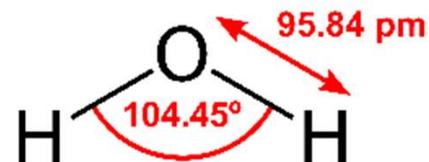




Since 1959



Affordable clean water using advanced materials

T. Pradeep

Institute Professor, IIT Madras

pradeep@iitm.ac.in

<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

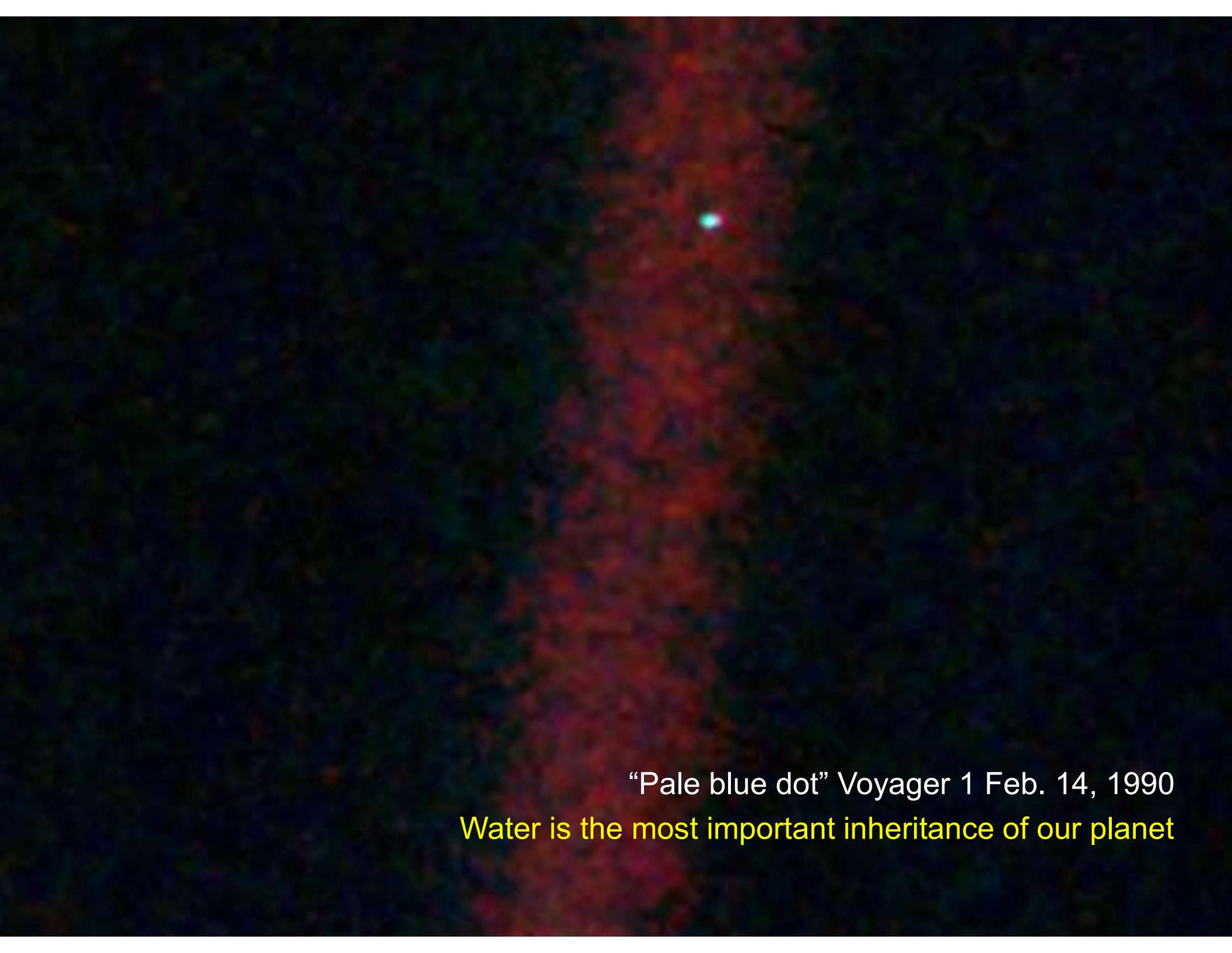


Associate Editor

ACS
Sustainable
Chemistry & Engineering



Water for Life, IIT Madras, Chennai, December 15-17, 2022



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

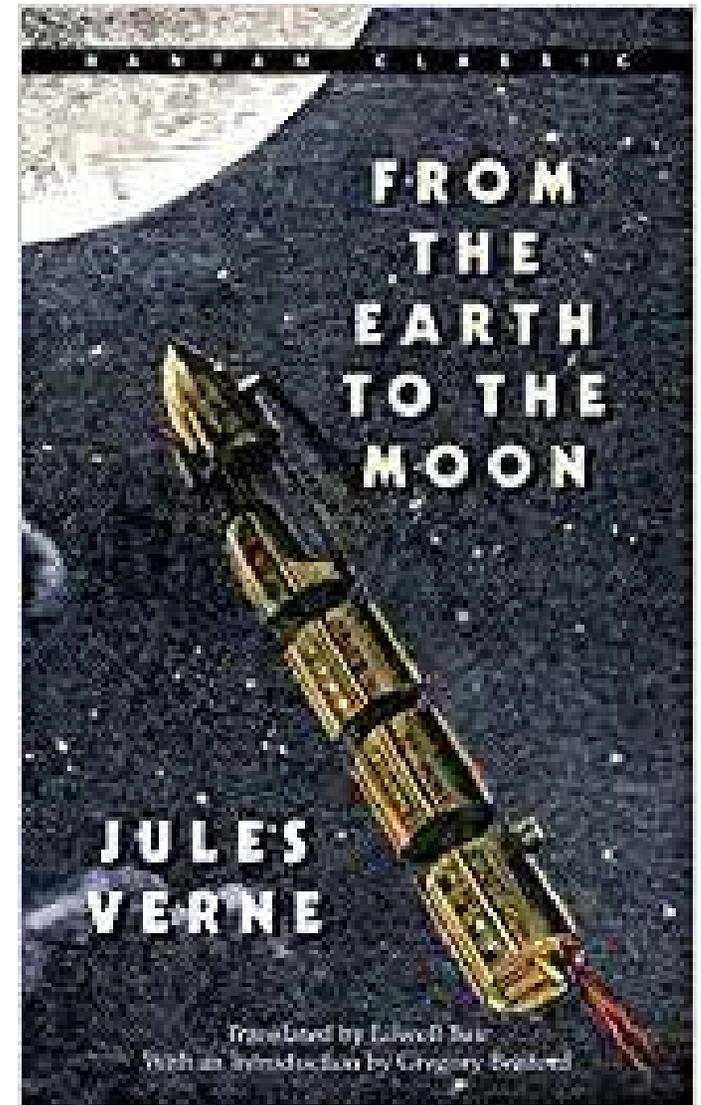
Water is the most important inheritance of our planet

Water is at the centre of action



There is water in everything we do.

Our dreams become reality with materials



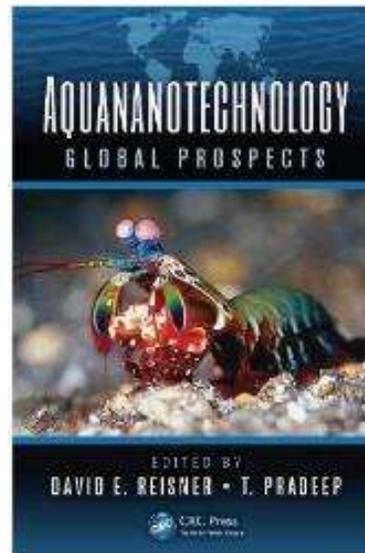
Water purification, history

Important milestones in the history of water purification (1800–2007) from the perspective of noble metal nanoparticles in water treatment (compiled from multiple sources on the World Wide Web).

Year	Milestone
1804	Setup of world's first city-wide municipal water treatment plant (Scotland, sand-filter technology)
1810	Discovery of chlorine as a disinfectant (H. Davy)
1852	Formulation of Metropolis Water Act (England)
1879	Formulation of Germ Theory (L. Pasteur)
1902	Use of chlorine as a disinfectant in drinking water supply (calcium hypochlorite, Belgium)
1906	Use of ozone as a disinfectant (France)
1908	Use of chlorine as a disinfectant in municipal supply, New Jersey
1914	Federal regulation of drinking water quality (USPHS)
1916	Use of UV treatment in municipal supplies
1935	Discovery of synthetic ion exchange resin (B. A. Adams, E. L. Holmes)
1948	Nobel Prize to Paul Hermann Muller (insecticidal properties of DDT)
1959	Discovery of synthetic reverse osmosis membrane (S. Yuster, S. Loeb, S. Sourirajan)
1962	<i>Silent Spring</i> published, first report on harmful effects of DDT (R. Carson)
1965	World's first commercial RO plant launched
1974	Reports on carcinogenic by-products of disinfection with chlorine Formulation of Safe Drinking Water Act (USEPA)
1975	Development of carbon block for drinking water purification
1994	Report on use of zerovalent iron for degradation of halogenated organics (R. W. Gillham, S. F. O'Hannesin)
1997	Report on use of zerovalent iron nanoparticles for degradation of halogenated organics (C-B. Wang, W.-X. Zhang)
1998	Drinking Water Directive applied in EU
2000	Adoption of Millennium Declaration during the UN Millennium Summit (UN Millennium Development Goals)
2003	Report on use of noble metal nanoparticles for the degradation of pesticides (A.S. Nair, R. T. Tom, T. Pradeep)
2004	Stockholm Convention, banning the use of persistent organic pollutants
2007	Launch of noble metal nanoparticle-based domestic water purifier (T. Pradeep, A. S. Nair, Eureka Forbes Limited)

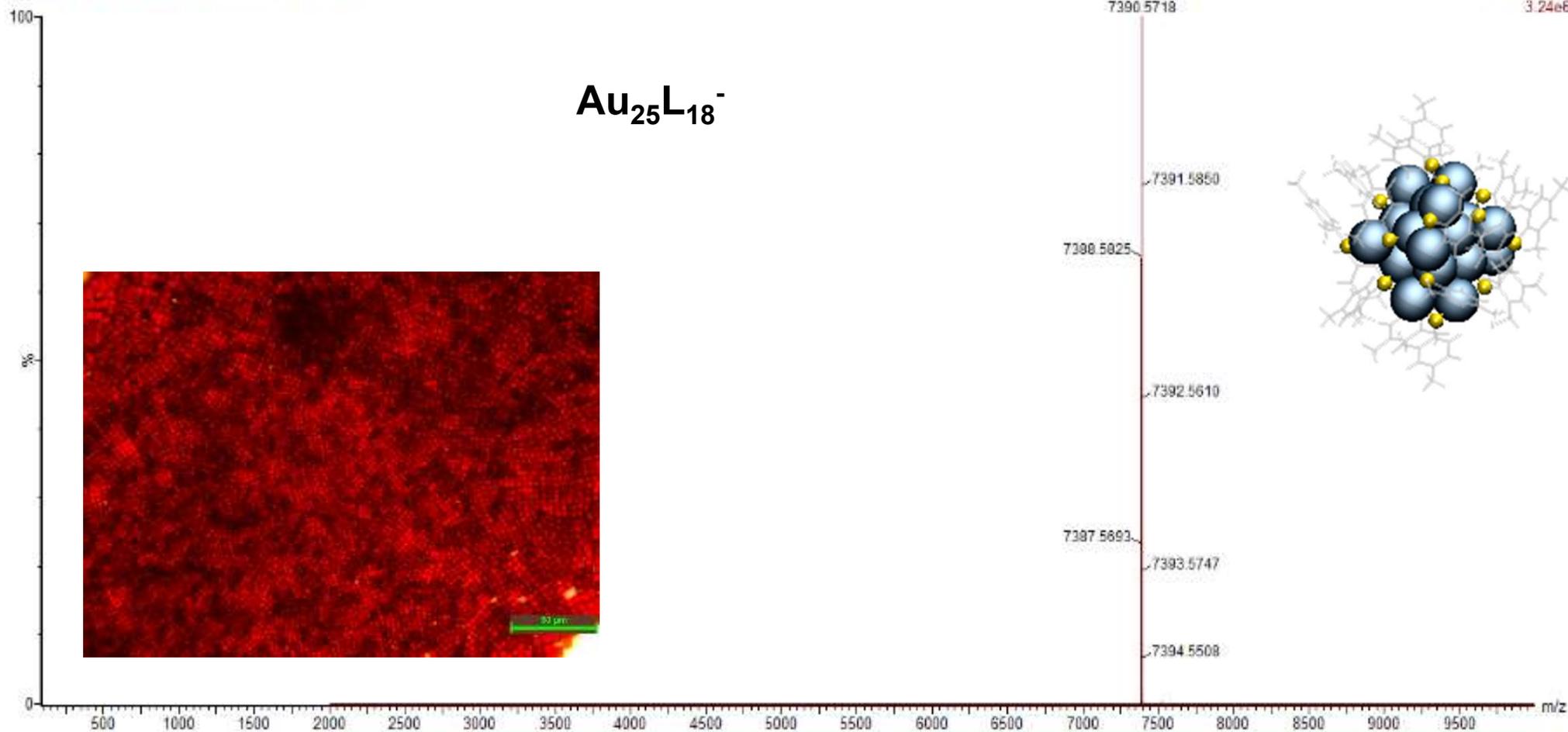
Affordable clean water is a problem of advanced materials

- New adsorbents
- New sensors
- New catalysts
- Novel phenomena
- New devices



Nanomaterials are now atomically precise

AU25PET16_RES_NEG_MS_3.32 (0.658) Cm (5:00)



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

Clean water for everyone



ACS Sustainable Chemistry & Engineering Editorial,
December 2016

Water positive materials

PNAS PNAS PNAS

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

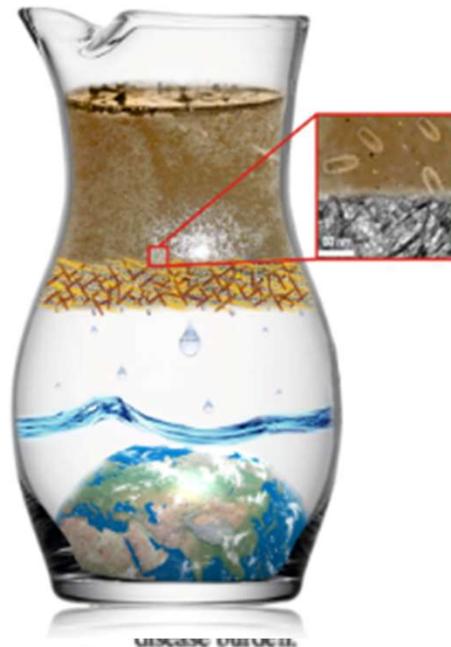
Mohan Udhaya Sankar¹, Sahaja Aigal¹, Shihabudheen M. Maliyekkal¹, Amrita Chaudhary, Anshup, Avula Anil Kumar, Kamalesh Chaudhari, and Thalappil Pradeep²

Unit of Nanoscience and Thematic Unit of Excellence

Edited by Eric Hoek, University of California, Los Angeles

Creation of affordable materials for constant clean drinking water is one of the most promising ways to provide drinking water for all. Combining the capabilities of nanocomposites to scavenge toxic species such as heavy metals and other contaminants along with the above capabilities, we demonstrate an affordable, all-inclusive drinking water purification system without electricity. The critical problem in the synthesis of stable materials that can release active species continuously in the presence of complex species in drinking water that deposit and cause scaling on surfaces. Here we show that such constant release can be synthesized in a simple and effective fashion without the use of electrical power. The nanocomposites exhibit sand-like properties, such as higher shear strength and stability. These materials have been used to develop a point-of-use water purifier to deliver clean drinking water continuously. The ability to prepare nanostructured composites at ambient temperature has wide relevance for water purification.

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



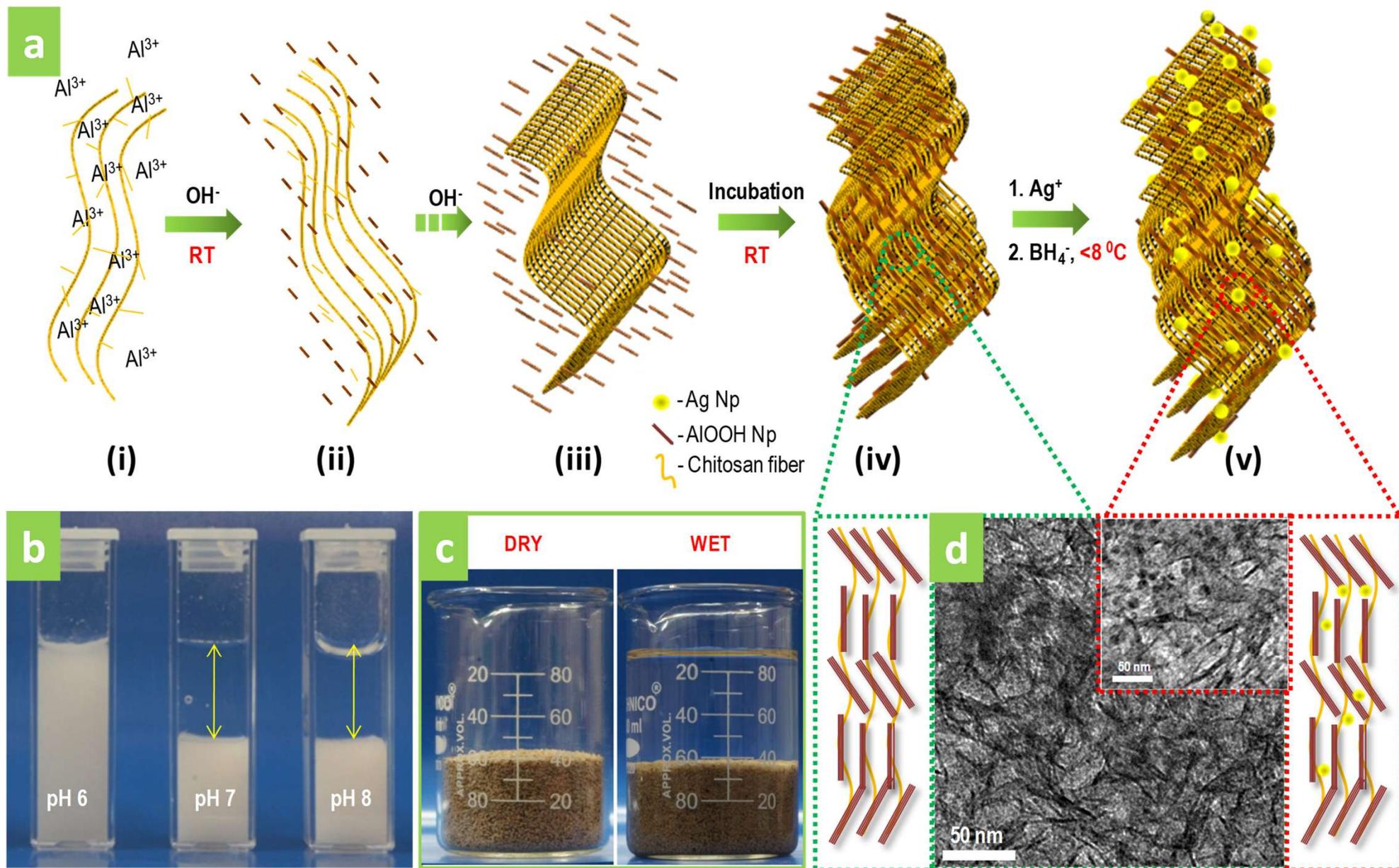
Indian Institute of Technology, Chennai 600 036, India

