Since 1959

Affordable clean water using advanced materials

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https://pradeepresearch.org

Prof. S. A. Sannasiraj and colleagues

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 Chemistry & Engineering

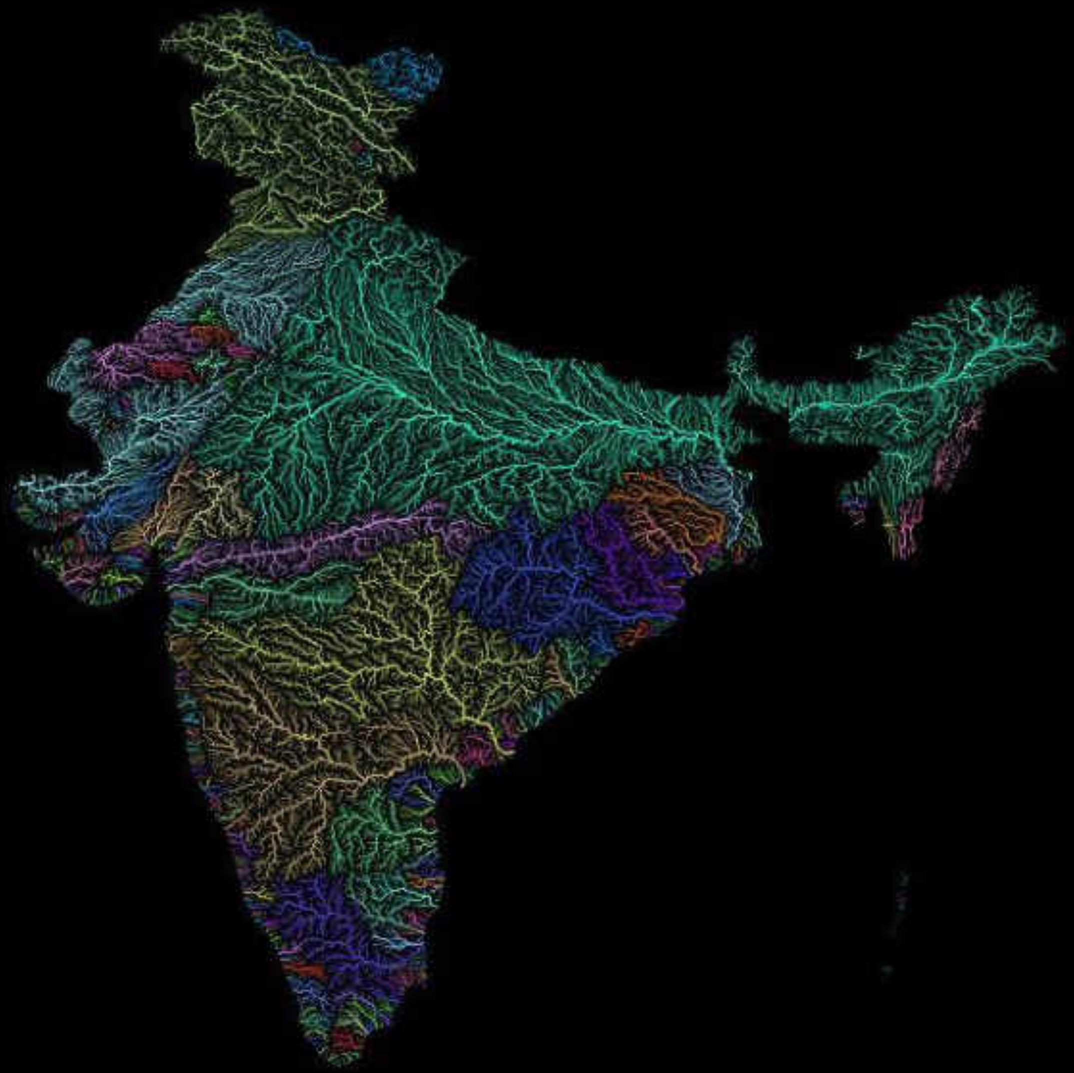
Professor-in-charge

ICCW International Centre for Clean Water


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

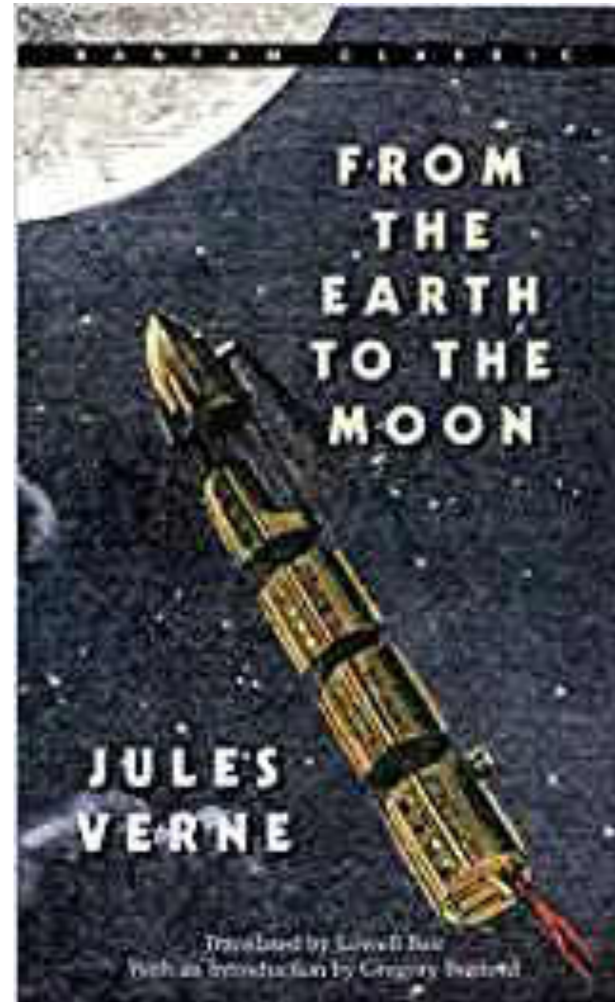
Water is at the entre of action

There is water in everything we do.



From S. Vishwanath

Our dreams become reality with materials



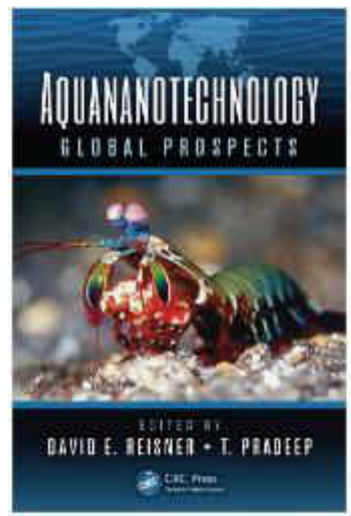
Water purification, history

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)

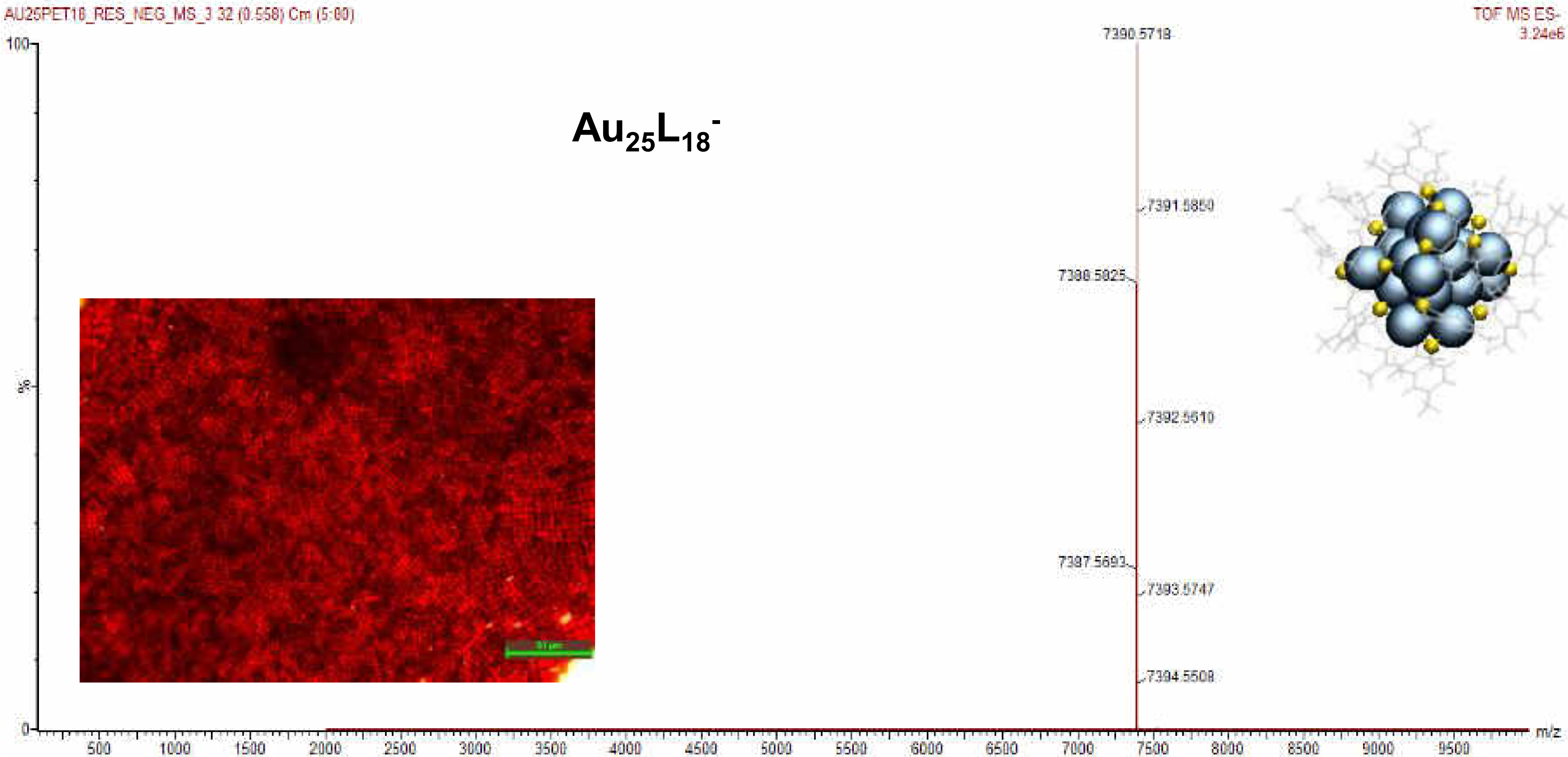
T. Pradeep and Anshup, *Thin Solid Films*, 2009

Affordable clean water is a problem of advanced materials



New adsorbents
New sensors
New catalysts
Novel phenomena
New devices

Nanomaterials are now atomically precise

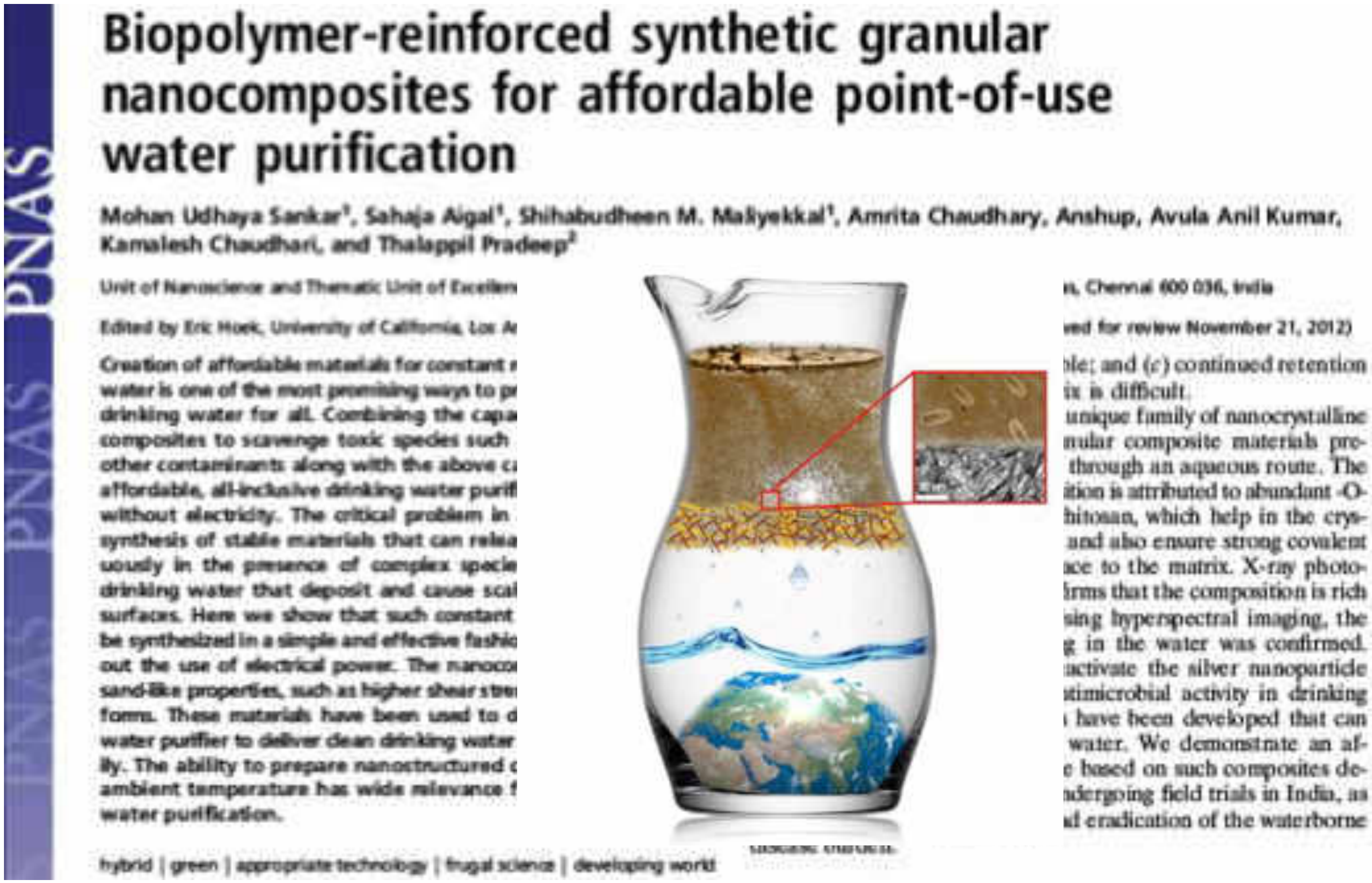


T. Pradeep et. al. *Acc. Chem. Res.* 2018; 2019.

Clean water for everyone

ACS Sustainable Chemistry & Engineering Editorial, December 2016

Water positive materials



PNAS PNAS PNAS PNAS

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

Mohan Udhaya Sankar[1], Sahaja Aigal[1], Shihabudheen M. Maliyekkal[1], Amrita Chaudhary, Anshup, Avula Anil Kumar, Kamalesh Chaudhari, and Thalappil Pradeep[2]

