



Since 1959

Affordable clean water using advanced materials

T. Pradeep

Institute Professor, IIT Madras

pradeep@iitm.ac.in

<https://pradeepresearch.org>

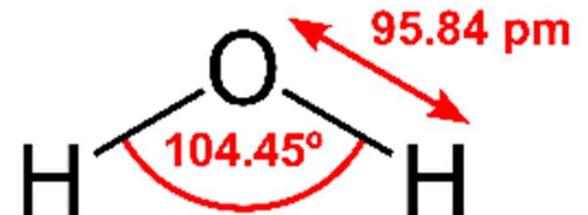
Co-founder

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



Thin Film Nanostructured Membranes for Gas Separation, Storage and Water Desalination, Online Workshop, Jan. 19 – 21, 2022, Organised by IISc., Bengaluru

The truth

Our economic, social and cultural outcomes can be traced to water.

Water is the simplest and simultaneously the most complex problem of humanity.

Everything simplifies to water.

There is water in everything we do.



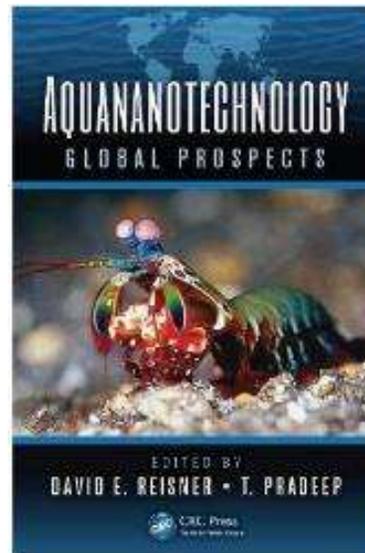
Water purification, history

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)

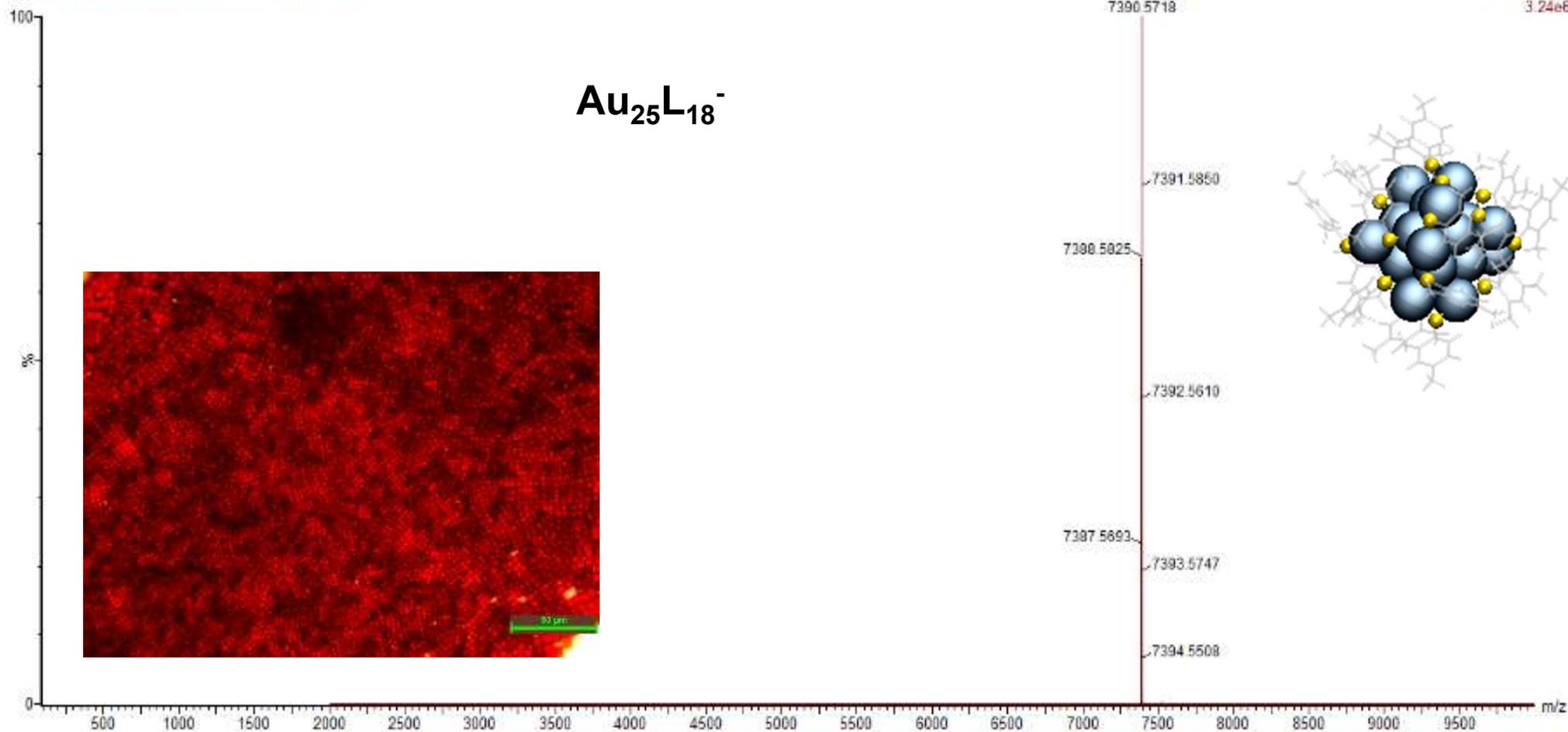
Affordable clean water is a problem of advanced materials

- 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.

