Since 195

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.

Professor-in-charge

ICCW

International Centre for Clean Water

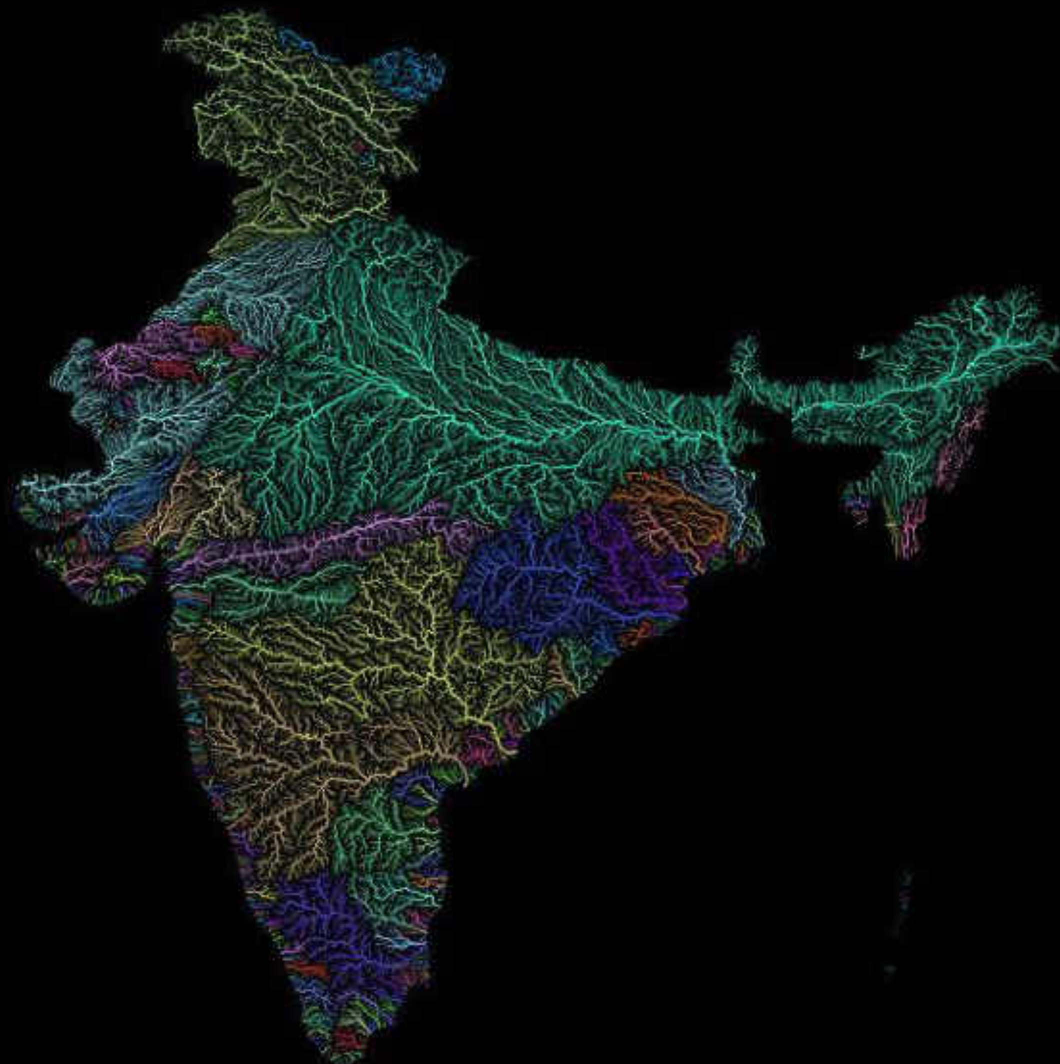
Associate Editor

ACS Sustainable Chemistry & Engineering

Eni Award Lectures, FEEM premises, Milan, May 21, 2024

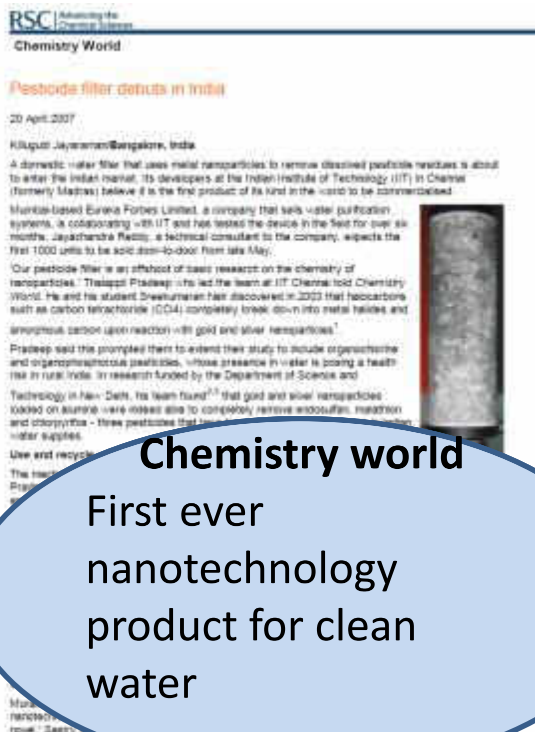

Lost in the countryside
Image from Wikipedia


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



From S. Vishwanath

World's first nanochemistry-based water purifier


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 ...

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

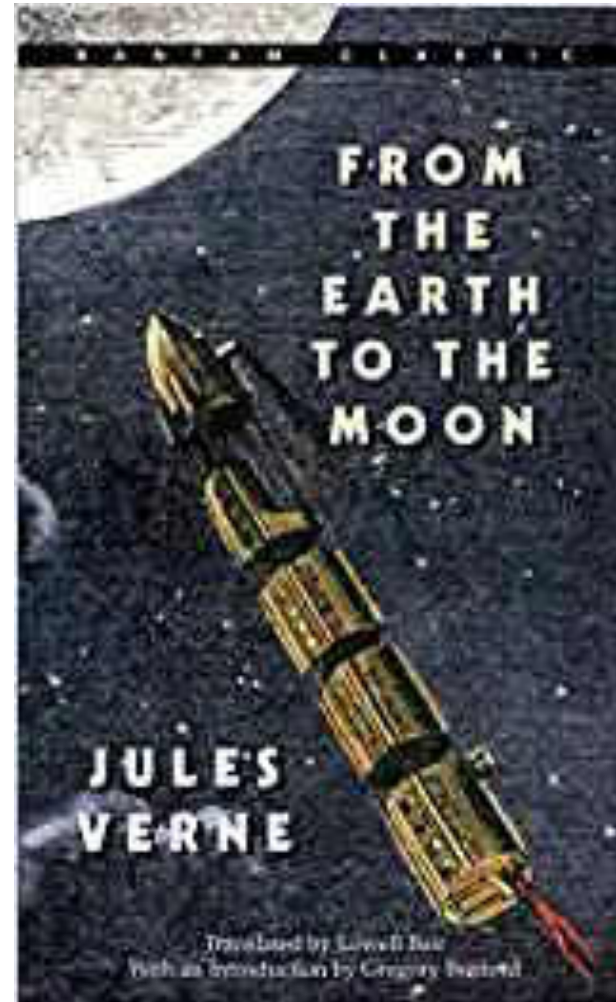
1. Patents: A method of preparing purified water from water containing pesticides, **Indian patent 200767**
2. Extraction of malatheon and chlorpiryhphos from drinking water by nanoparticles , **US 7,968,493** A method for decontaminating water containing pesticides, **EP 17,15,947**

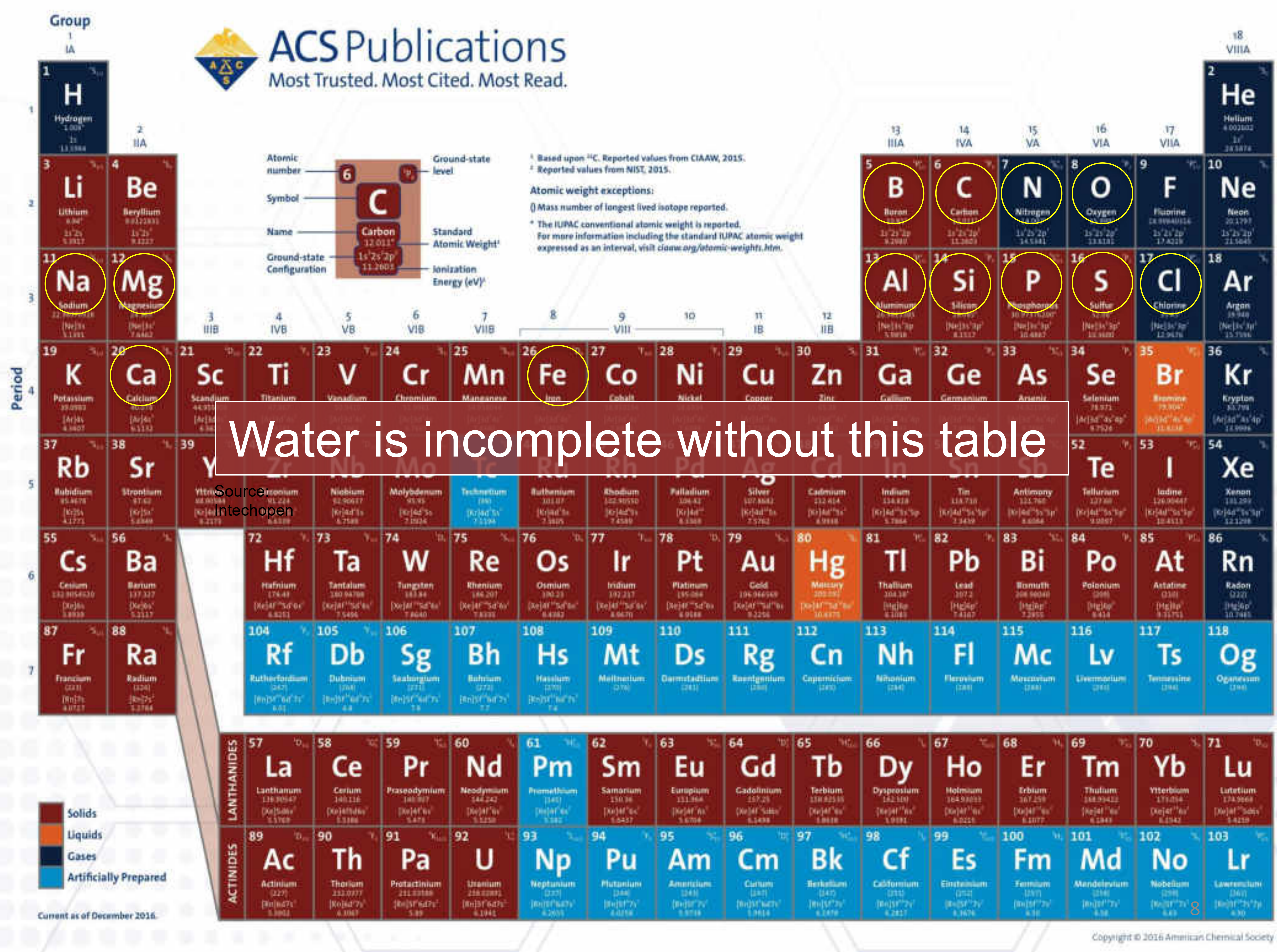
Product is marketed now by a Eureka Forbes Ltd.
Several new technologies are now available

Water is at the centre of action

There is water in everything we do.