Received for review November 21, 2012

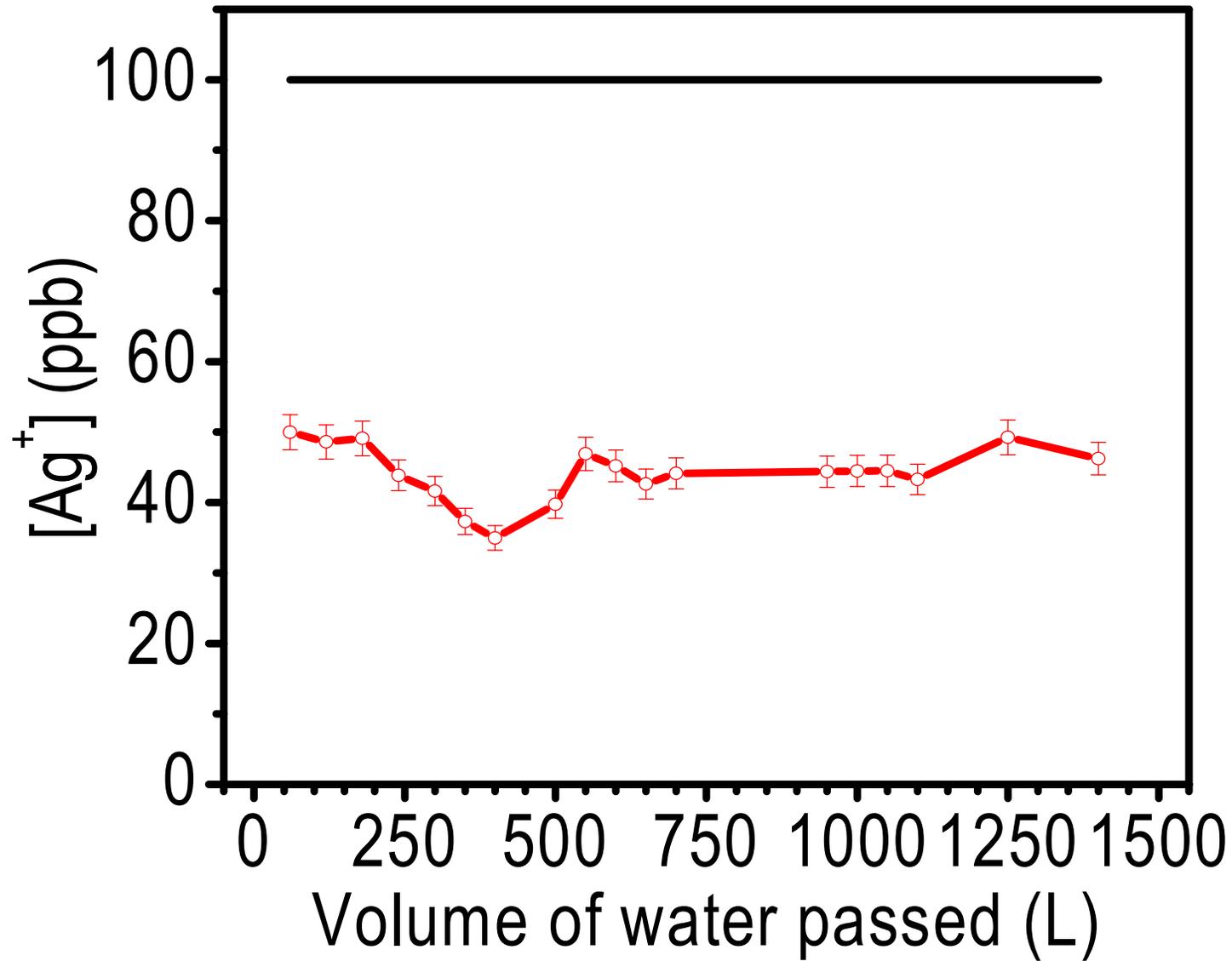
...ble; and (c) continued retention of active species is difficult. This work introduces a unique family of nanocrystalline nanocomposite materials prepared through an aqueous route. The stability of the material is attributed to abundant -OH groups and chitosan, which help in the crystallization and also ensure strong covalent crosslinking to the matrix. X-ray photoelectron spectroscopy confirms that the composition is rich in silver. Using hyperspectral imaging, the release of silver in the water was confirmed. The silver ions activate the silver nanoparticle antimicrobial activity in drinking water. These materials have been developed that can be used for water purification. We demonstrate an affordable and sustainable system based on such composites undergoing field trials in India, as well as the eradication of the waterborne

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

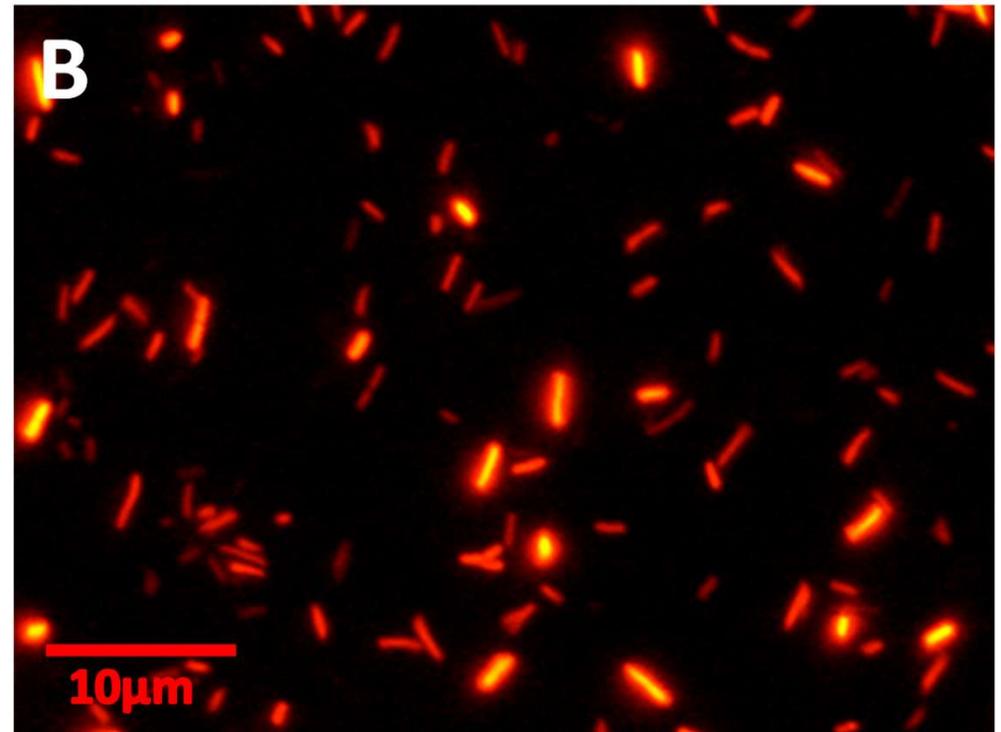
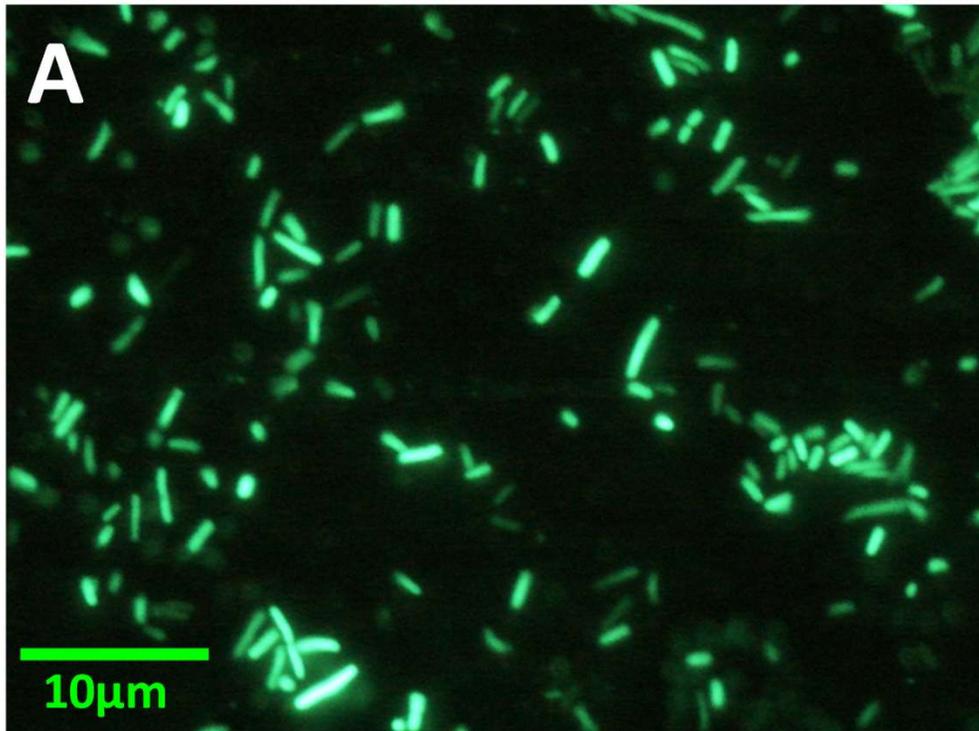
How to make?



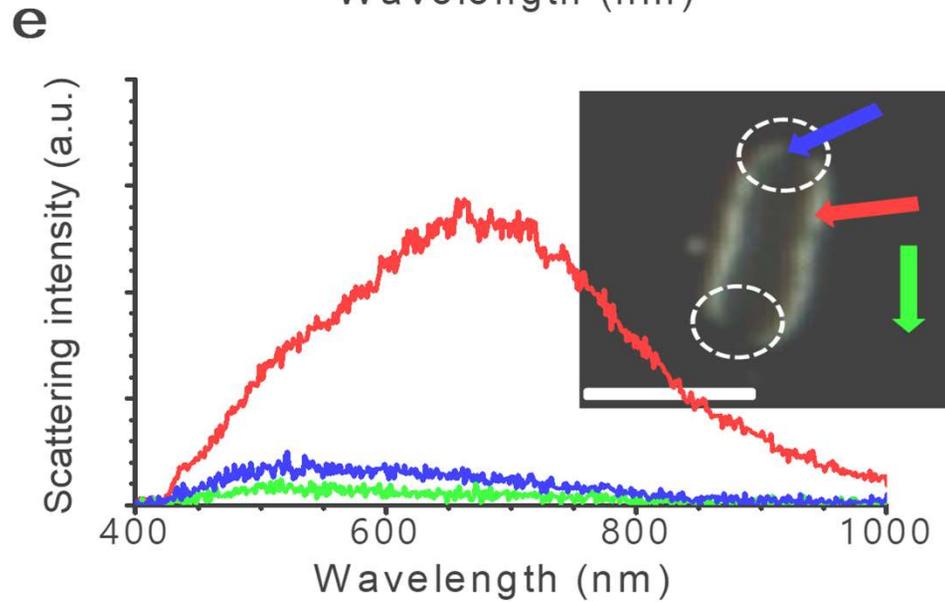
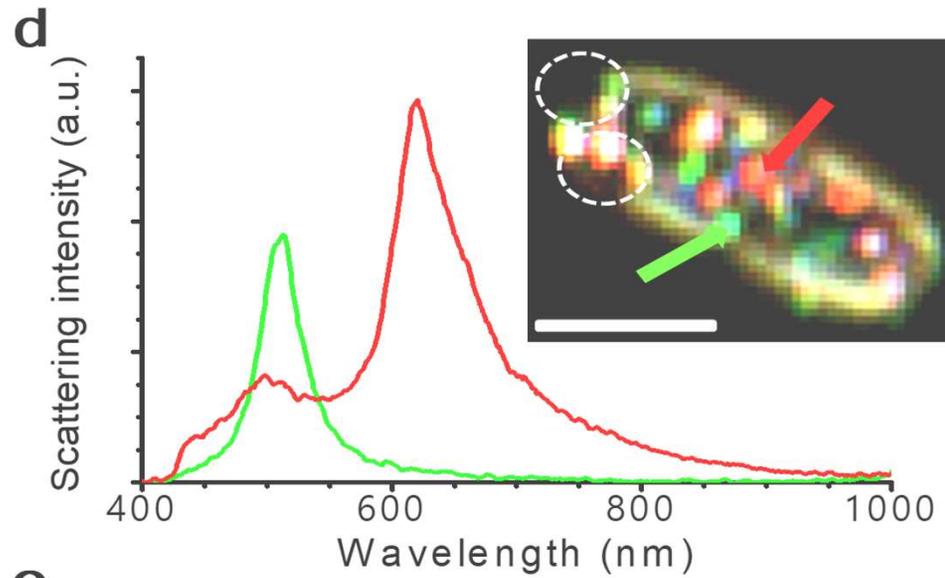
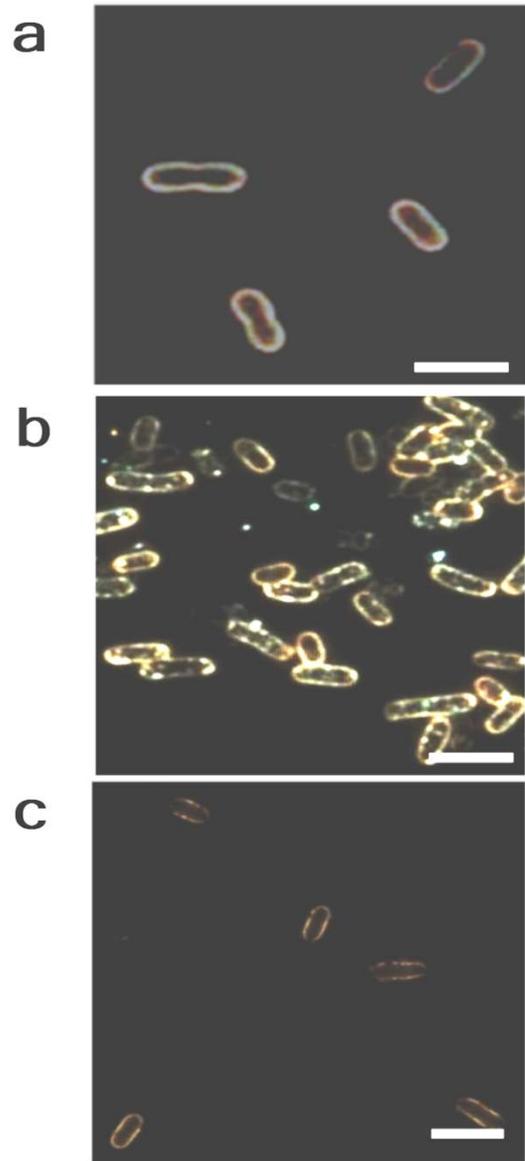
What is special?



