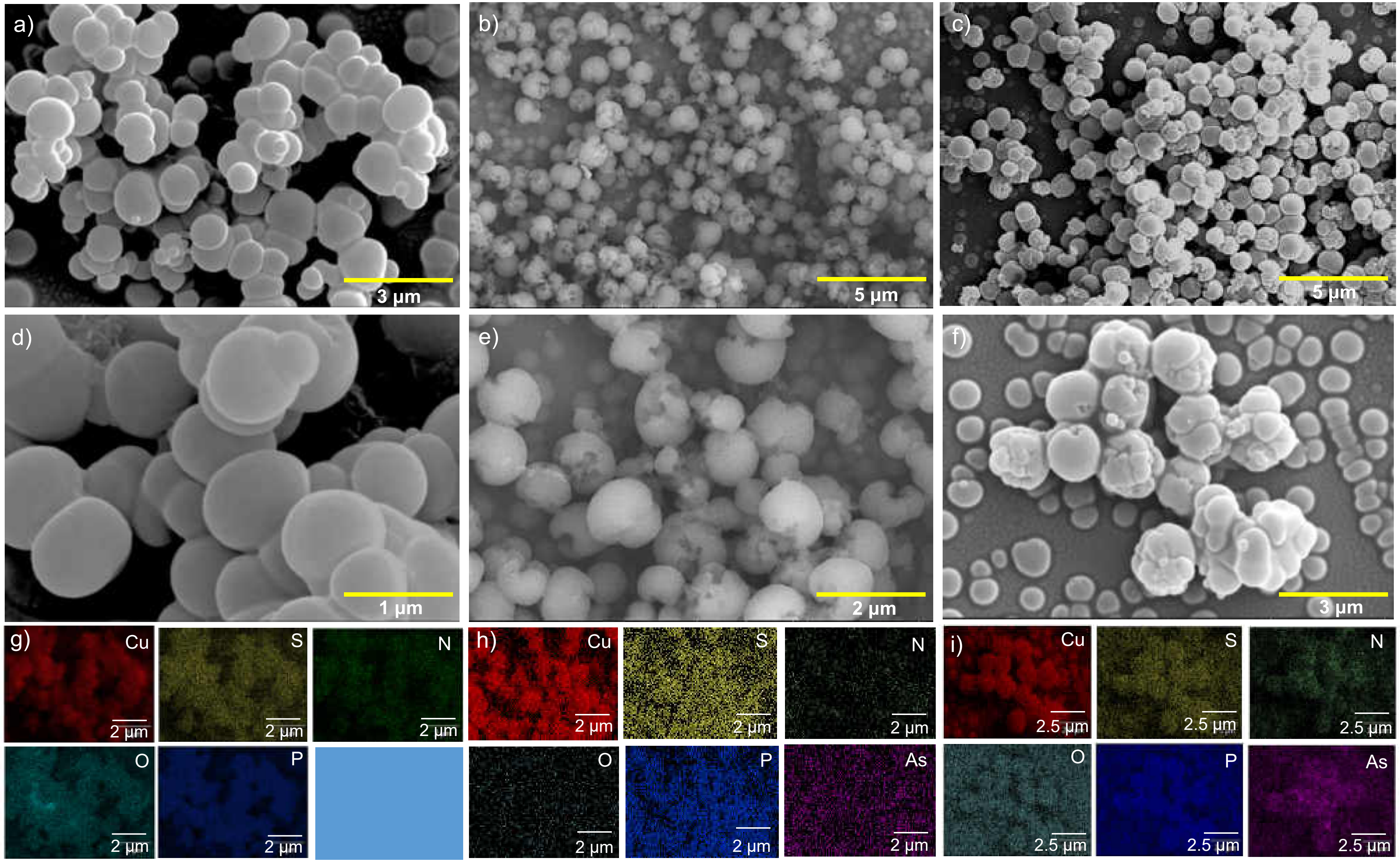




J. S. Kumar, Environ. Sci. Technol. Lett. 2024, 11, 8, 831–837.

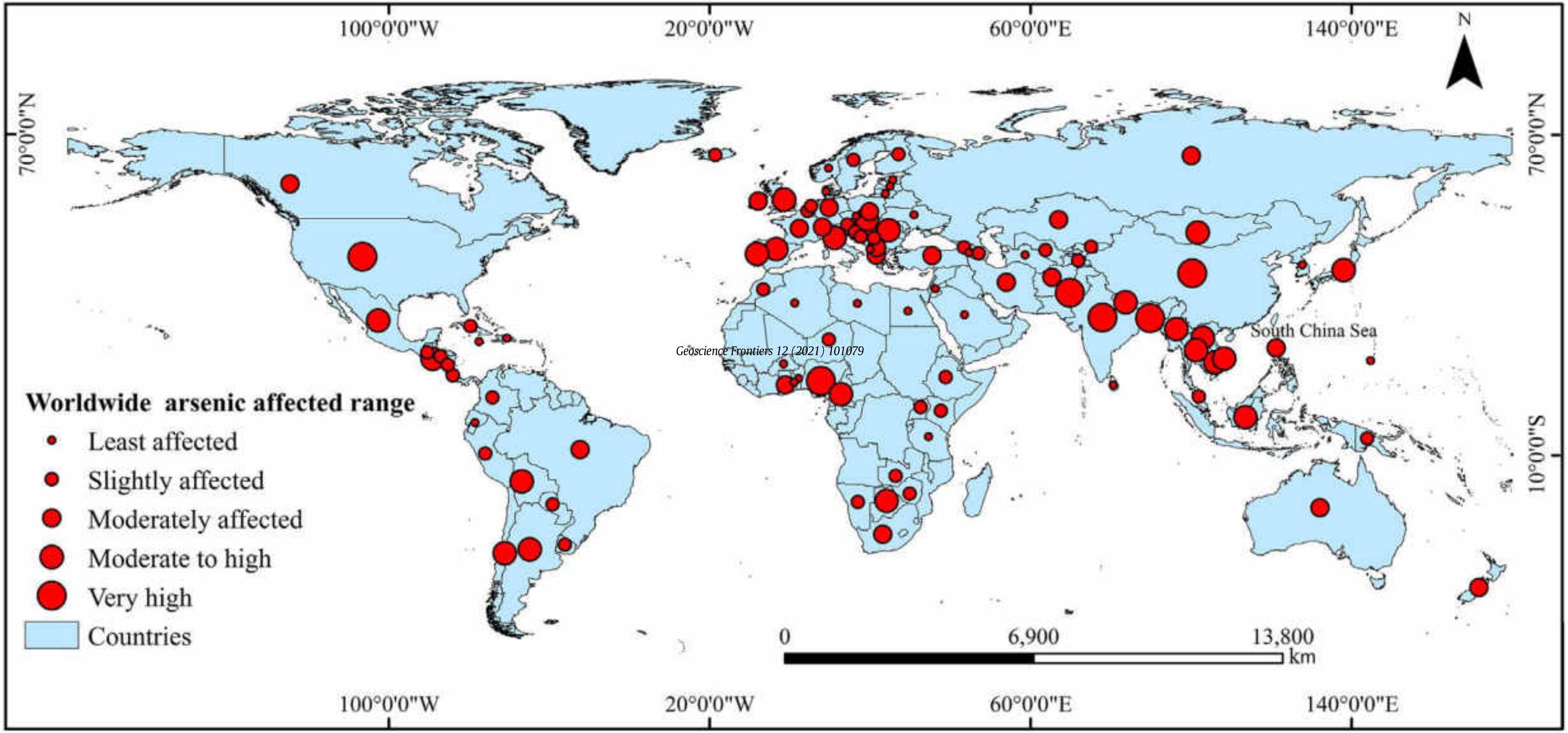


a)
Arsenite
0 ppb
1 ppb
10 ppb
10^2 ppb
10^3 ppb
10^4 ppb
10^5 ppb
10^6 ppb
643 nm
PL Intensity (a.u.)
Wavelength (nm)
1 cm
b)
Arsenate
c)
Cu $2p_{3/2}$
Cu $2p_{1/2}$
$Cu_{17}+As^{5+}$
$Cu_{17}+As^{3+}$
Cu_{17}
d)
N 1s
e)
P $2p_{3/2}$
P $2p_{1/2}$
f)
As 3d
Binding energy (eV)