Our dreams become reality with materials





Water is incomplete without this table

Source: Intechopen

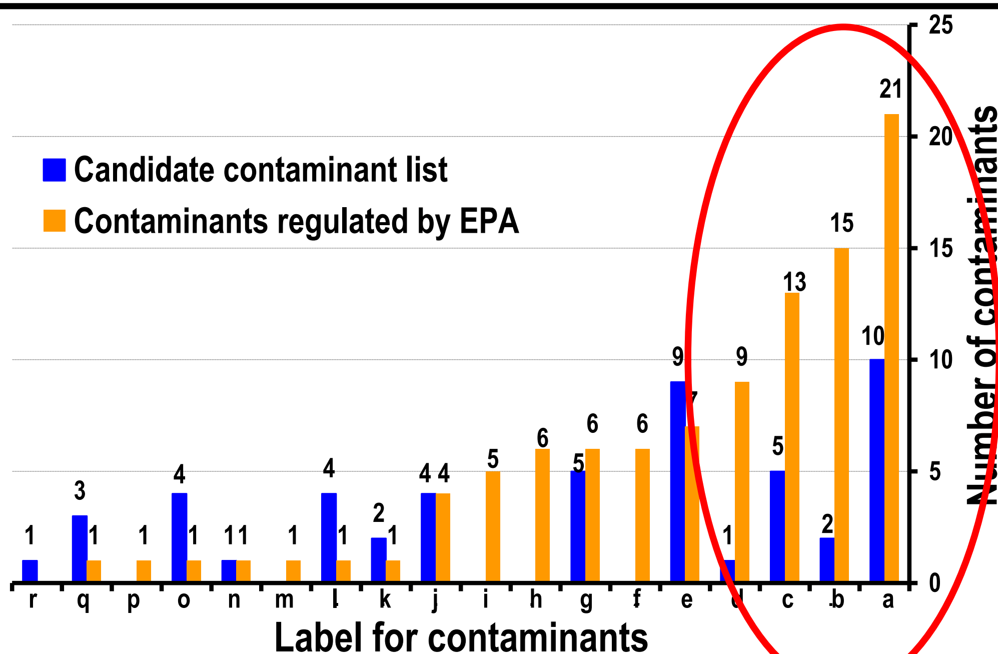
Water purification, history

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

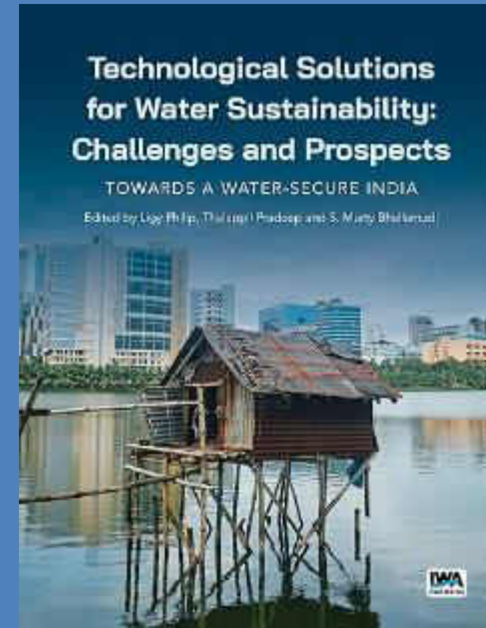
New adsorbents

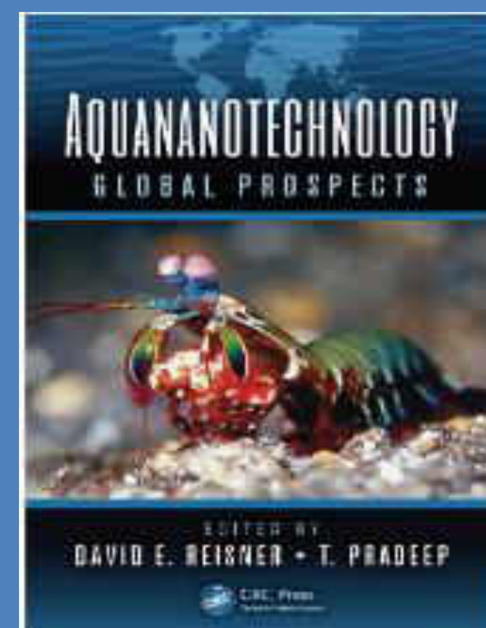
New sensors

New catalysts

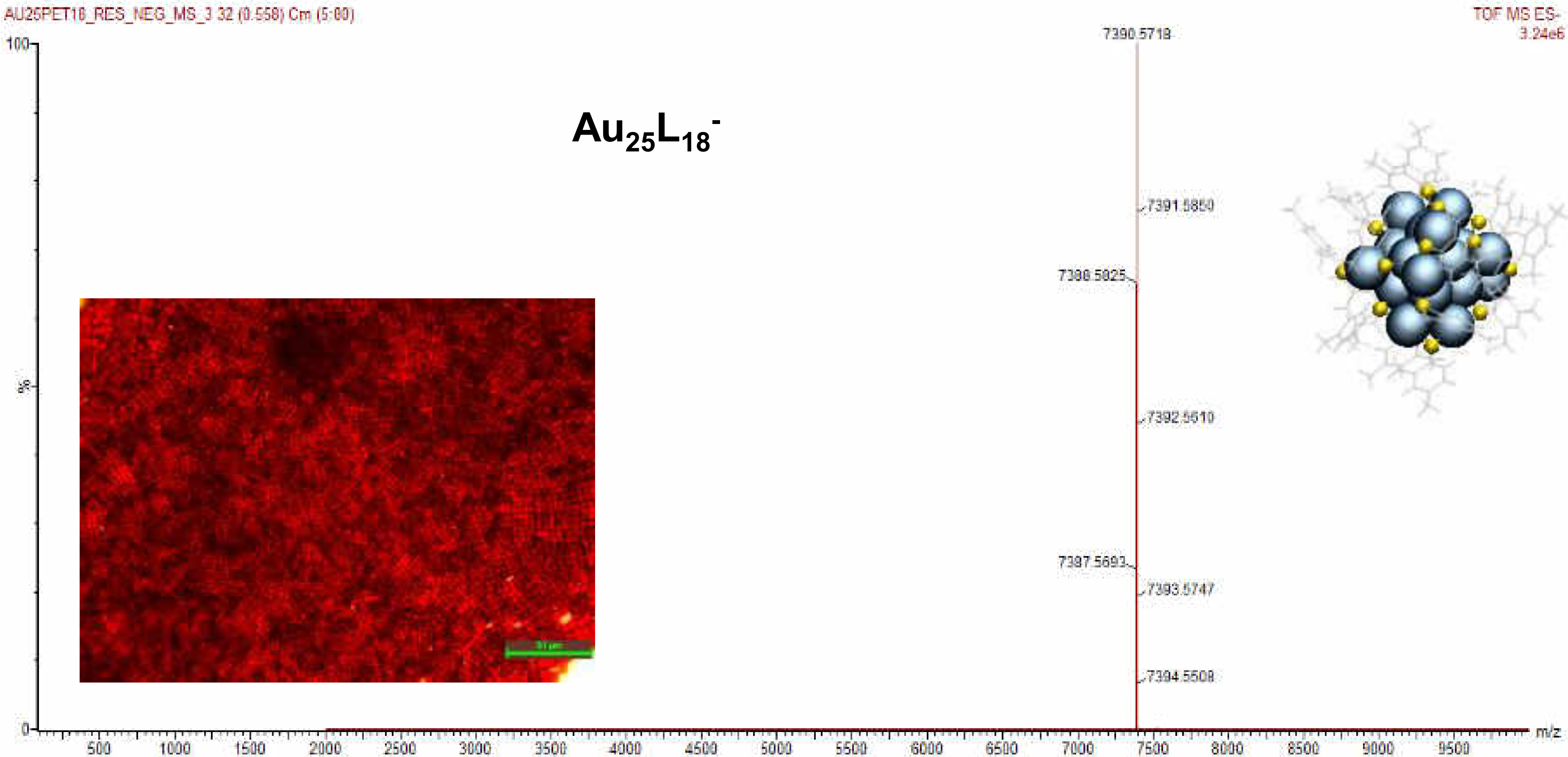
Novel phenomena

New devices





Nanomaterials are now atomically precise

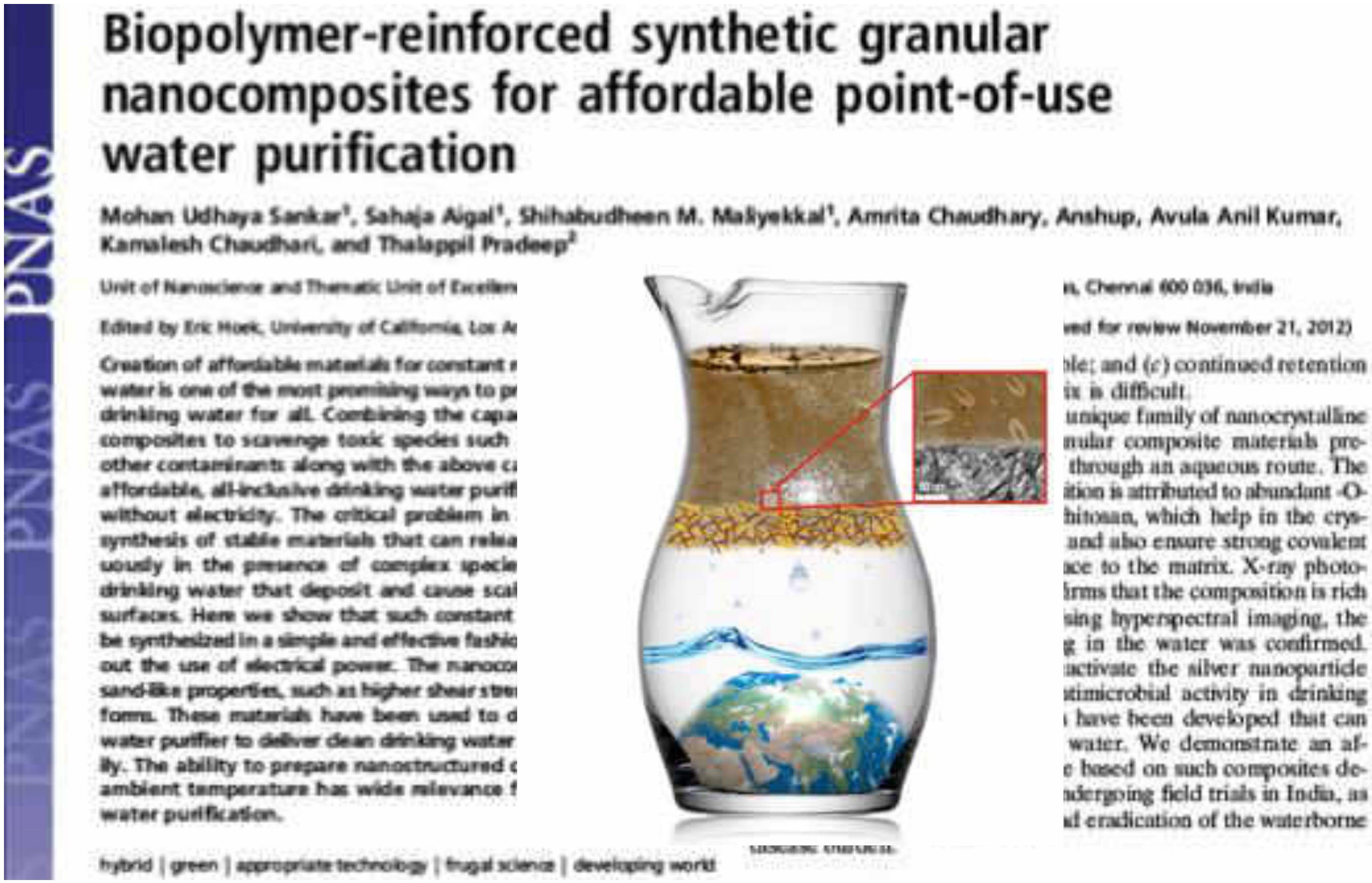


T. Pradeep et. al. *Acc. Chem. Res.* 2018; 2019.

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 … s, Chennai 600 036, India

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

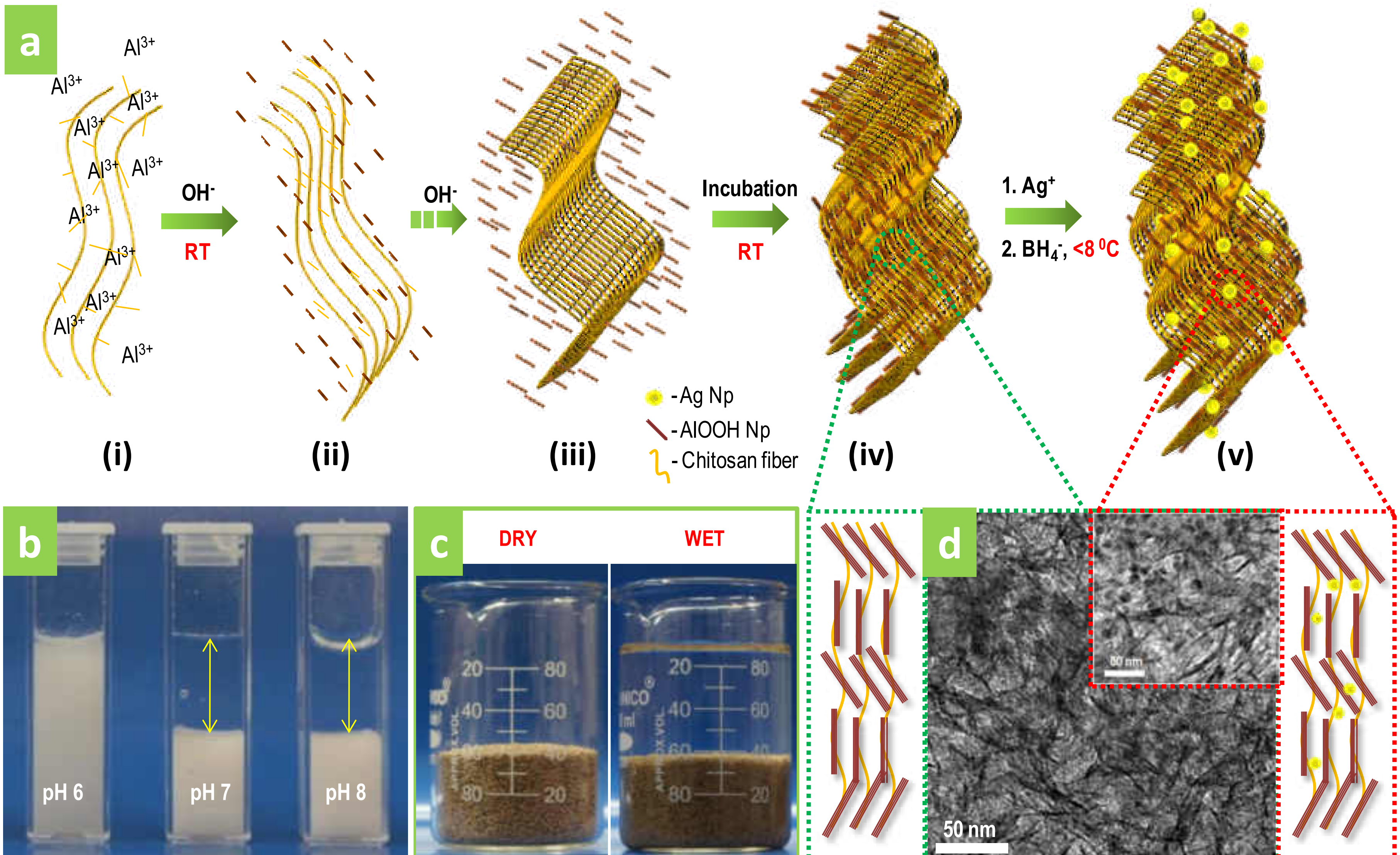
Creation of affordable materials for constant r… water is one of the most promising ways to pr… drinking water for all. Combining the capa… composites to scavenge toxic species such… other contaminants along with the above ca… affordable, all-inclusive drinking water purif… without electricity. The critical 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… ily. 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

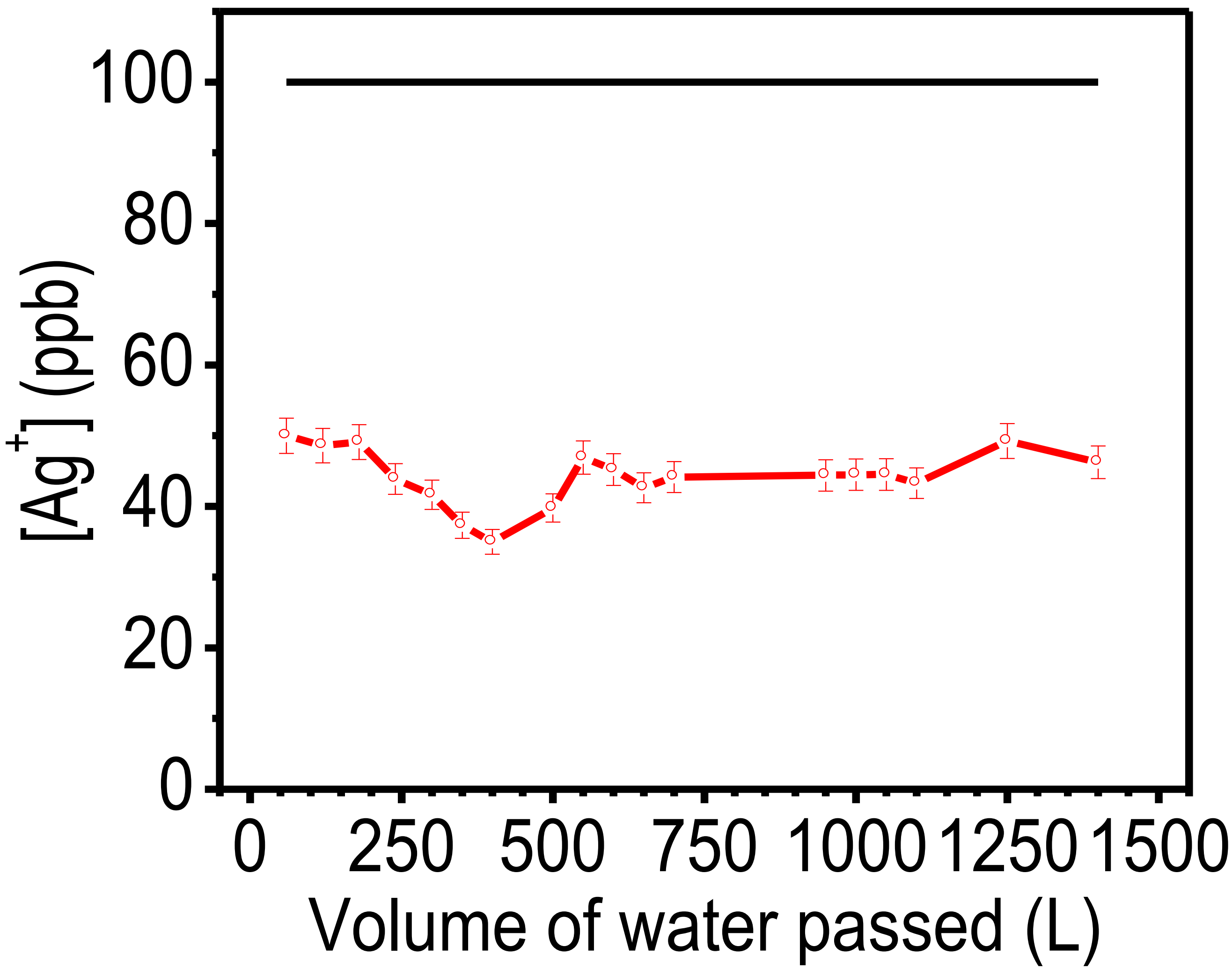
M. Udhaya Sankar, et. al. *Proc. Natl. Acad. Sci.,* 110 (2013) 8459-8464.