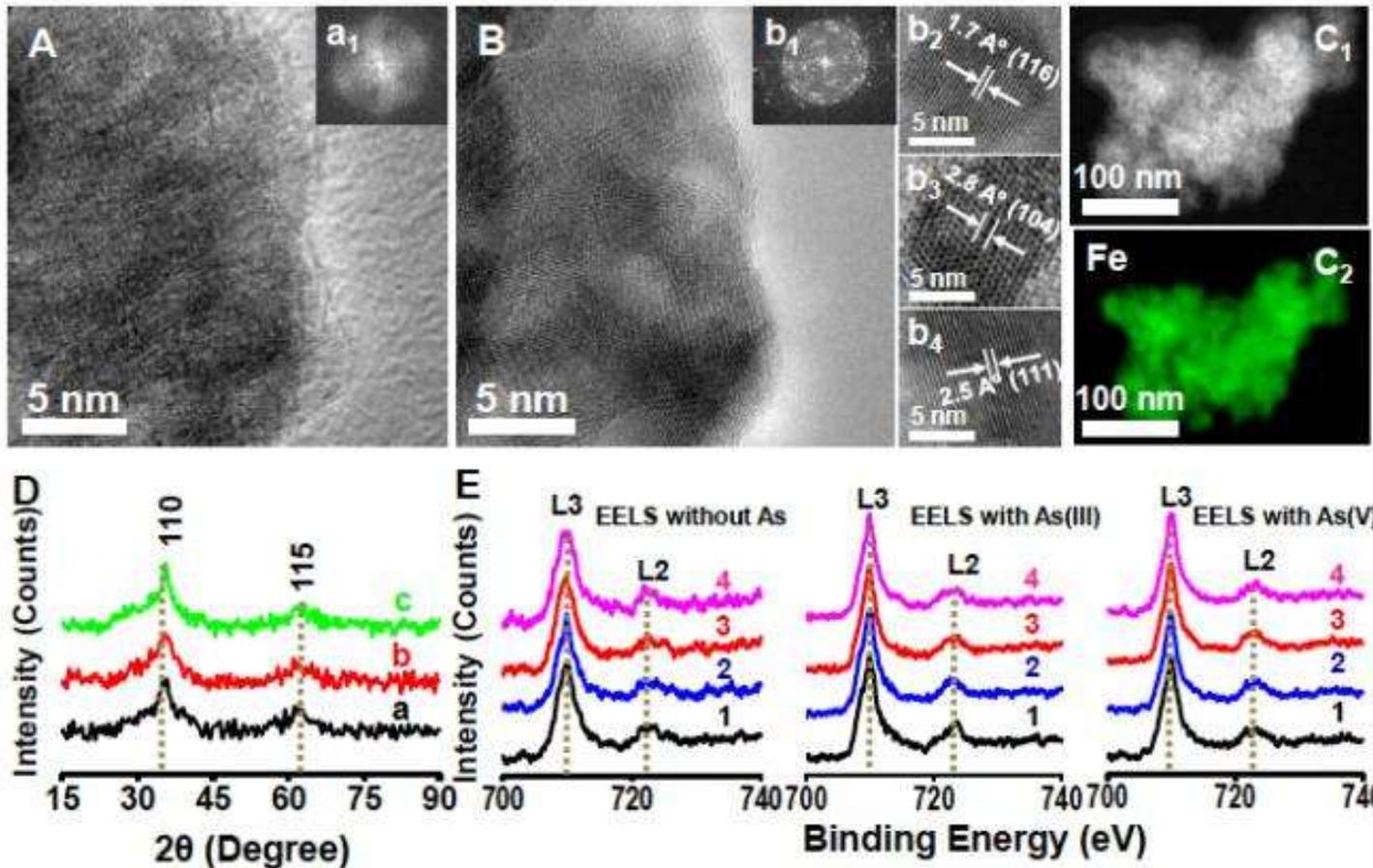
Live/dead staining experiments



No nanotoxicity



Variety of materials



www.advmat.de

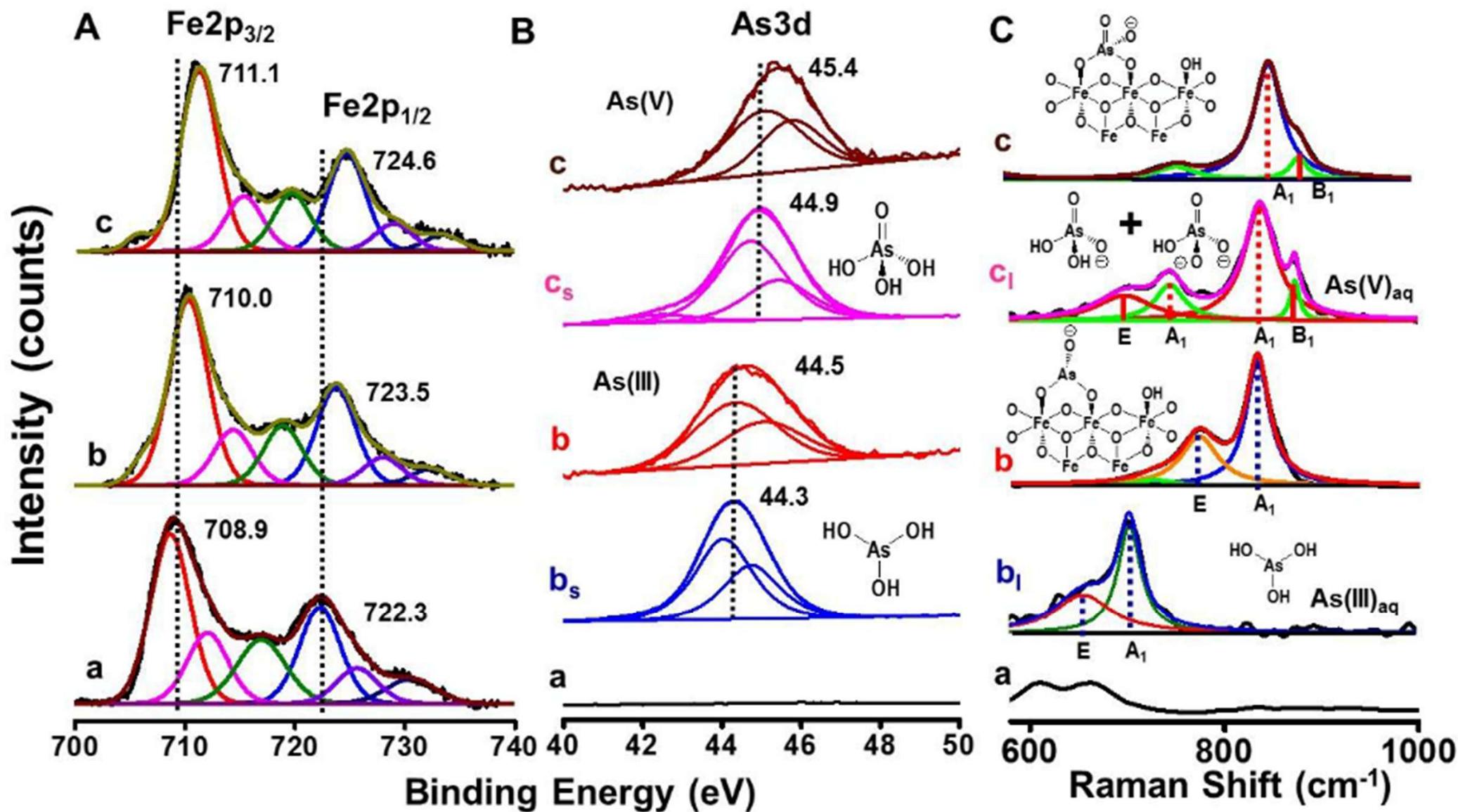
Author Pr **ADVANCED MATERIALS**

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

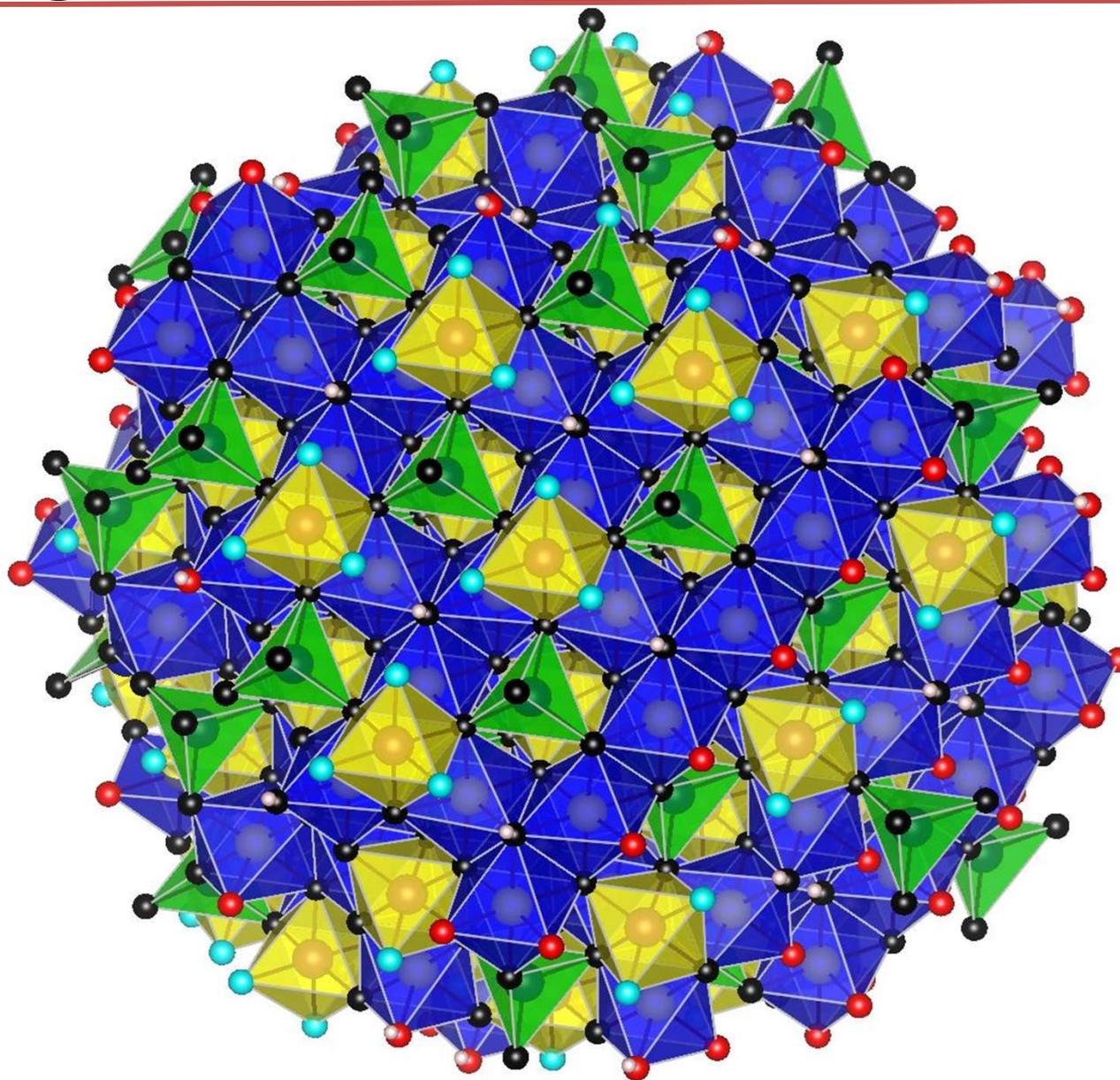
By Avula Anil Kumar, Anirban Som, Paolo Longo, Chennu Sudhakar, Radha Gobinda Bhuin, Soujit Sen Gupta, Anshup, Mohan Udhaya Sankar, Amrita Chaudhary, Ramesh Kumar, and T. Pradeep*

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

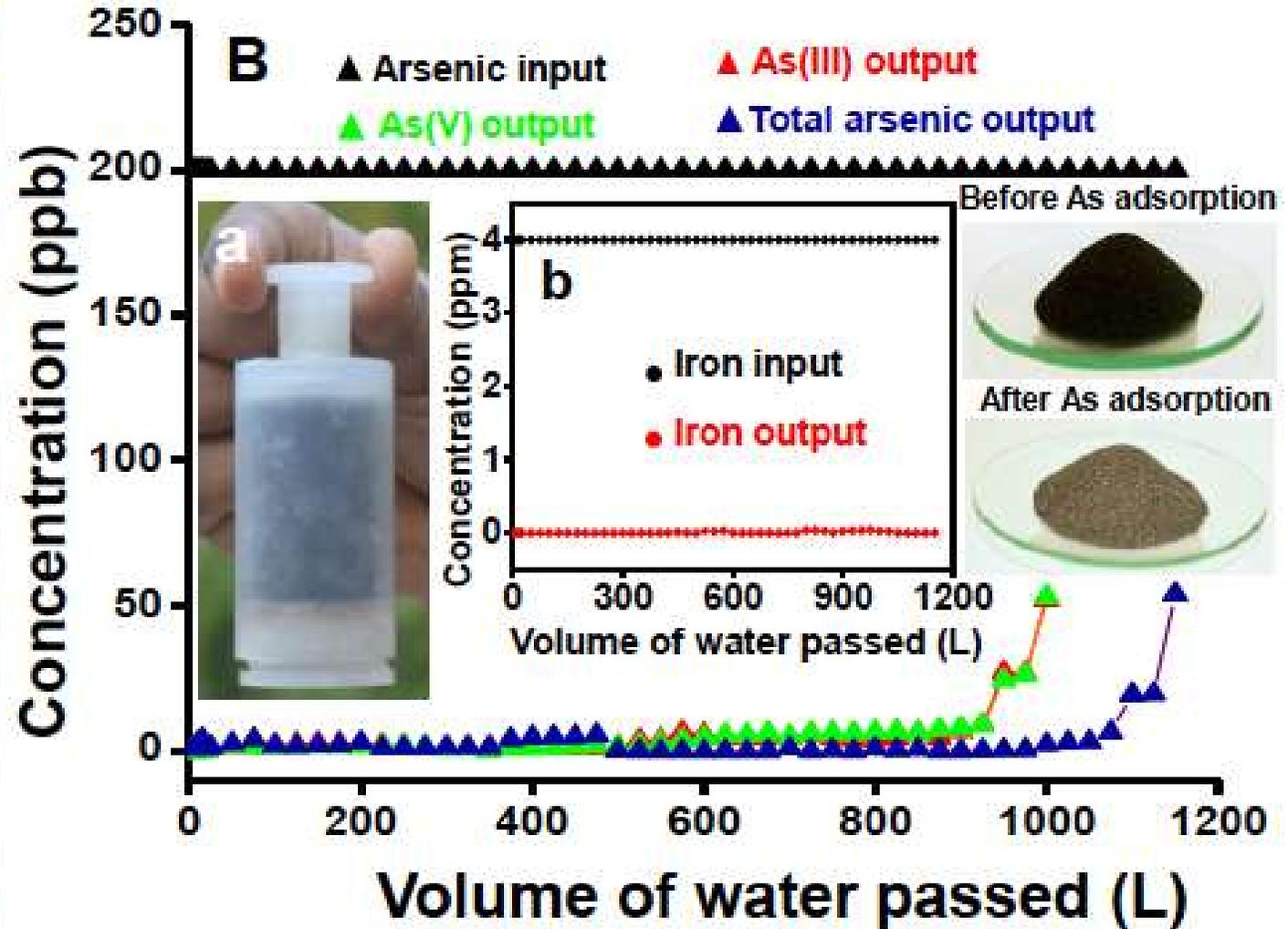
Mechanism



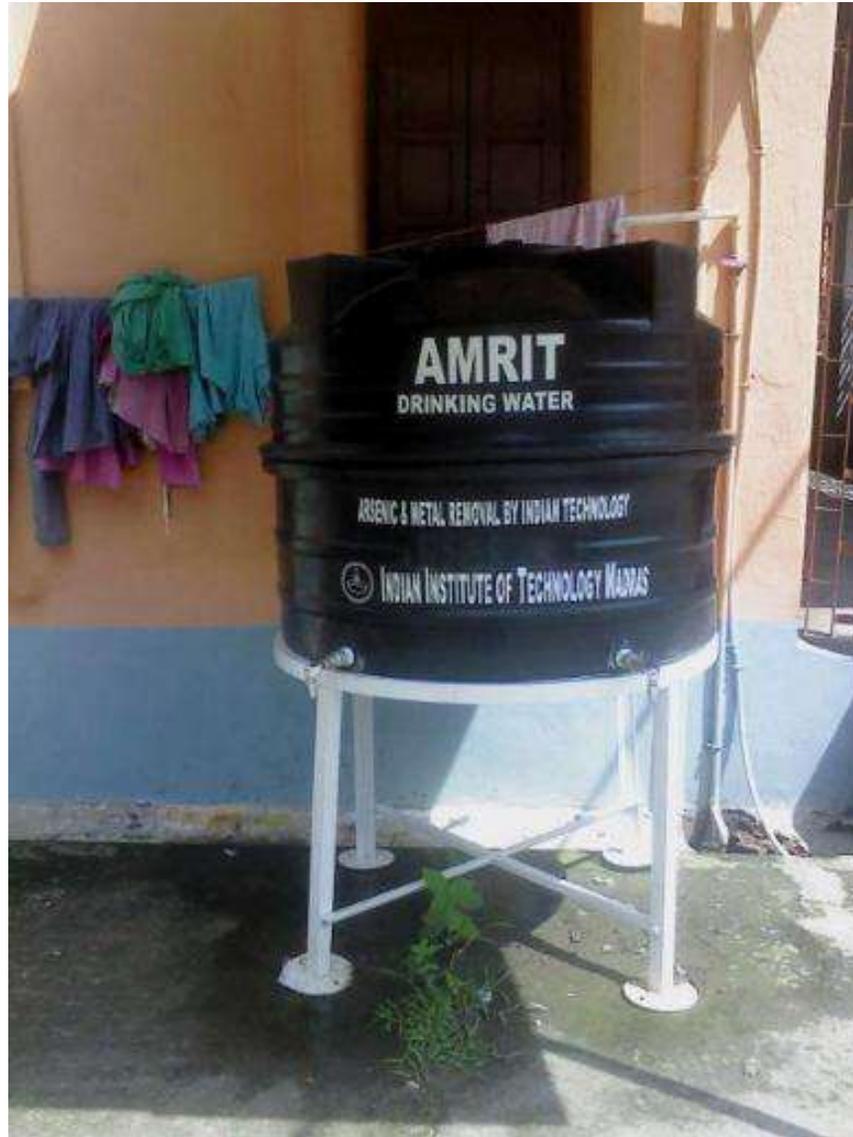
Modeling surfaces



Lab studies

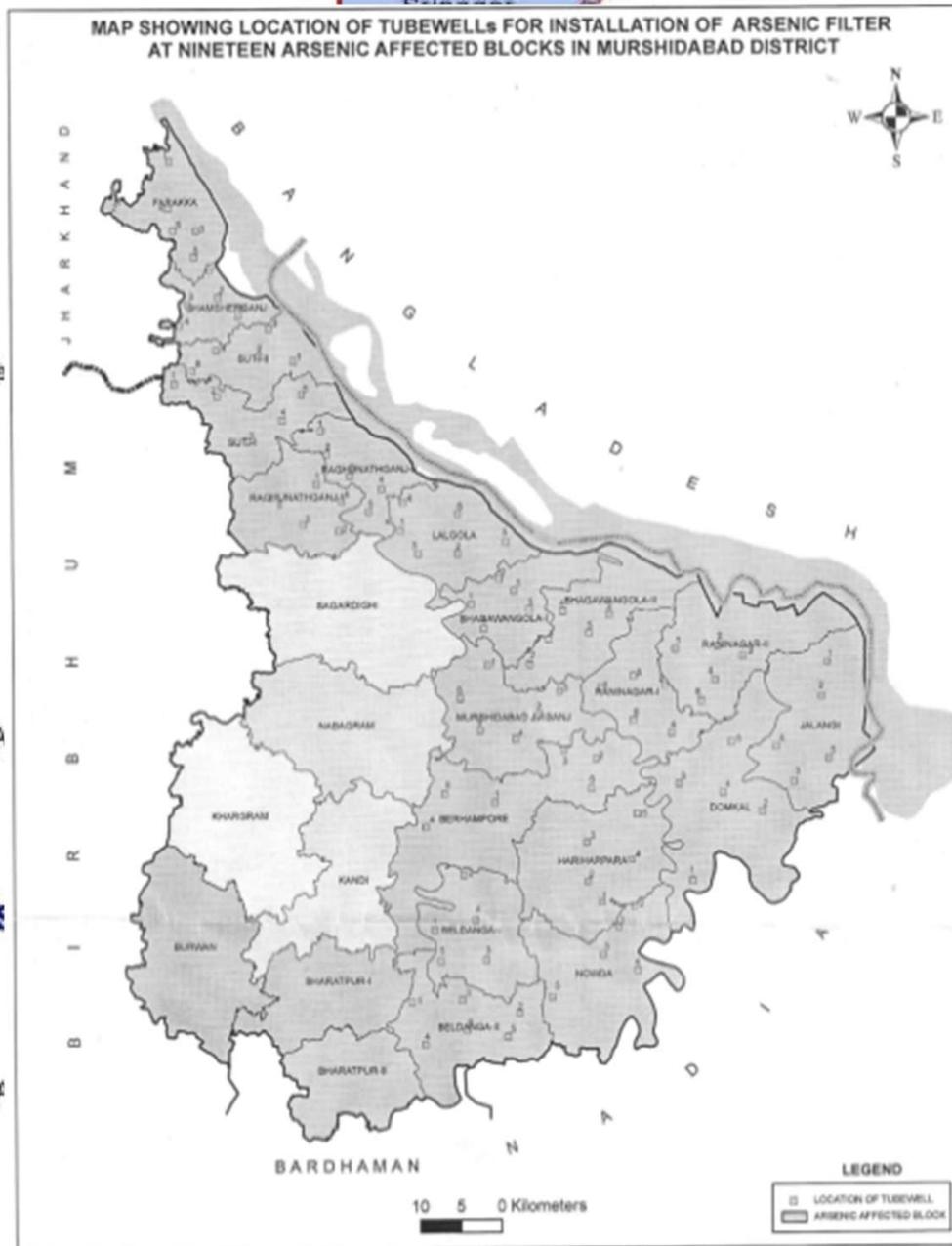


Initial pilot studies



Larger pilot studies

Population Map Of India-2001



Changing the dynamics in the field



Existing plant in 40 cents



New plant in 3 cents

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

- Existing unit for iron and arsenic removal – 18 m³/h
- Uses iron oxyhydroxide (new generation of adsorbents)
- Input arsenic concentration: 168 ppb
- Output arsenic concentration: 2 ppb

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



স্বল্পলারিত
= 03471-250221
ফোন-03471-
লক্স-03471-

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

Glimpse of Installed units (330 nos)

Implementation - From 25 KLD to 1 MLD



Large water supply schemes
Capacity: above 1 MLD

5 schemes in use across India



Retrofitted Water Purification Plant
Capacity: 0.1-1 MLD

Over 180 units in use across India

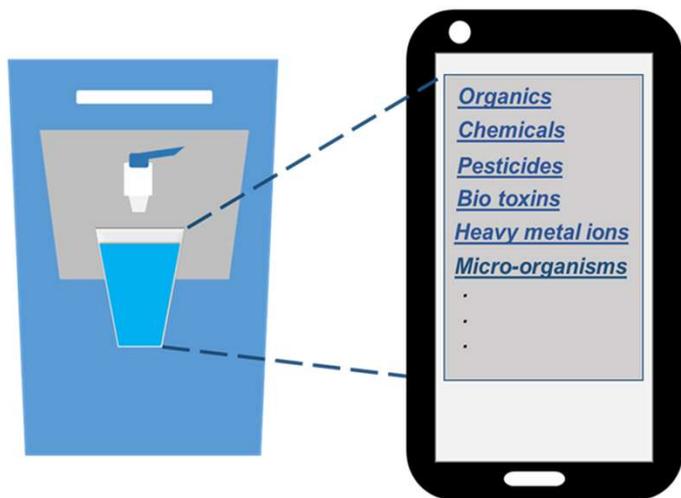
Cleanwater at 2.1 paise per litre!