Unit of Nanoscience and Thematic Unit of Excellen… …, Chennai 600 036, India

Edited by Eric Hoek, University of California, Los A… …ved for review November 21, 2012)

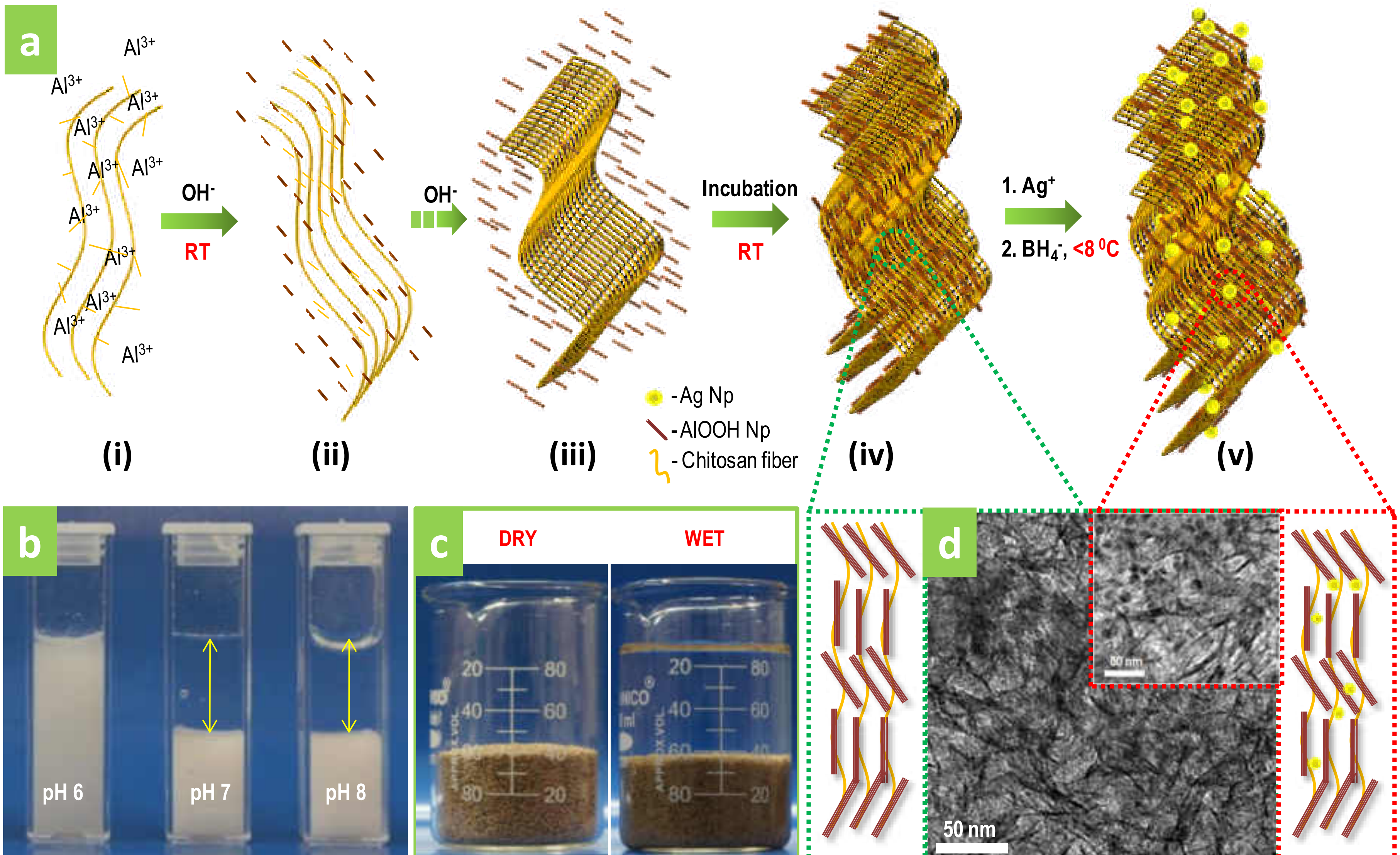
Creation of affordable materials for constant r… water is one of the most promising ways to pr… drinking water for all. Combining the capa… composites to scavenge toxic species such… other contaminants along with the above ca… affordable, all-inclusive drinking water purif… without electricity. The critical problem in… synthesis of stable materials that can relea… uously in the presence of complex specie… drinking water that deposit and cause scal… surfaces. Here we show that such constant… be synthesized in a simple and effective fashio… out the use of electrical power. The nanocor… sand-like properties, such as higher shear stre… forms. These materials have been used to d… water purifier to deliver clean drinking water… lly. The ability to prepare nanostructured c… ambient temperature has wide relevance f… water purification.

…ble; and (c) continued retention …ix is difficult. …unique family of nanocrystalline …nular composite materials pre- …through an aqueous route. The …ition is attributed to abundant -O- …hitosan, which help in the crys- …and also ensure strong covalent …ace to the matrix. X-ray photo- …firms that the composition is rich …sing hyperspectral imaging, the …g in the water was confirmed. …activate the silver nanoparticle …ntimicrobial activity in drinking …have been developed that can …water. We demonstrate an af- …e based on such composites de- …ndergoing field trials in India, as …d eradication of the waterborne …disease burden.

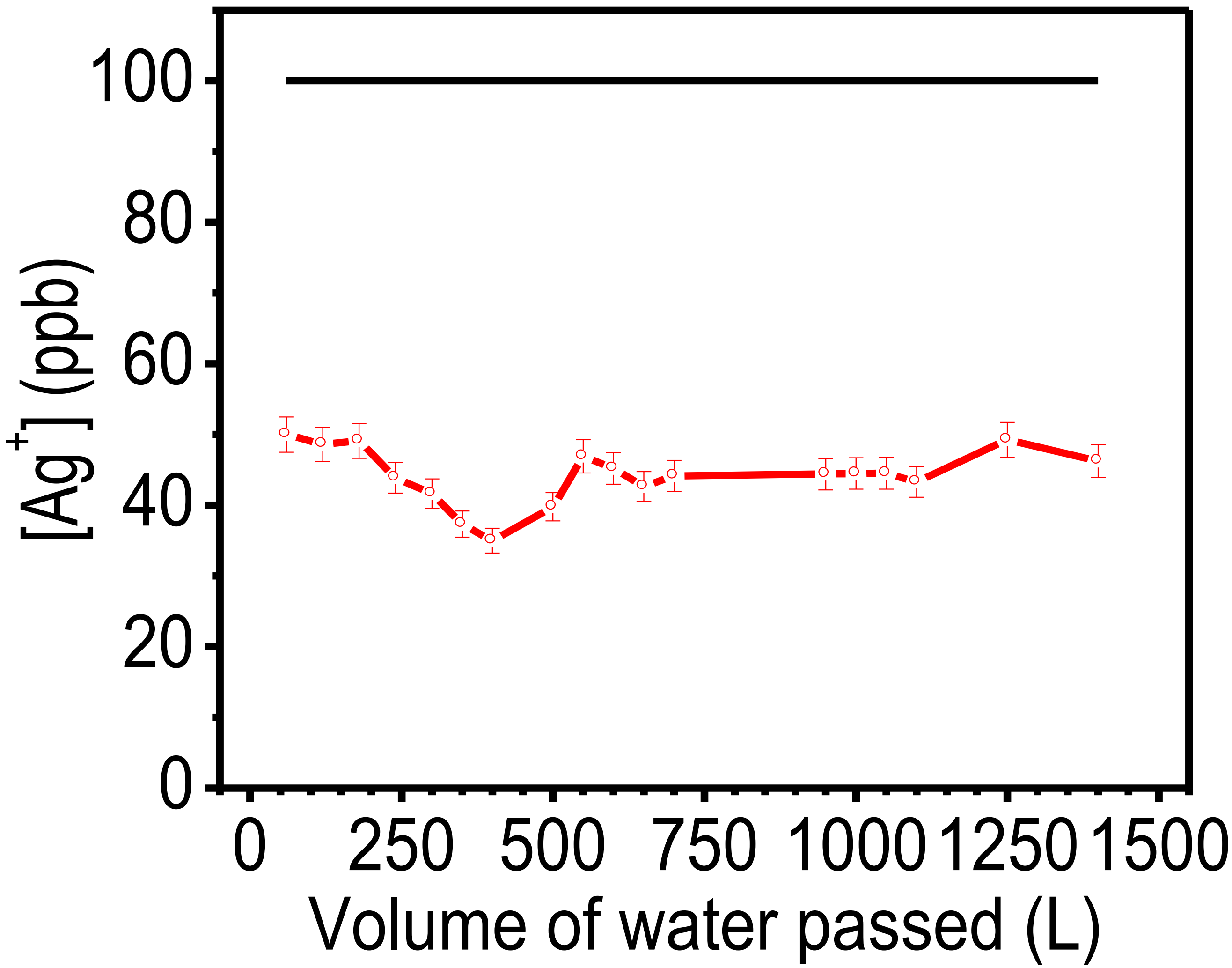
hybrid | green | appropriate technology | frugal science | developing world

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

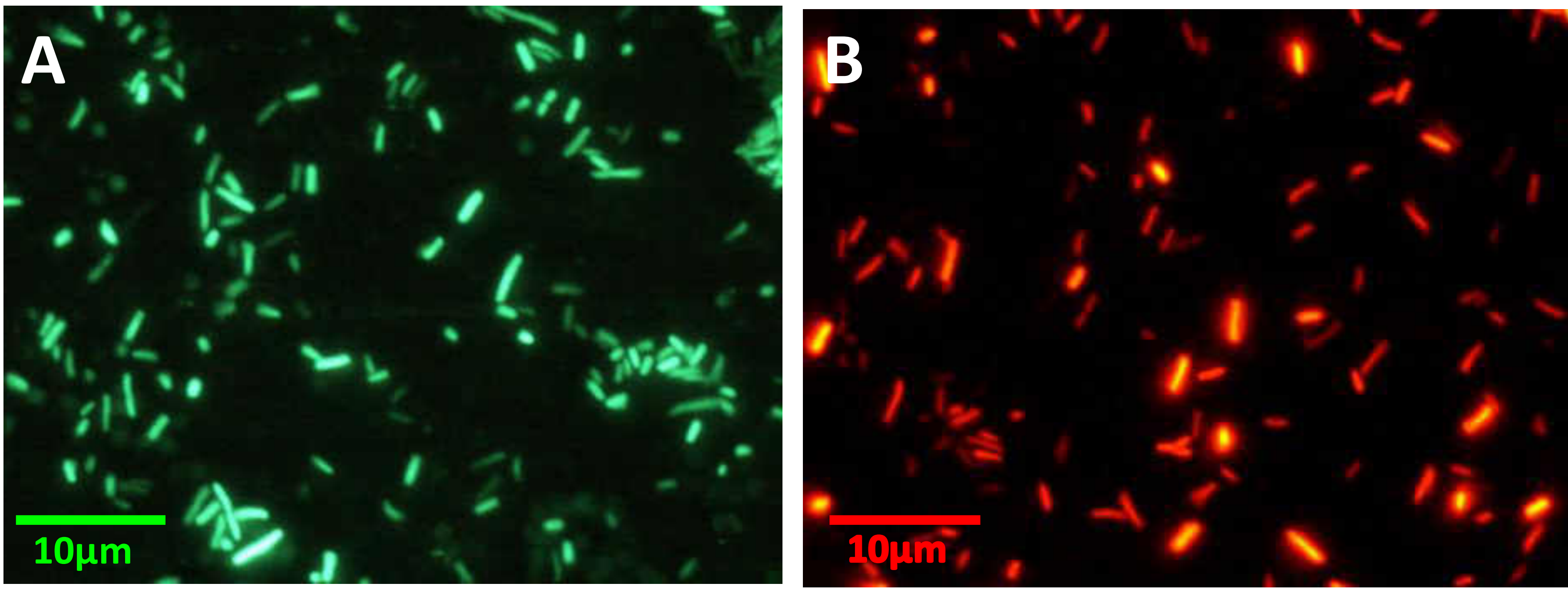
How to make?