How to make?

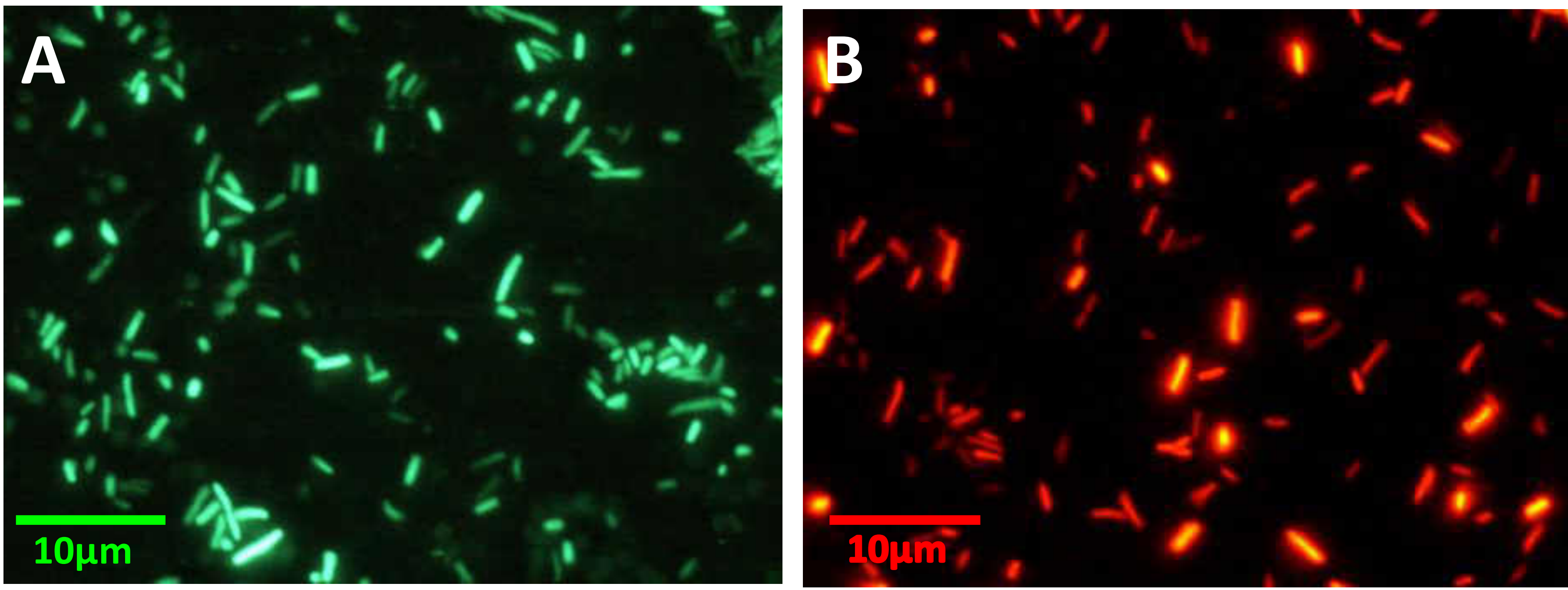


a
Al3+
OH-
RT
OH-
Incubation
RT
1. Ag+
2. BH4-, <8 0C
-Ag Np
-AlOOH Np
-Chitosan fiber
(i)
(ii)
(iii)
(iv)
(v)
b
pH 6
pH 7
pH 8
c
DRY
WET
d
50 nm

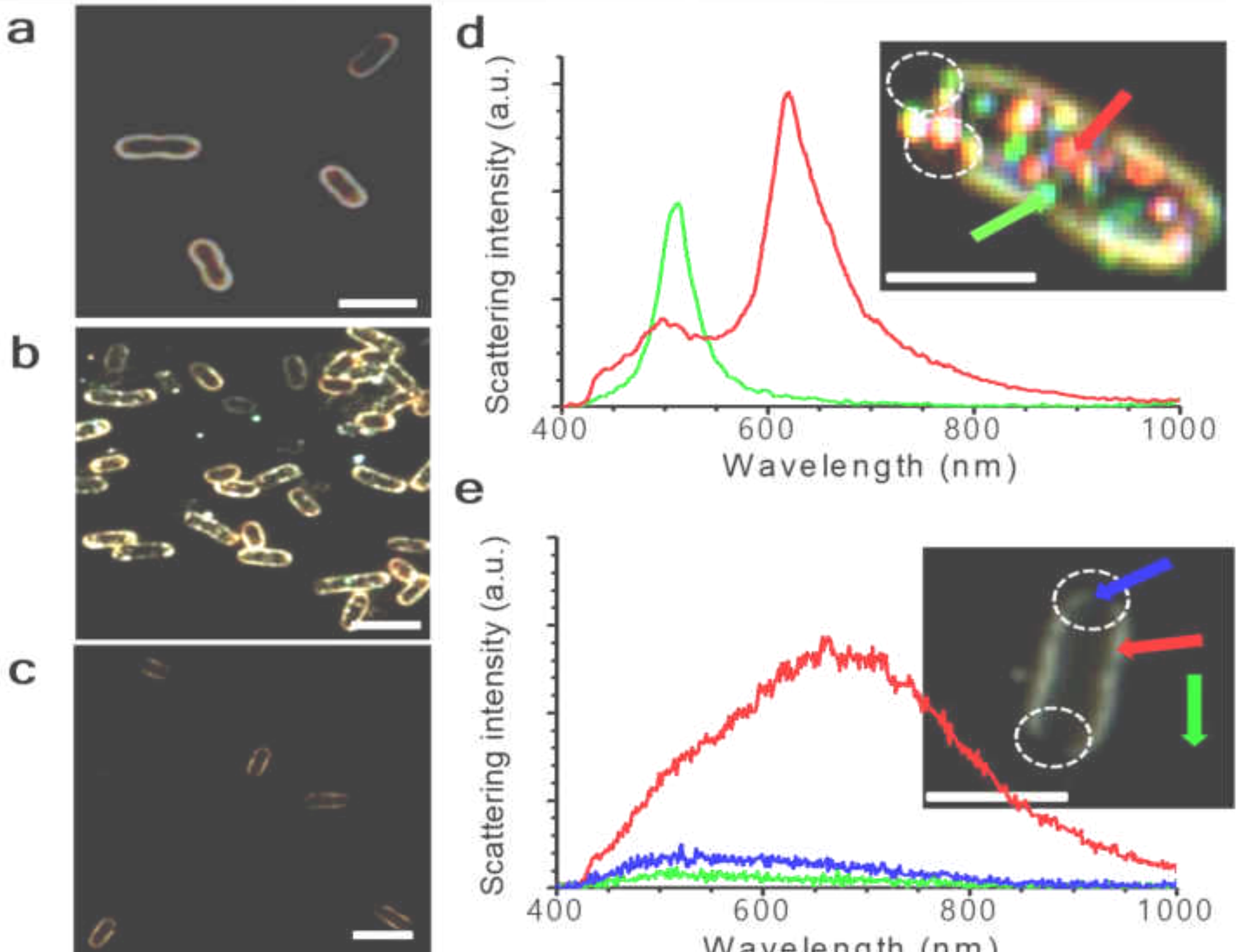
What is special?