Calculation for the Tariff to be collected for treated water (Revision if Required)

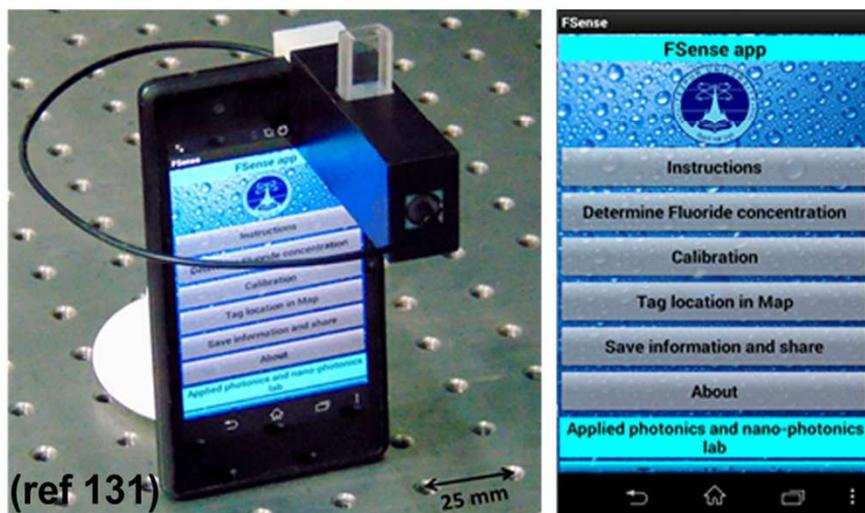
Sr.No	Design population	1,071	Plant capacity/70 LPCD
	Item/Description	Cost / Quantity	Remarks
1	Cost of Replacement of Iron removal media	56400	After minimum two years if Iron concentration is more than 5 ppm. But iron concentration is more than 5 ppm at only two to three places. Therefore media may work for 3 years also.
2	Cost of Replacement of Arsenic removal media	978660	After minimum two years if Arsenic concentration is more than 100 ppb. But arsenic concentration is more than 100 ppb at only two to three places. Therefore media may work for 3 years also.
3	Cost of replacement of Activated Carbon	28560	
4	Total cost of Replacement of media	1063620	After minimum two years.
5	Total cost of Replacement of media for one year	531810	
6	Plant capacity	75000	ltr per day
7	Design population	1,071	Plant capacity/70 LPCD
8	Cost per liter of water	2.1 Paise per ltr	0.025 cents
9	Cost of replacement of media	1.36	Rs. per head per day =Media replacement cost per year/365/Design population
		<u>40.80</u>	per head per month for 70 LPCD water

Smart water purifiers and big data

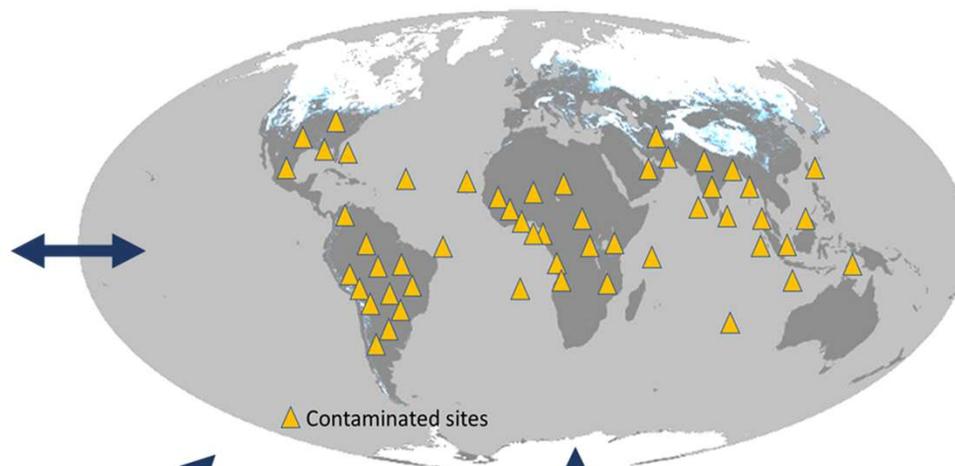
Smart Water Purifiers linked to IoT



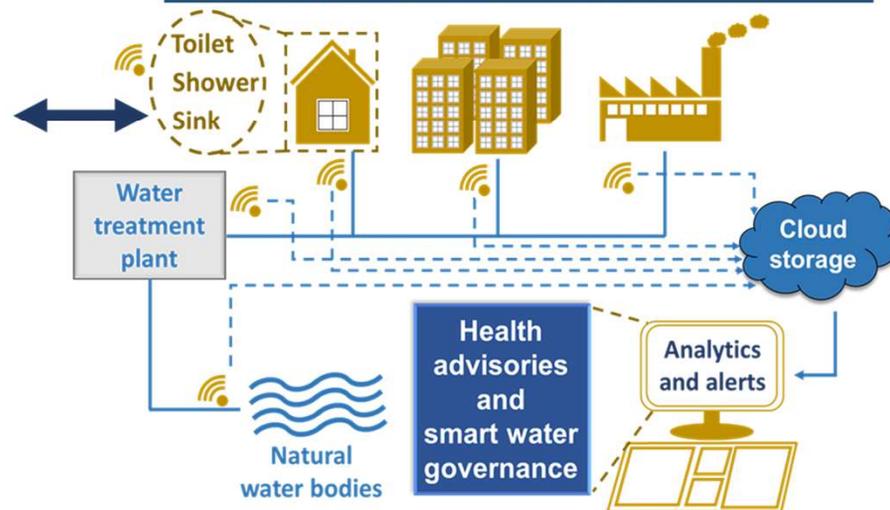
Cost-effective sensor accessory for point-of-use applications



Global Map of Water Health



IoT-enabled sensing for households and distribution networks



Waste management

Adsorbents conform to toxicity characteristic leaching procedure

Elemental waste goes back to local environment

Safe disposal of arsenic (or any other) laden waste

Additional protection could be considered, if necessary

Exploring viable uses

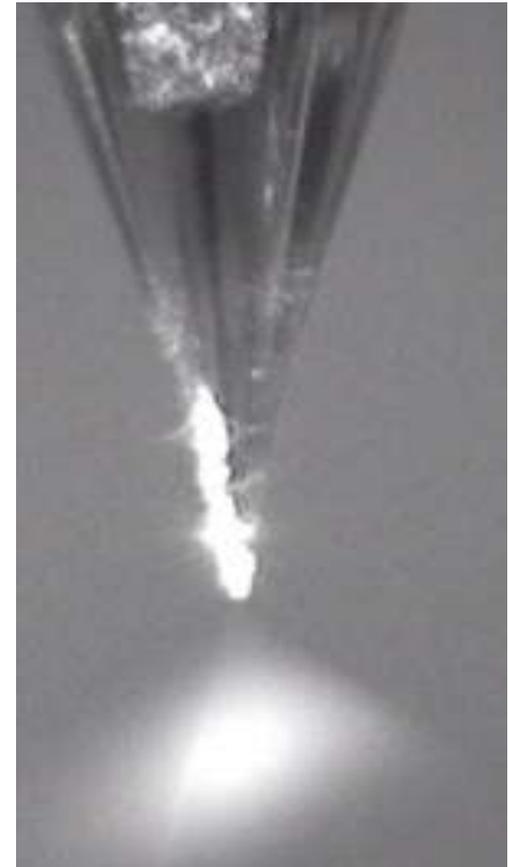
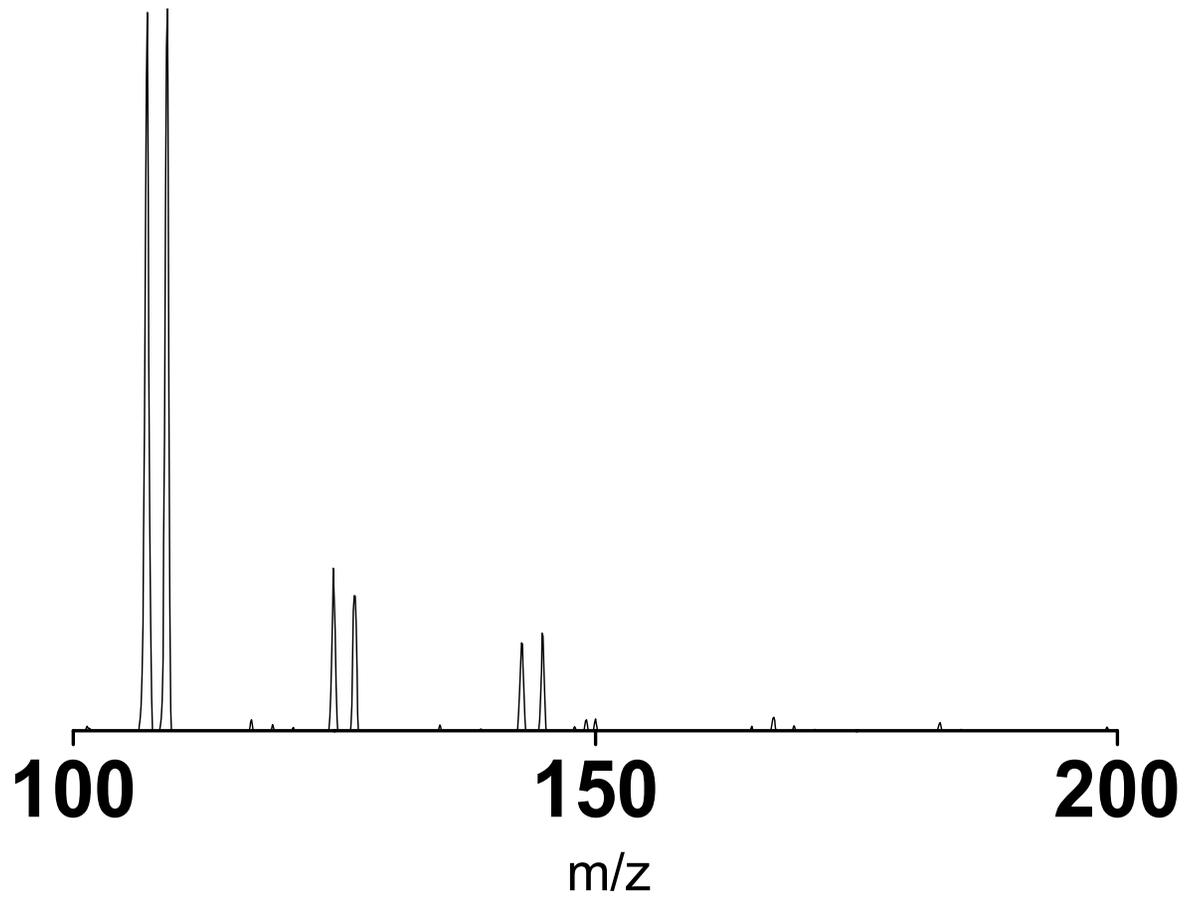
A sample of new installations



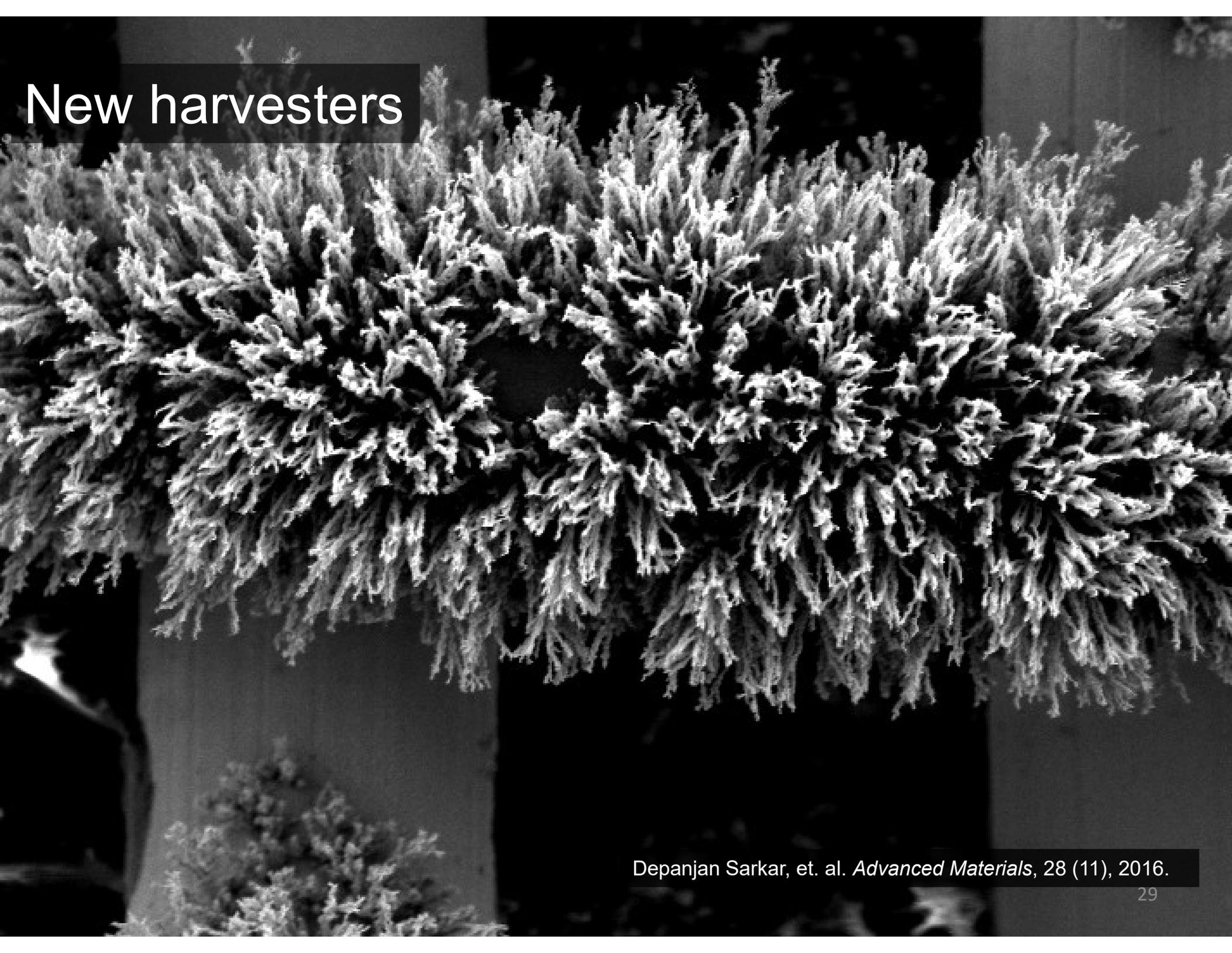
Across the country



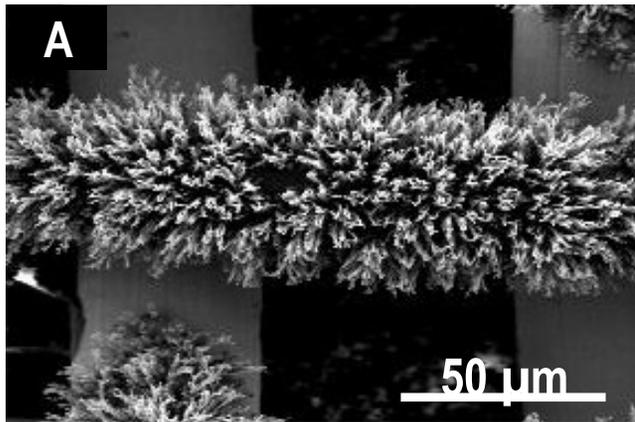
Atmospheric water harvesting



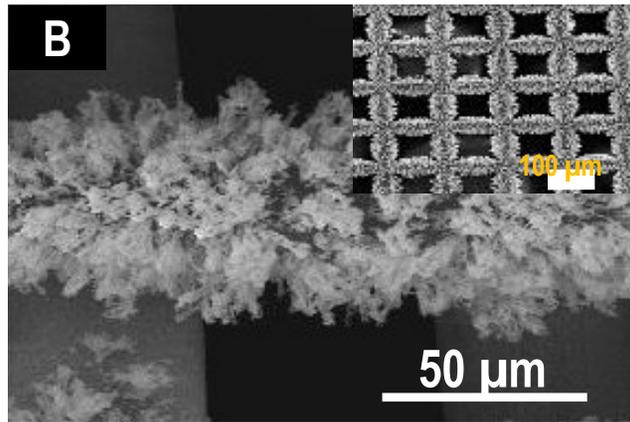
New harvesters



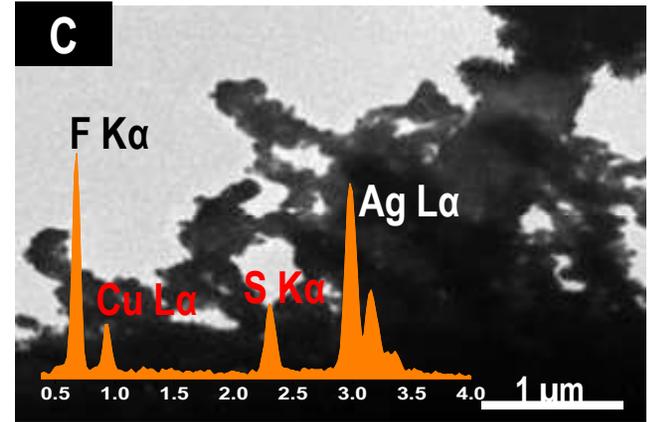
Depanjan Sarkar, et. al. *Advanced Materials*, 28 (11), 2016.



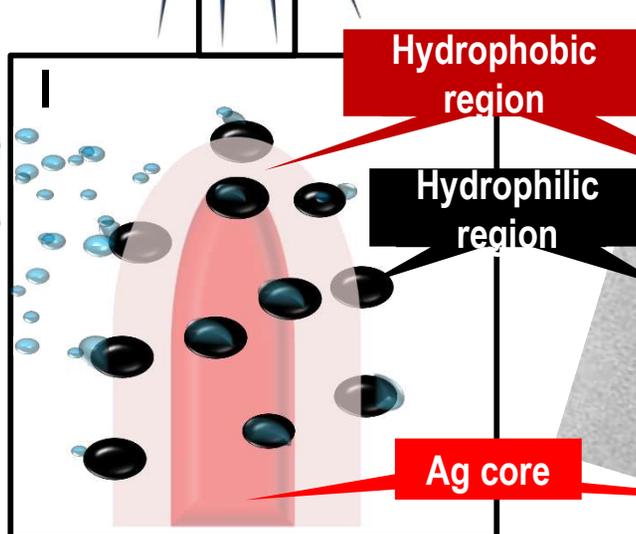
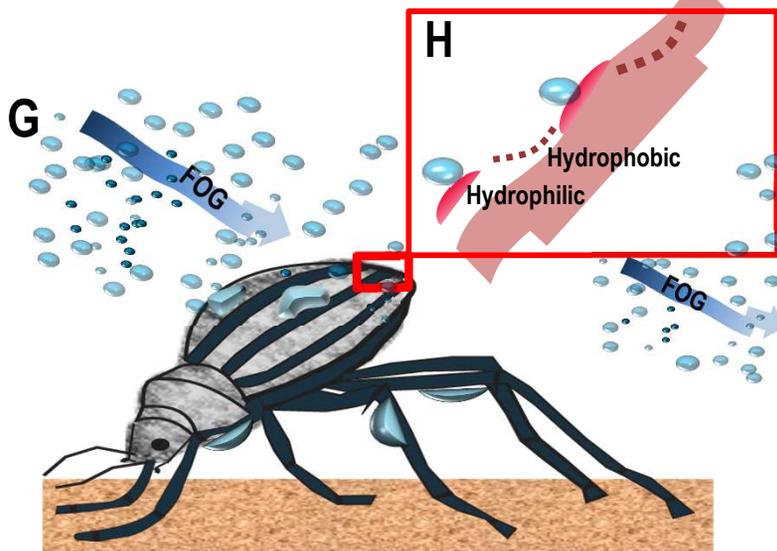
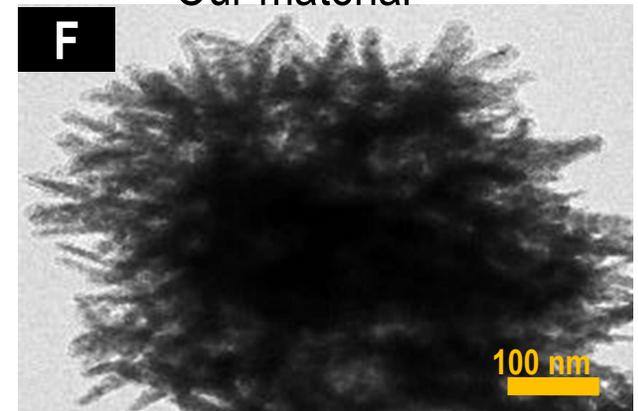
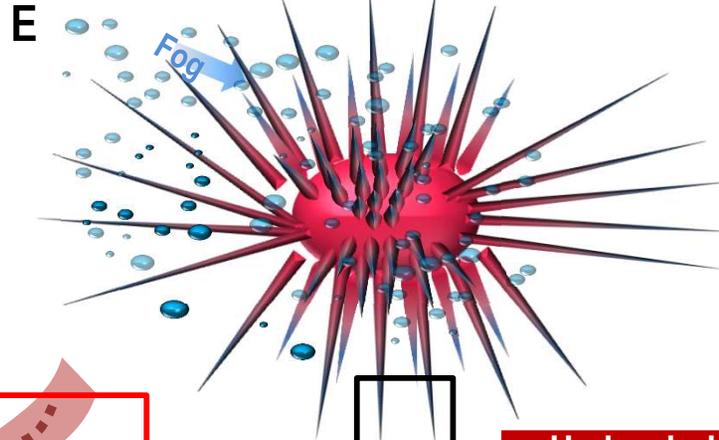
Nature