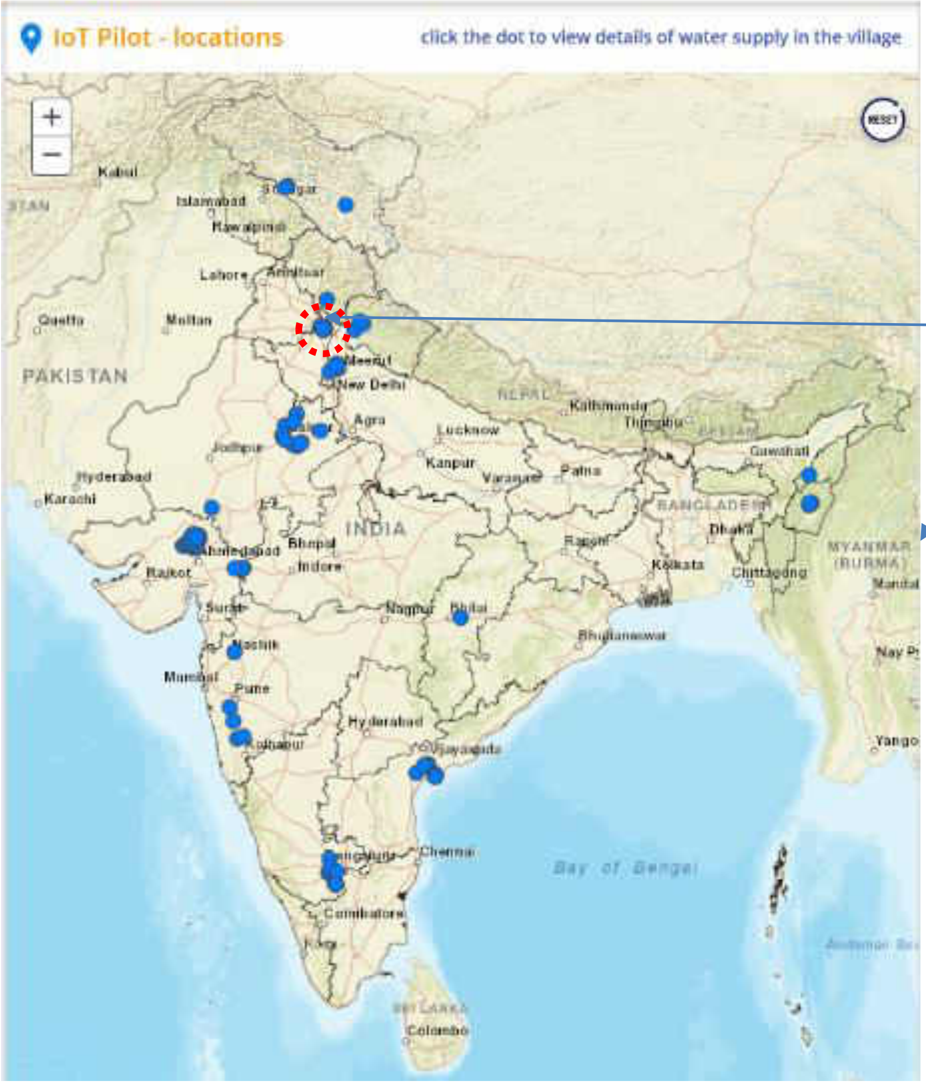
a)
3 µm
b)
5 µm
c)
5 µm
d)
1 µm
e)
2 µm
f)
3 µm
g)
Cu
2 µm
S
2 µm
N
2 µm
O
2 µm
P
2 µm
h)
Cu
2 µm
S
2 µm
N
2 µm
O
2 µm
P
2 µm
As
2 µm
i)
Cu
2.5 µm
S
2.5 µm
N
2.5 µm
O
2.5 µm
P
2.5 µm
As
2.5 µm