Nanomaterials can solve real problems



ACS Sustainable Chemistry & Engineering Editorial, December 2016

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

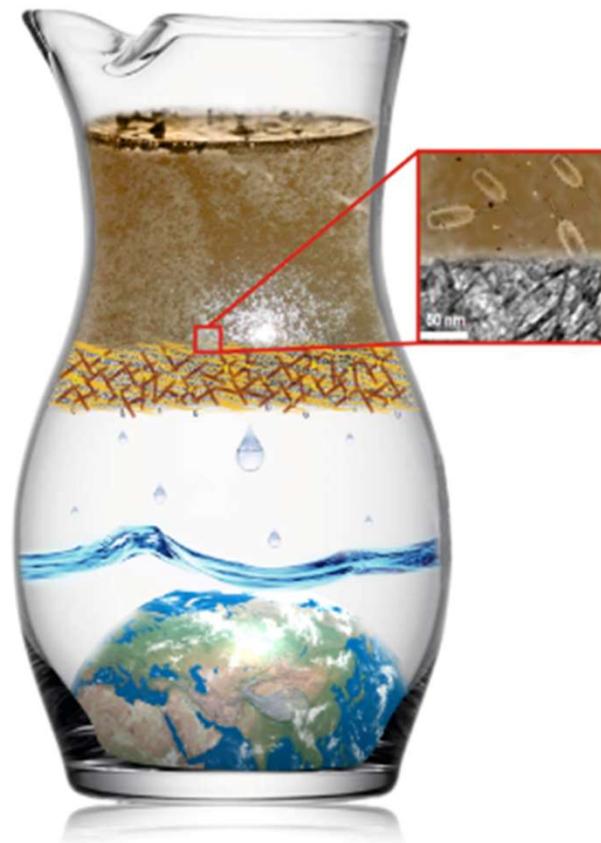
Mohan Udhaya Sankar¹, Sahaja Aigal¹, Shihabudheen M. Maliyekkal¹, Amrita Chaudhary, Anshup, Avula Anil Kumar, Kamalesh Chaudhari, and Thalappil Pradeep²

Unit of Nanoscience and Thematic Unit of Excellence, Department of Chemistry, Indian Institute of Technology Madras, Chennai 600 036, India

Edited by Eric Hoek, University of California, Los Angeles, CA and accepted by the Editorial Board April 4, 2013 (received for review November 21, 2012)

Creation of affordable materials for constant release of silver ions in water is one of the most promising ways to provide microbially safe drinking water for all. Combining the capacity of diverse nanocomposites to other contaminants, these materials can be synthesized out of the use of sand-like porous forms. These nanocomposites can be used as a water purifier in rural areas. The ability to purify water at ambient temperature is a significant advantage for water purification in rural areas.