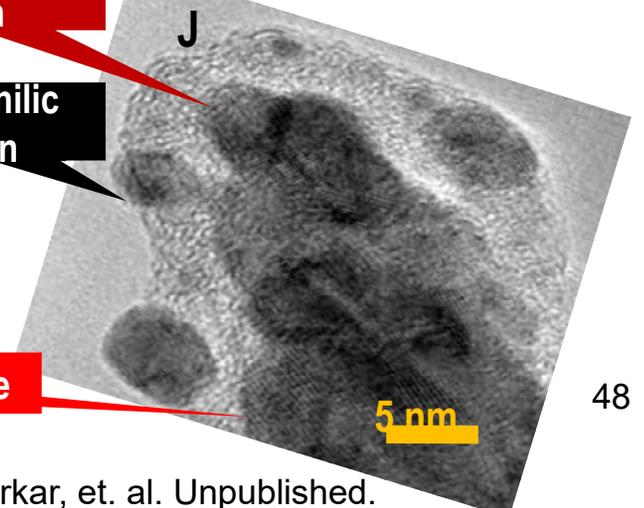
Schematic

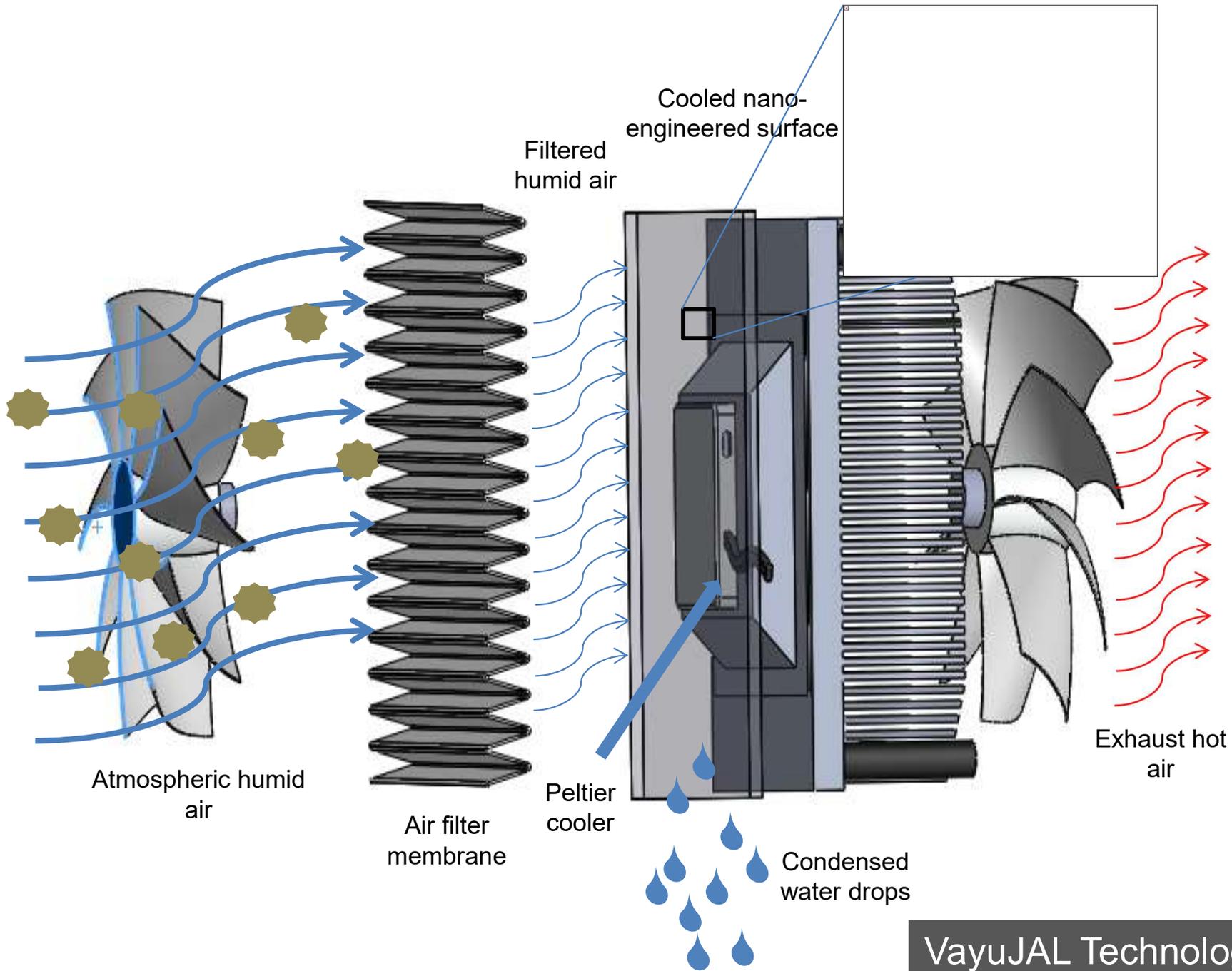


Our material



Combination of cactus and Namib desert beetle effect





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

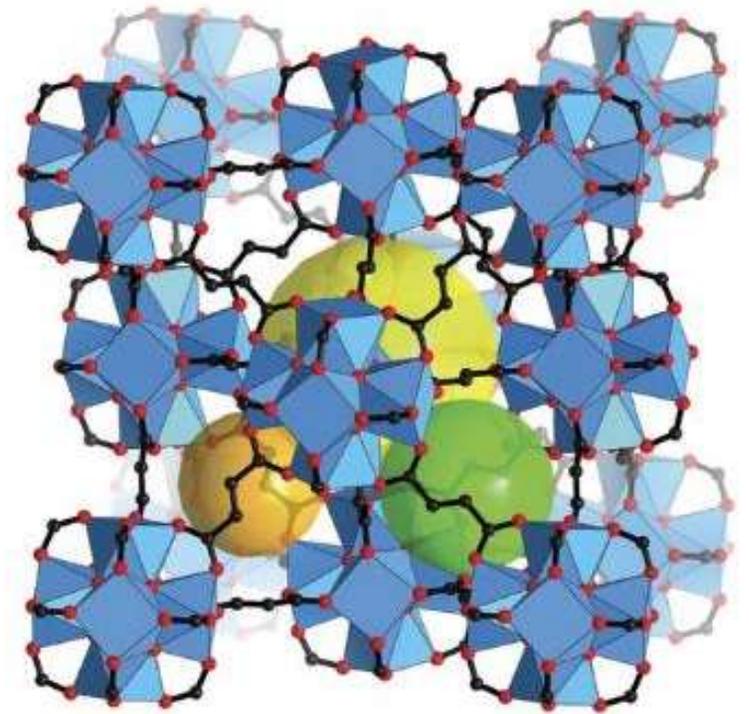
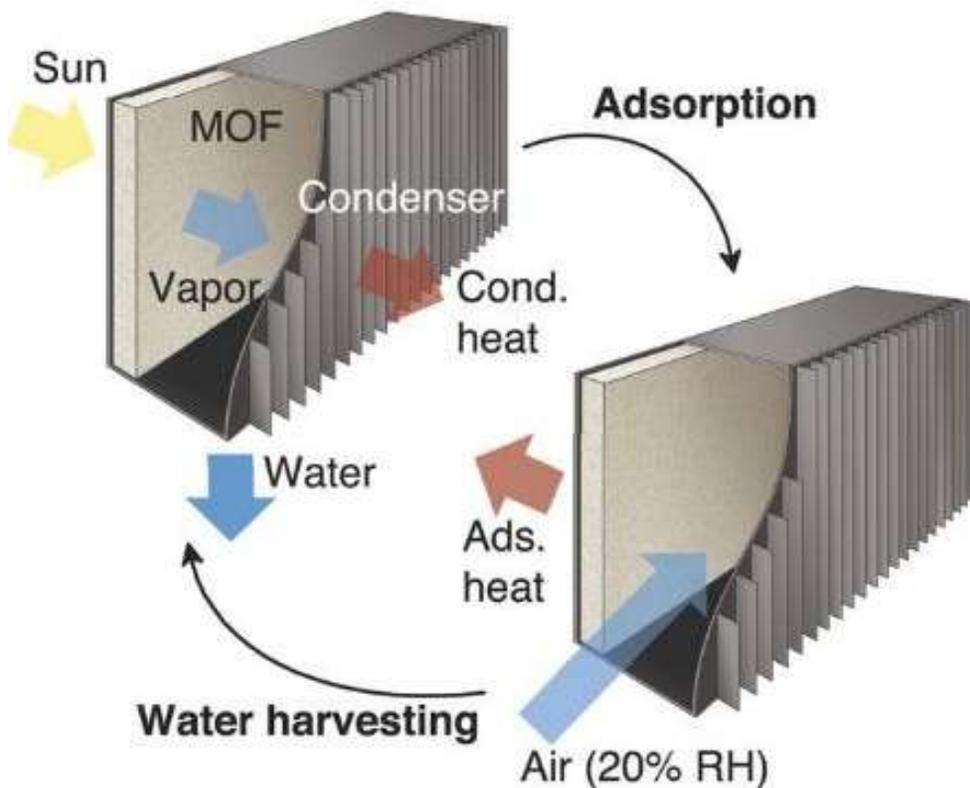
Products in the field



(LPD: Litres per day)

Sustainable atmospheric water harvesting

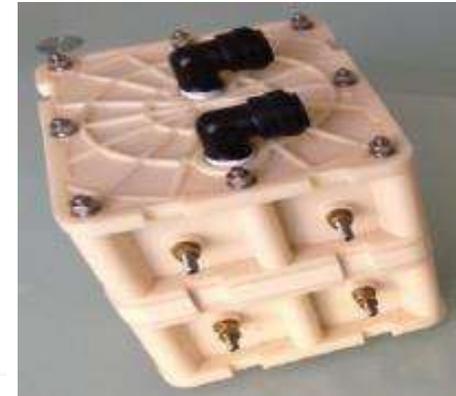
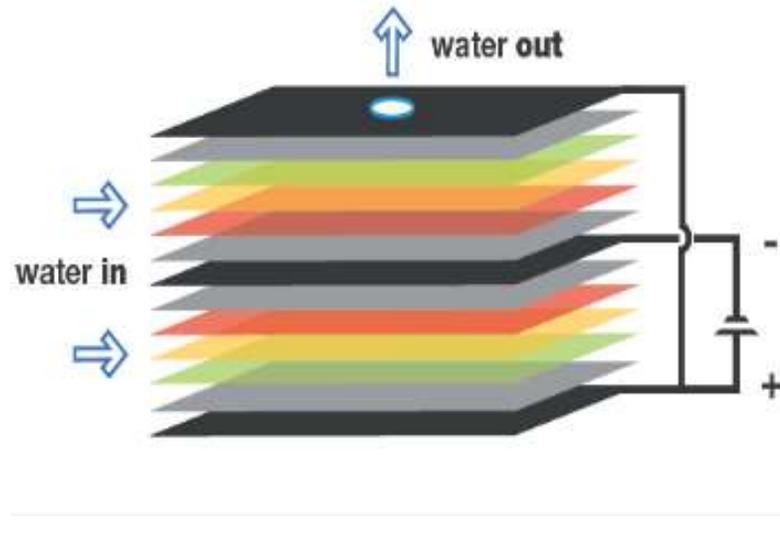
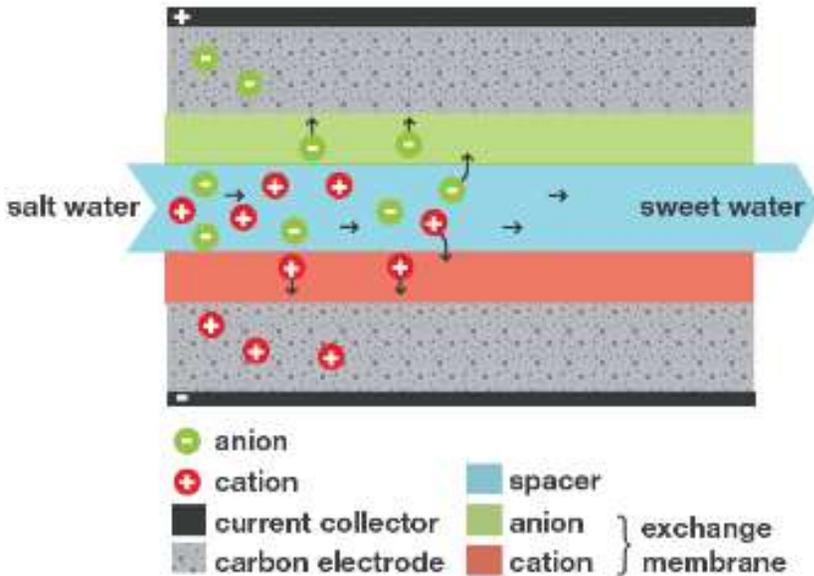
Solar- heat-enabled atmospheric water capture at a relative humidity as low as 20%



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

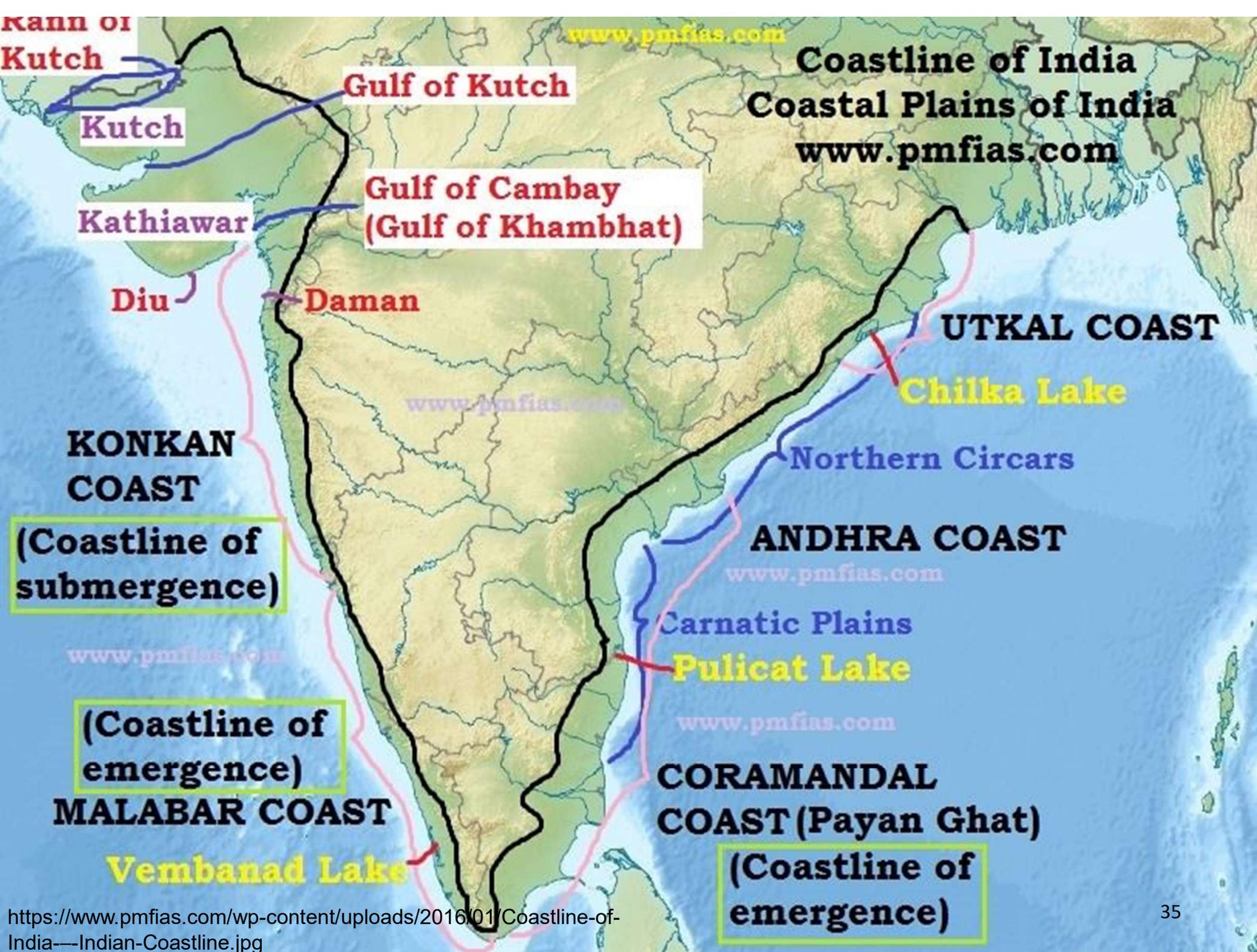
Kim Hyunho, et al. *Science*, 356 (6336) 2017

Capacitive Desalination (CDI)