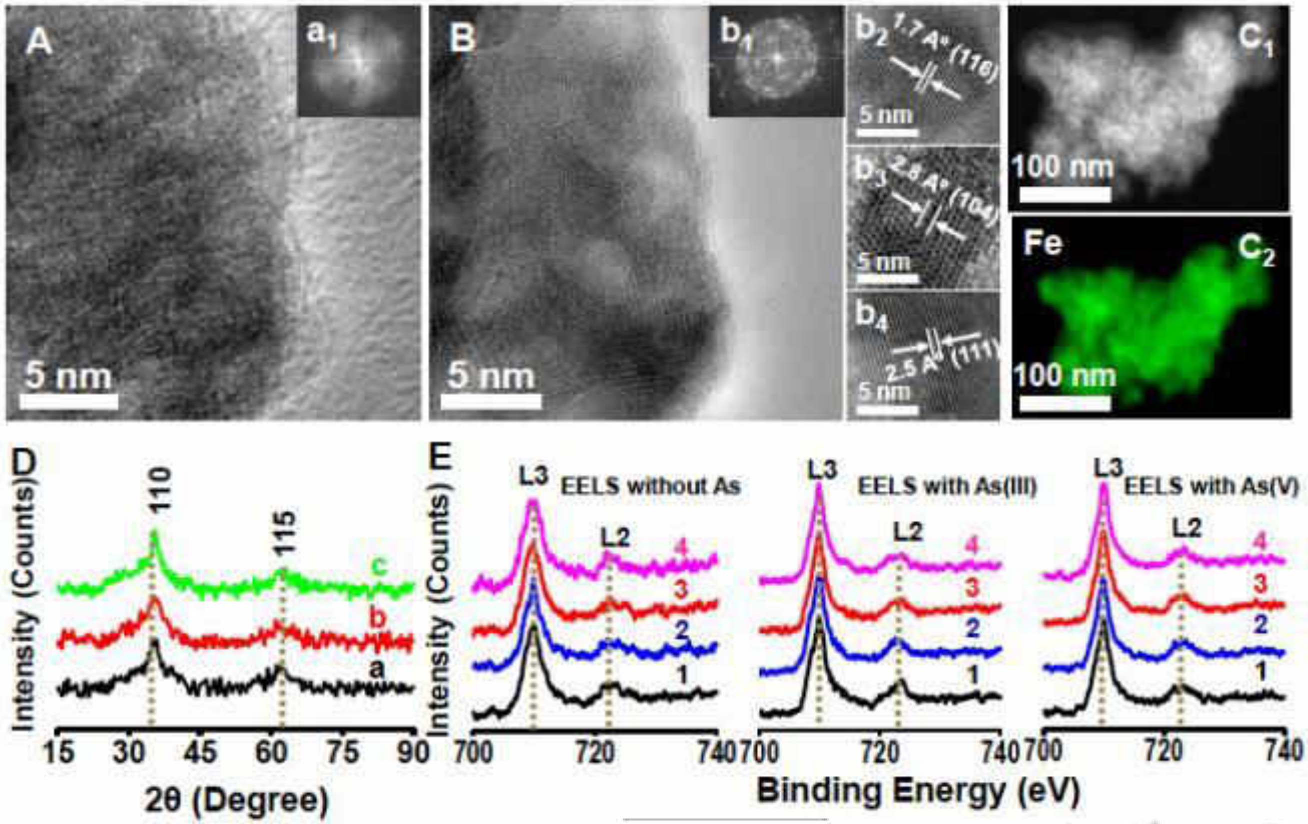
Live/dead staining experiments



No nanotoxicity



Variety of materials



www.advmat.de ADVANCED MATERIALS

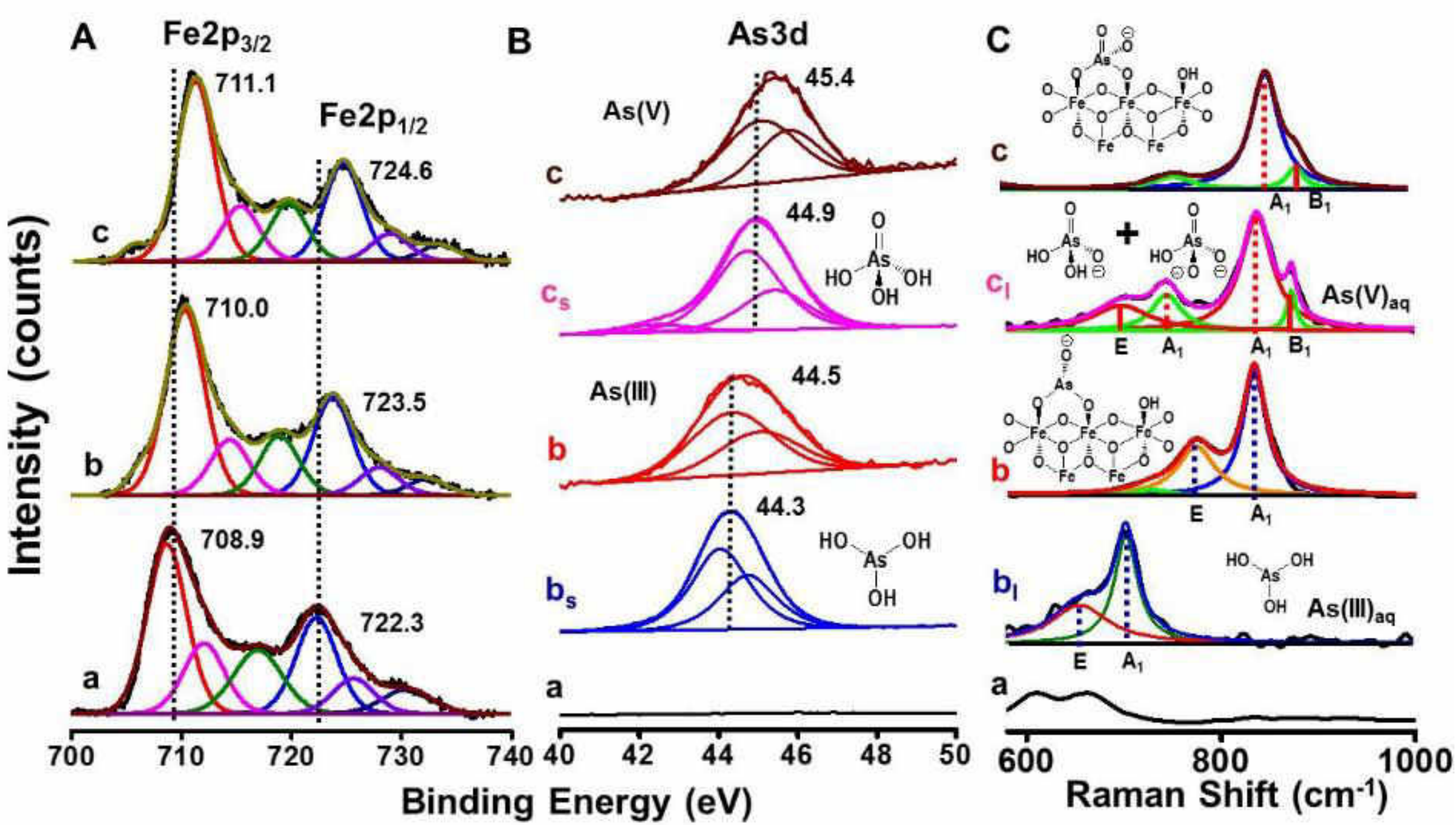
Communication

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*

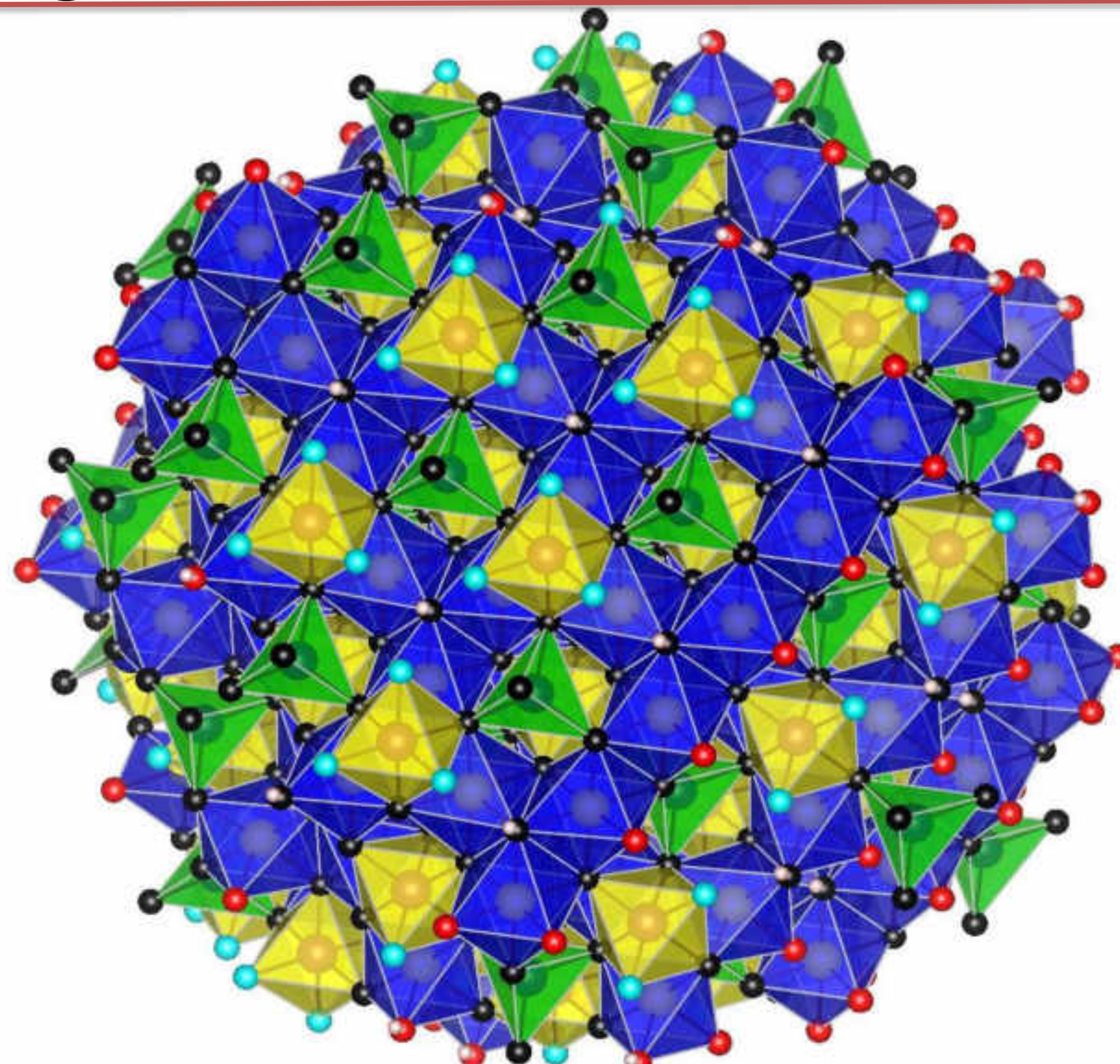
A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

Mechanism



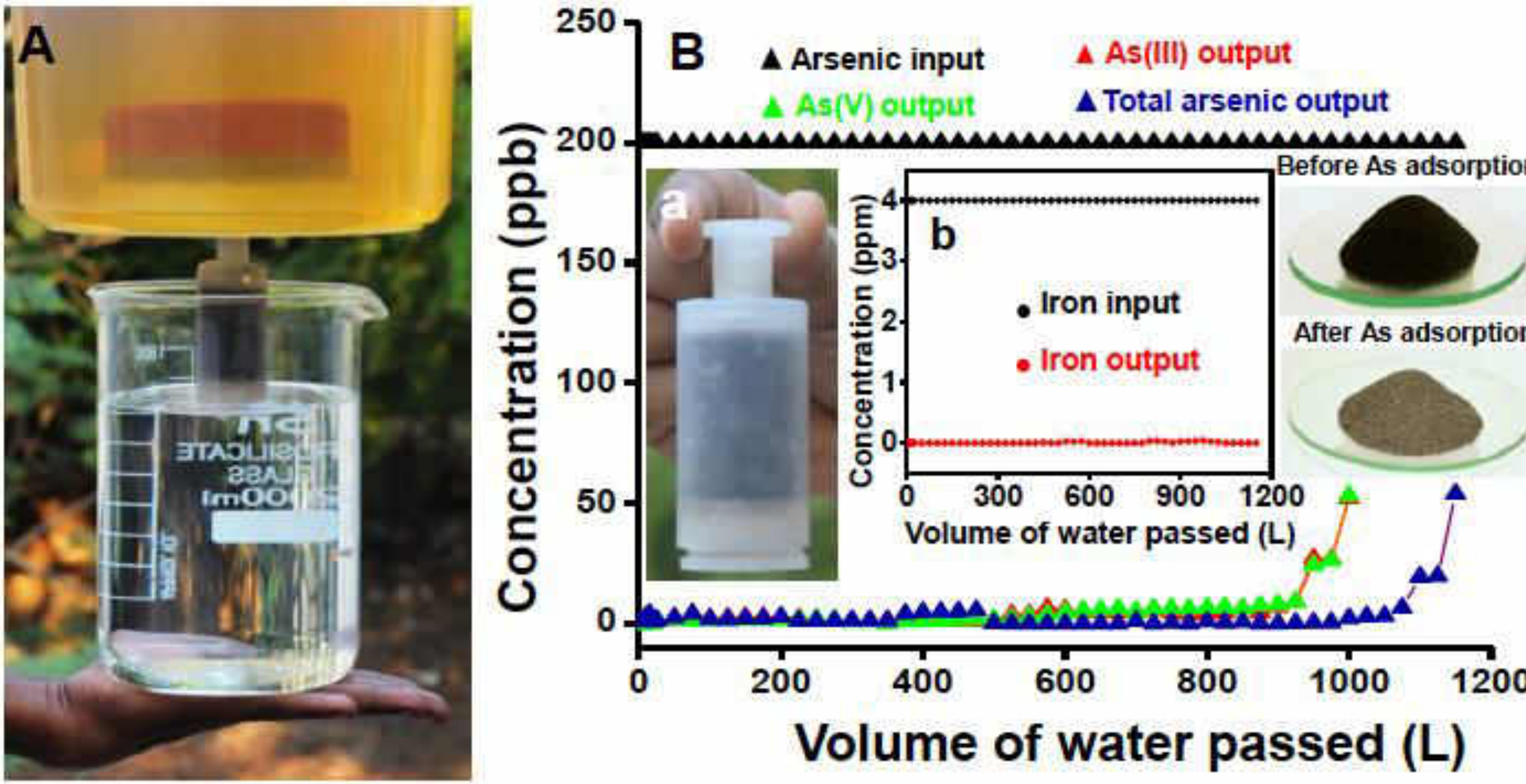
A
Fe2p3/2
711.1
Fe2p1/2
724.6
710.0
723.5
708.9
722.3
Intensity (counts)
B
As3d
As(V)
45.4
44.9
As(III)
44.5
44.3
Binding Energy (eV)
C
As(V)aq
As(III)aq
Raman Shift (cm-1)

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

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

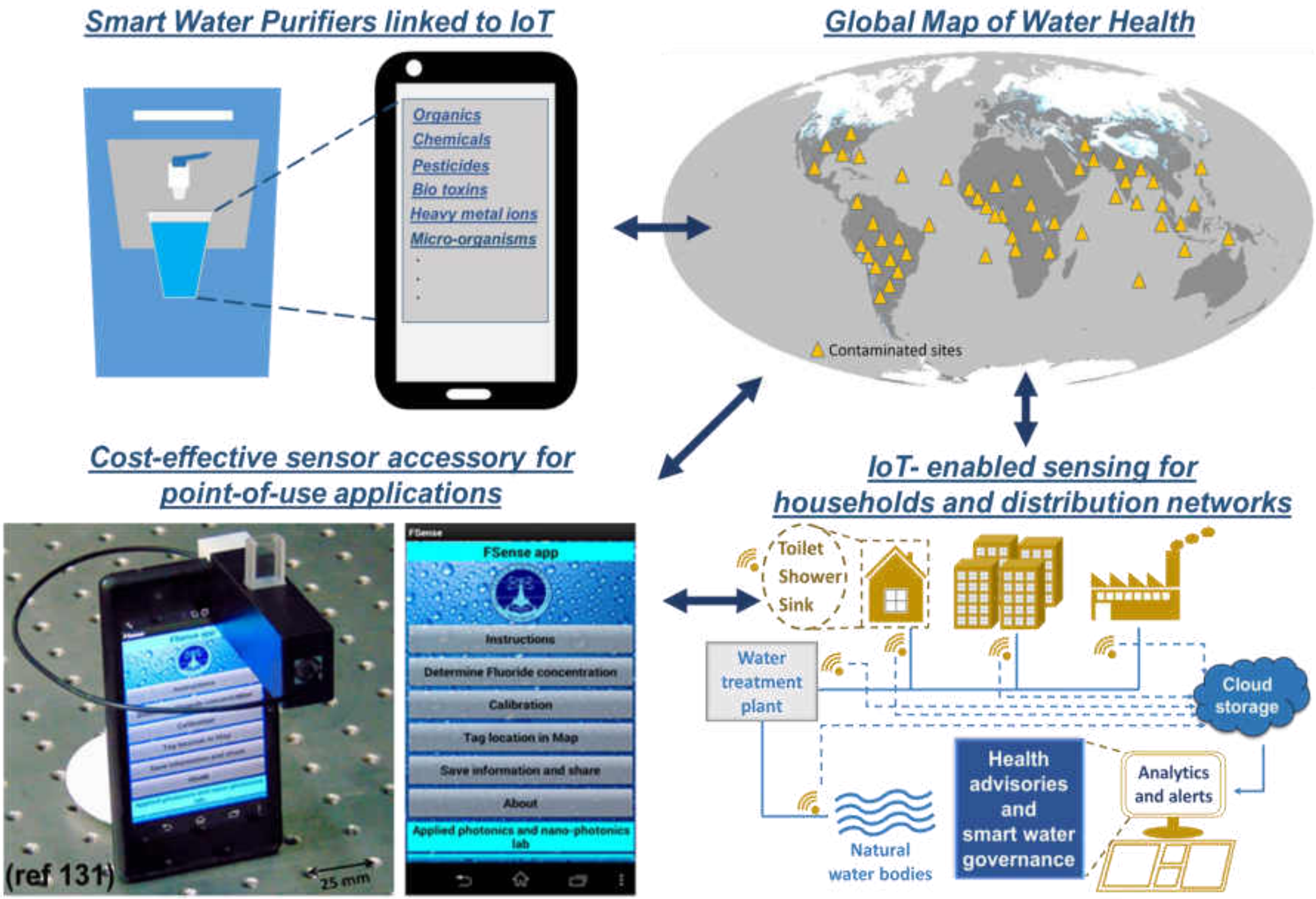
Retrofitted Water Purification Plant
Capacity: 0.1-1 MLD

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

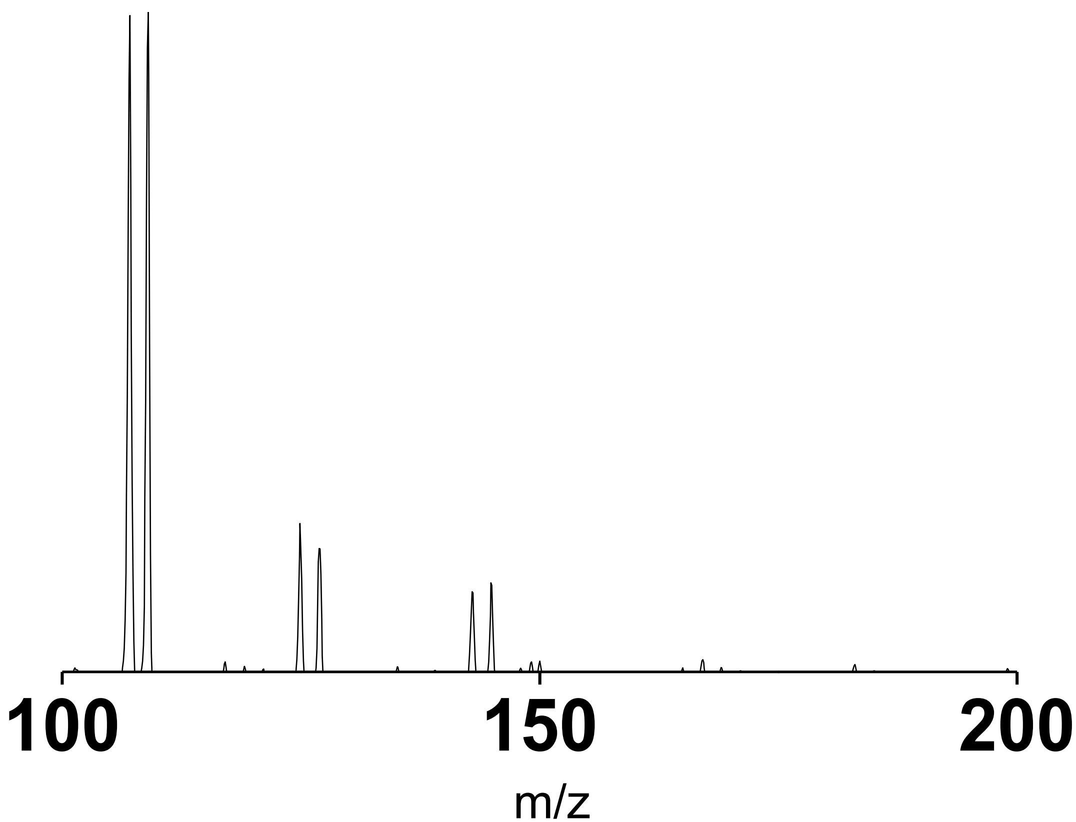
- Adsorbents conform to toxicity characteristic leaching procedure
- Elemental waste goes back to local environment
- Safe disposal of arsenic (or any other) laden waste
- Additional protection could be considered, if necessary
- Exploring viable uses