a
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

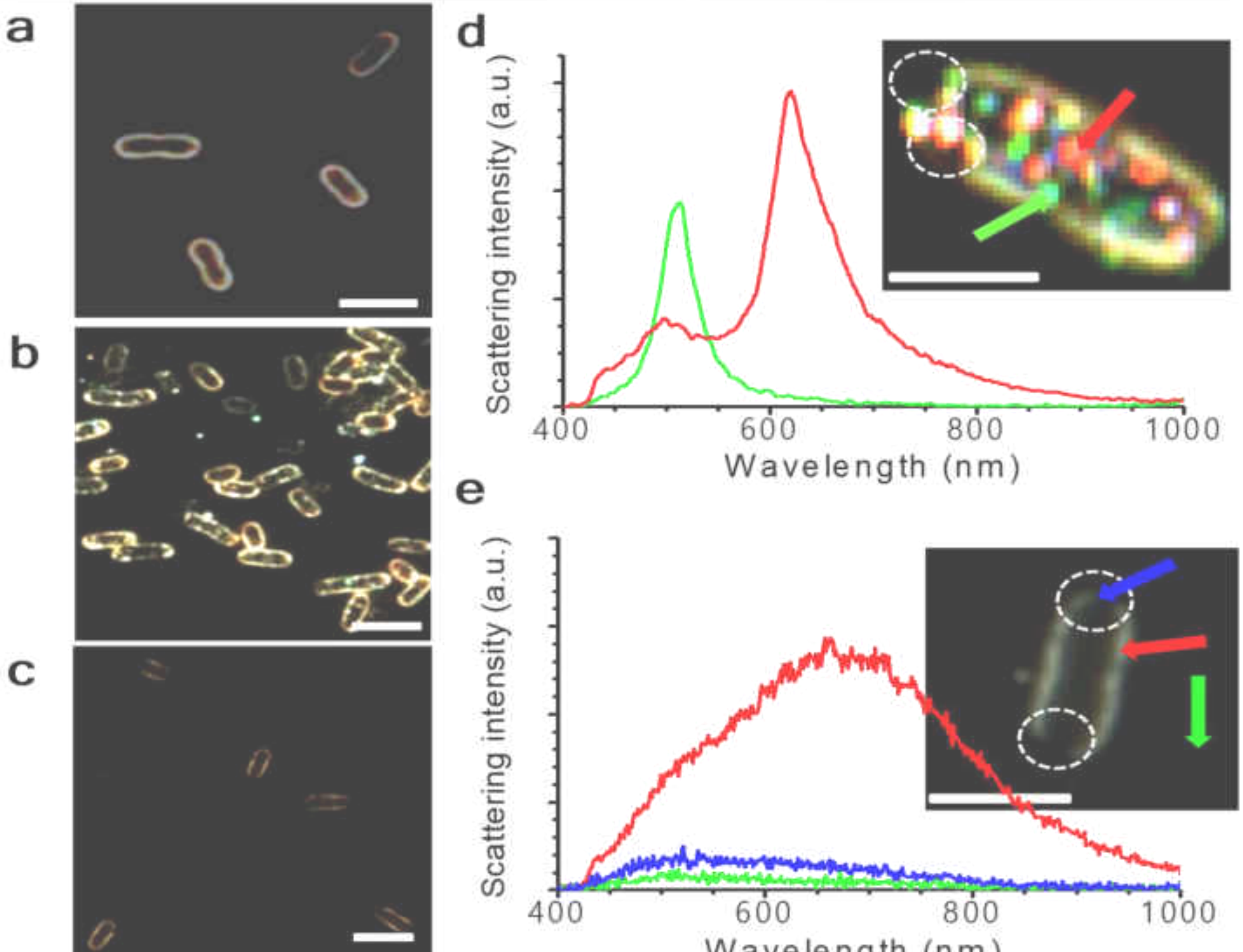
What is special?



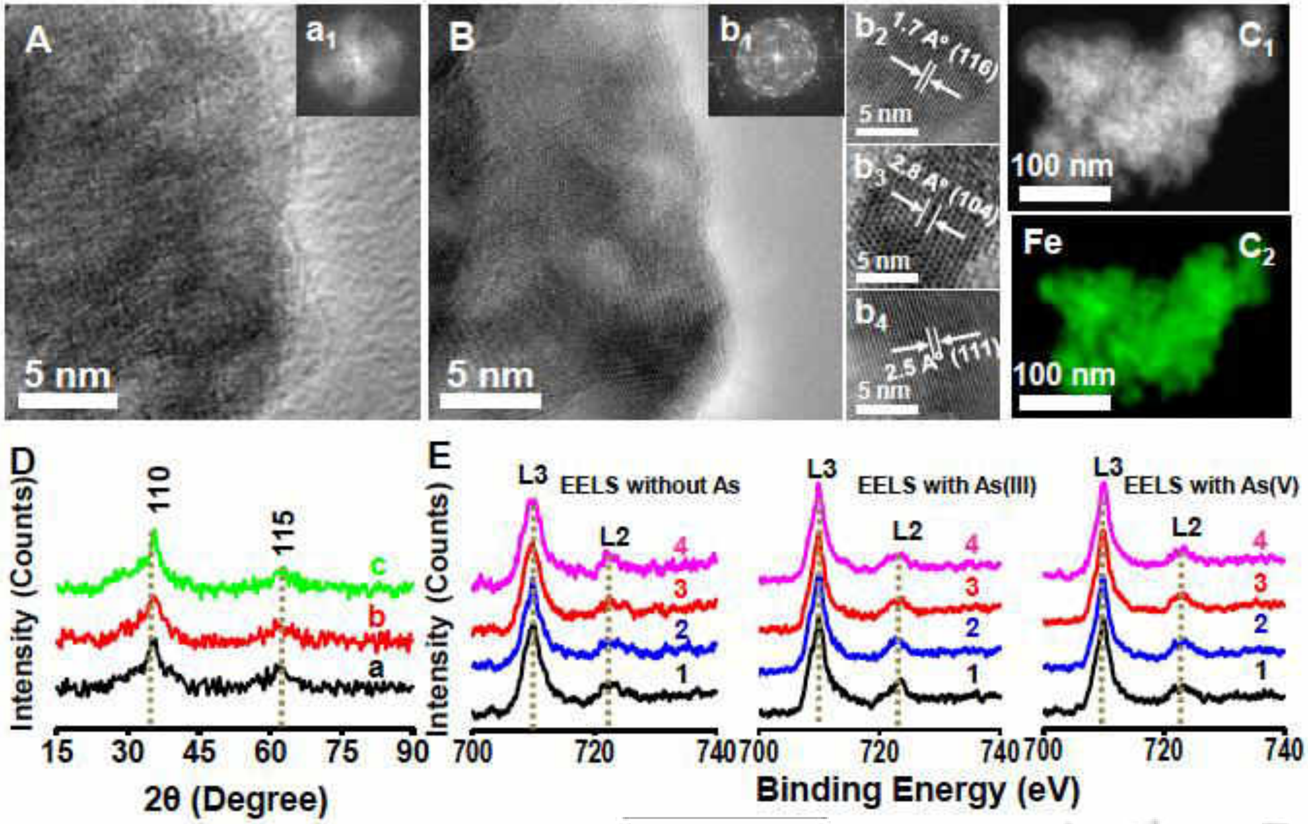
Live/dead staining experiments

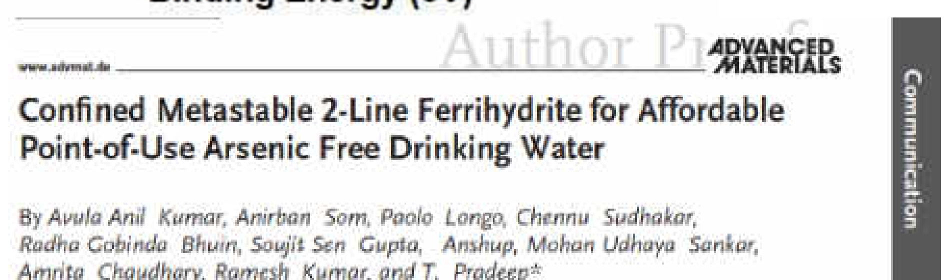


No nanotoxicity



Variety of materials



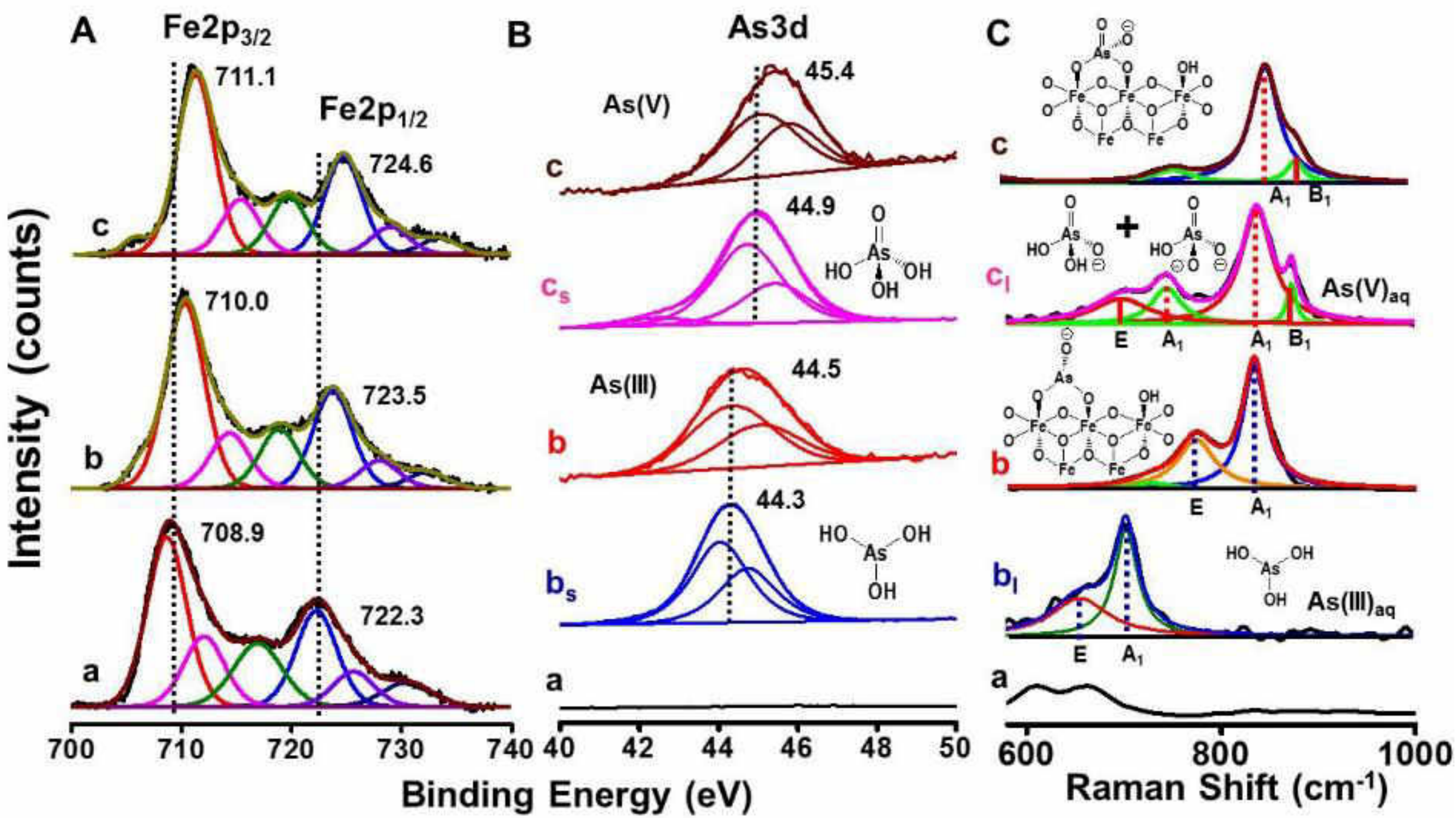


Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

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

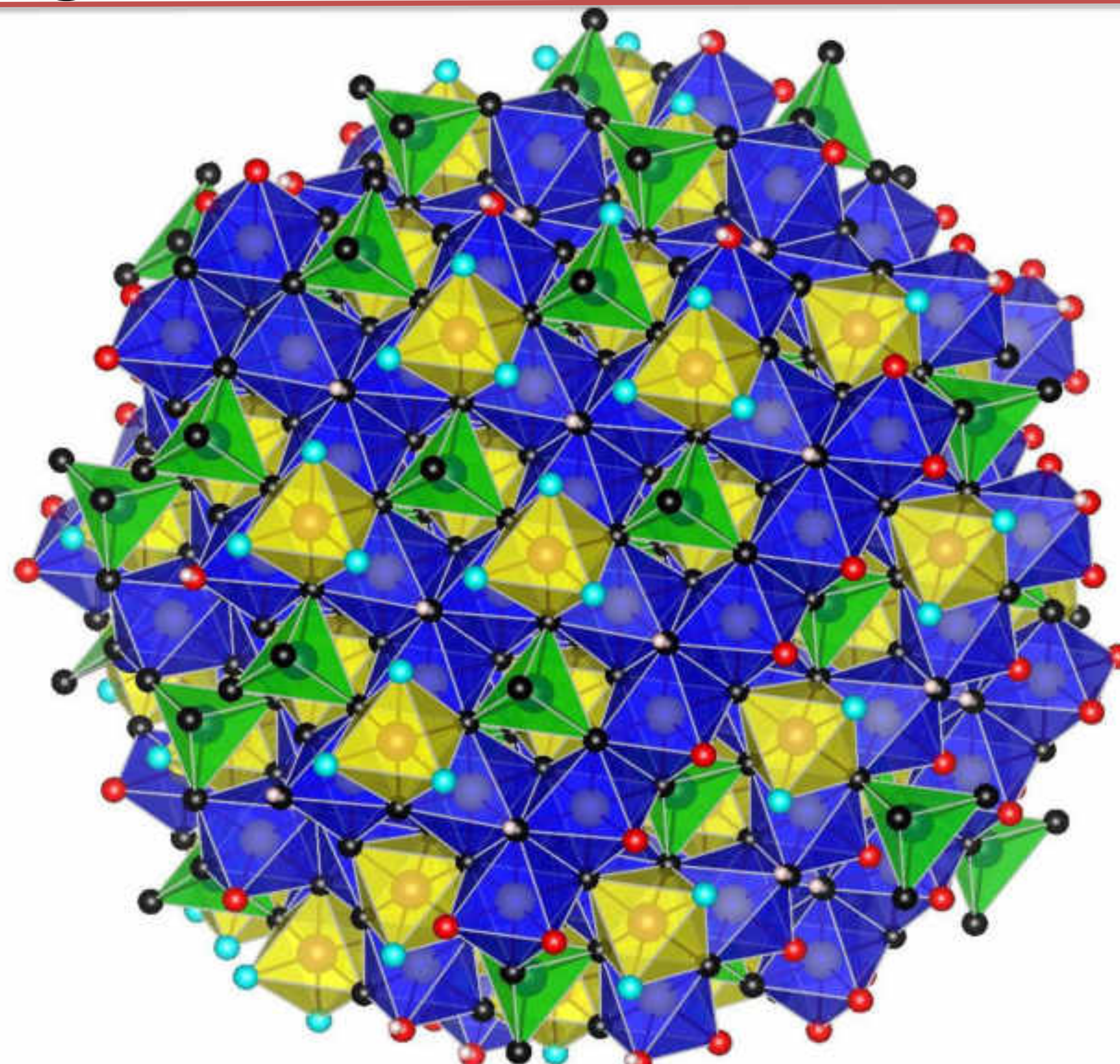
A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