Arsenic poisoning across the world



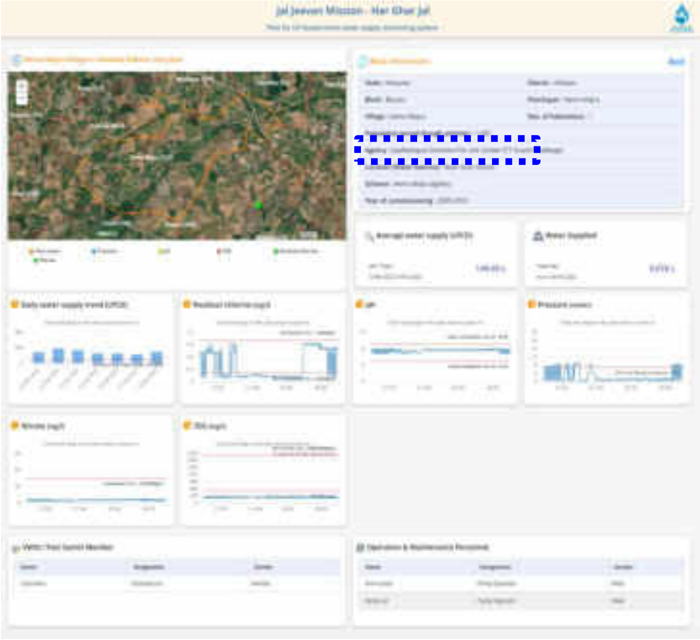
E. Shaji, M. Santosh, K. V. Sarath, Pranav Prakash, V. Deepch and B. V. Divya, Geoscience Frontiers, 12 (2021) 101079.