Across the country

Components of IoT architecture implemented by DWSS, GoP

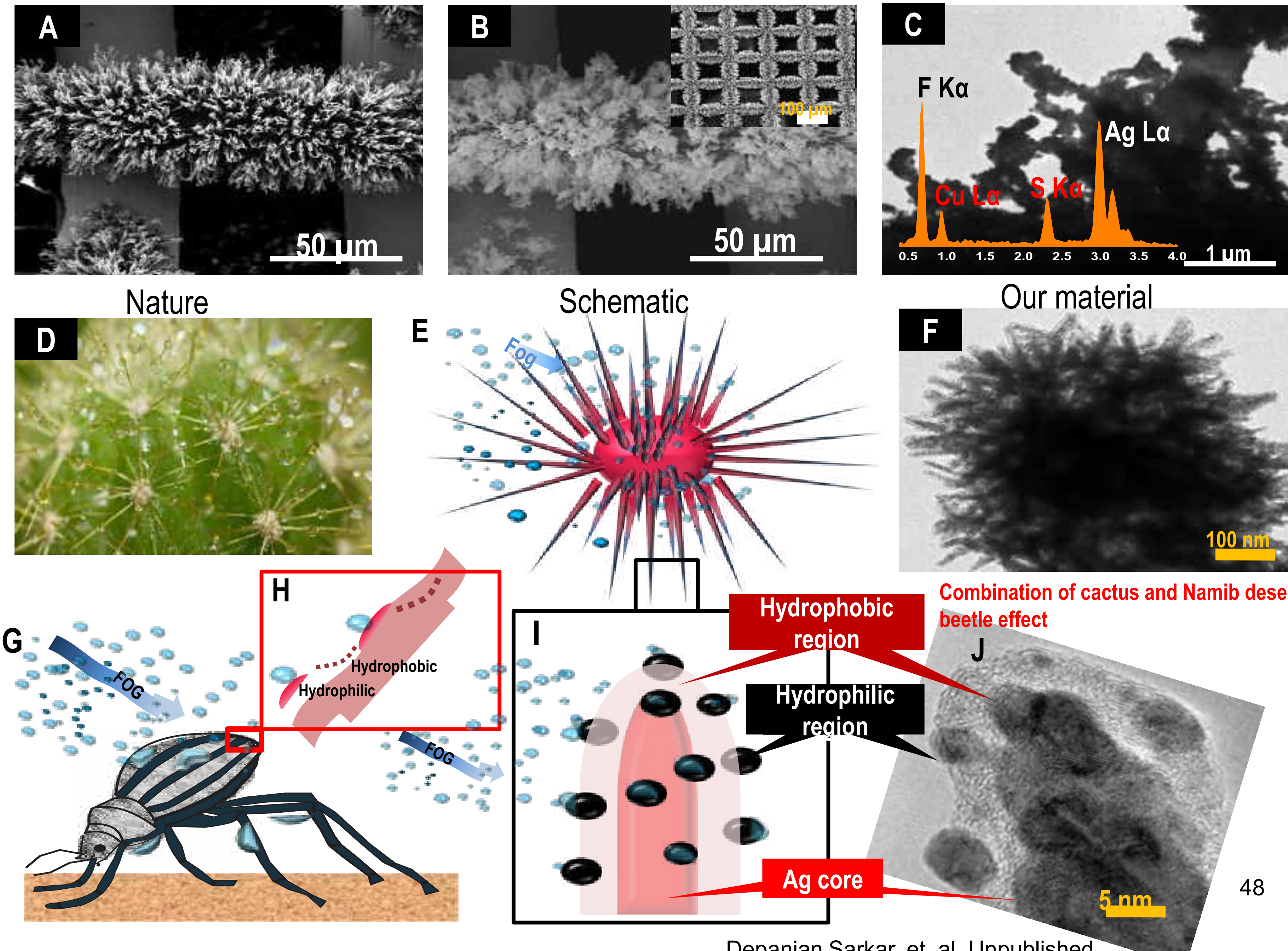
Typical IoT architecture comprises various sensors and meters, communication gateway, Cloud Server, SMS gateway, Webservices and mobile phone application for operator

Atmospheric water harvesting

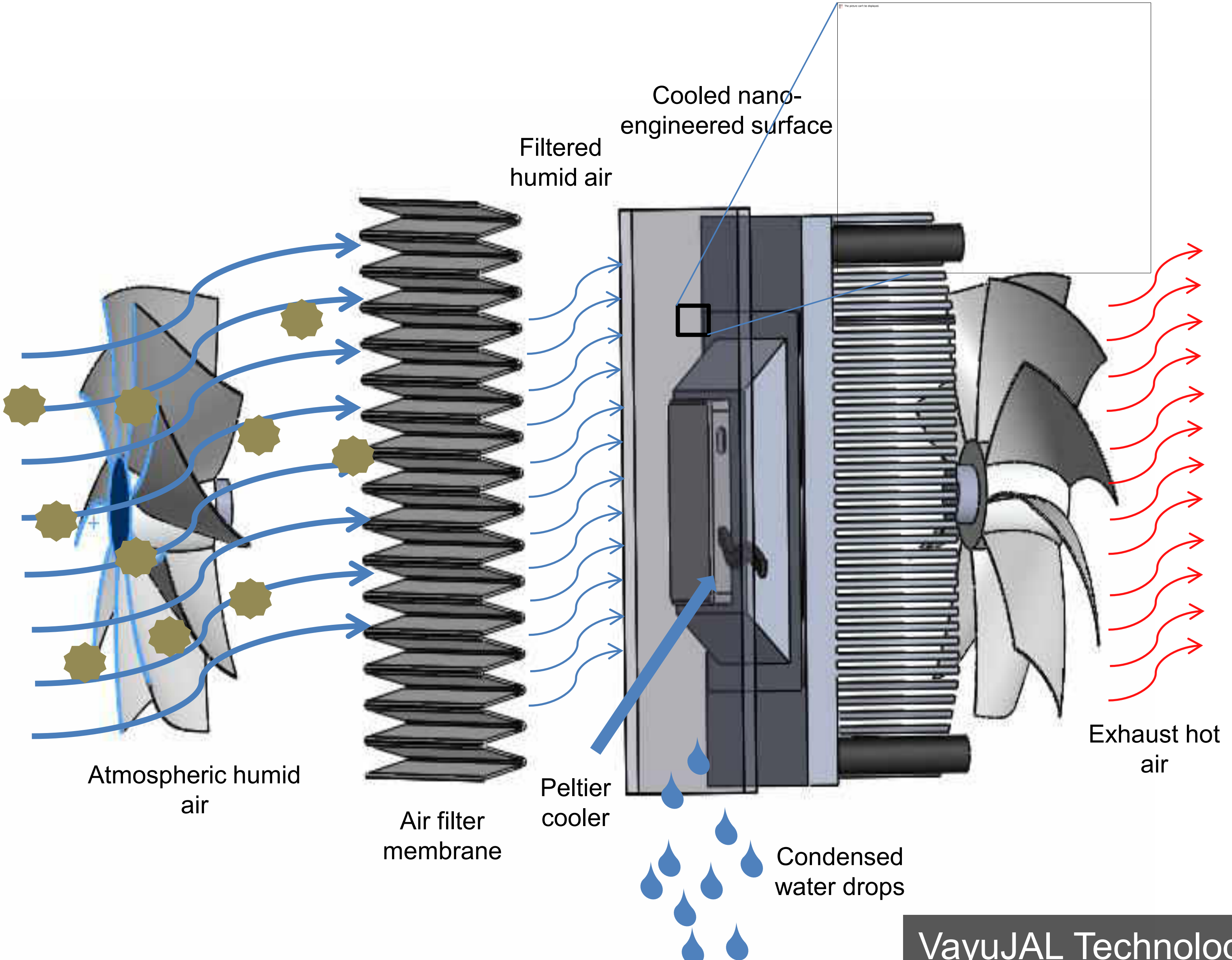


New harvesters

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



Depanjan Sarkar, et. al. Unpublished.



VayuJAL Technologies Pvt. Ltd.

Ramesh Kumar Soni and Ankit Nagar

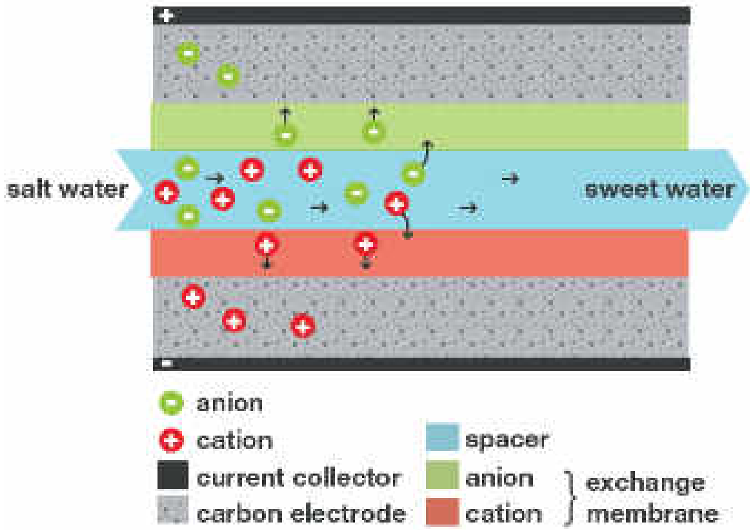
Products in the field

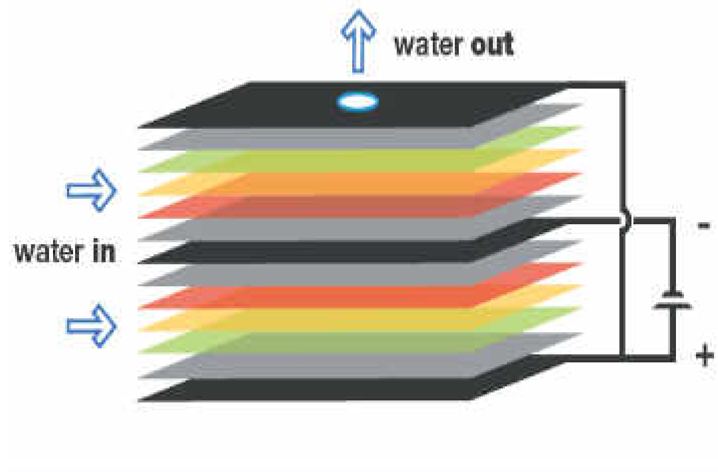
35 LPD 120 LPD 400 LPD 1000 LPD 2000 LPD

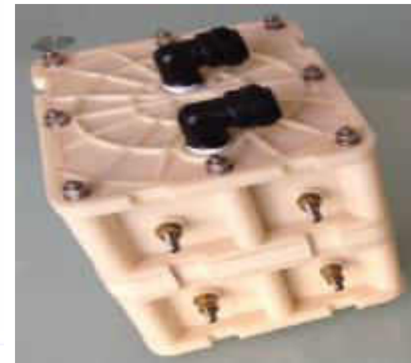
(LPD: Litres per day)

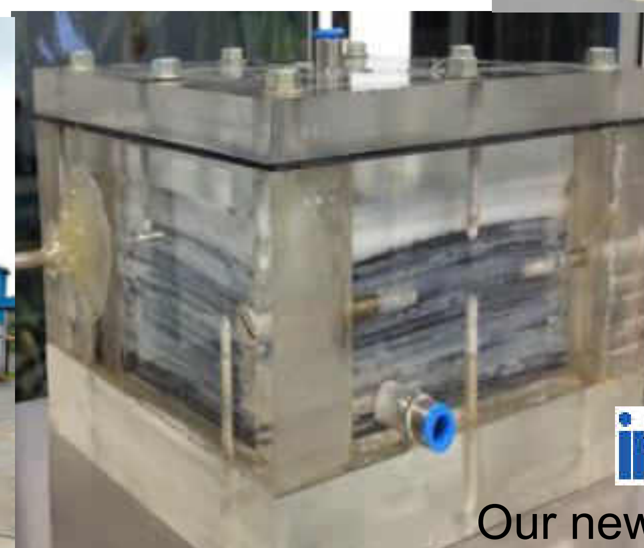
July 2023

Capacitive Desalination (CDI)