hybrid | green |

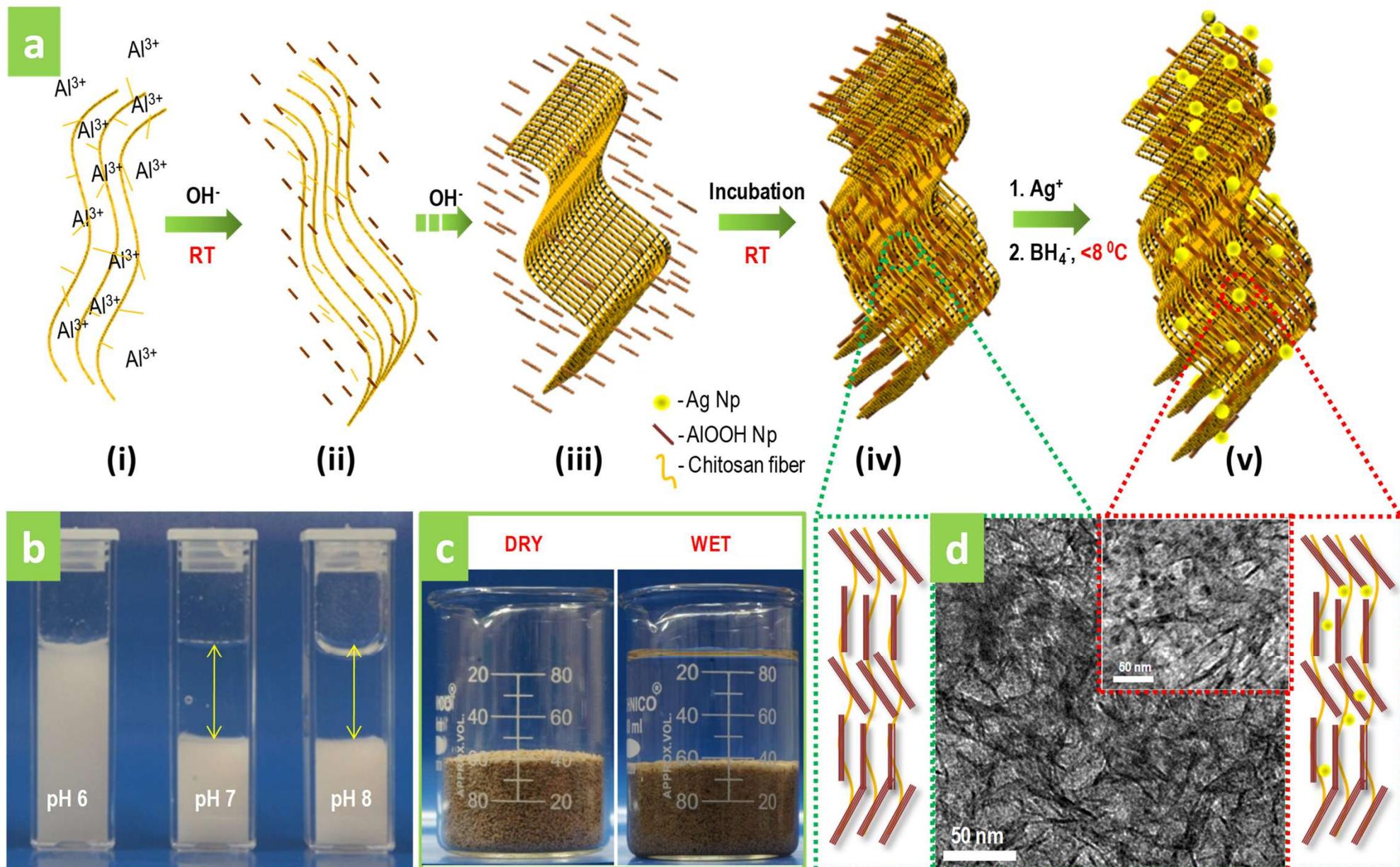


release into water are not available; and (c) continued retention of the nanoparticles in the matrix is difficult.

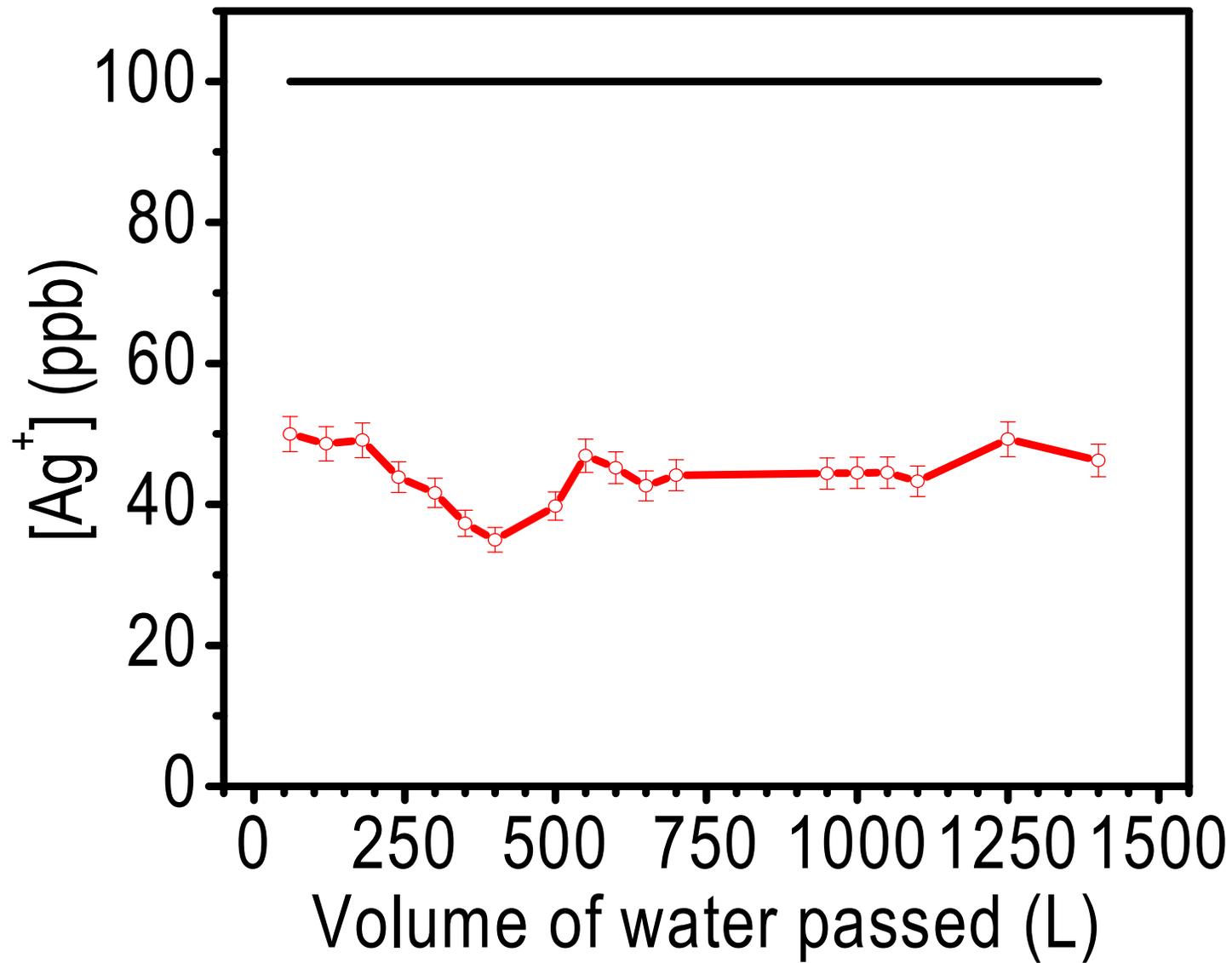
In this work, we demonstrate a unique family of nanocrystalline metal oxyhydroxide-chitosan granular composite materials prepared at near room temperature through an aqueous route. The degree of crystallinity in the composition is attributed to abundant $-OH$ functional groups on chitosan, which help in the crystallization of metal oxyhydroxide and also ensure strong covalent binding of the nanoparticle surface to the matrix. X-ray photoelectron spectroscopy (XPS) confirms that the composition is rich in surface hydroxyl groups. Using hyperspectral imaging, the presence of nanoparticle leaching in the water was confirmed. Further, a unique scheme to reactivate the silver nanoparticle surface is used for continual antimicrobial activity in drinking waters. Several other composites have been developed that can remove other contaminants in water. We demonstrate an affordable water purification device based on such composites developed over several years and undergoing field trials in India, as a potential solution for widespread eradication of the waterborne disease burden.