Mechanism



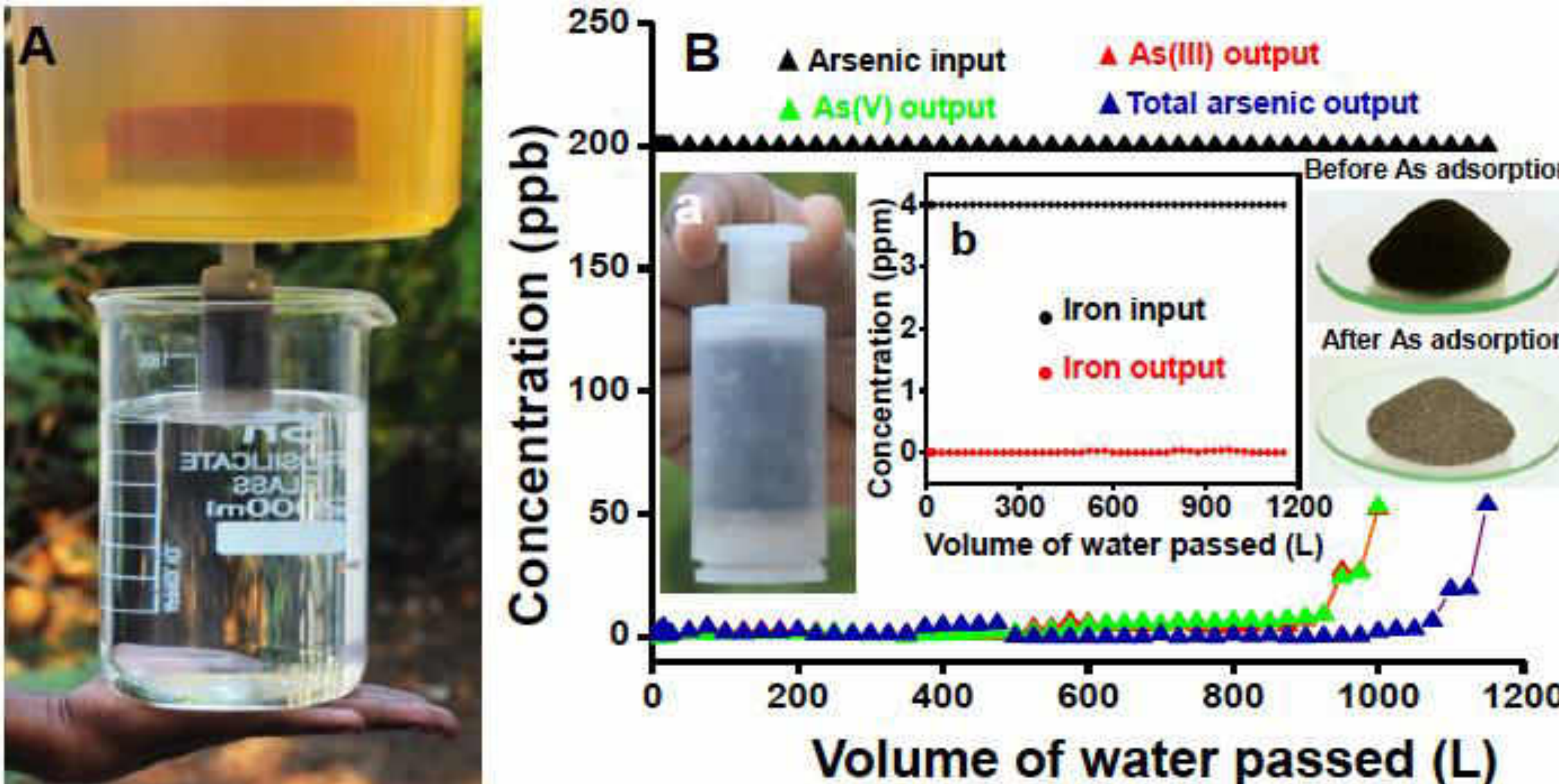
A
Fe2p3/2
711.1
Fe2p1/2
724.6
710.0
723.5
708.9
722.3
Intensity (counts)
B
As3d
As(V)
45.4
44.9
As(III)
44.5
44.3
C
As(V)aq
As(III)aq
E
A1
B1
700
710
720
730
740
40
42
44
46
48
50
600
800
1000
Binding Energy (eV)
Raman Shift (cm-1)

Modeling surfaces



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

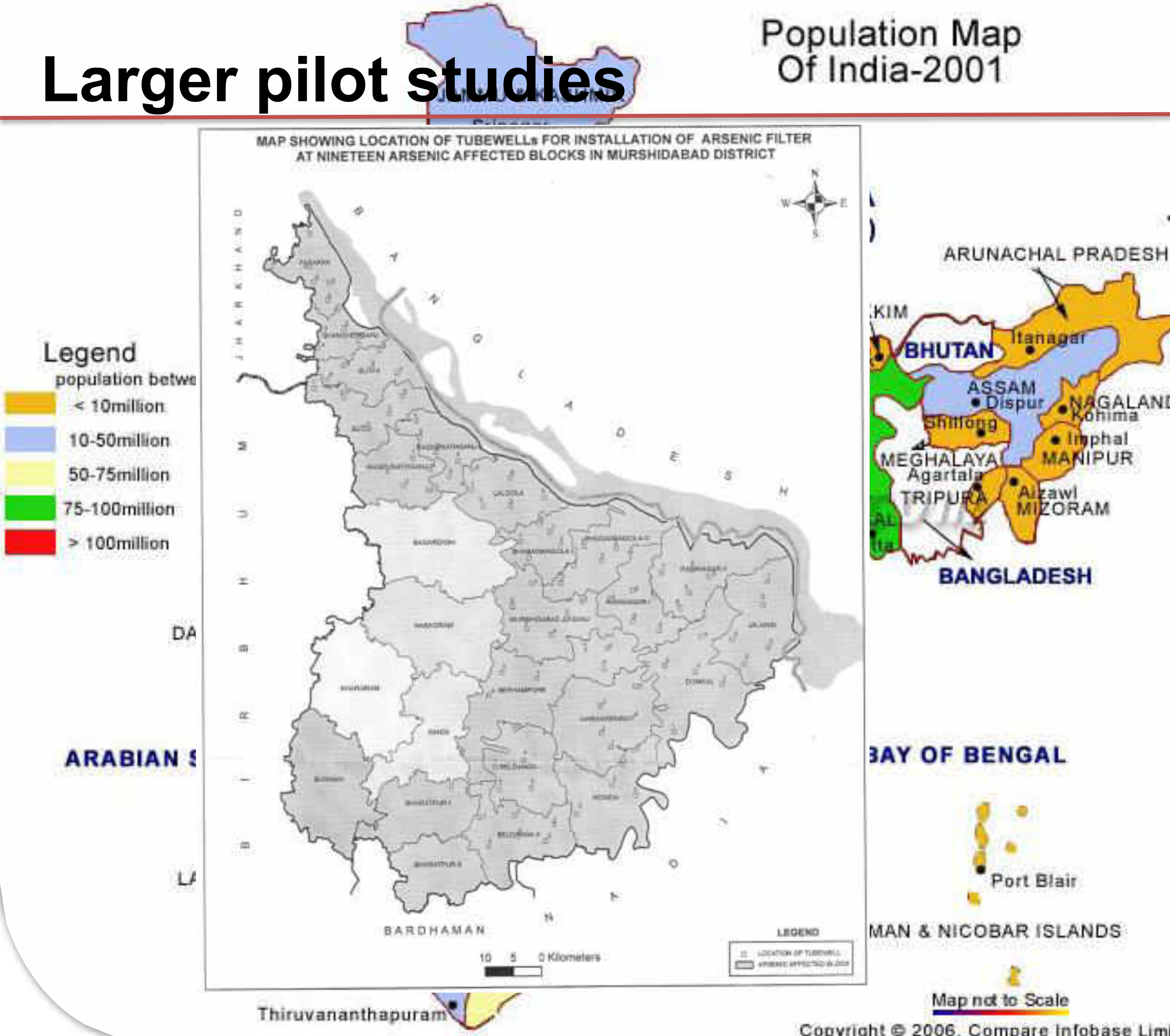
Lab studies



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
03471-250221
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