Our new company

Soujit Sengupta, Rabiul Islam and others



Kutch

Gulf of Kutch

Kutch

Coastline of India
Coastal Plains of India
www.pmfias.com

Kathiawar

**Gulf of Cambay
(Gulf of Khambhat)**

Diu

Daman

UTKAL COAST

Chilka Lake

**KONKAN
COAST**

Northern Circars

**(Coastline of
submergence)**

ANDHRA COAST

www.pmfias.com

www.pmfias.com

Carnatic Plains

**(Coastline of
emergence)**

Pulicat Lake

www.pmfias.com

MALABAR COAST

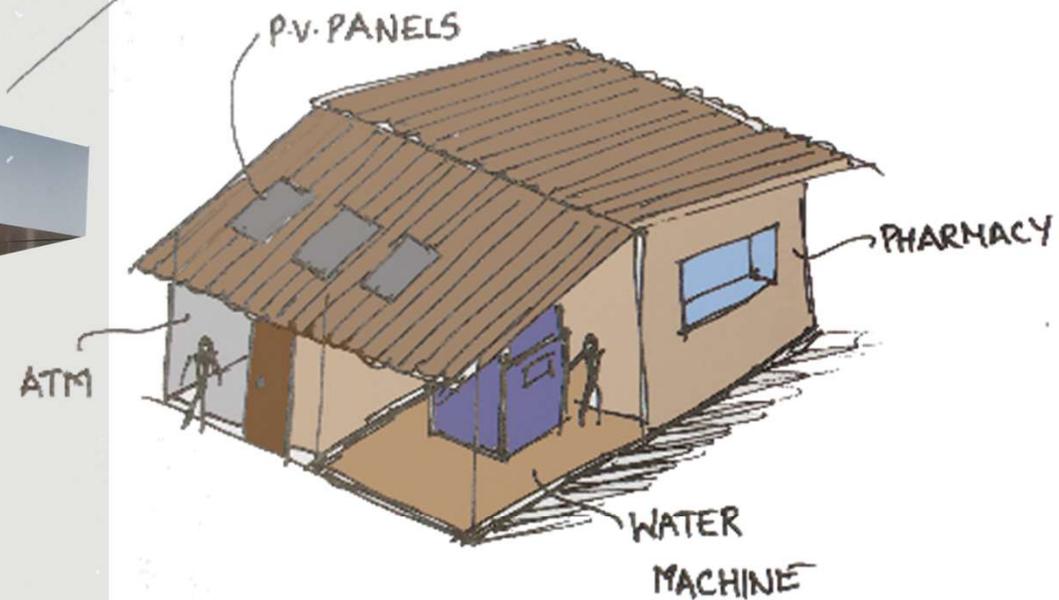
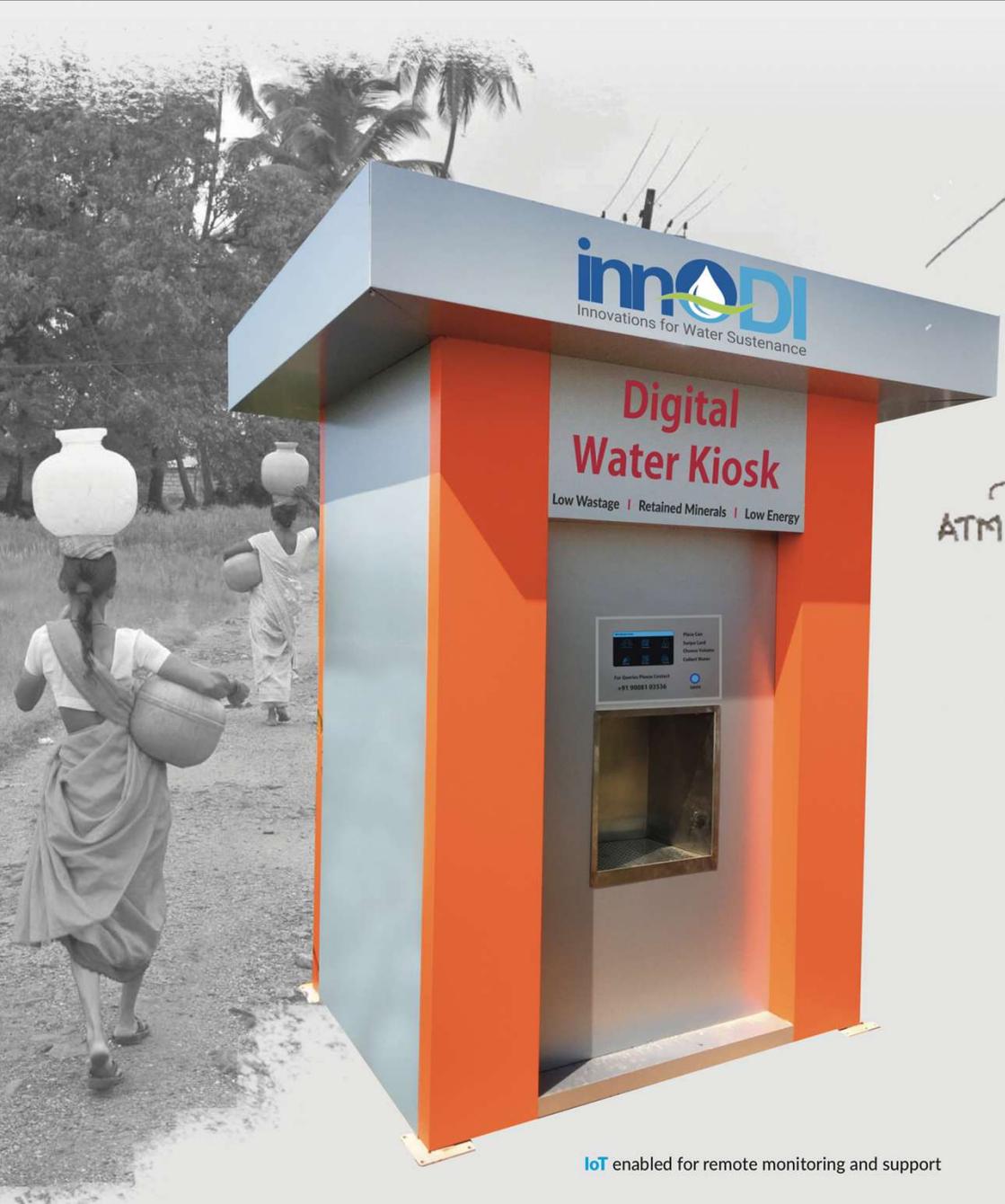
**CORAMANDAL
COAST (Payan Ghat)**

Vembanad Lake

**(Coastline of
emergence)**

DIGITAL WATER KIOSK

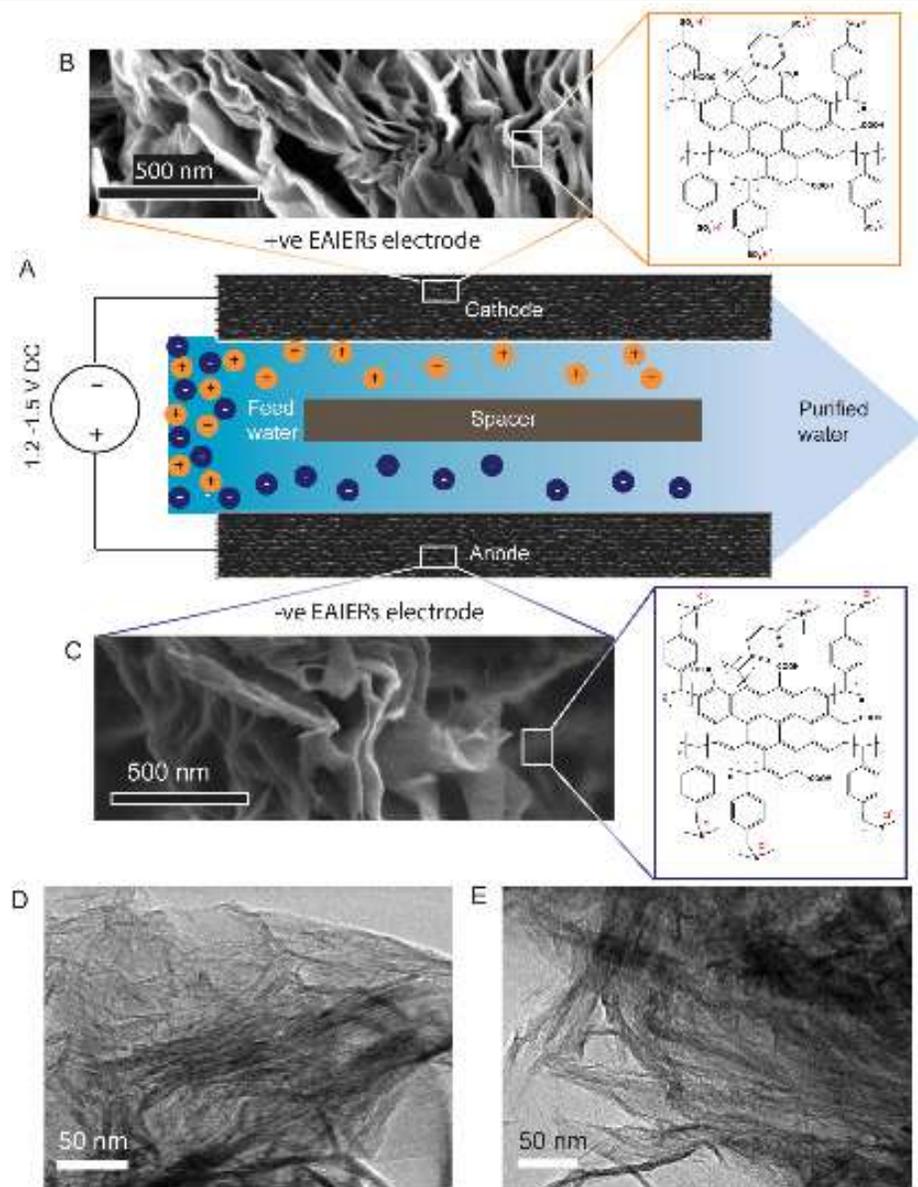
for community drinking using CDI Technology



Products under implementation

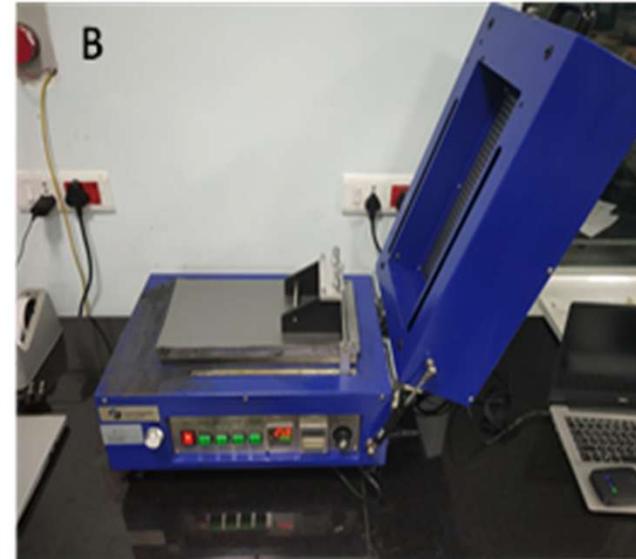
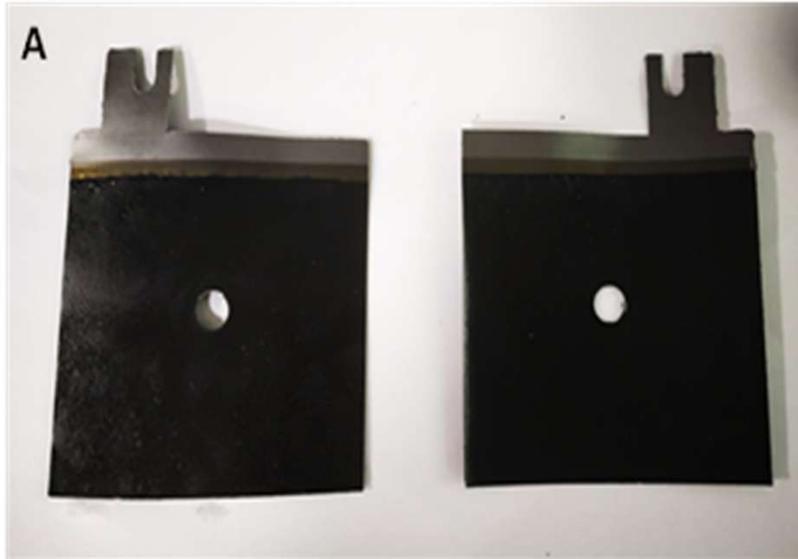
Vijay Sampath and Tullio Servida

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

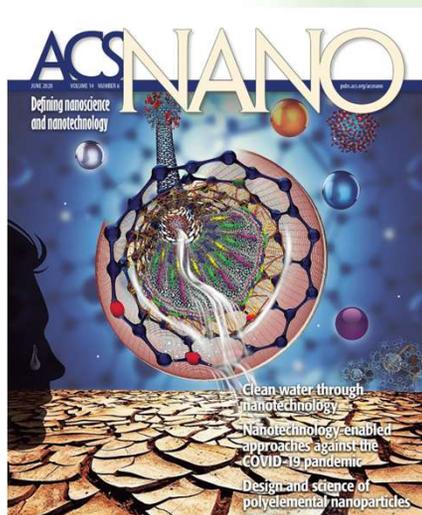
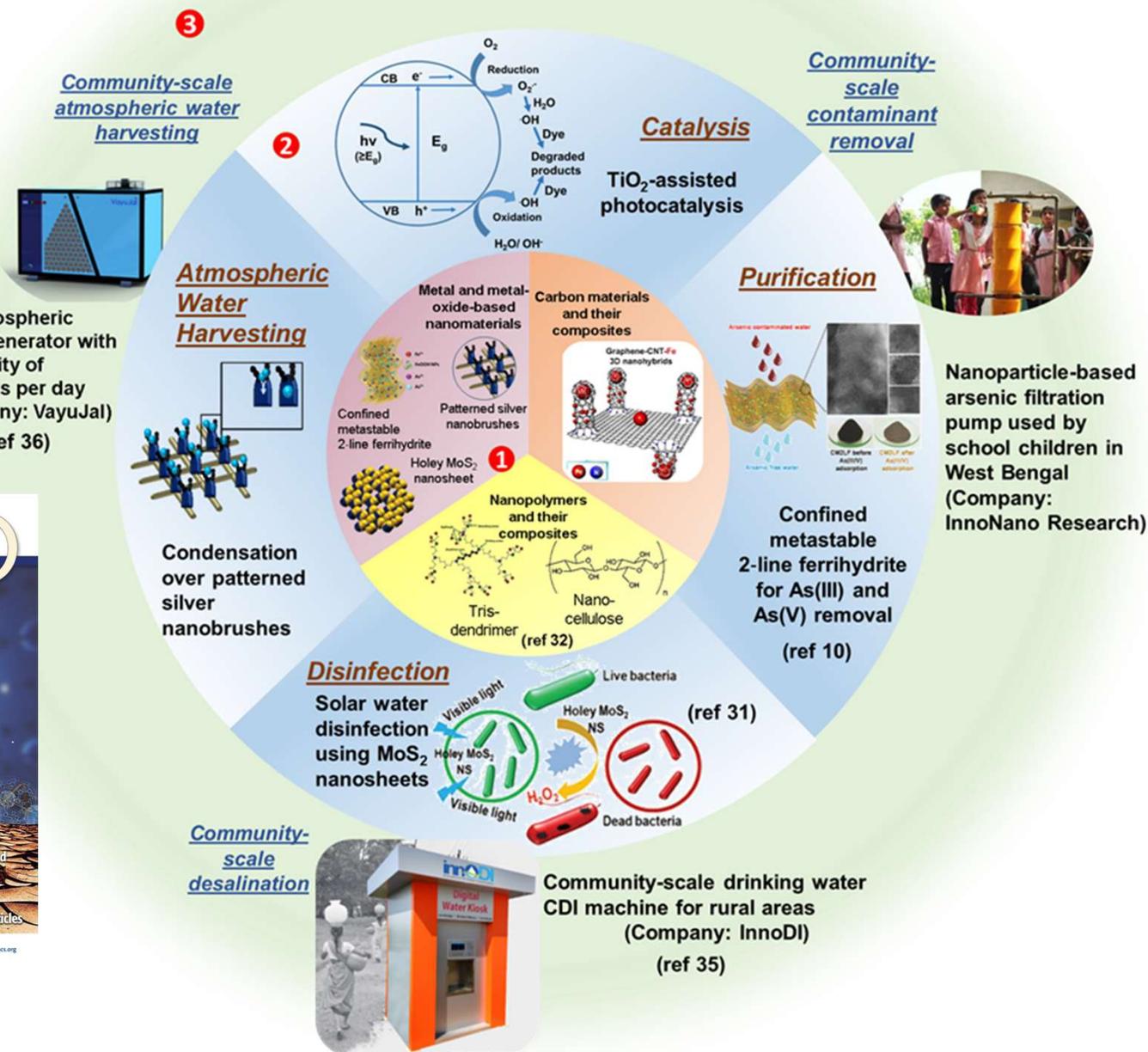


Rabiul *et al.*, *Adv. Mater. Interfaces* **2021**, *8*, 2001998

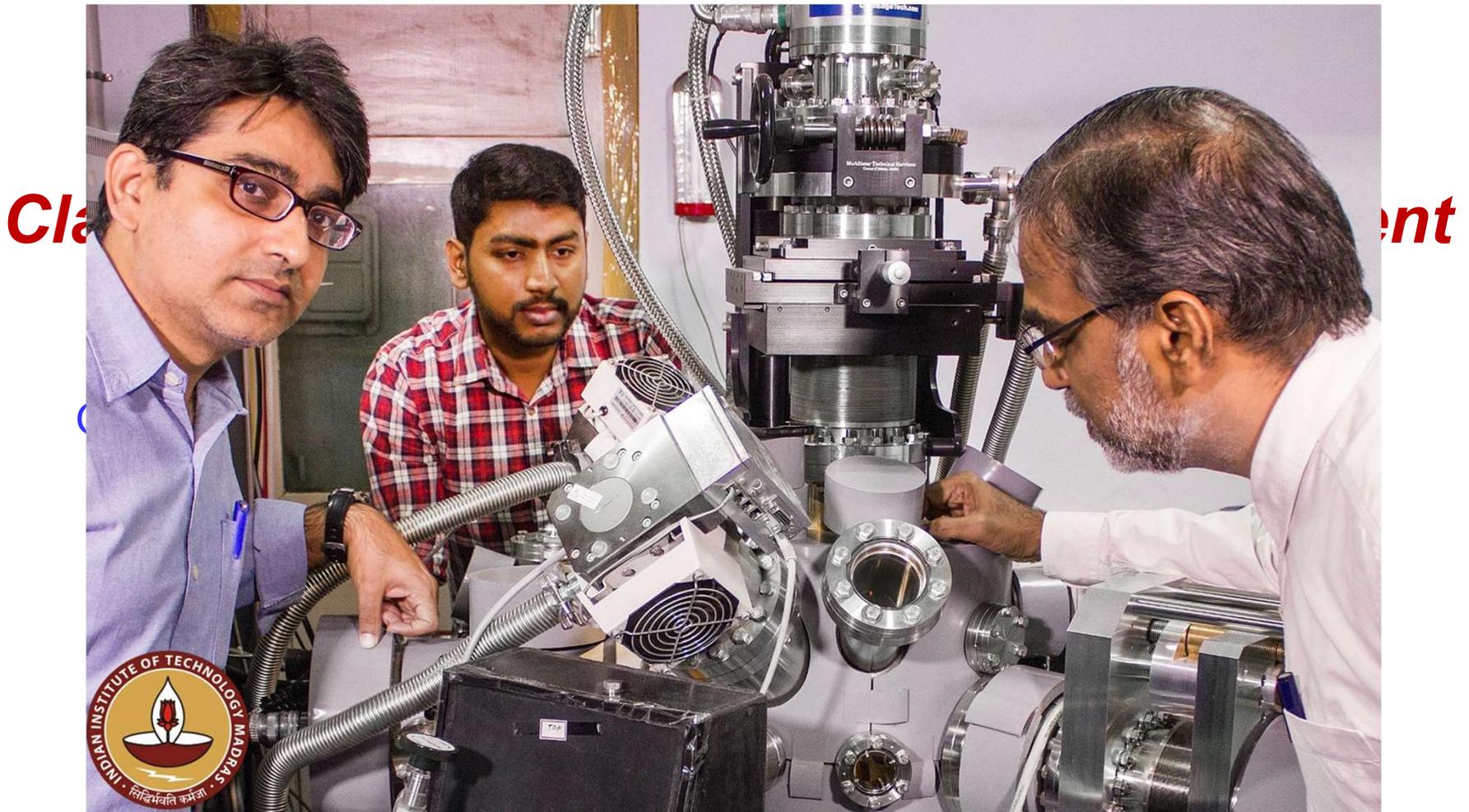
Various stages of electrode preparation



Evolution of materials to products

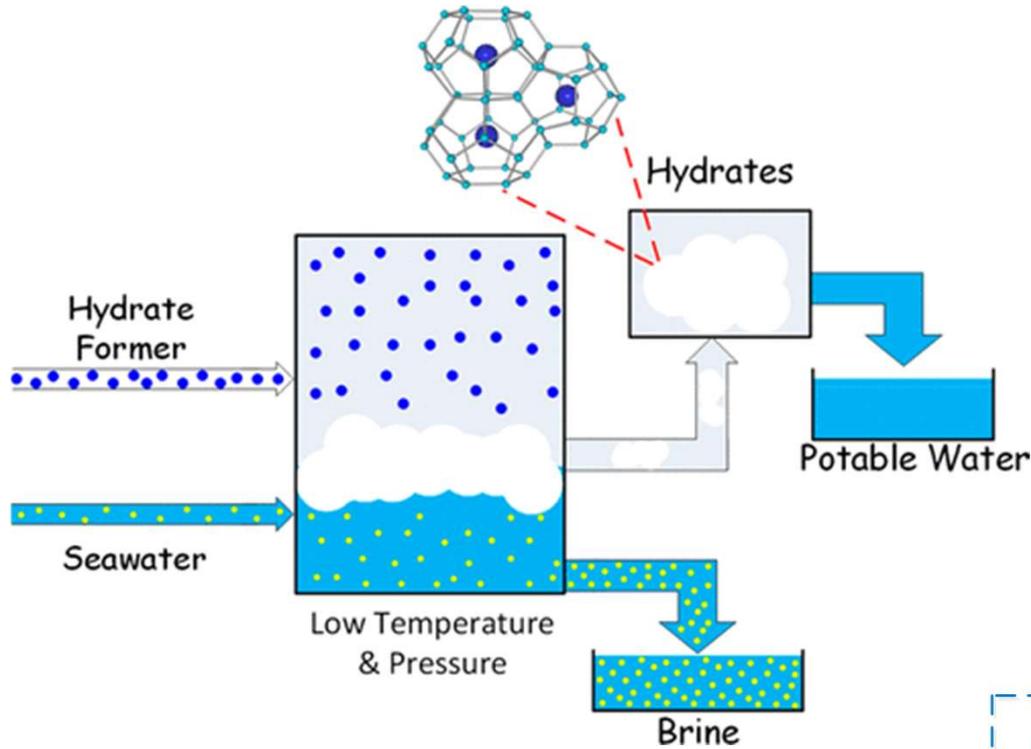


New phenomena



With Rajnish Kumar

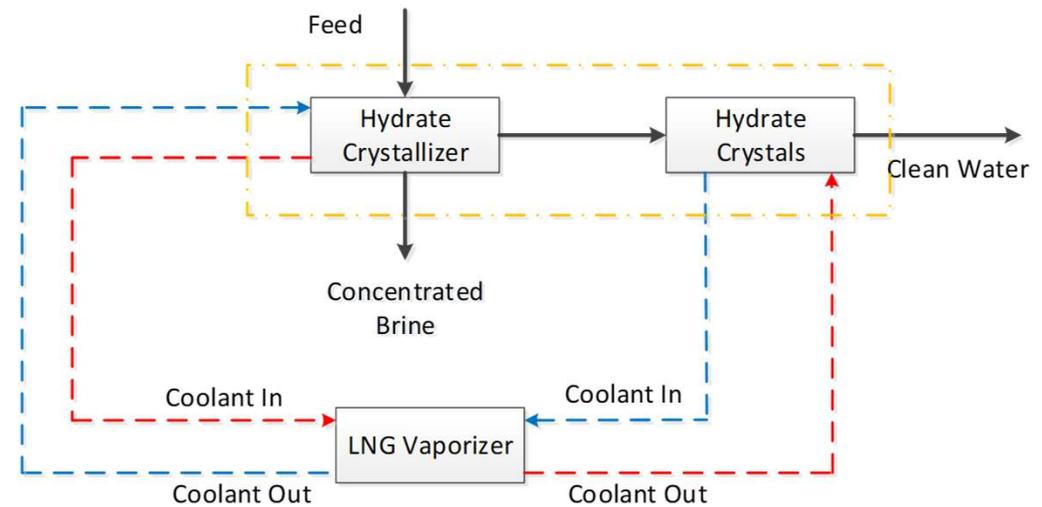
Hydrate-based desalination (HyDesal)