Results and Discussion

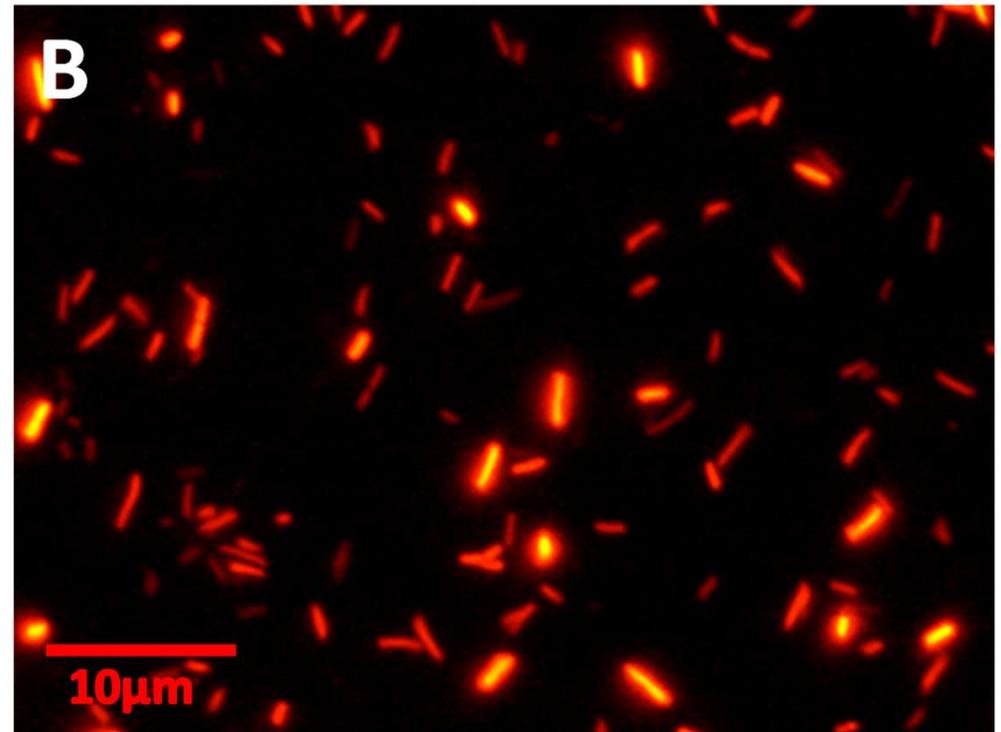
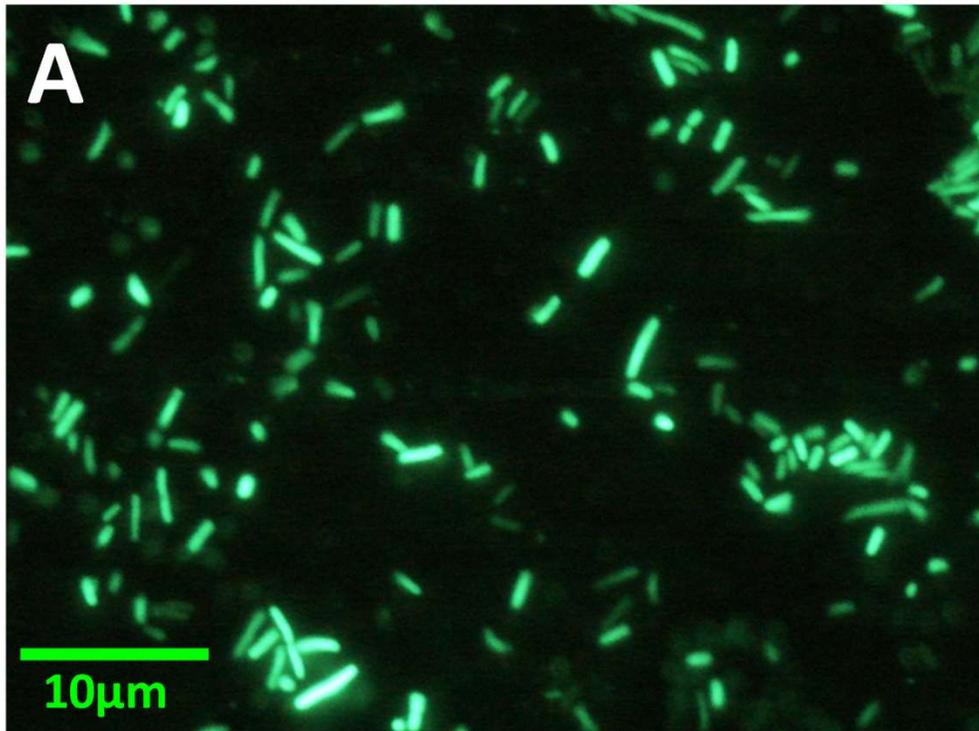
New materials