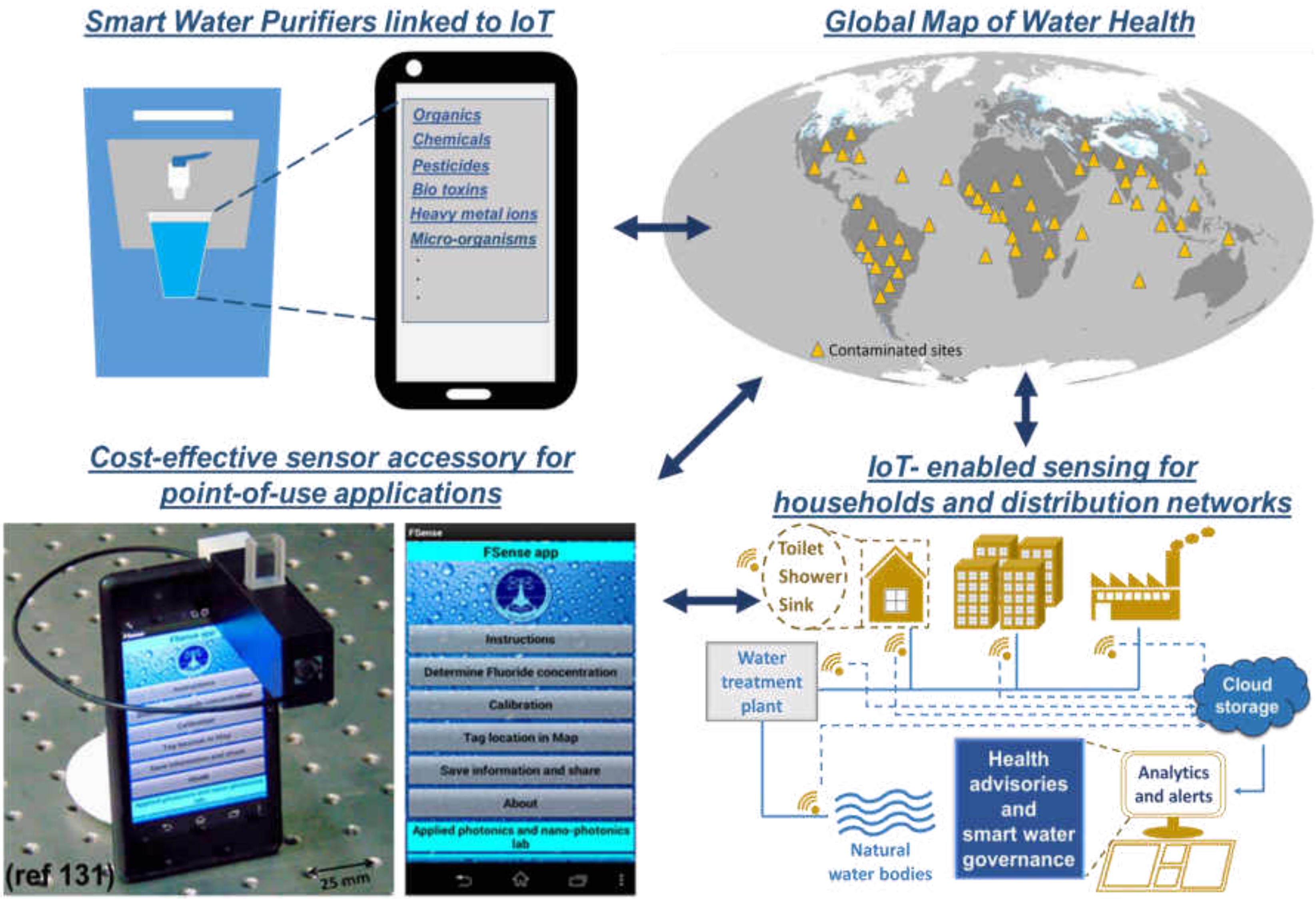
Over 180 units in use across India

Cleanwater 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

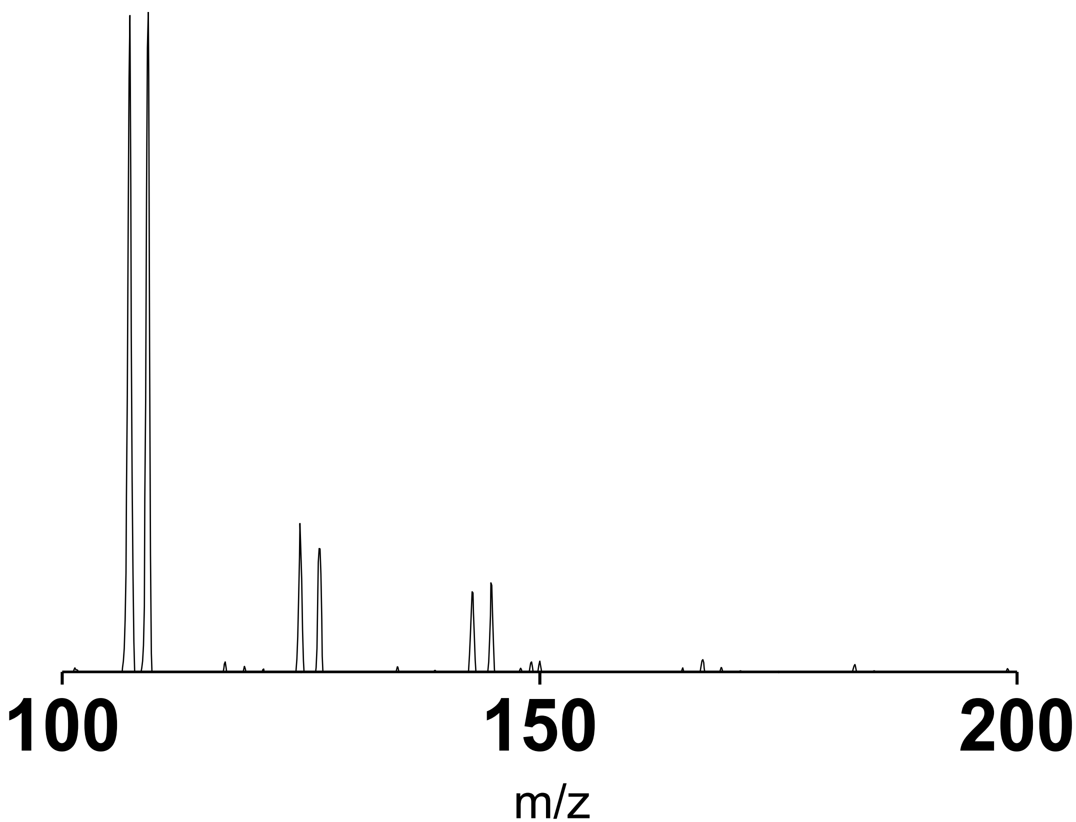
Safe disposal of arsenic (or any other) laden waste

Additional protection could be considered, if necessary

Exploring viable uses

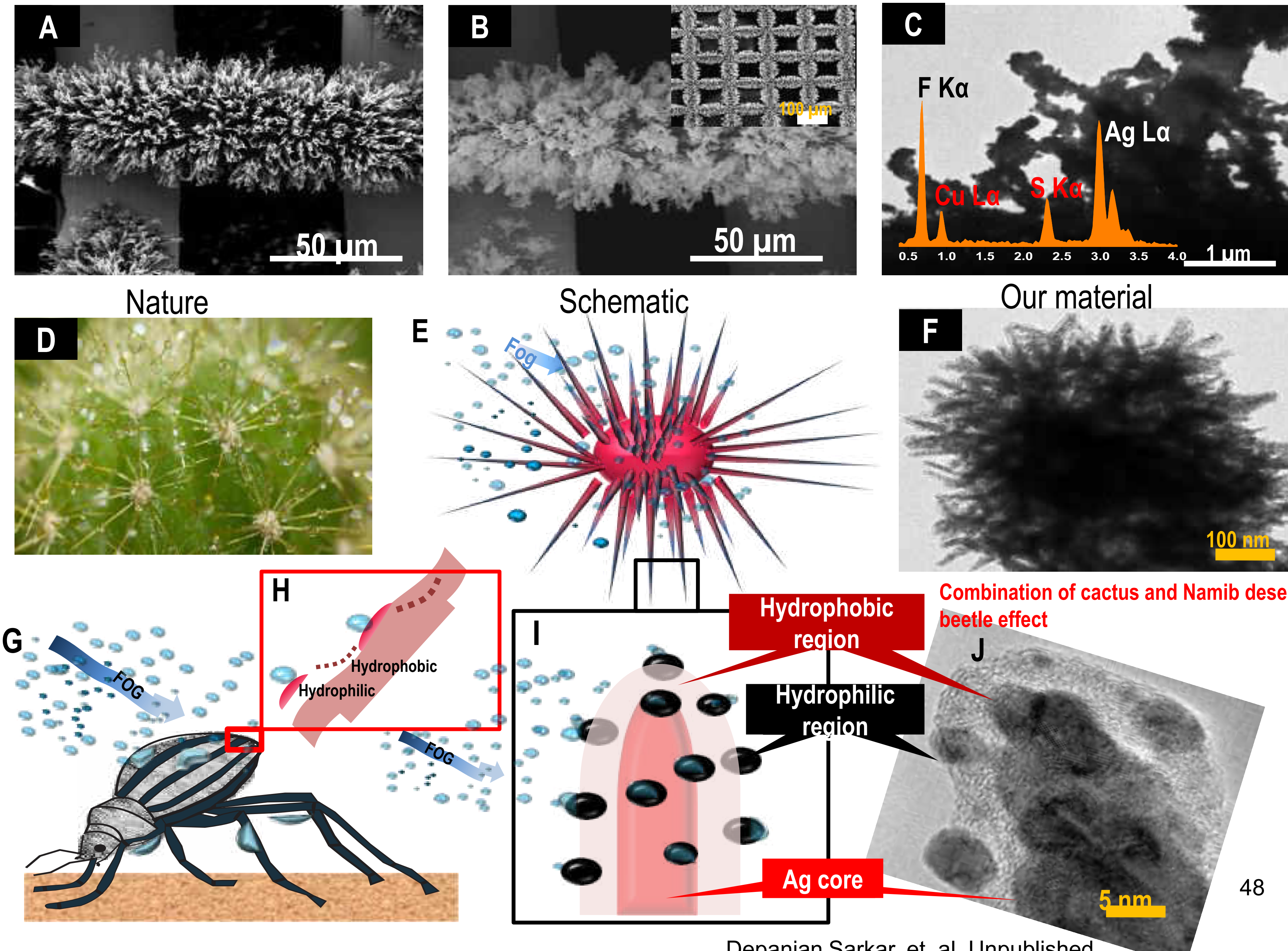
Across the country

Atmospheric water harvesting

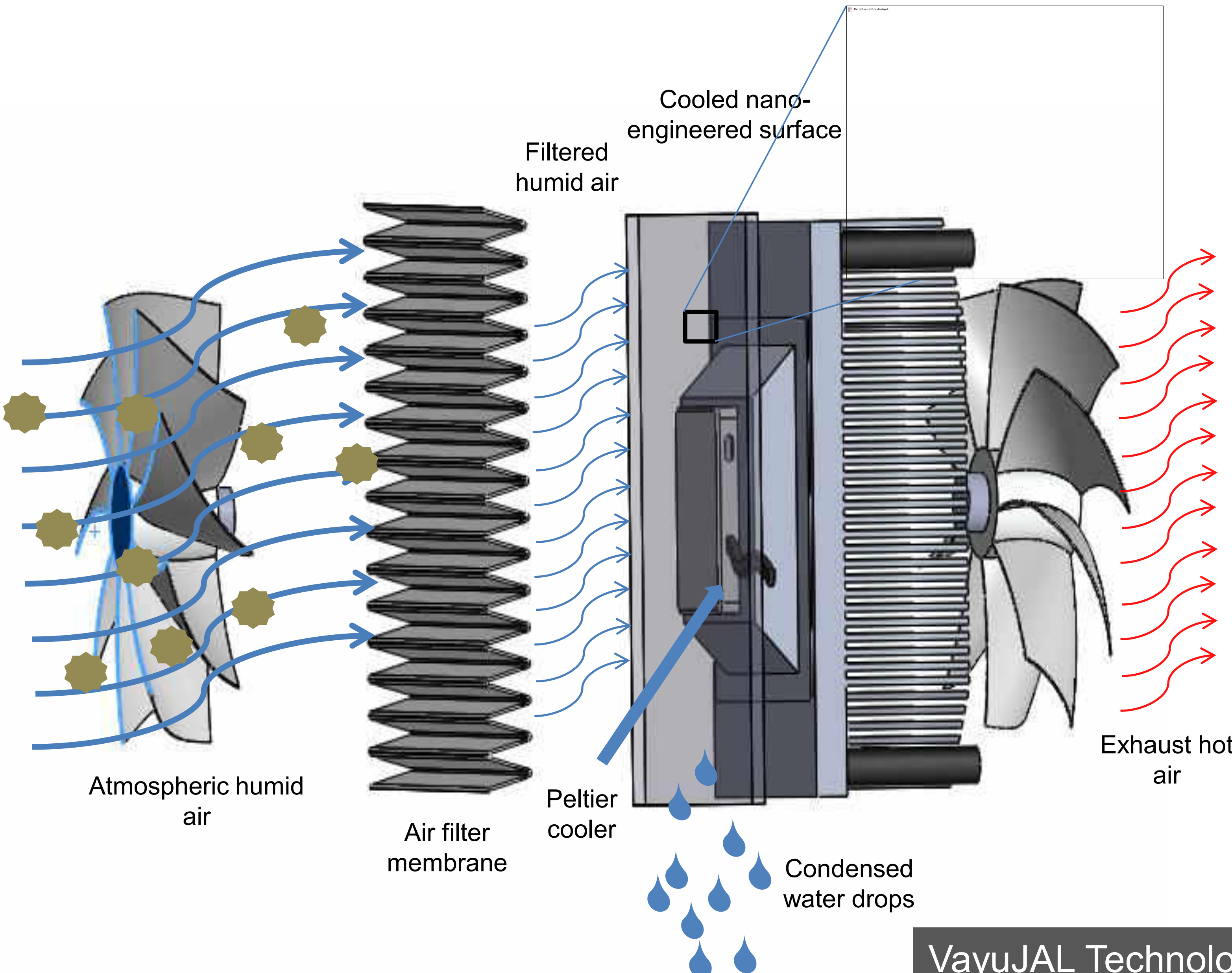


New harvesters

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

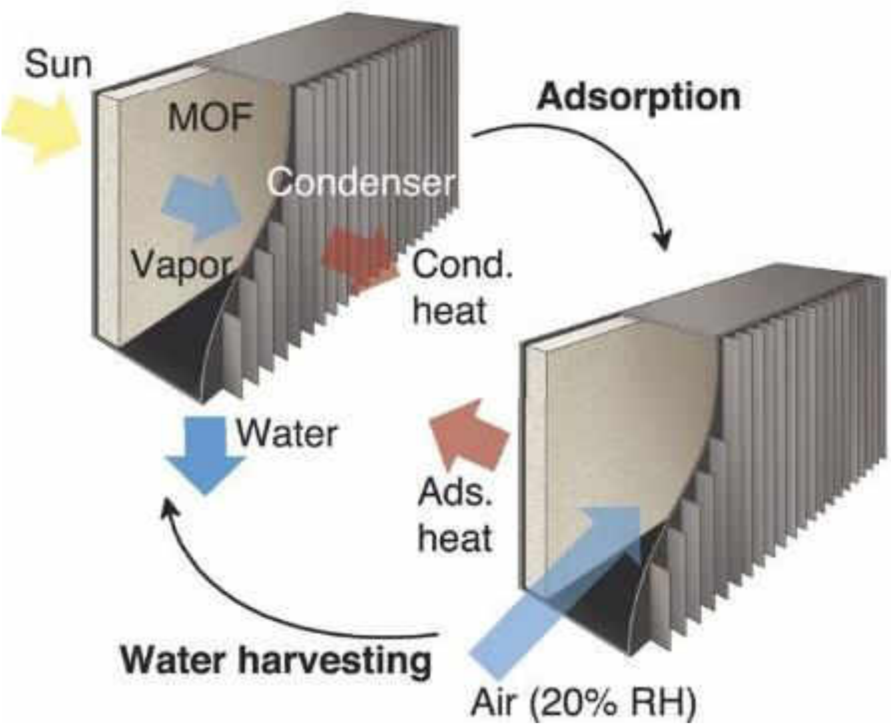
2000 LPD

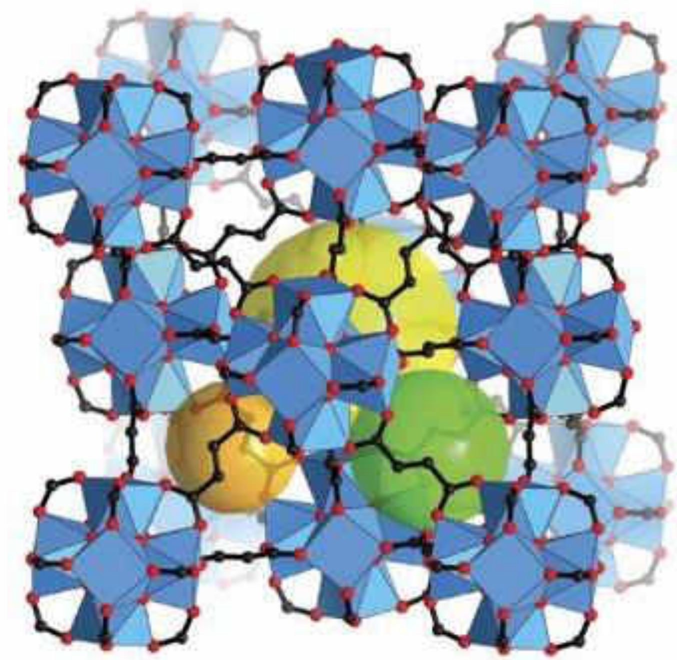
(LPD: Litres per day)

July 2023

Sustainable atmospheric water harvesting

Solar- heat-enabled atmospheric water capture at a relative humidity as low as 20%