India’s water is being monitored



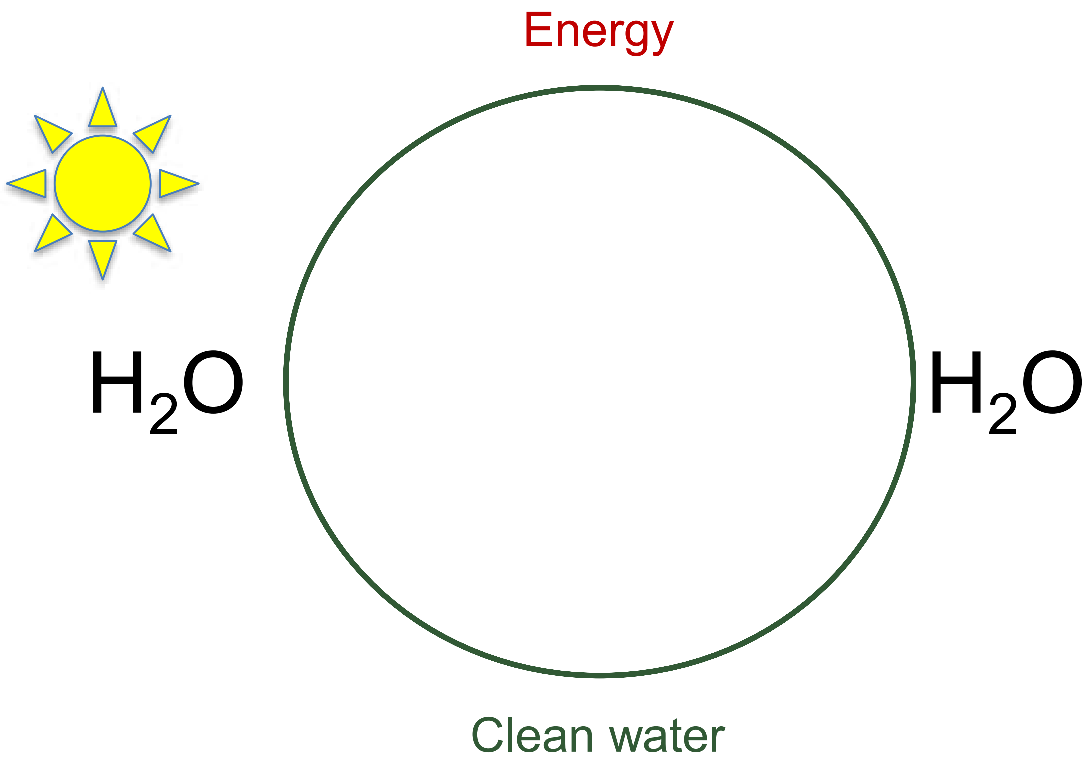
IITM/IISc

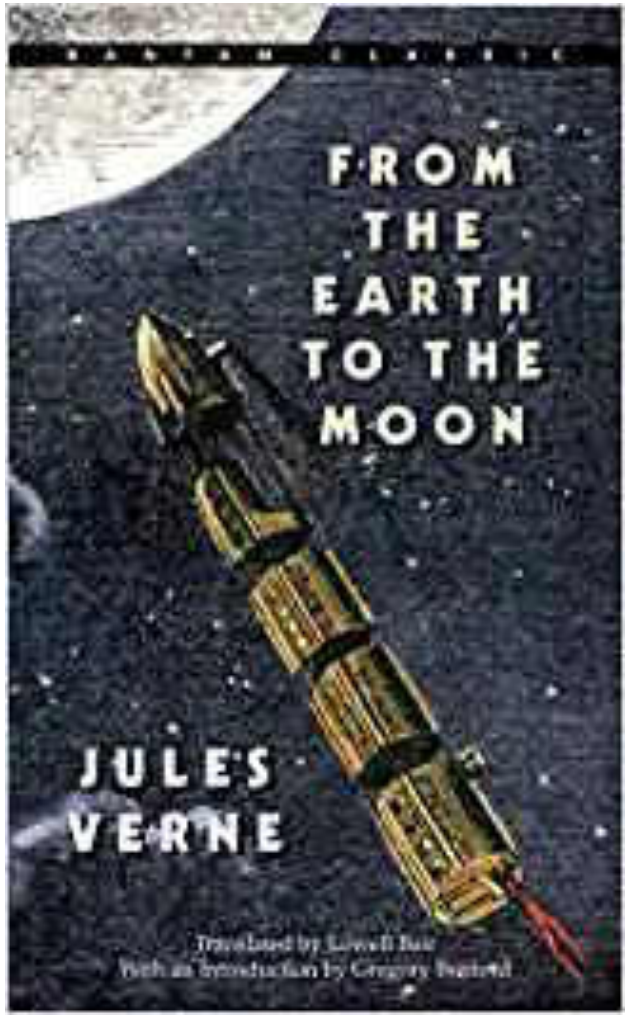
Installations made by four companies



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