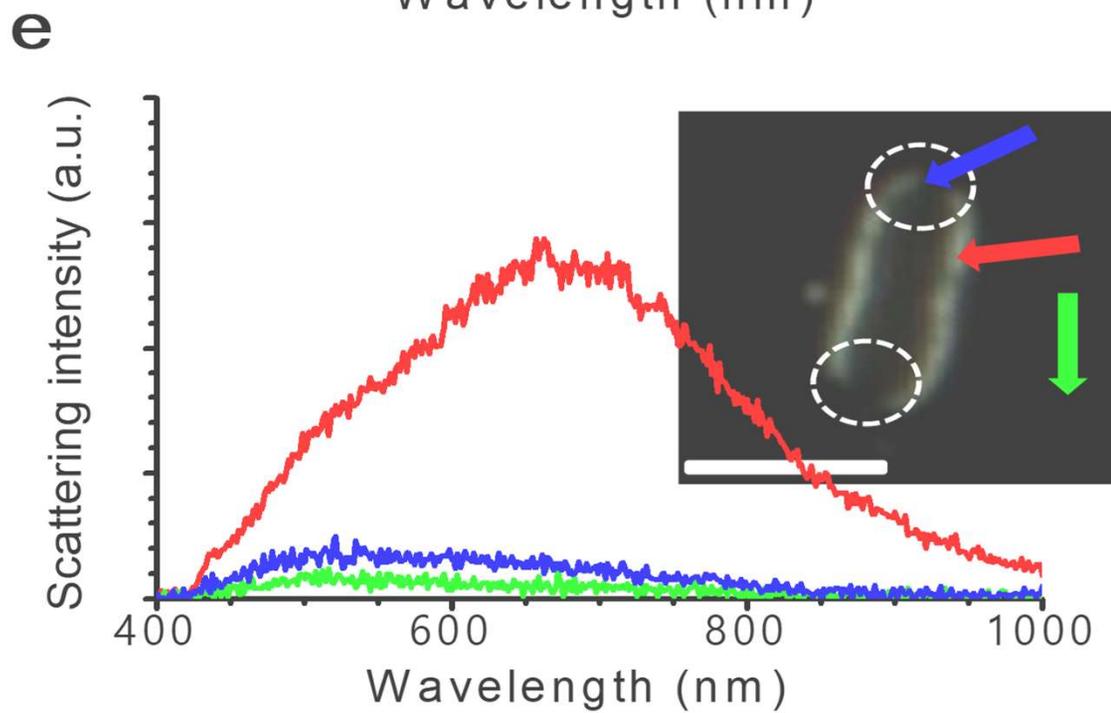
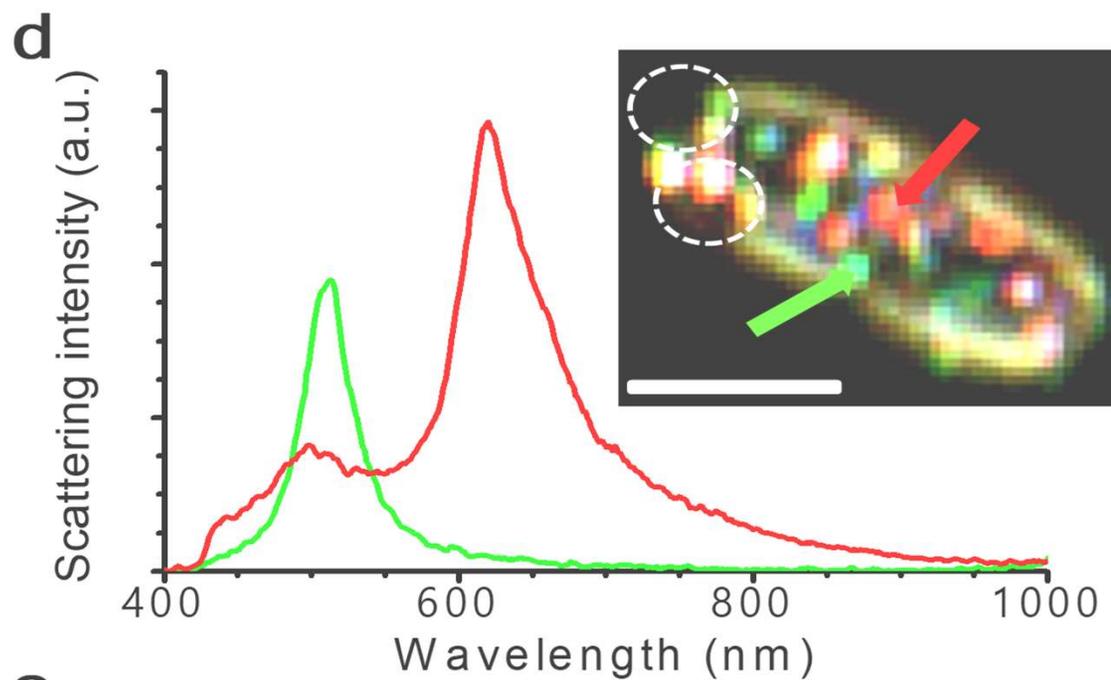
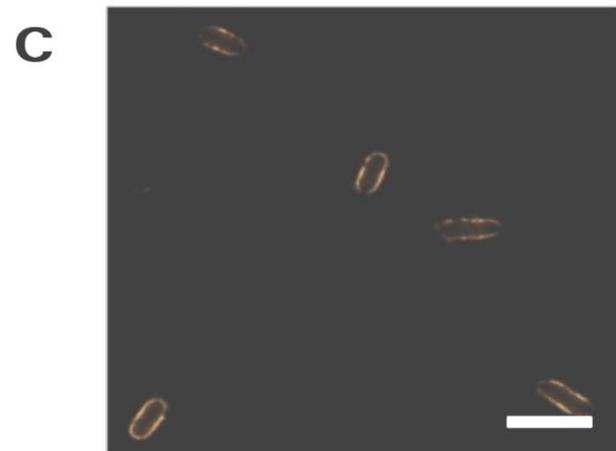
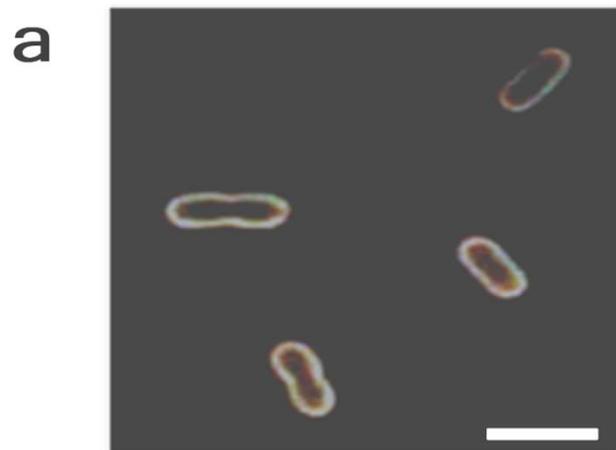