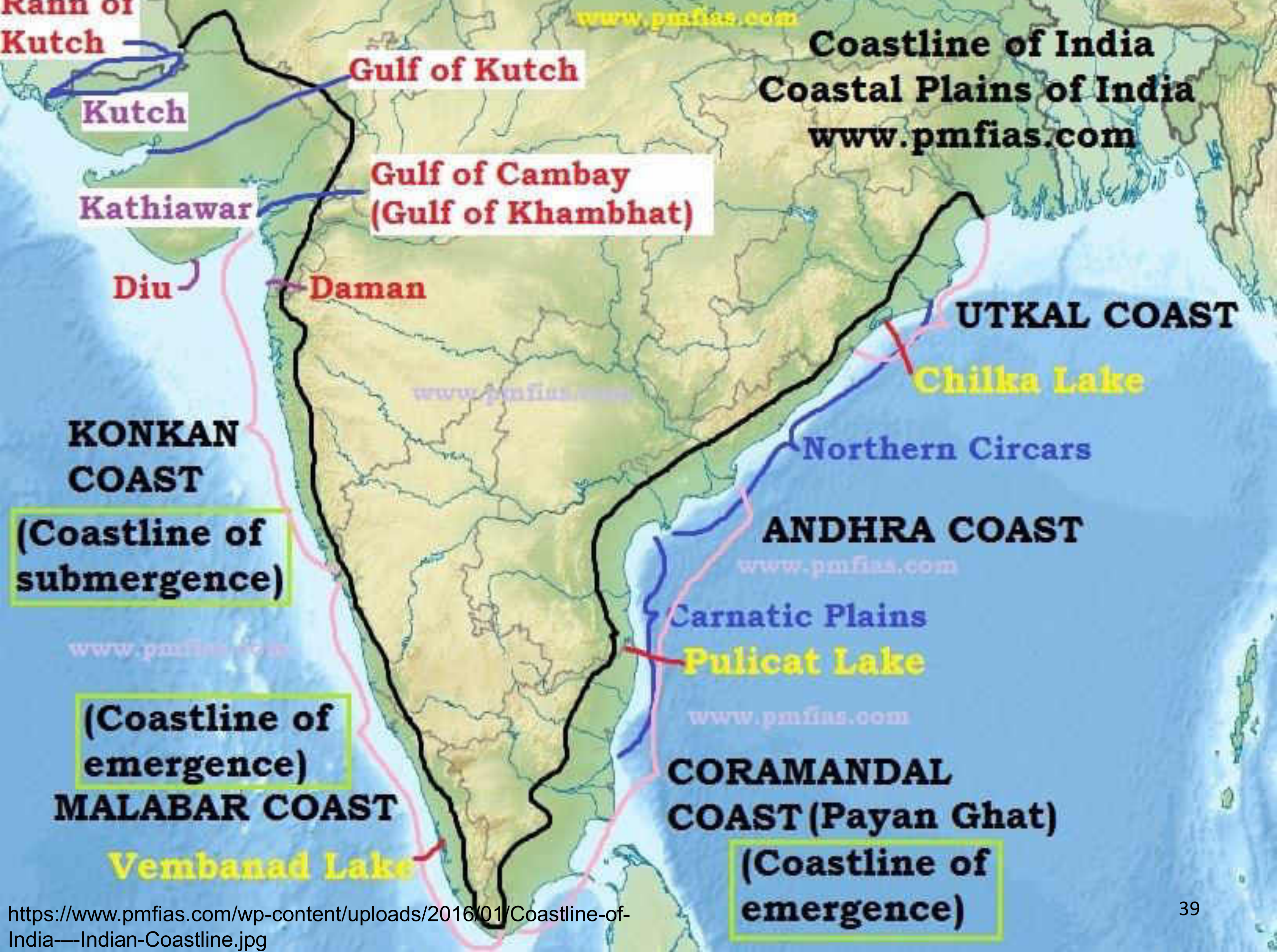




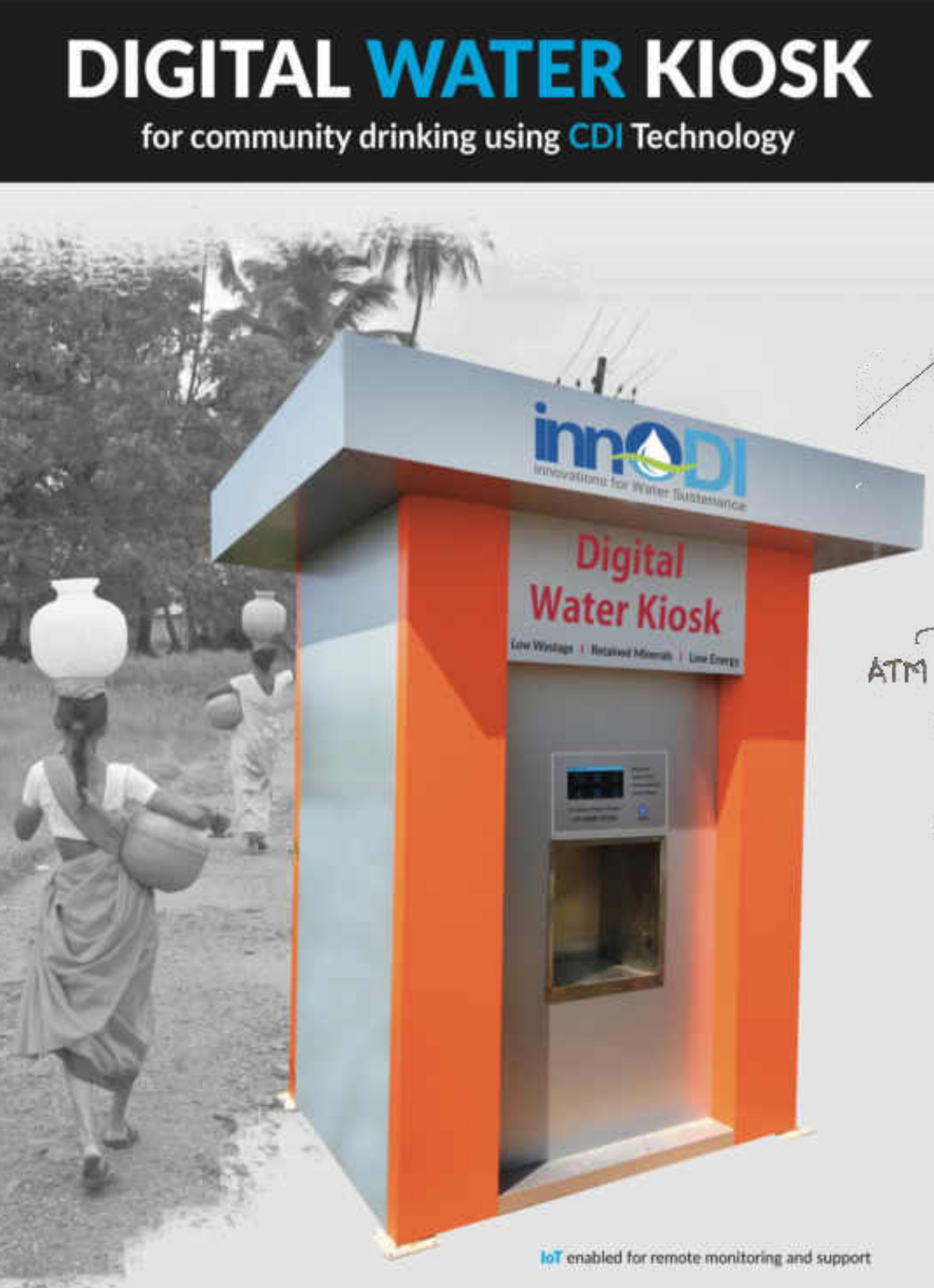
innoDI

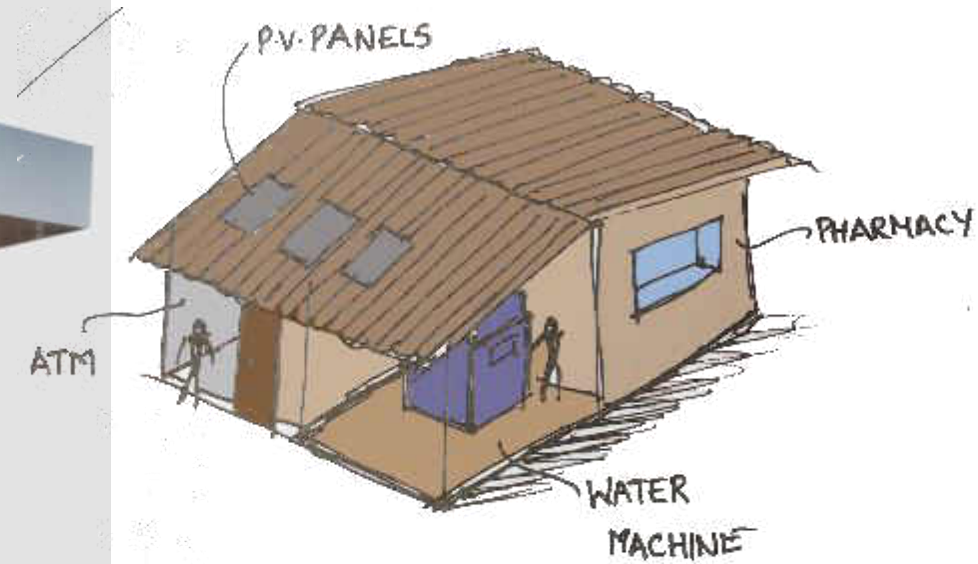
Our new company

Soujit Sengupta, Rabiul Islam and others



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

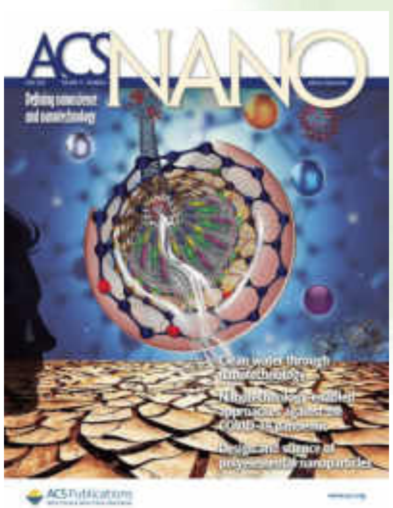


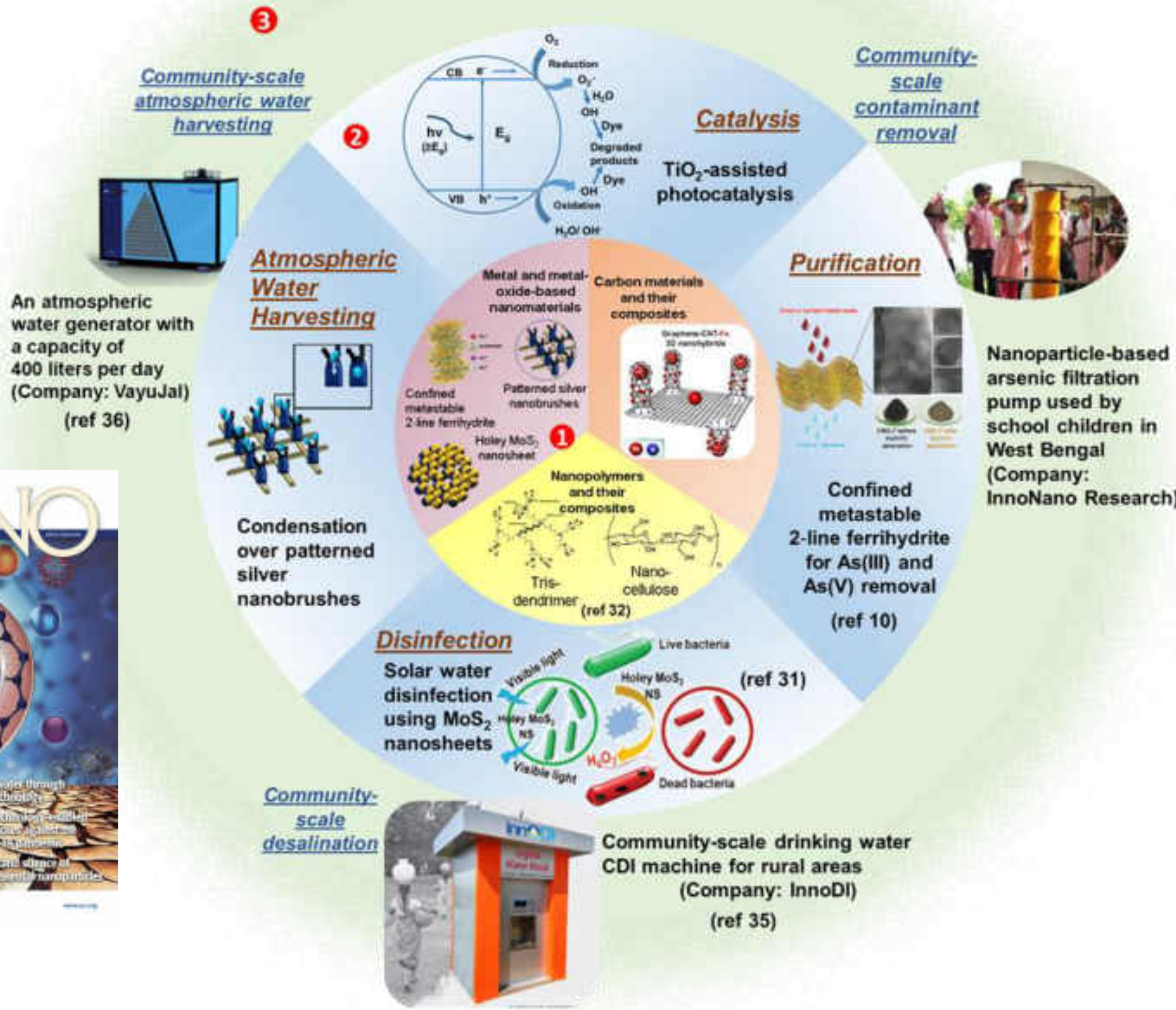


Products under implementation

Vijay Sampath and Tullio Servida

Evolution of materials to products



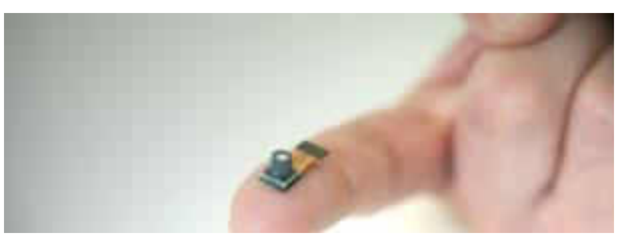


Ankit Nagar and T. Pradeep, *ACS Nano* 14 (2020) 6420-6435.

Sensors and new opportunities

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

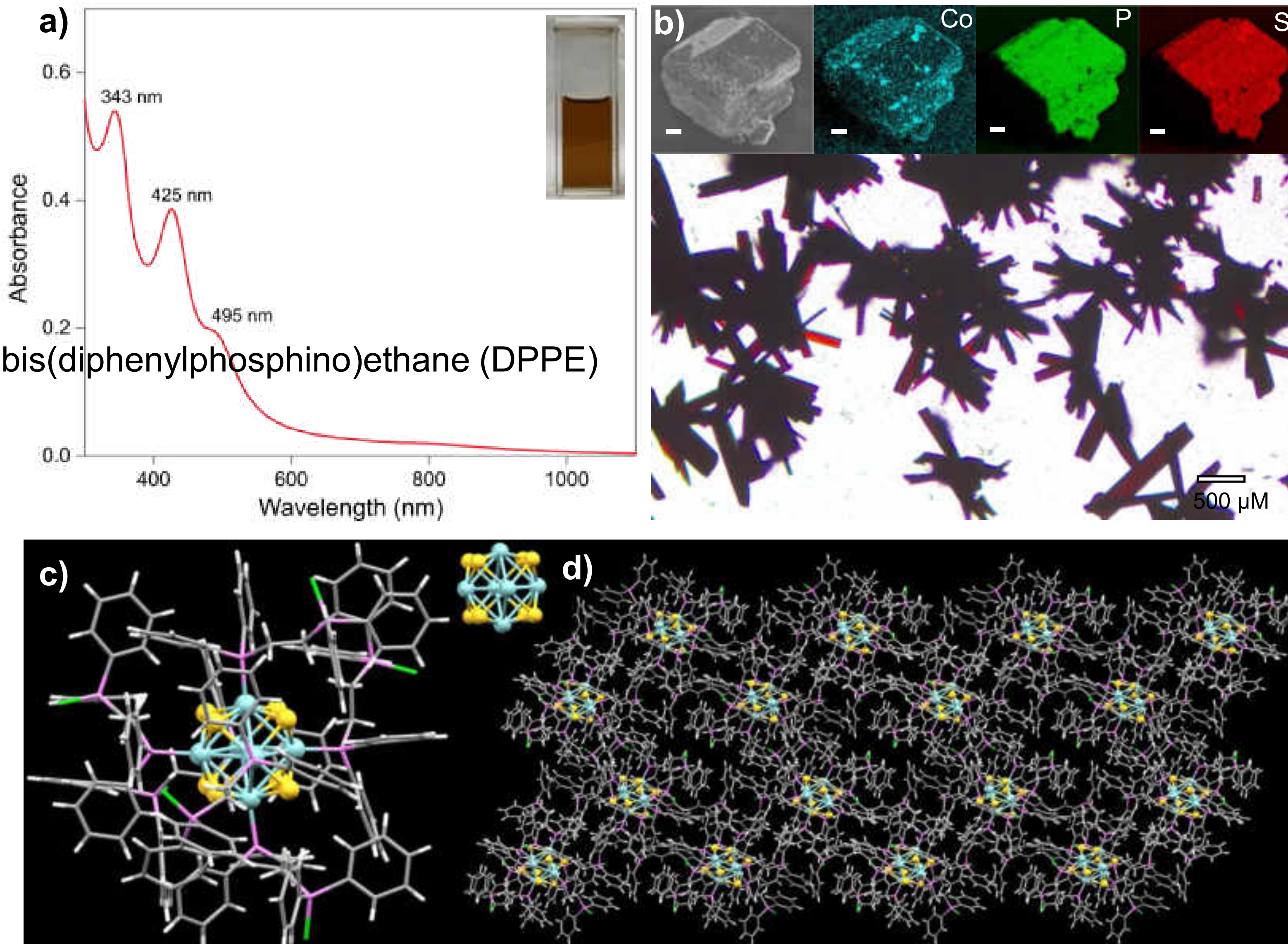
Ultra compact Low Cost Spectral Sensor Module
~ Billions units (? 2027)