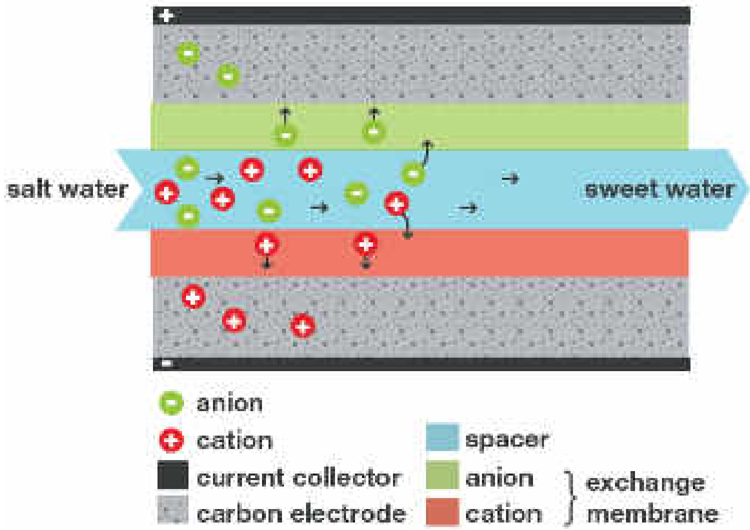


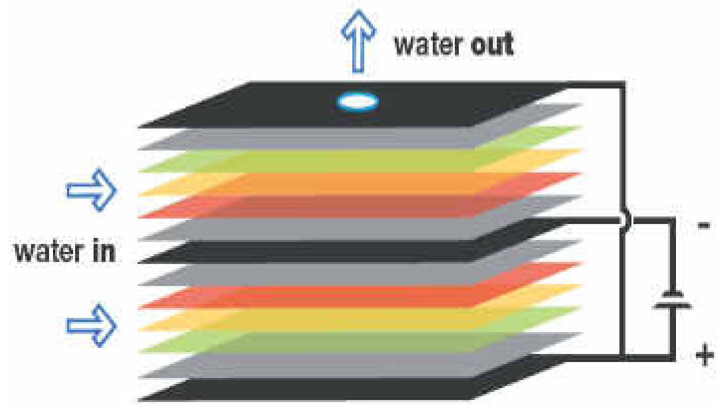


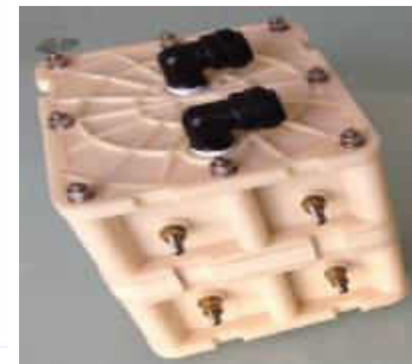
Porous metal-organic framework (MOF-801, $Zr_6O_4(OH)_4(fumarate)_6$)

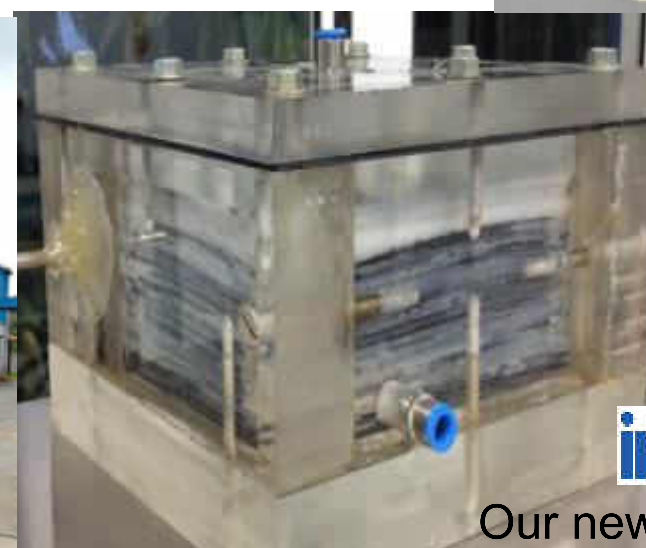
Kim Hyunho, et al. *Science,* 356 (6336) 2017

Capacitive Desalination (CDI)



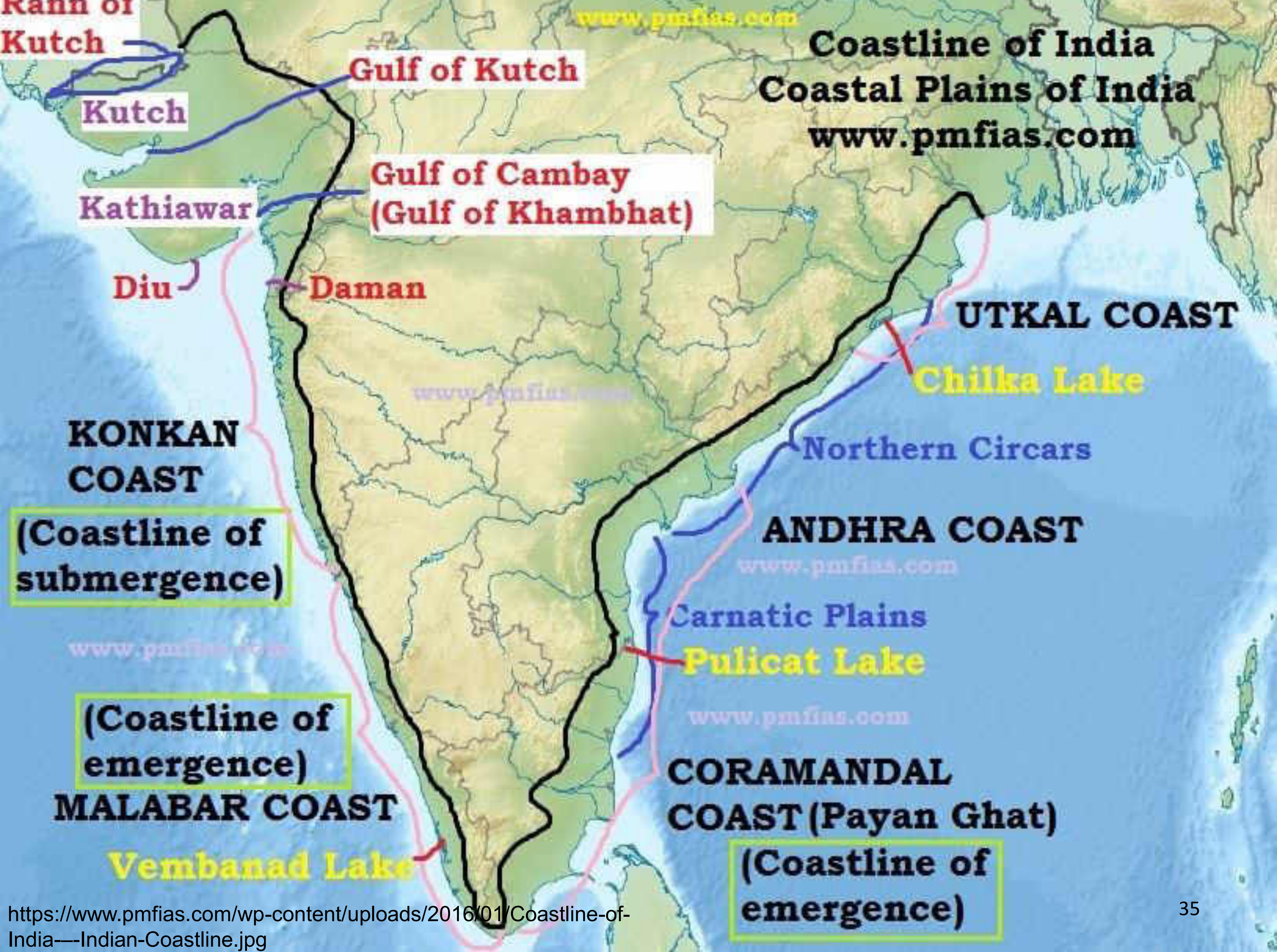




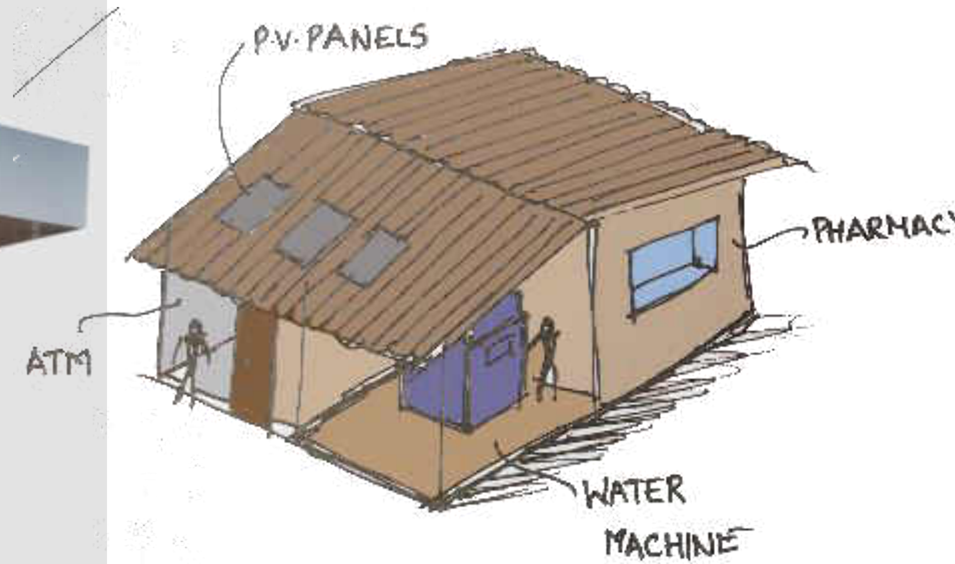


Our new company

Soujit Sengupta, Rabiul Islam and others



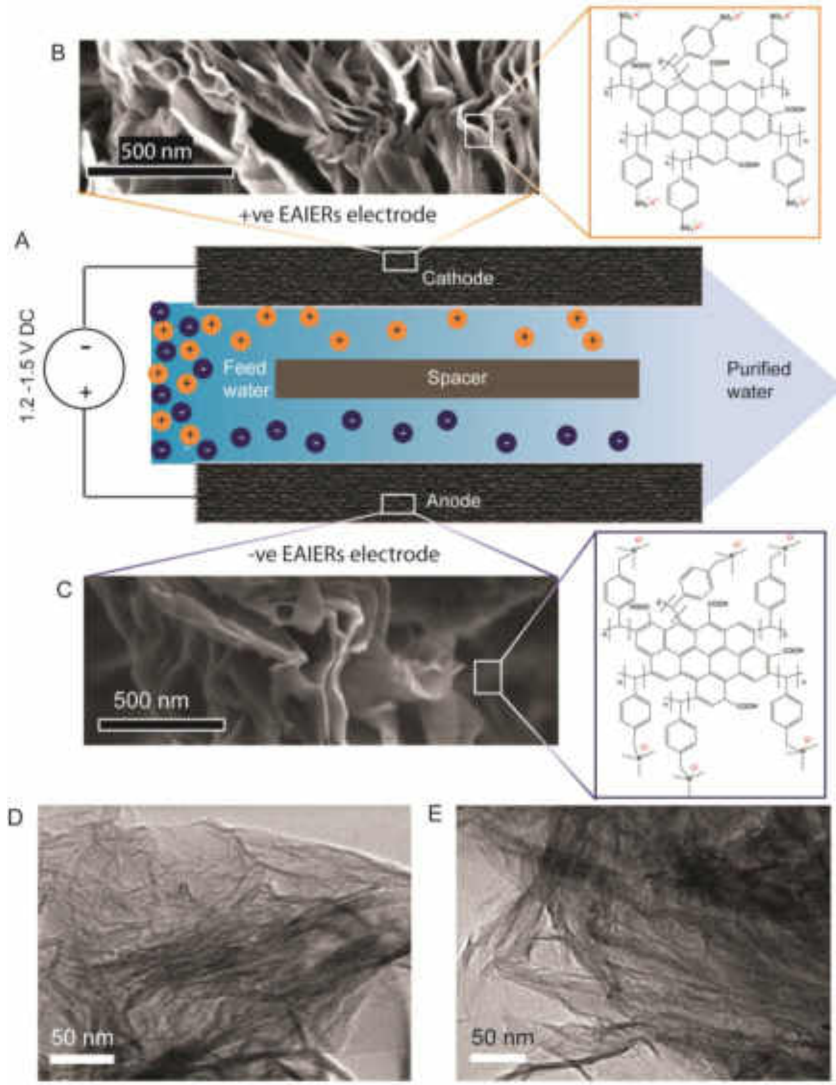
https://www.pmfias.com/wp-content/uploads/2016/01/Coastline-of-India-–-Indian-Coastline.jpg