Our dreams become reality with materials



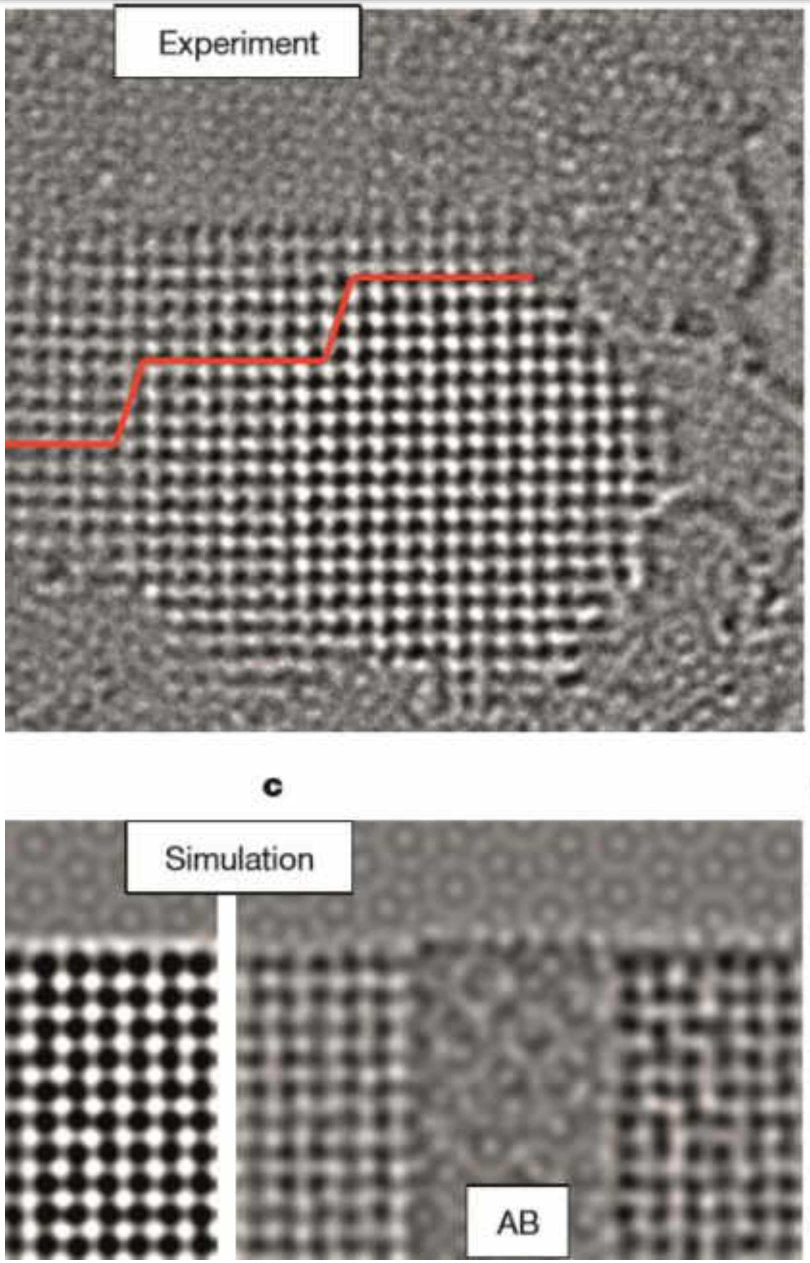


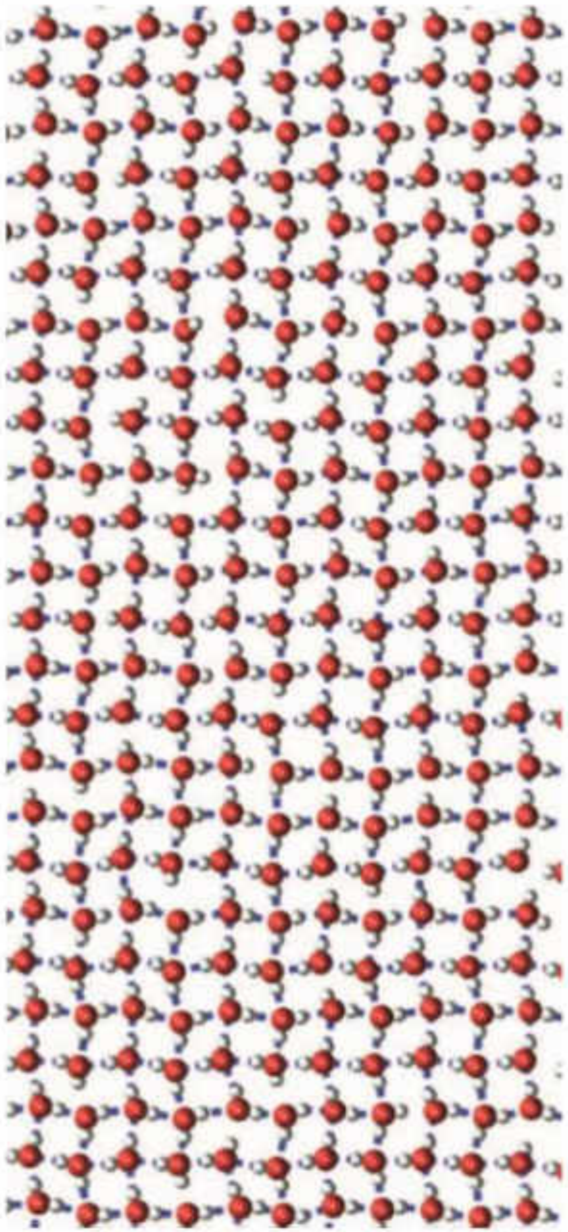
Affordable, inclusive, sustainable and contextual excellence