Water quality measurement – In the pipeline

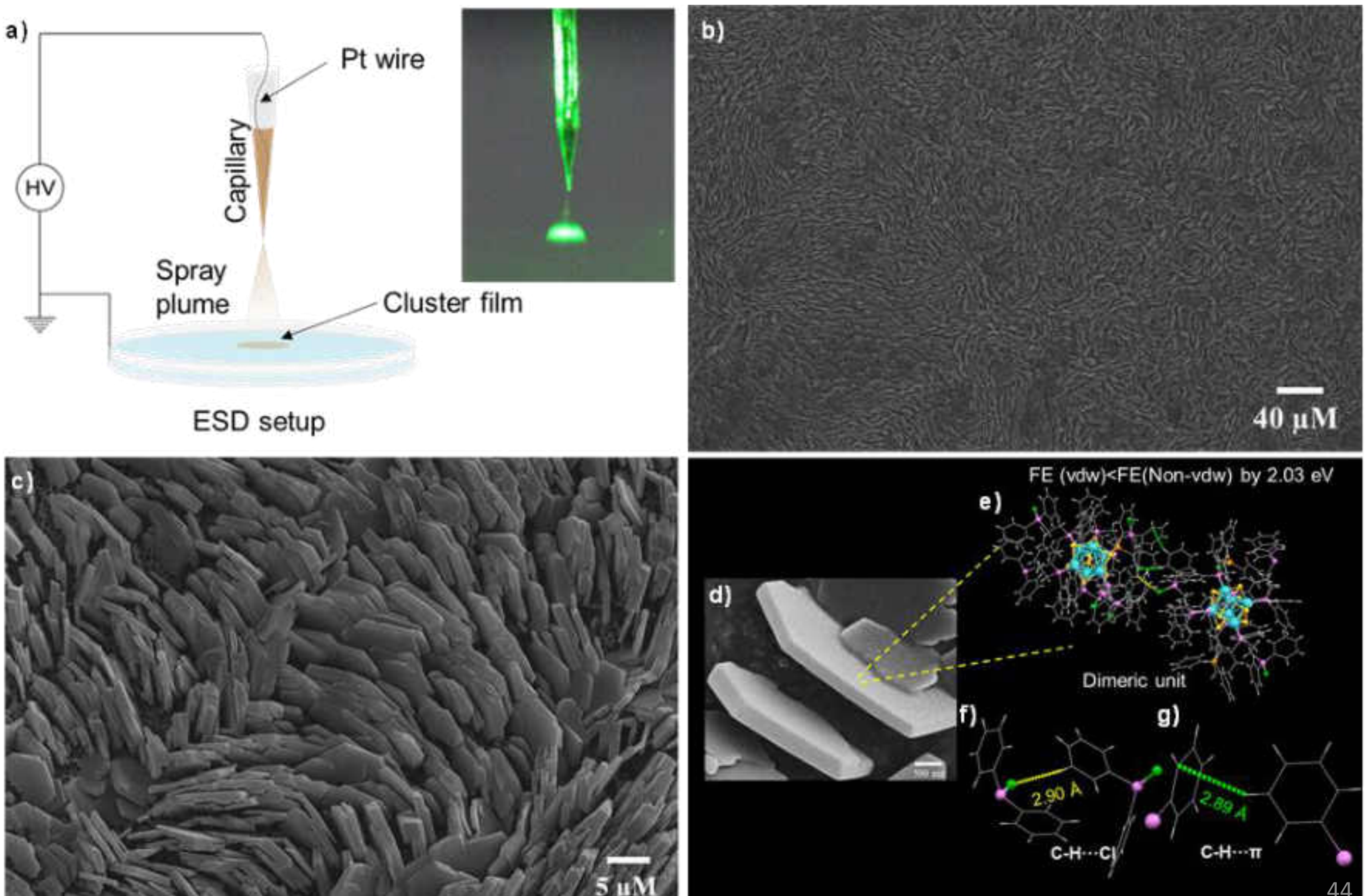
nanoλ

New electrodes - Aligned nanoplates of Co_6S_8

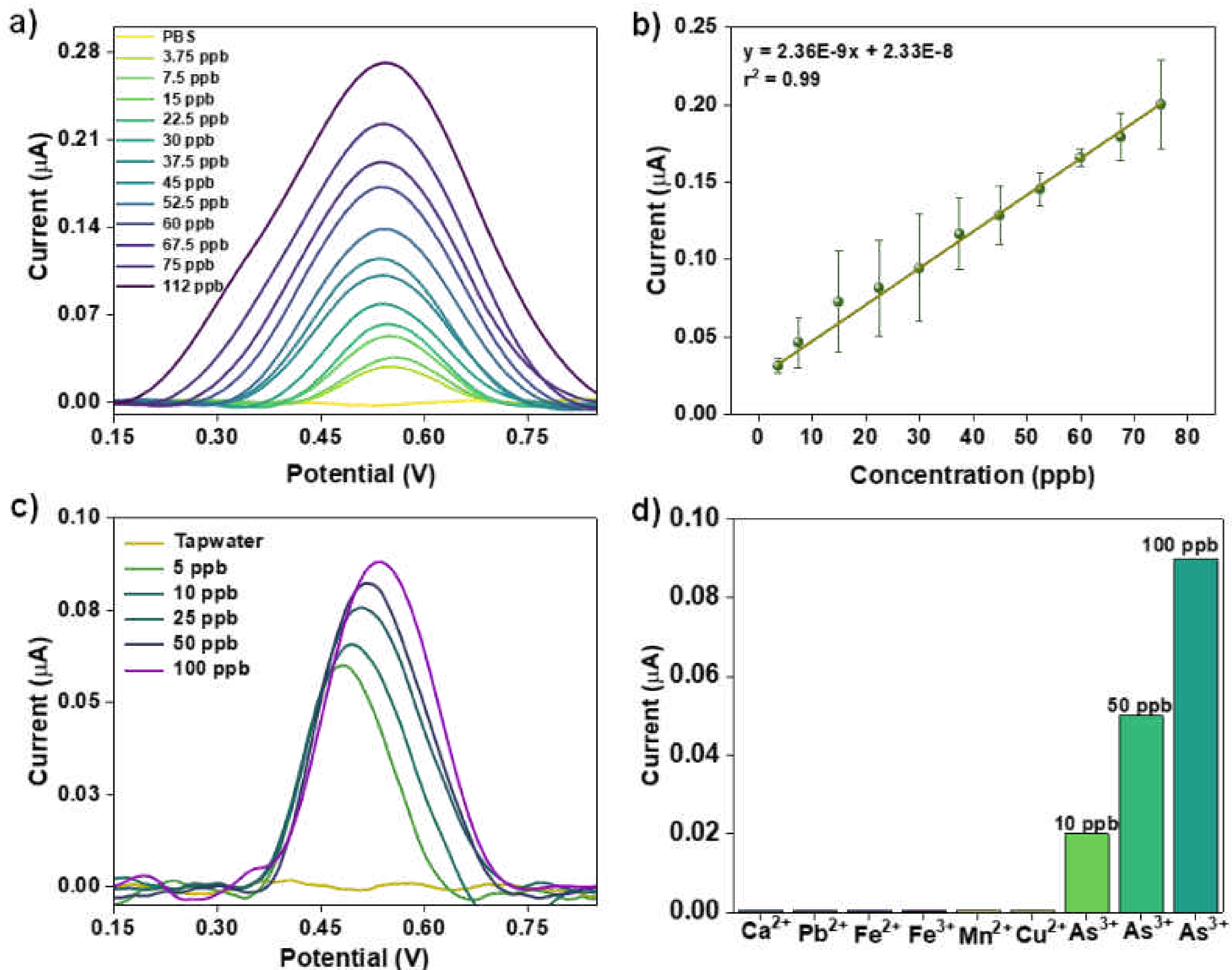


1,2-bis(diphenylphosphino)ethane (DPPE)

Electrospray deposition

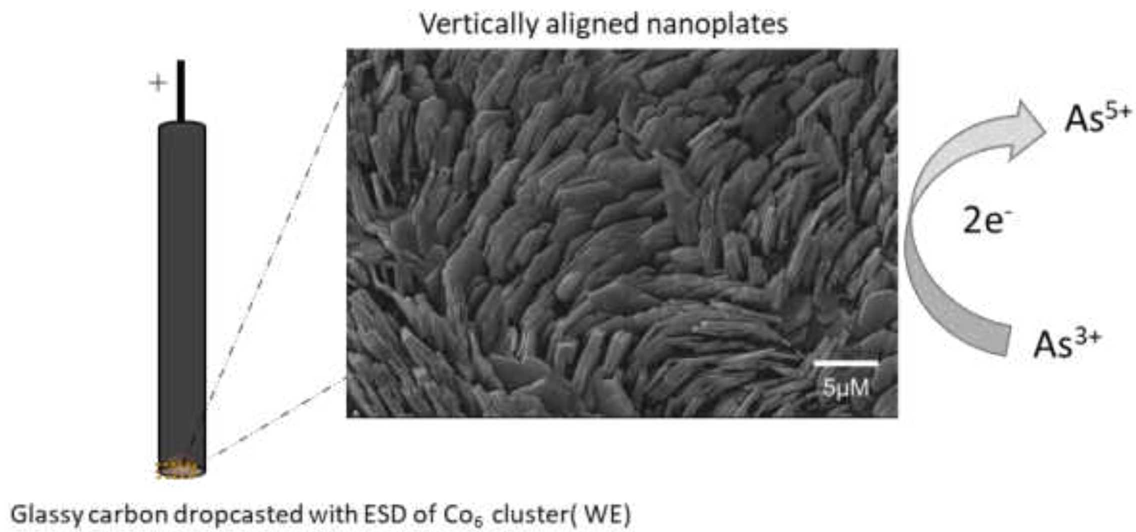


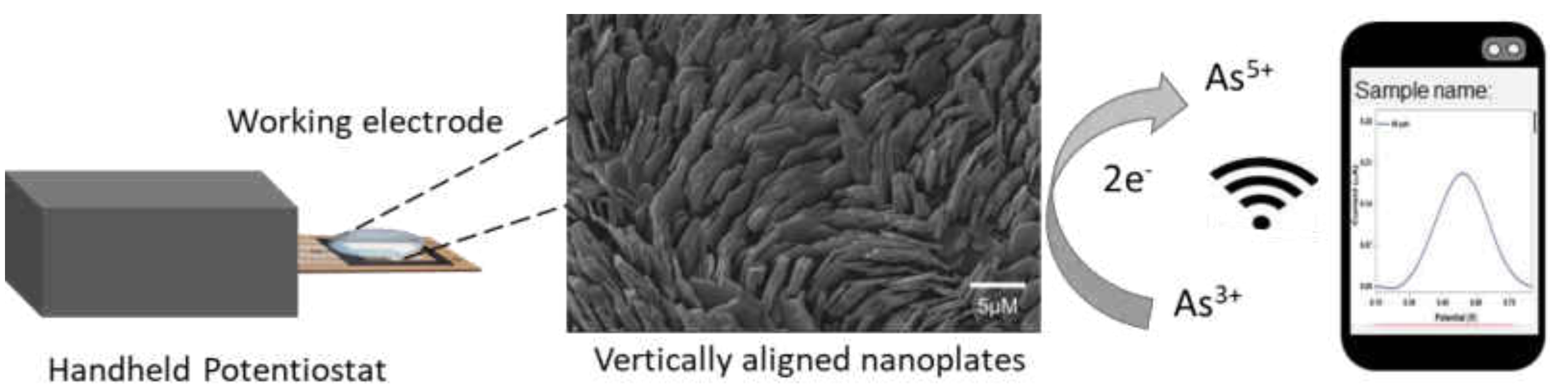
Sensing



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)
0.00
0.07
0.14
0.21
0.28
0.15
0.30
0.45
0.60
0.75
b)
y = 2.36E-9x + 2.33E-8
r² = 0.99
Current (μA)
Concentration (ppb)
0.00
0.05
0.10
0.15
0.20
0.25
0
10
20
30
40
50
60
70
80
c)
Tapwater
5 ppb
10 ppb
25 ppb
50 ppb
100 ppb
Current (μA)
Potential (V)
0.00
0.03
0.05
0.08
0.10
d)
100 ppb
50 ppb
10 ppb
Current (μA)
0.00
0.02
0.04
0.06
0.08
0.10
Ca2+
Pb2+
Fe2+
Fe3+
Mn2+
Cu2+
As3+
As3+
As3+

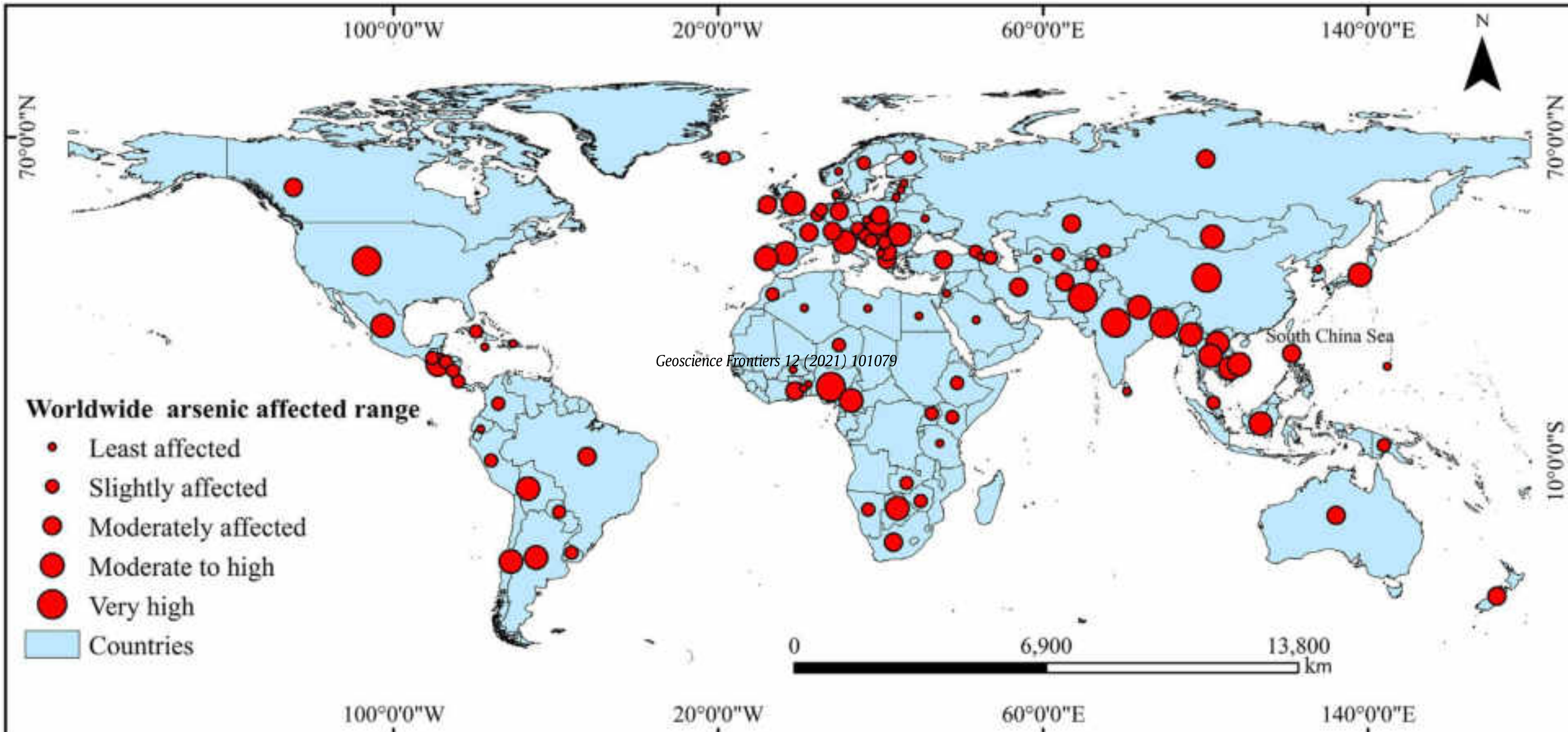
Working electrode





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.