Products under implementation

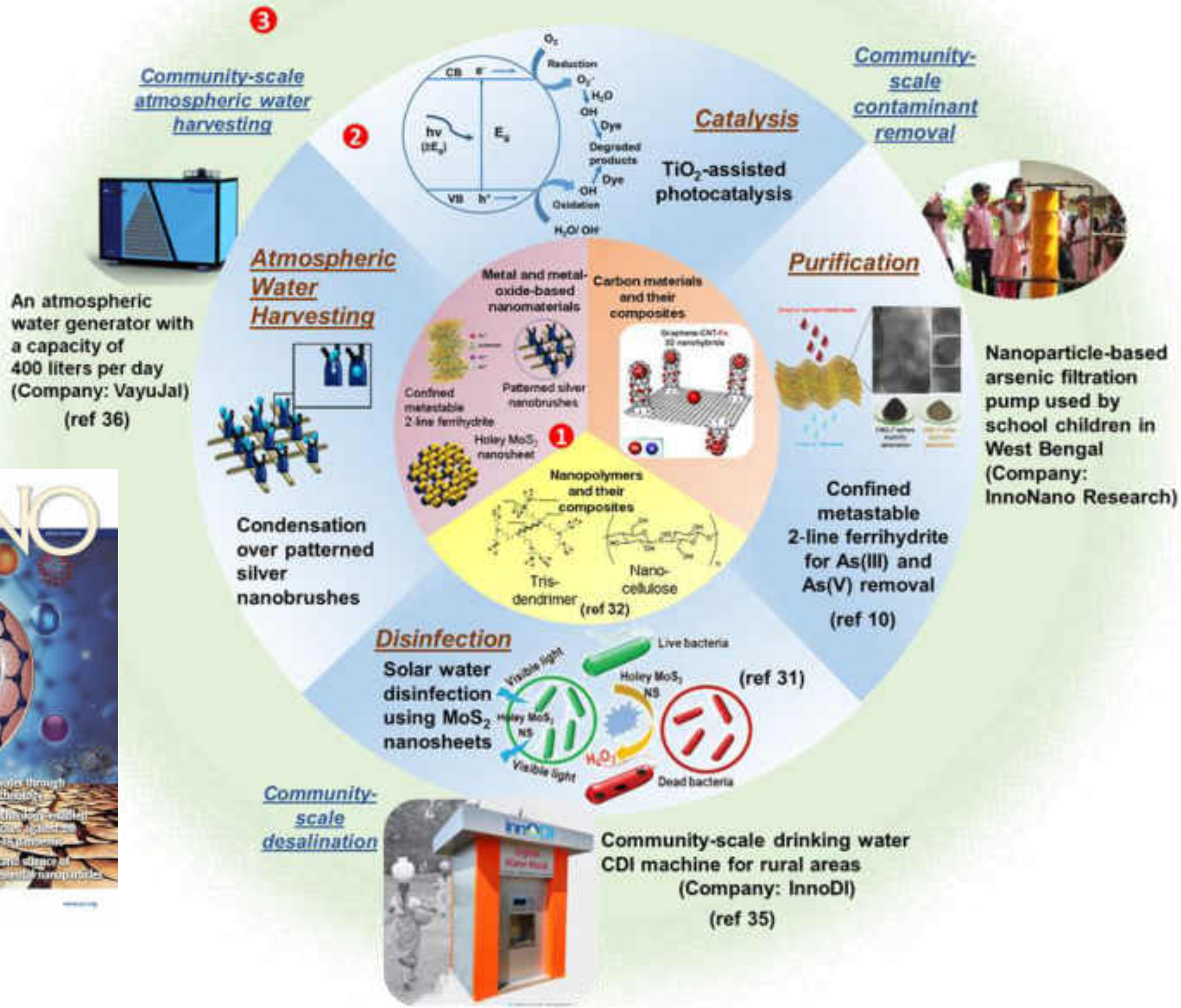
Vijay Sampath and Tullio Servida

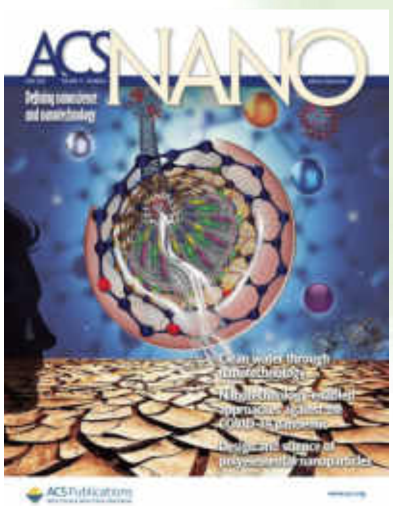
A Covalently Integrated Reduced Graphene Oxide -Ion Exchange Resin Electrode for Efficient CDI



Rabiul *et al., Adv. Mater. Interfaces* **2021**, *8,* 2001998

Evolution of materials to products





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

Sensors and new opportunities



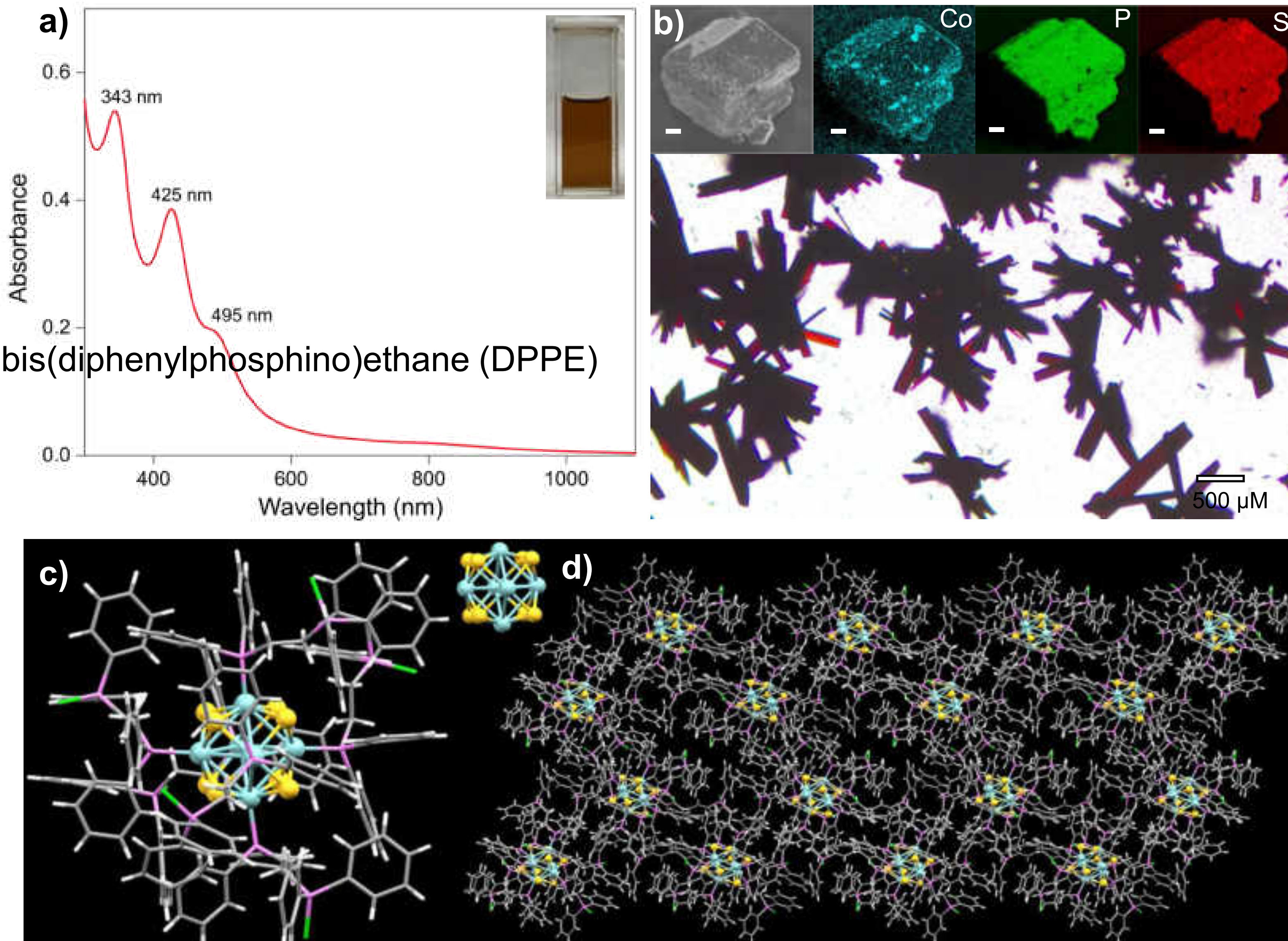
Analog/Grating
Equipment
$ 5~6 Billion (2017)
a few **100k units (2017)**

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

Water quality measurement – In the pipeline

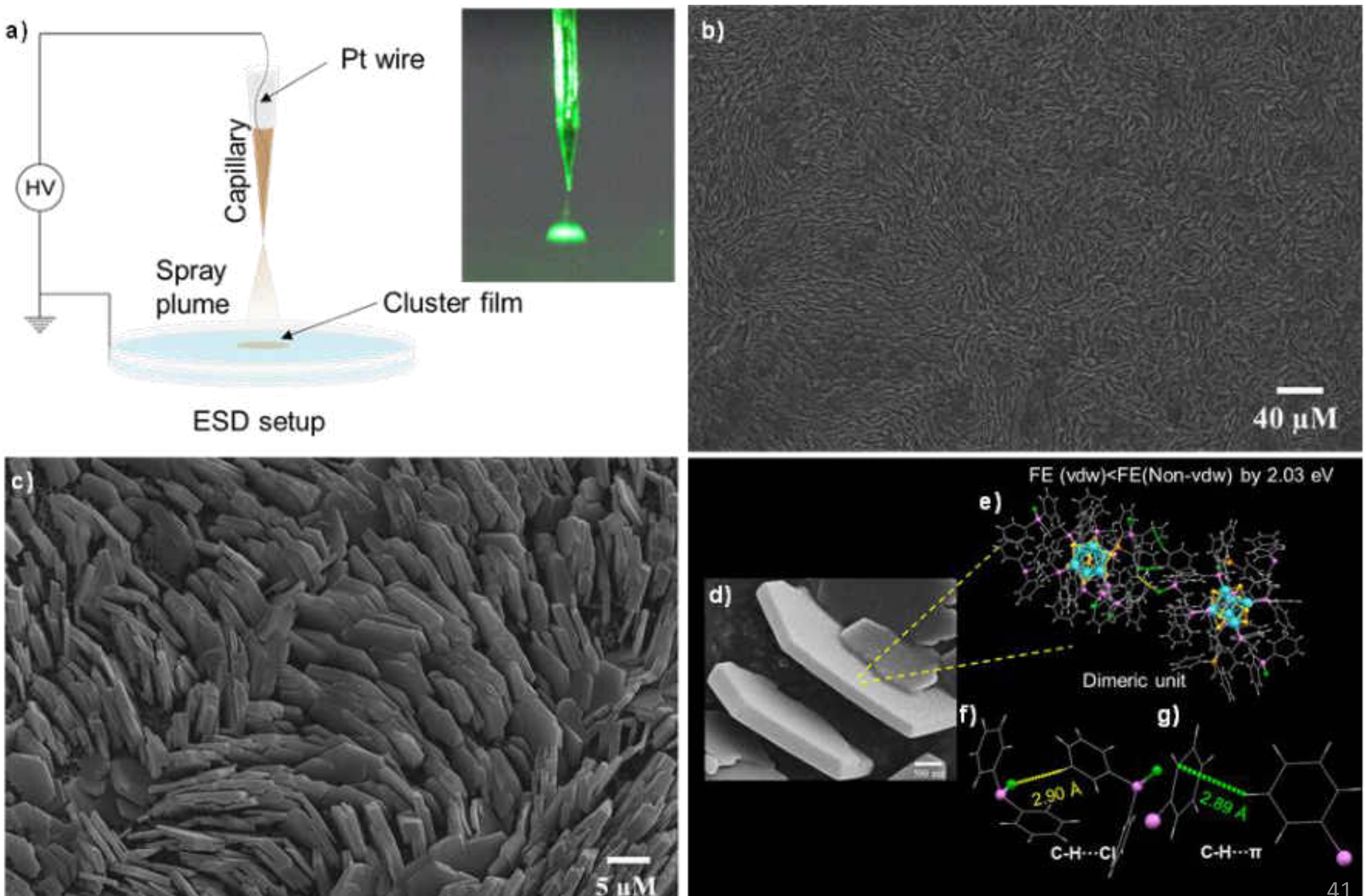
nanoλ

New electrodes - Aligned nanoplates of Co_6S_8

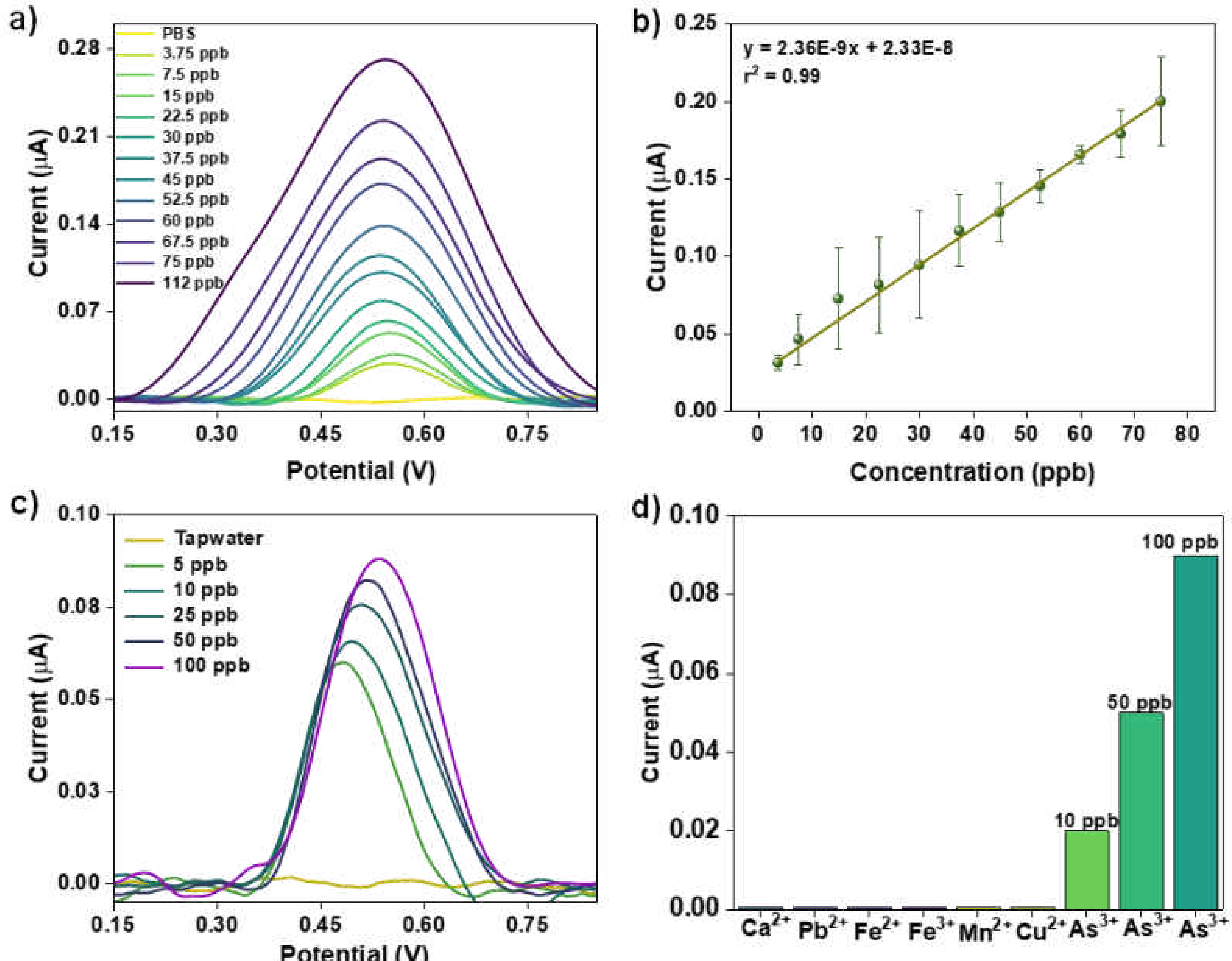


1,2-bis(diphenylphosphino)ethane (DPPE)