International Centre for Clean Water


IIT Madras Research Park

Observing water



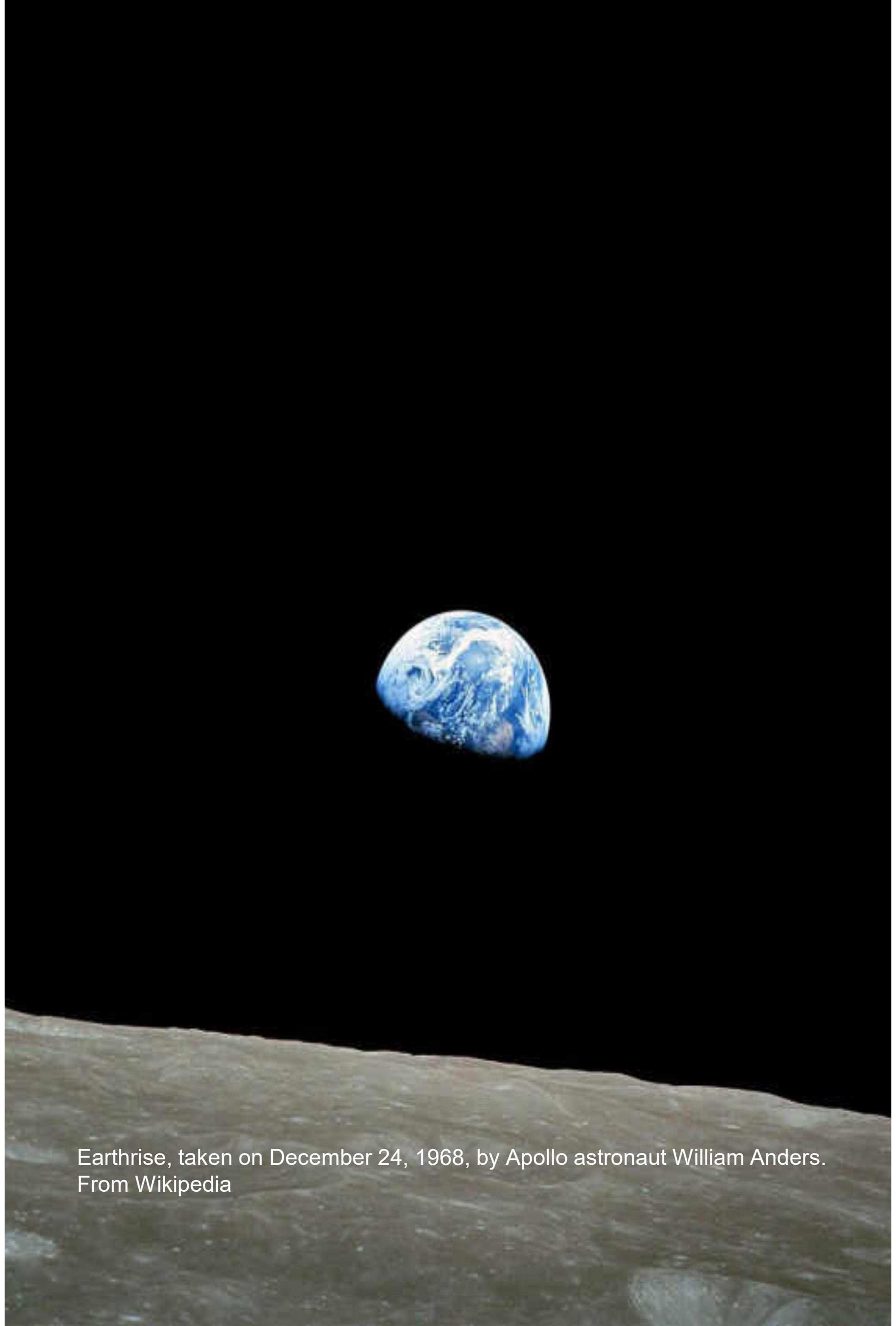


Algara-Siller, G.; Lehtinen, O.; Wang, F. C.; Nair, R. R.; Kaiser, U.; Wu, H. A.; Geim, A. K.; Grigorieva, I. V., Square ice in graphene nanocapillaries. *Nature* **2015**, *519* (7544), 443-445.