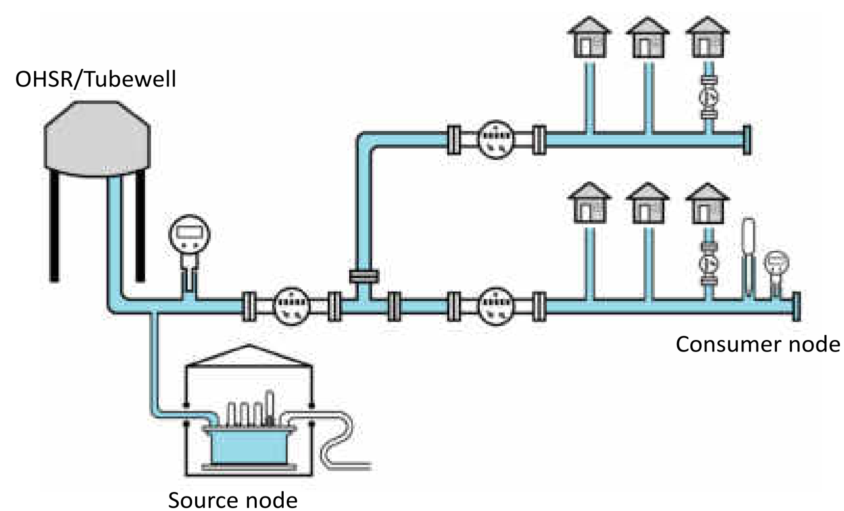
Monitoring in the field

EyeNetAqua Solutions Pvt. Ltd.
An ICCW incubated company

Eye of internet on quality, quantity and compliance for all

EyeNetAqua Solutions Private Limited

Installation model as per NJJM specifications



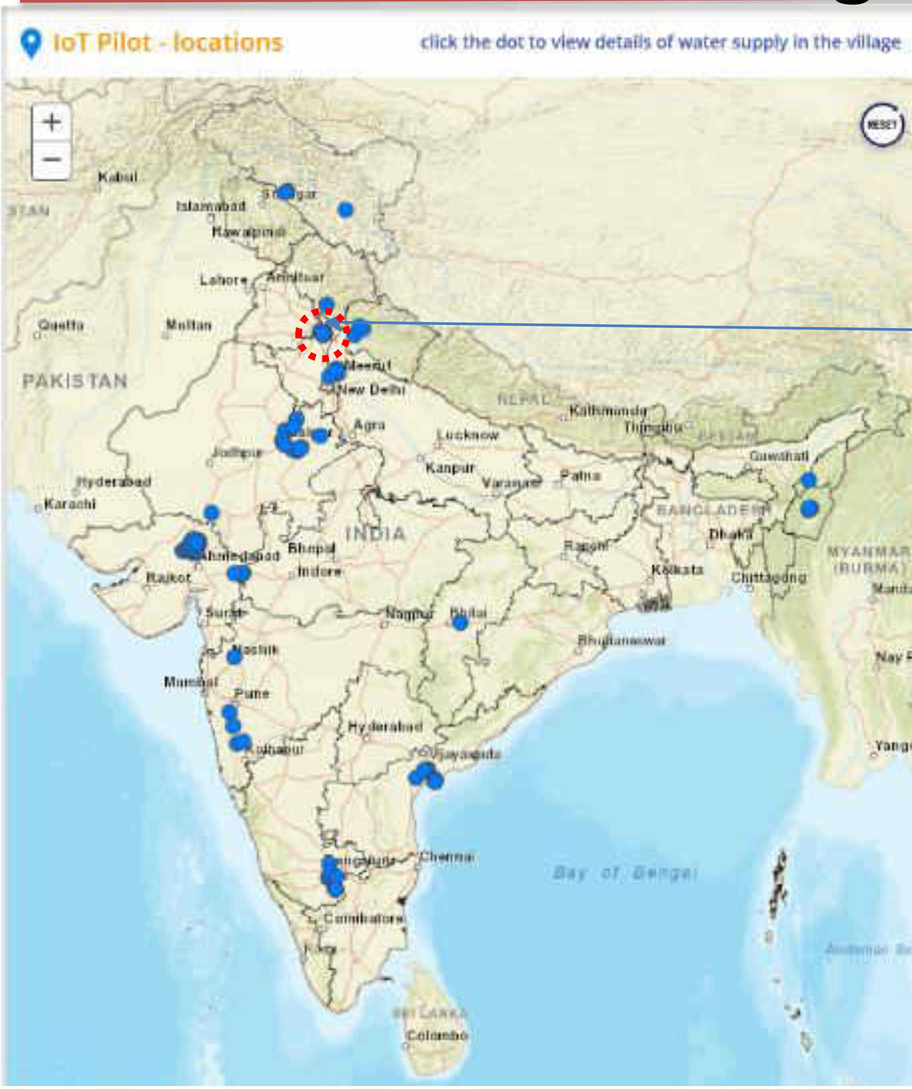
Tubewell/OHSR (Source node):

1. Flow meter (80-150mm) x 1
2. Pressure sensor x 1
3. pH sensor x 1
4. TDS sensor x 1
5. Residual Chlorine sensor x 1
6. In-house MVP of Free Residual Chlorine sensor x 1

Consumer tap (End tail node):

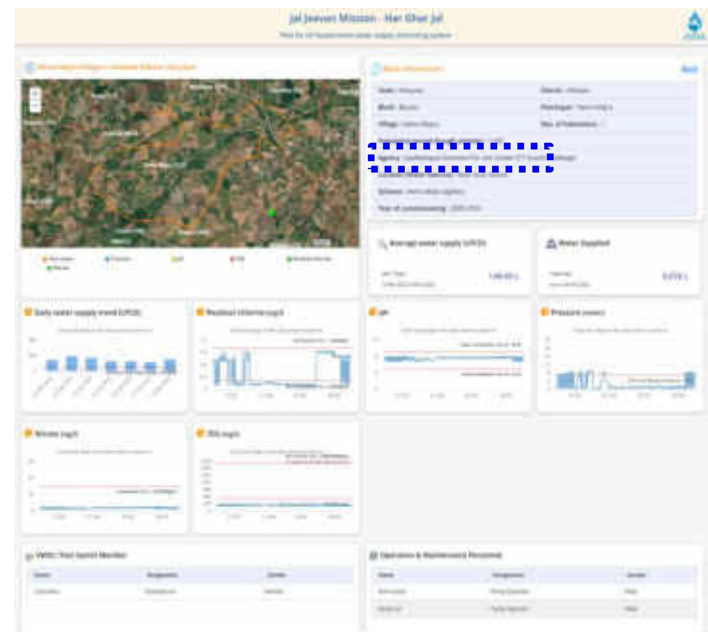
1. Flow meter (15-20mm) x 1
2. Pressure sensor x 1
3. Residual Chlorine sensor x 1
4. In-house MVP of Free Residual Chlorine sensor x 1

India's water is being monitored



IITM/IISc

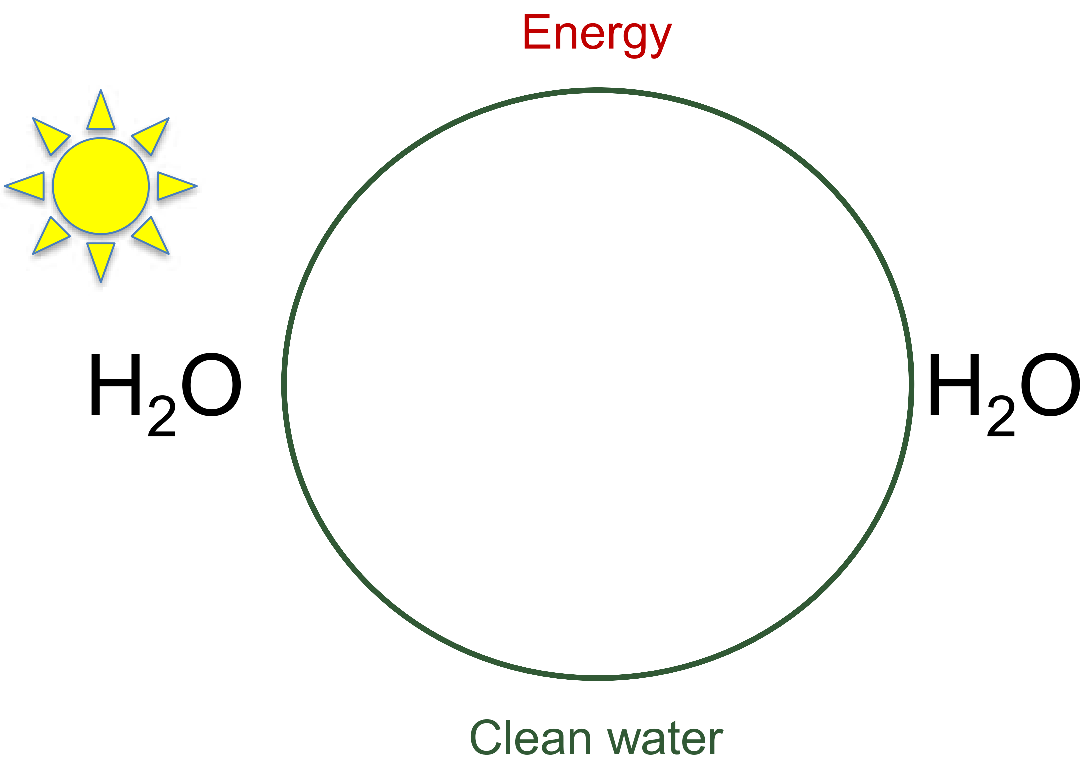
Installations made by four companies

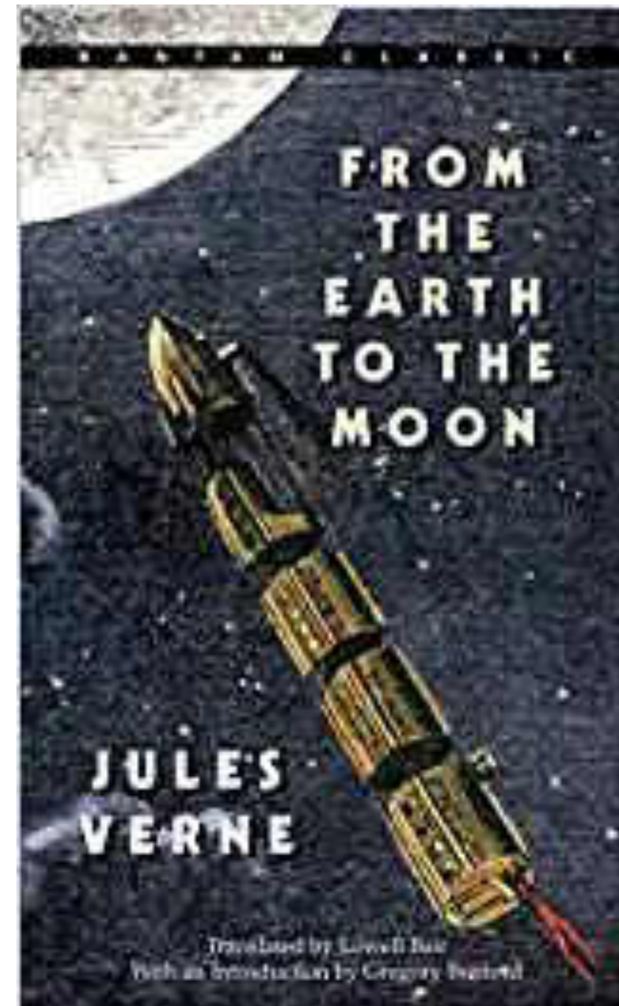



Policy

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

Our dreams become reality with materials



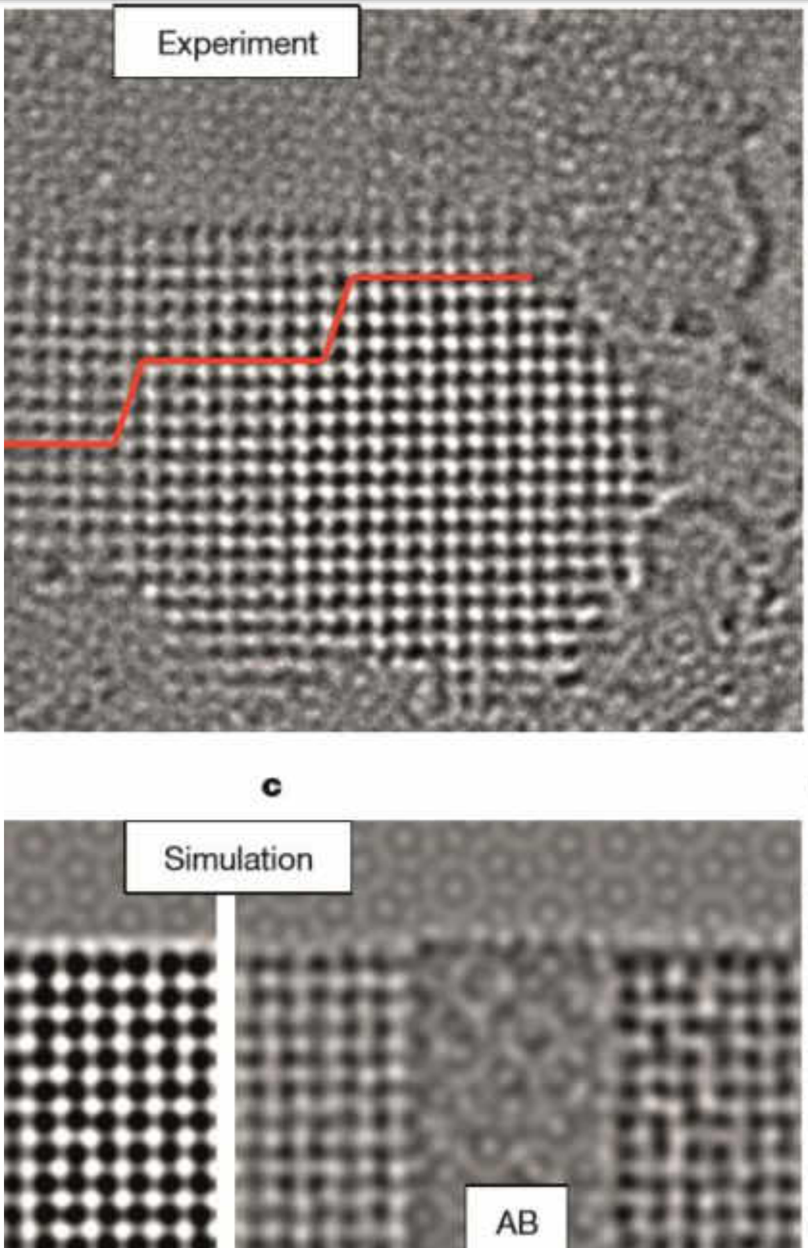


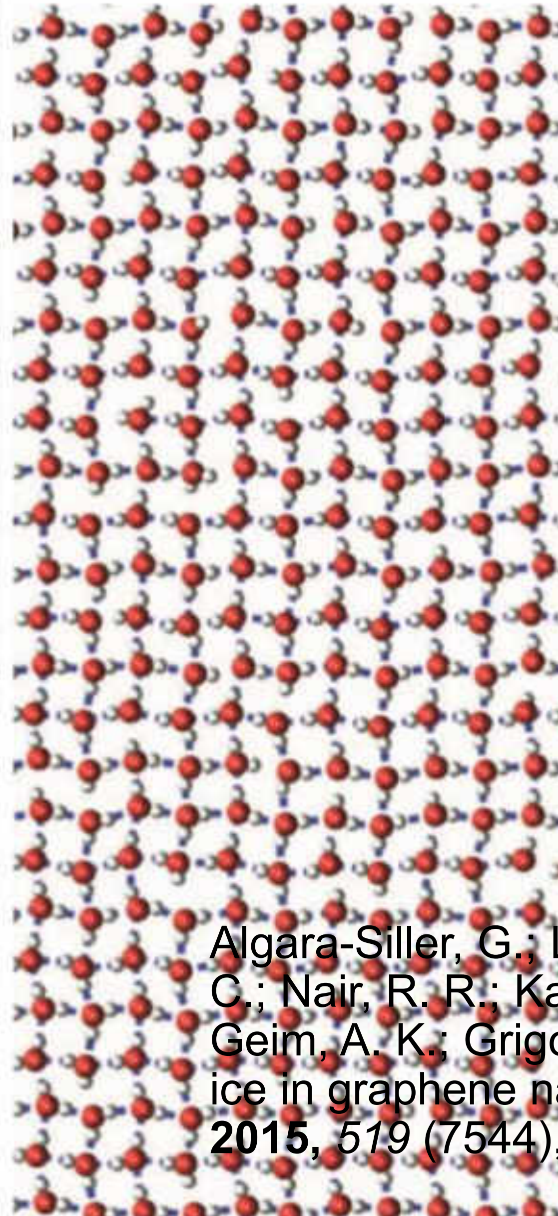
Affordable, inclusive, sustainable and contextual excellence

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.

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



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Nonappa

Tomas Base

Manfred Kappes

Olli Ikkala

Horst Hahn

Tatsuya Tsukuda
Keisaku Kimura
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Funding: Department of Science and Technology, Government of India

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

Indian Institute of Technology Madras

Bhaskar Ramamurthi/V. Kamakoti

Associate Editor

ACS Sustainable Chemistry & Engineering

Pradeep Research Group

Thematic Unit of Excellence

Manswita Mandal for help with the slides