Electrospray deposition

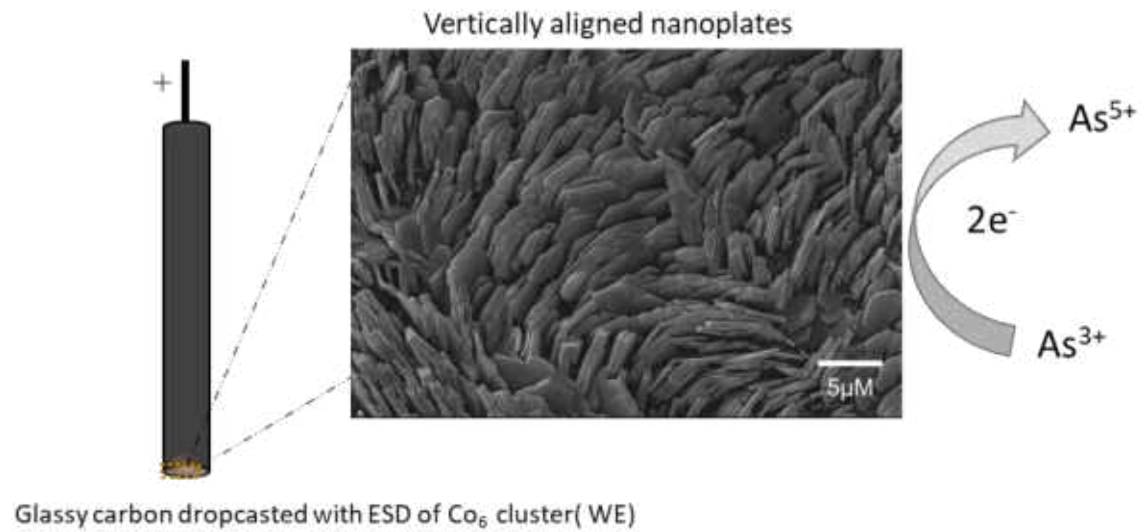


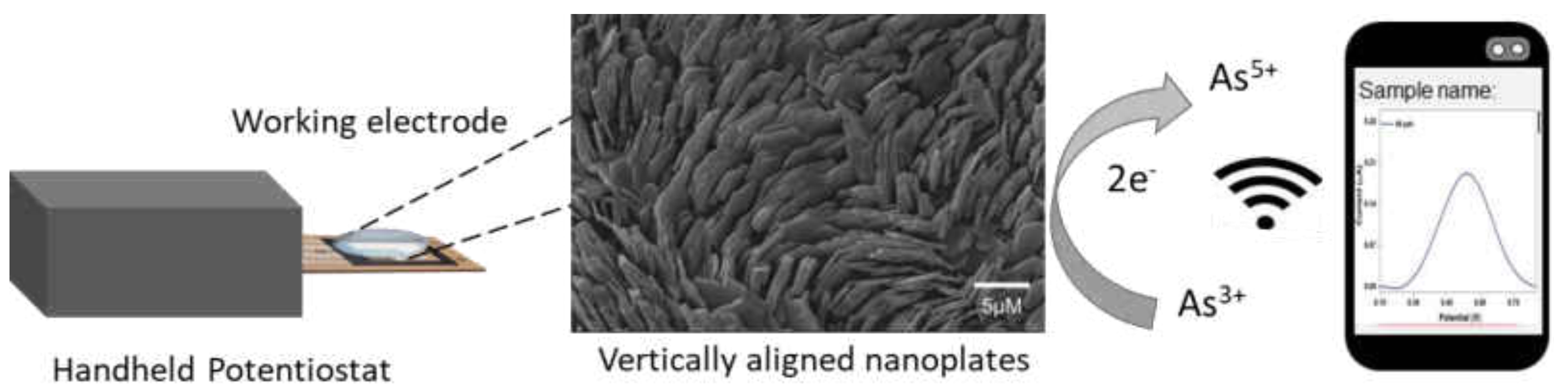
Sensing



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+

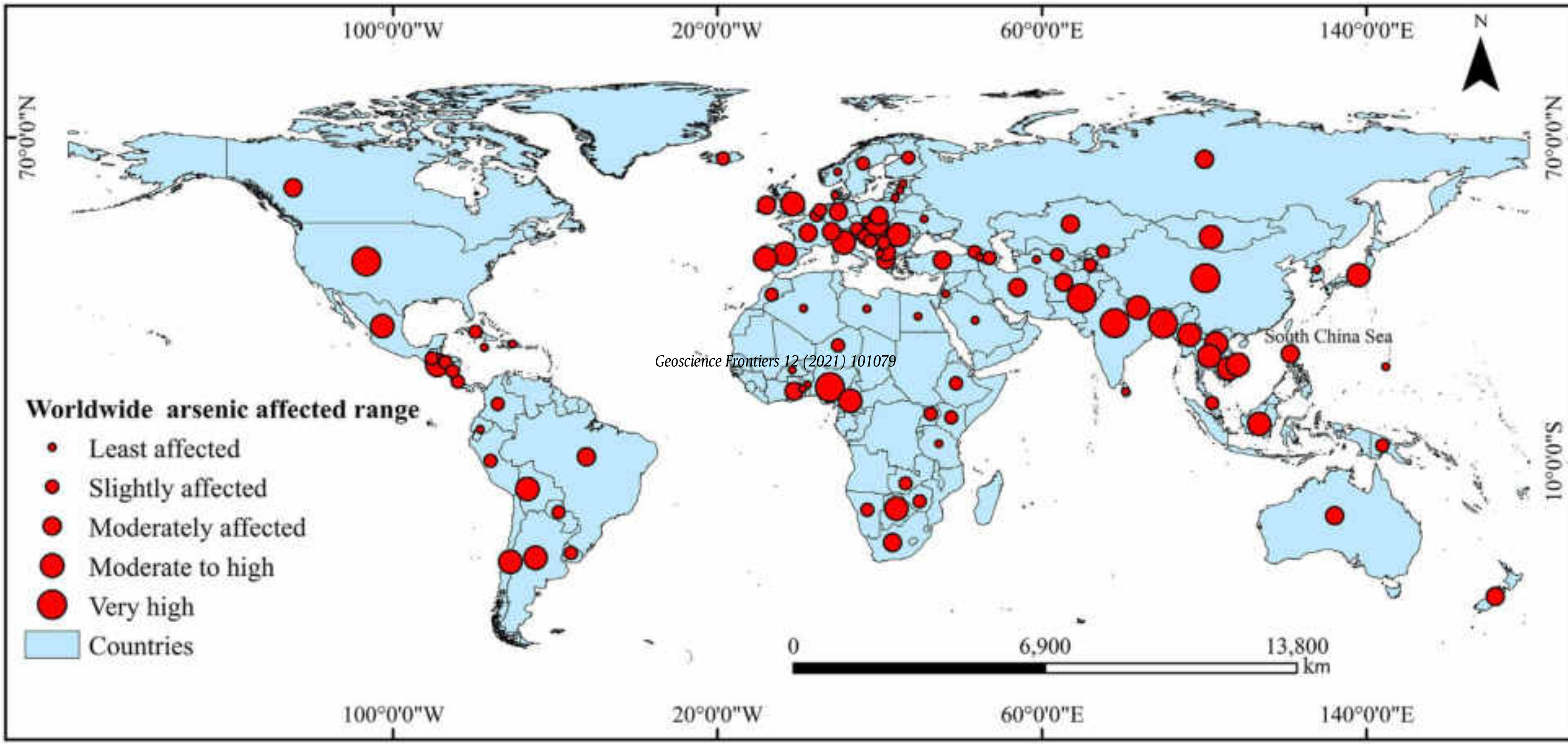
Working electrode





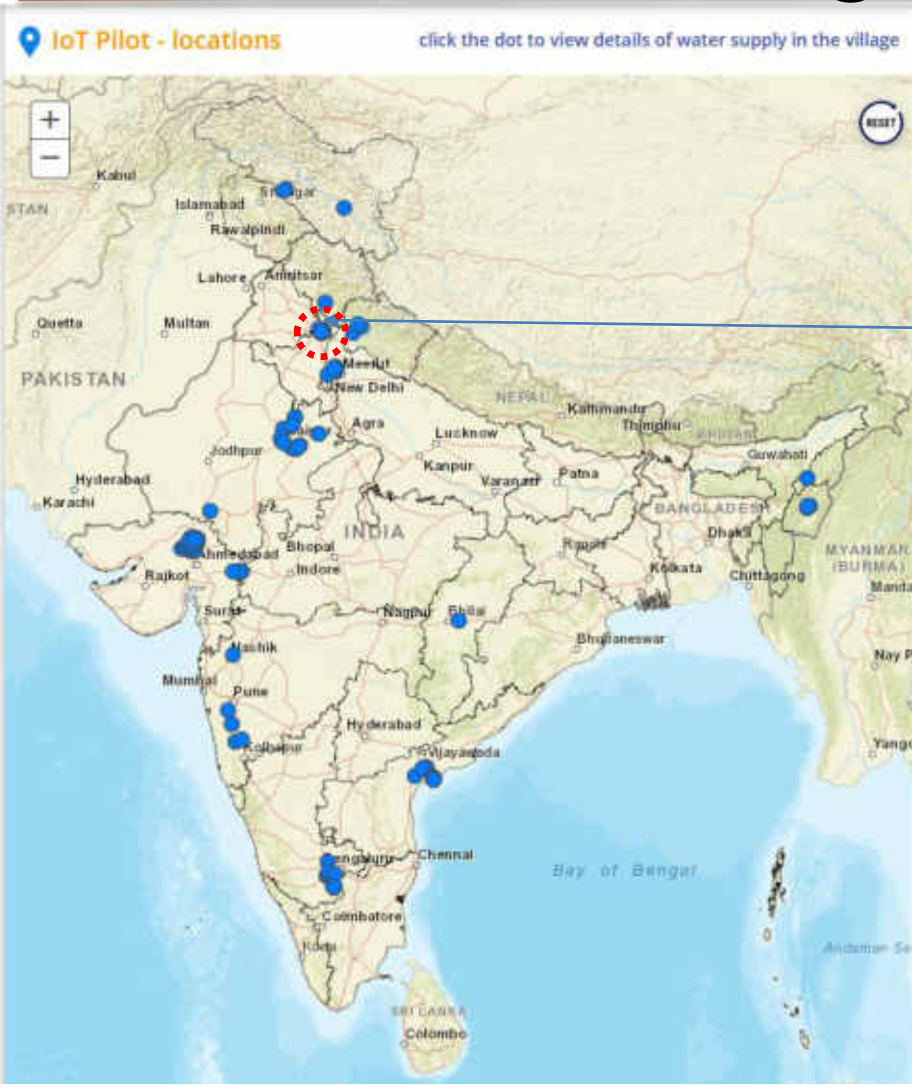
Anagha Jose et al. *ACS Materials Lett.,* 5 (2023) 893–899.

Arsenic poisoning across the world



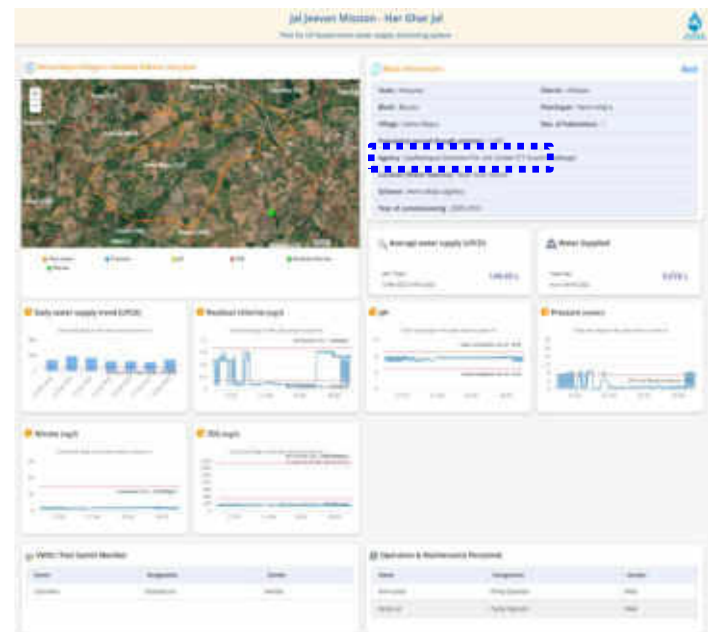
E. Shaji, M. Santosh, K. V. Sarath, Pranav Prakash, V. Deepch and B. V. Divya, Geoscience Frontiers, 12 (2021) 101079.

India’s water is being monitored



IITM/IISc

Installations made by four companies



International Centre for Clean Water


IIT Madras Research Park

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,...

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:

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