Water dissociated from hydrate is pure

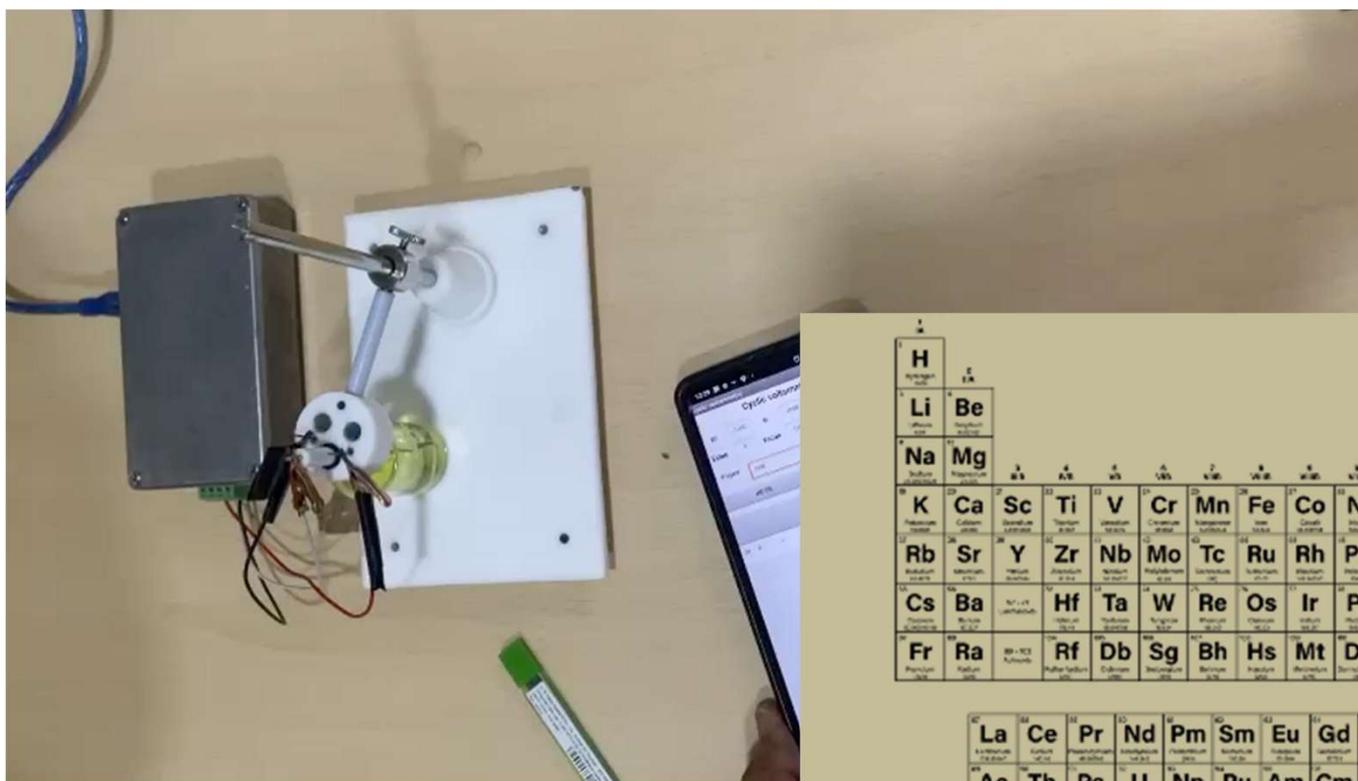
HyDesal process advantages

- ✓ Salts get occluded
- ✓ No chemical reaction, recovery of water is very easy
- ✓ Hydrates consist of 85% water and rest guest gas
- ✓ Not sensitive to impurities or salt concentration



Cold Energy in LNG terminals can be harvested to produce water

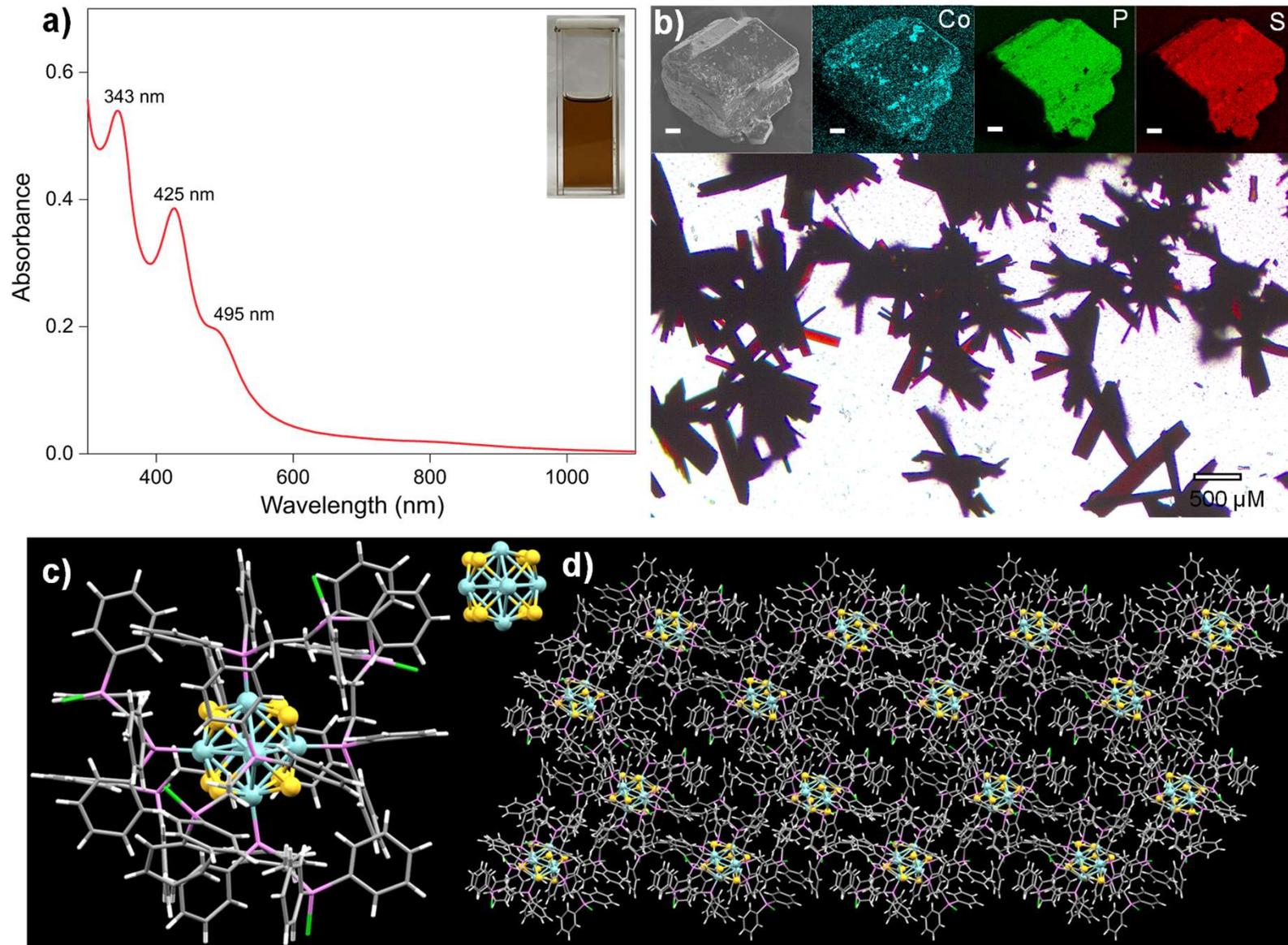
Sensors and analytical devices



1																	18		
1	H											He							
2	Li	Be											B	C	N	O	F	Ne	
3	Na	Mg											Al	Si	P	S	Cl	Ar	
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
6	Cs	Ba	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
7	Fr	Ra	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og		
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		

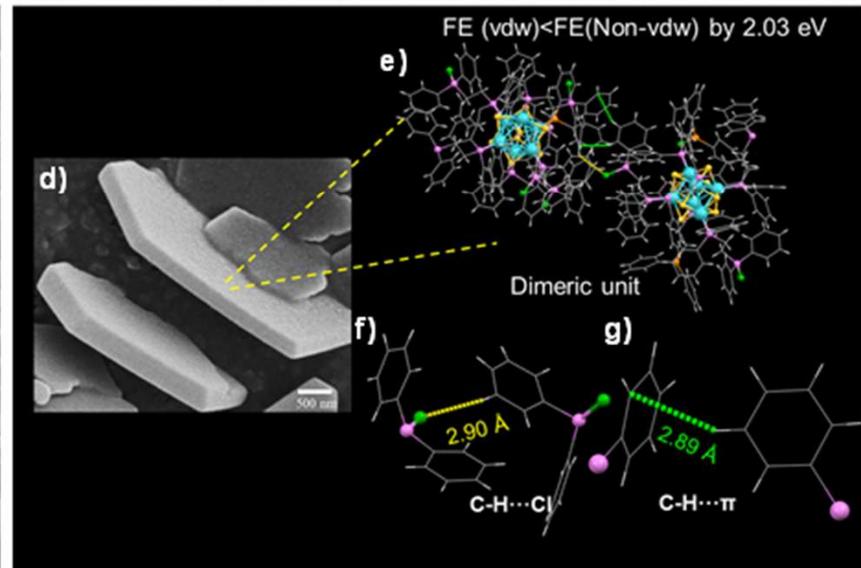
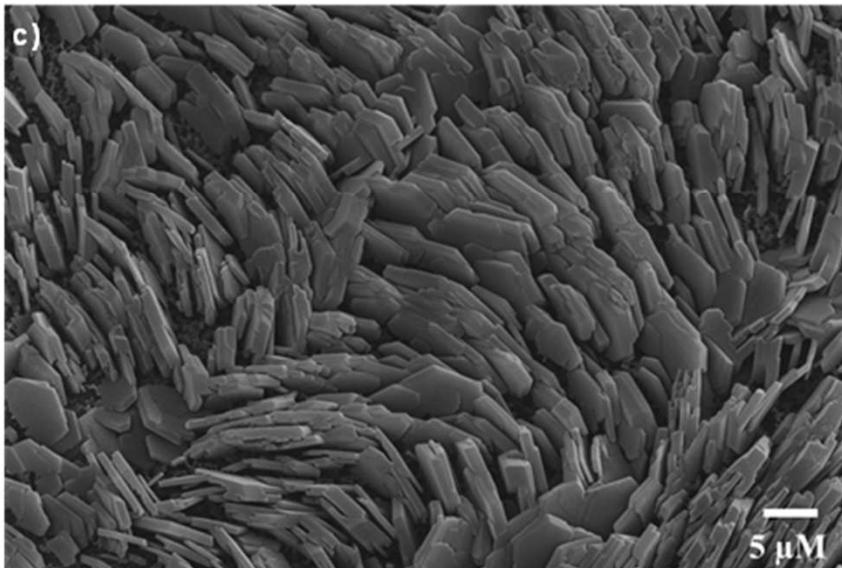
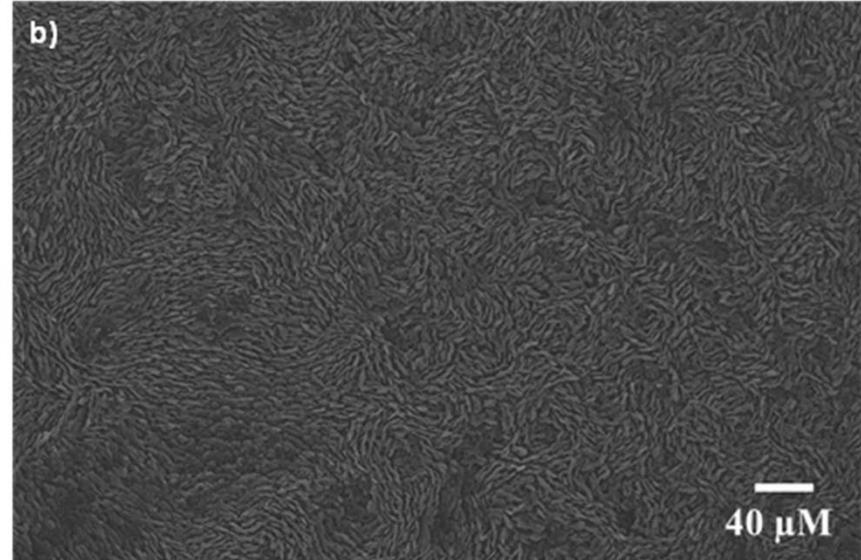
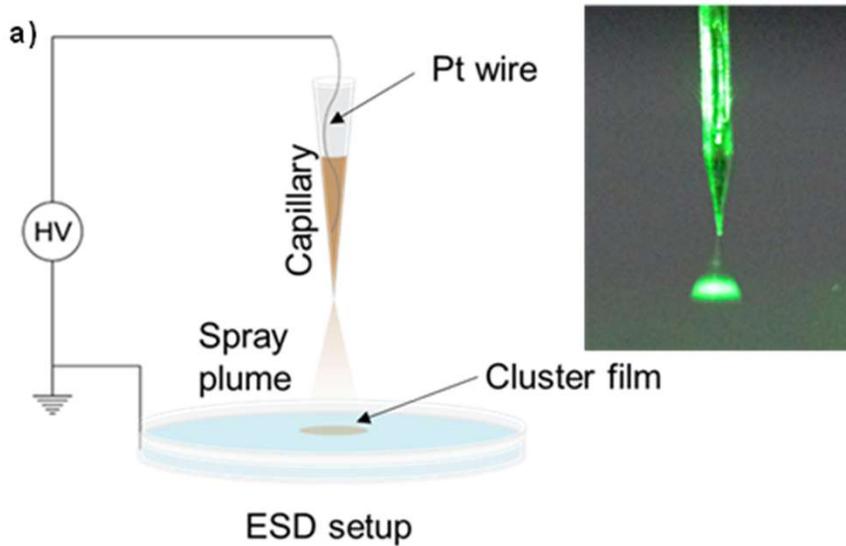
Sourav Kanti Jana

New electrodes - Aligned nanoplates

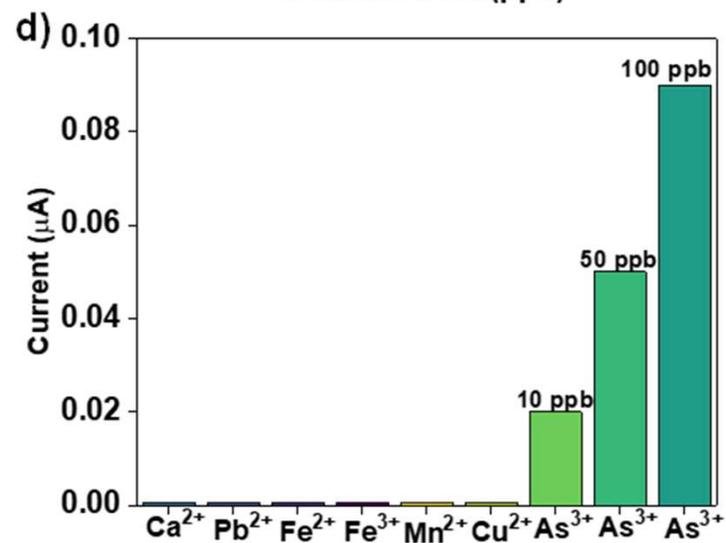
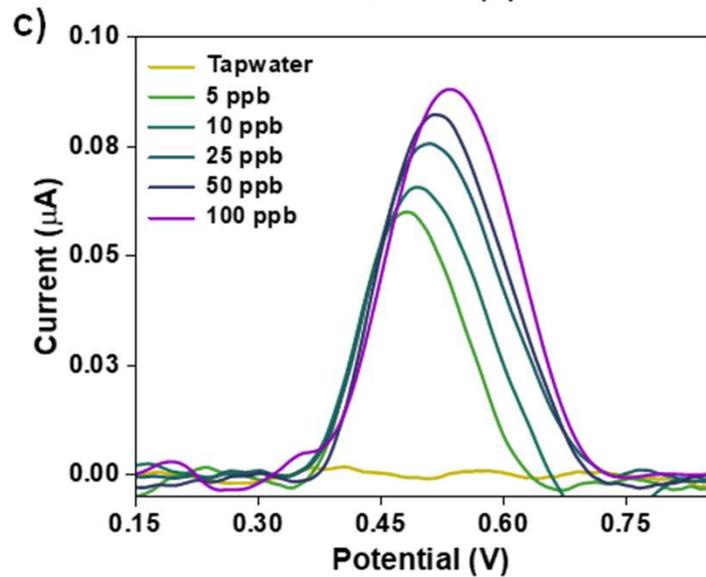
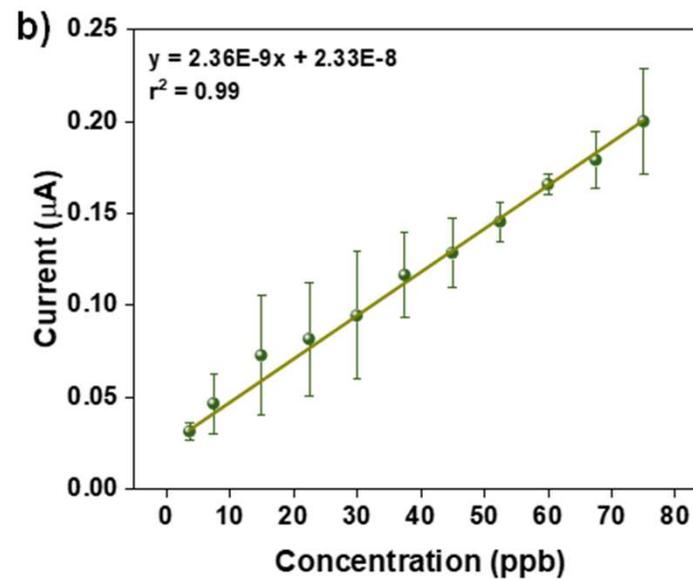
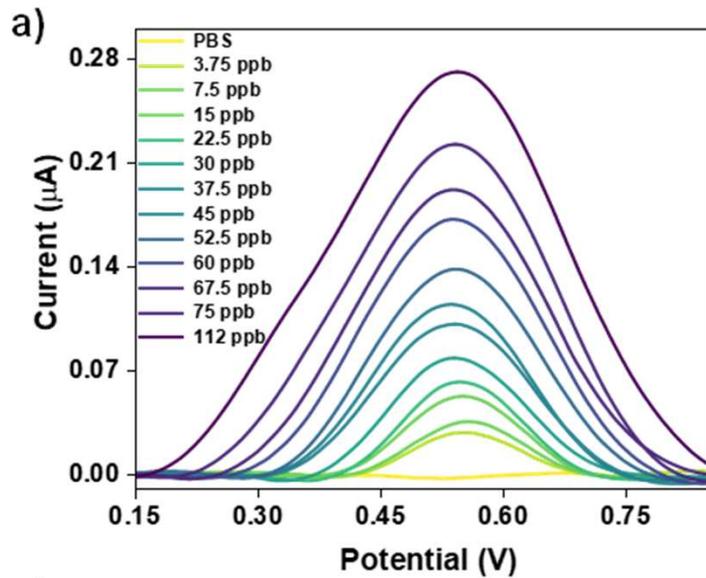