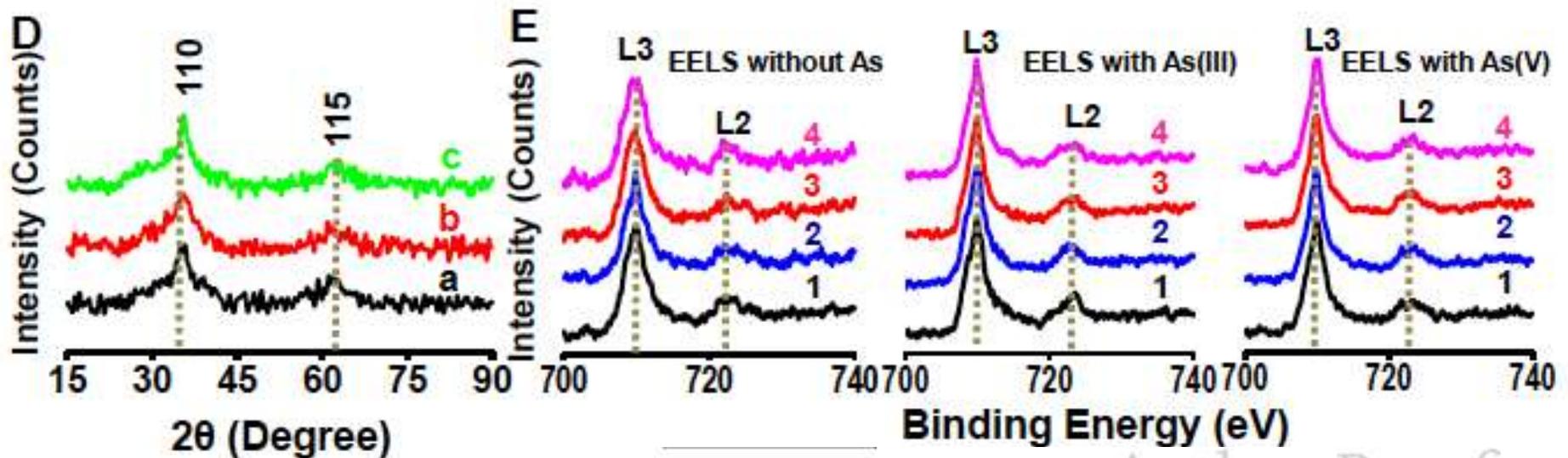
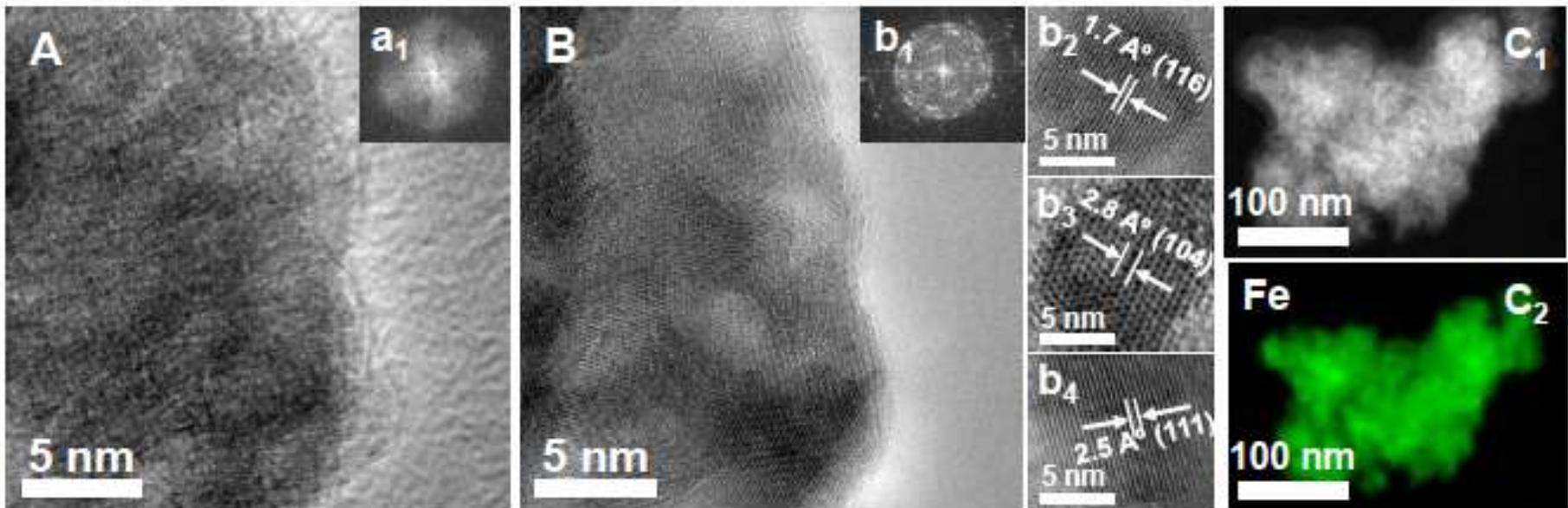
What is special?