thermo scientific

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

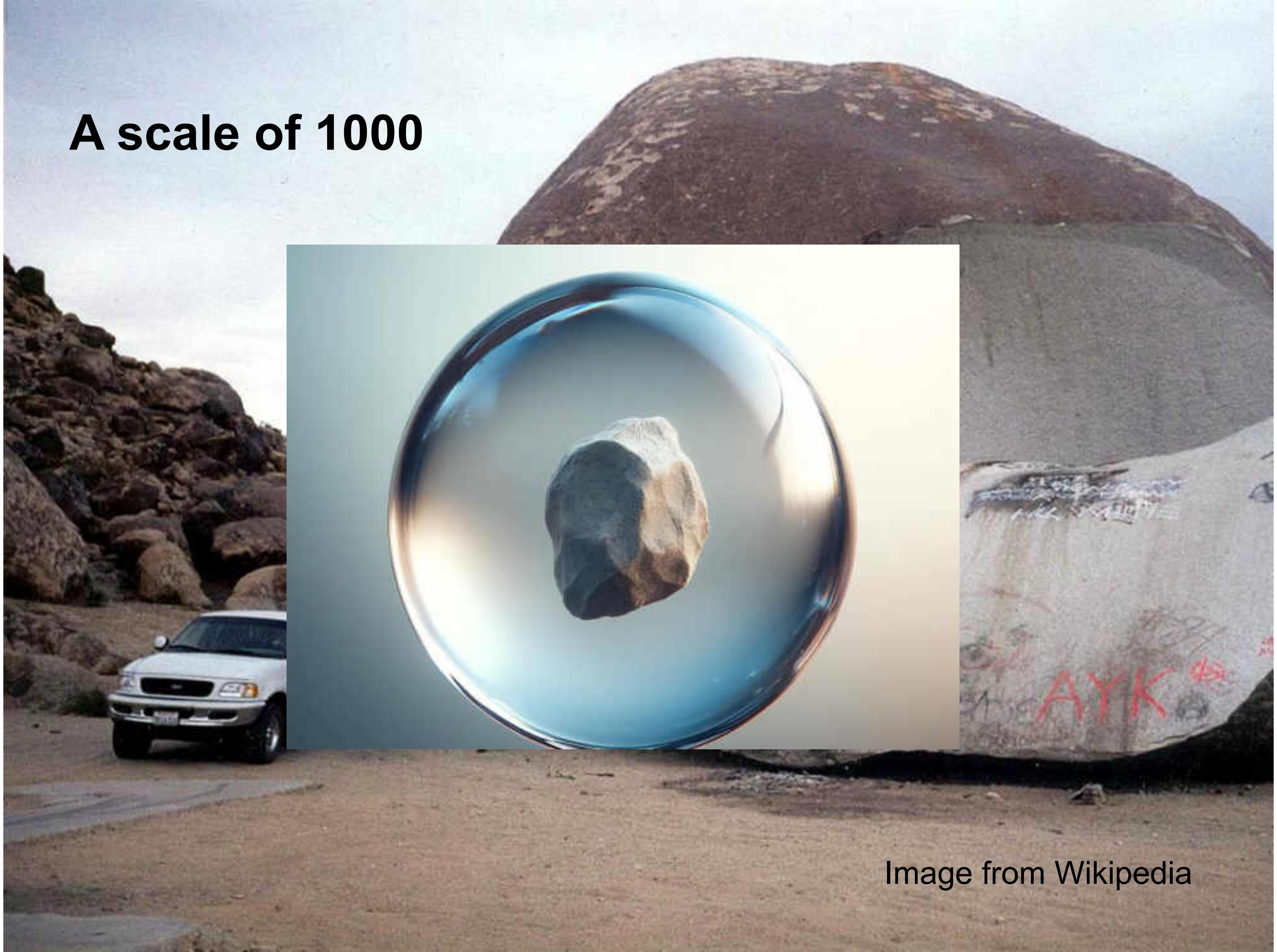


Image from Wikipedia

Science

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 microscale 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 nm 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 nm, 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

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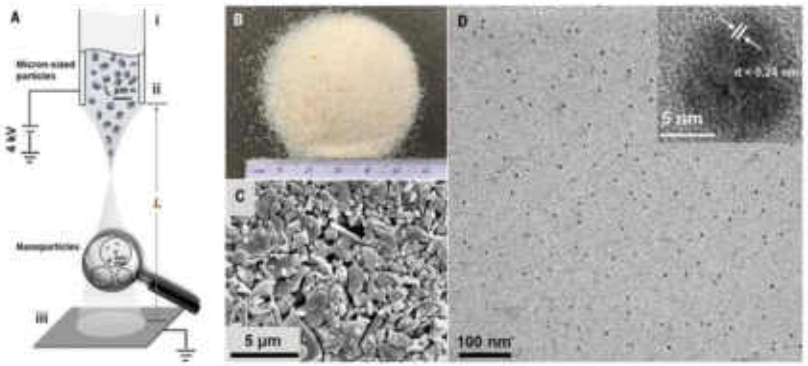

Spoorthi et al., Science 384, 1012–1017 (2024)   31 May 2024

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

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