Anagha Jose et al, 2022 (unpublished)

Electrospray deposition



Sensing



Anagha Jose et al, 2022 Patent filed

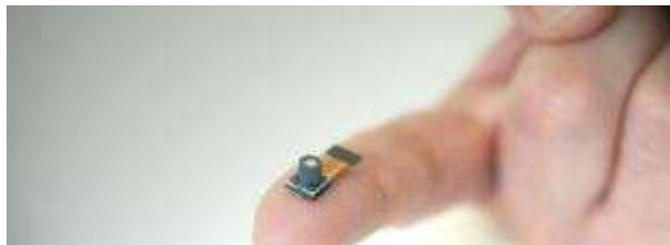
Sensors and new opportunities



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



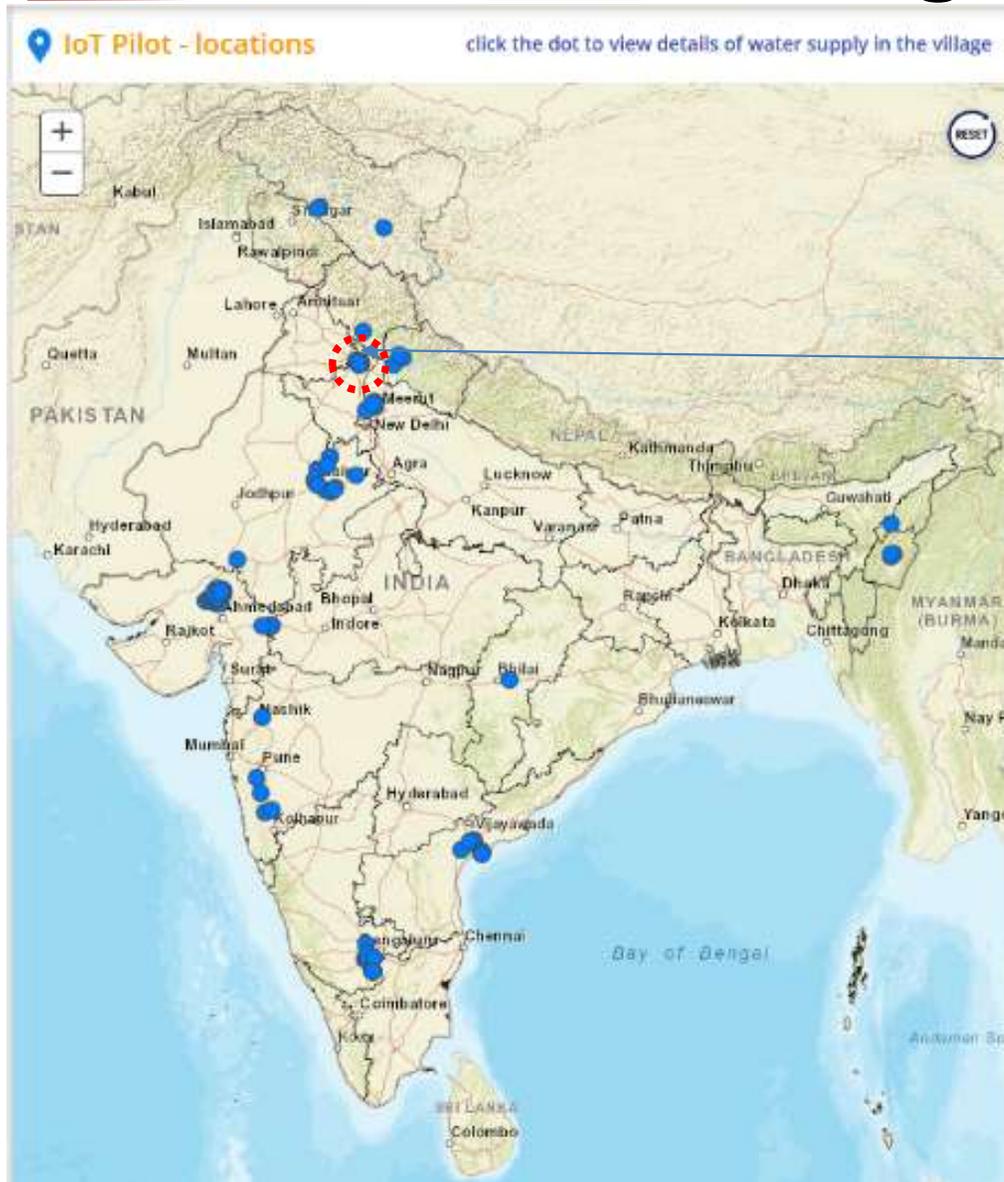
**Ultra compact Low Cost
Spectral Sensor Module**
~ **Billions units (? 2027)**



Water quality measurement – In the pipeline

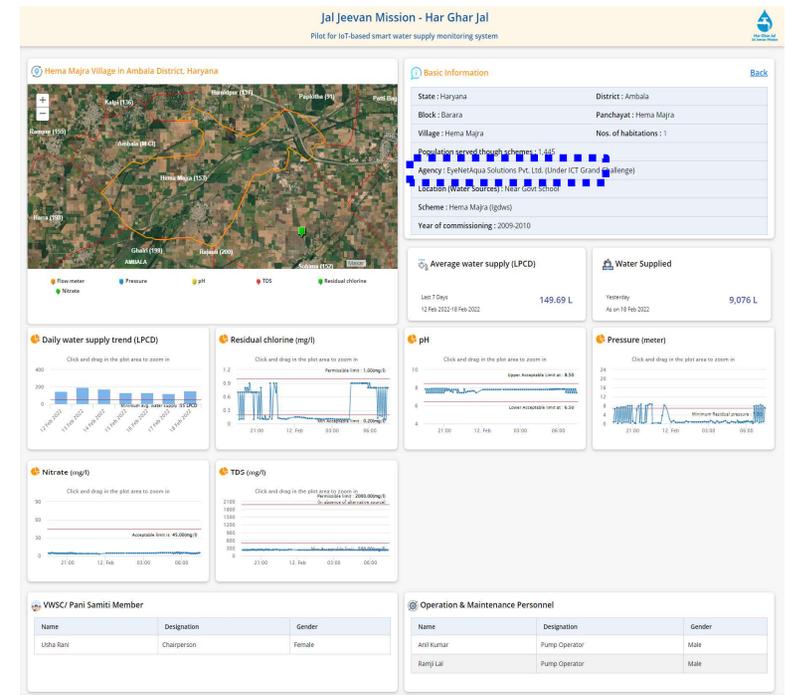
nano λ

India's water is being monitored



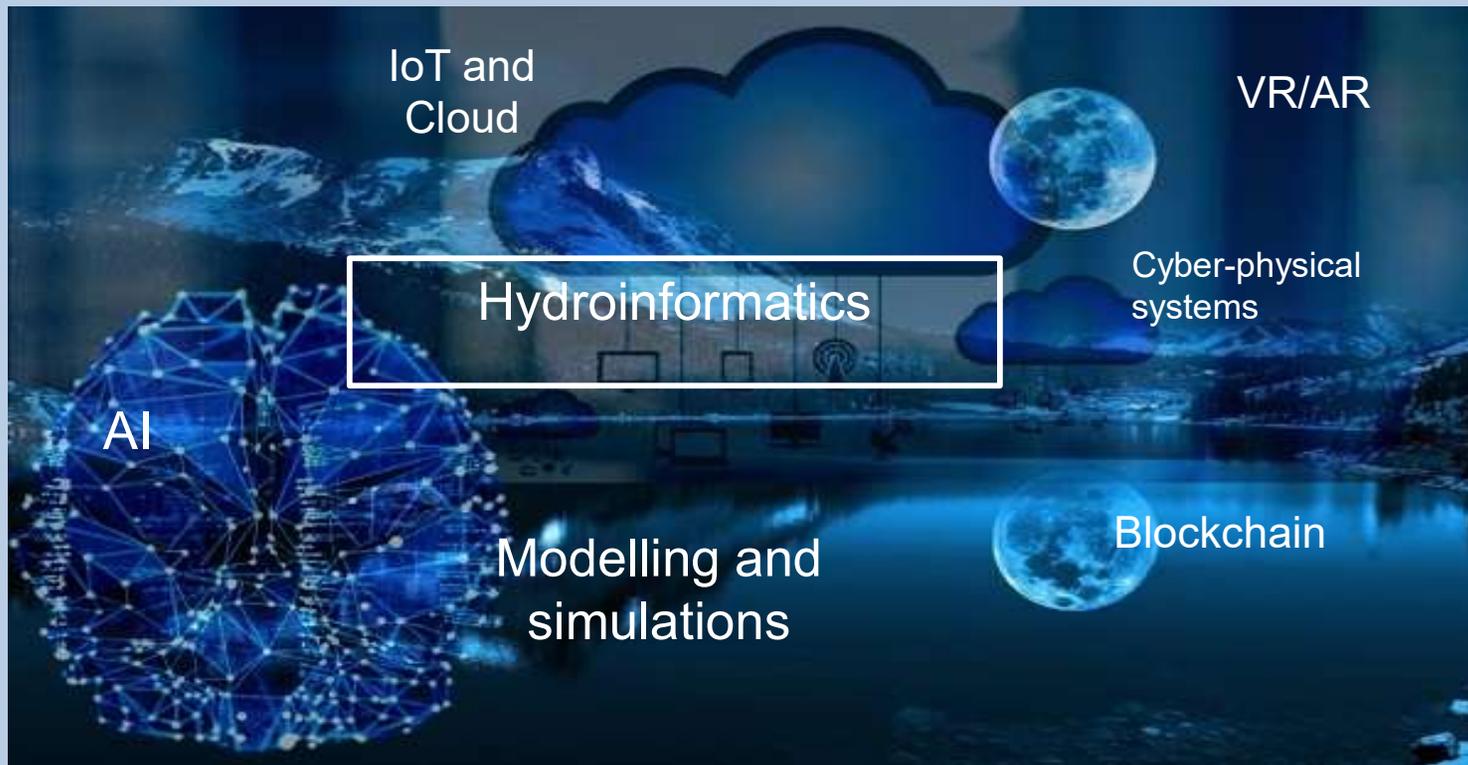
IITM/IISc

Installations made by four companies



Hydroinformatics

Application of computing technologies for efficient, sustainable and equitable water management.

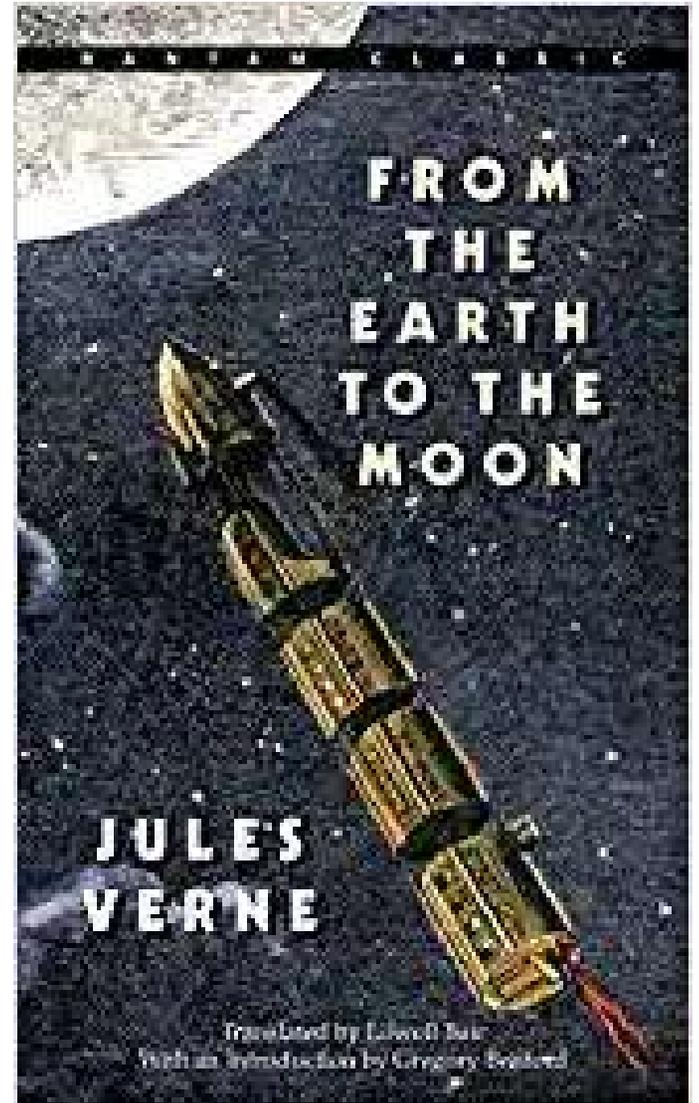
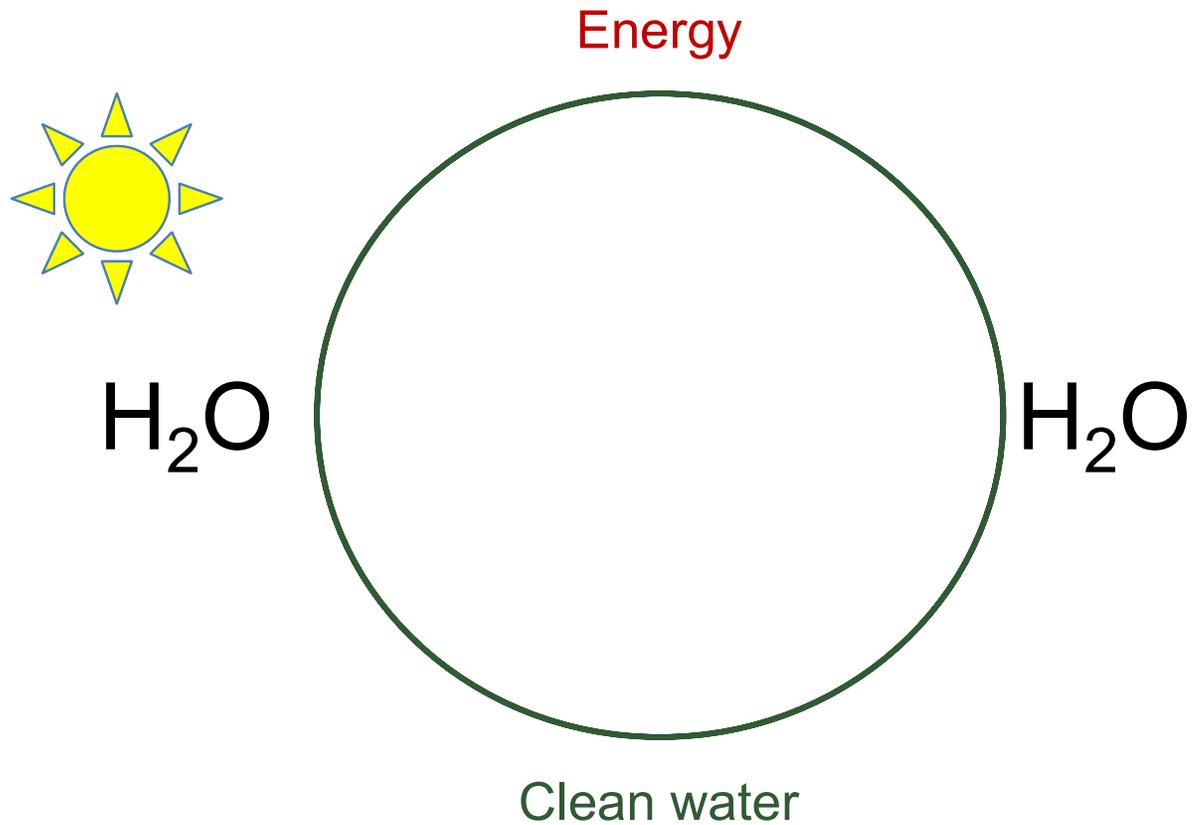


Digital water or water 4.0 will revolutionize water management.



Policy

Our dreams become reality with materials



Affordable, inclusive, sustainable and contextual excellence

Some simple calculations

Hydrogen + Oxygen → Water + 286,000 joules of energy per mole

1 kg of solar hydrogen is now at Rs. XX and could be Rs. 150 soon.

It can make 143 million J of energy.

Desalination needs 2.4 kWh or 8.84 million joules for 1 CM of water.

1 kg of hydrogen can therefore make 16.56 CM of water.

Or Rs. 9.06 (\$0.009) per cubic meter, 0.9 paise (0.0001 cents) per litre!

Well, add efficiency, other costs of plant, transportation, etc.

That world will need water literacy



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:

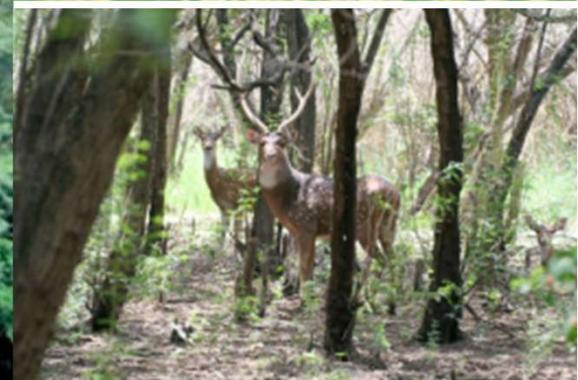
PhD Theses: Bindhu Varughese, M. R. Resmi, M. Venkataramanan, N. Sandhyarani, R. Selvan, A. Sreekumaran Nair, M. J. Rosemary, Renjis T. Tom, C. Subramaniam, Jobin Cyriac, V. R. Rajeev Kumar, D. M. David Jeba Singh, Akshaya Kumar Samal, E. S. Shibu, M. A. Habeeb Muhammed, P. R. Sajanlal, T. S. Sreeprasad, J. Purushothaman, T. Udayabhaskararao, M. S. Bootharaju, Soumabha Bag, Robin John, Kamalesh Chaudhari, Ammu Mathew, Indranath Chakraborty, Radha Gobinda Bhui, 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, Esmā 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

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





Indian Institute of Technology Madras



Associate Editor



Bhaskar Ramamurthi/V. Kamakoti

Thank you all