Live/dead staining experiments







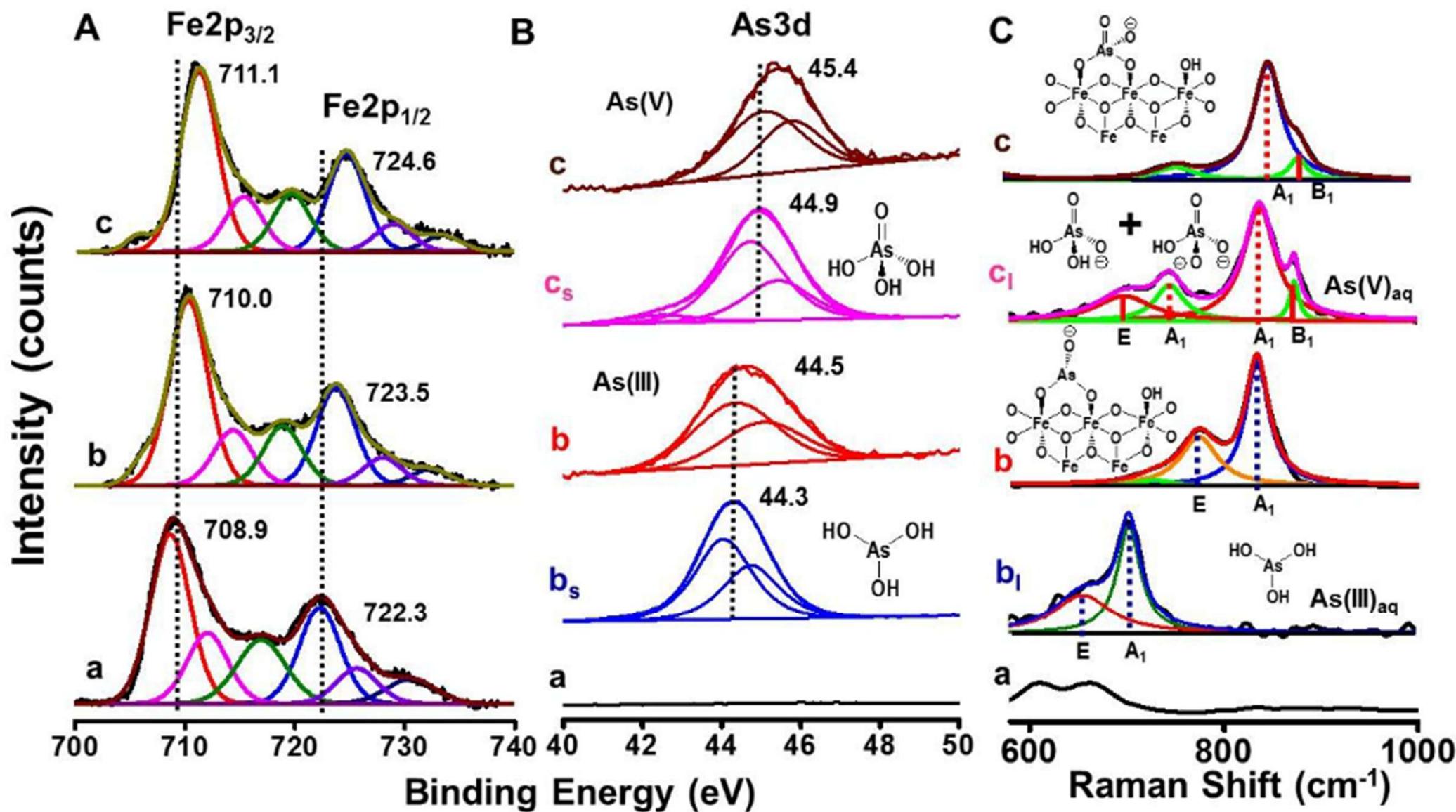
www.advmat.de

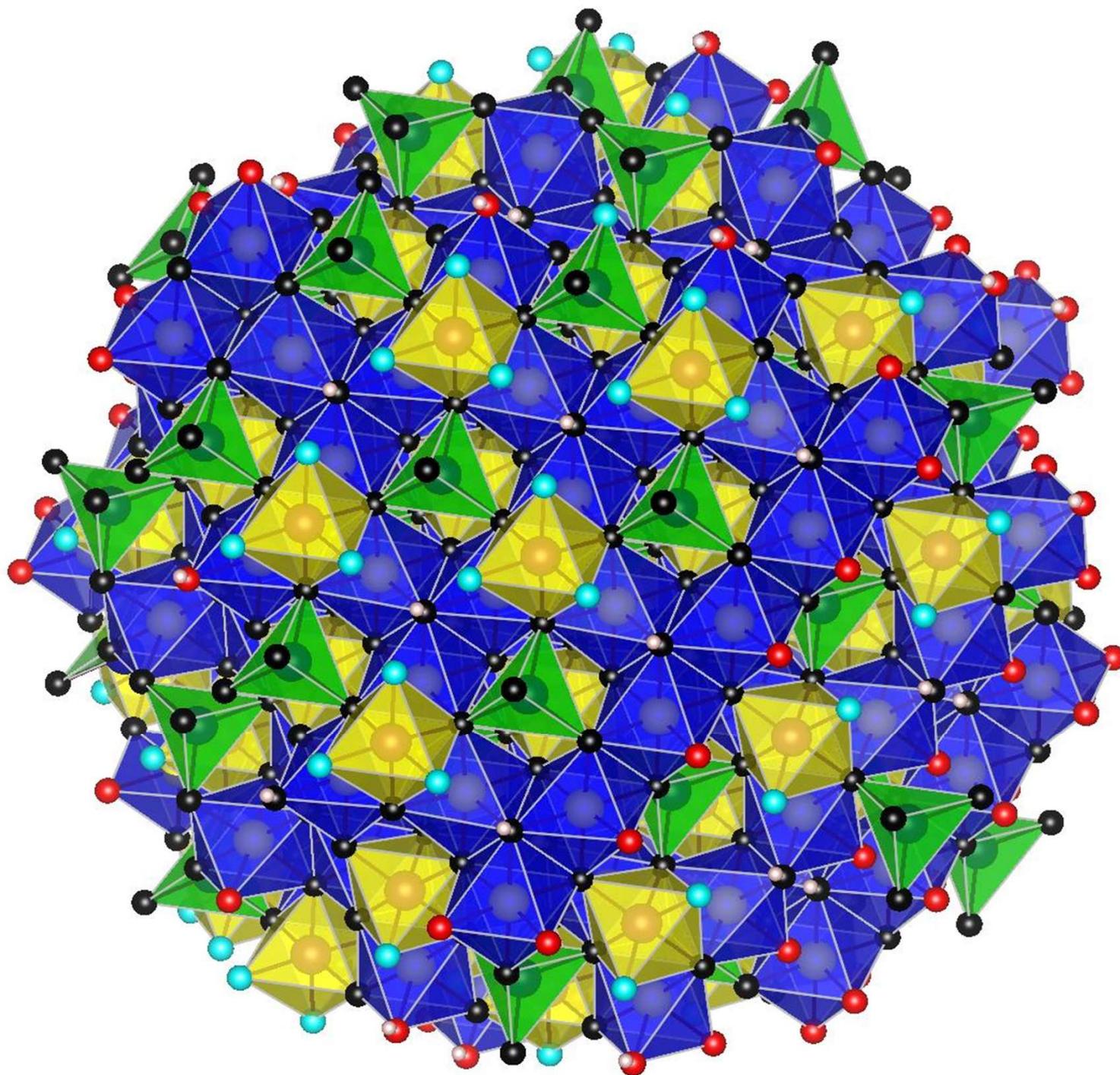
Author Pr ⁶ ADVANCED MATERIALS

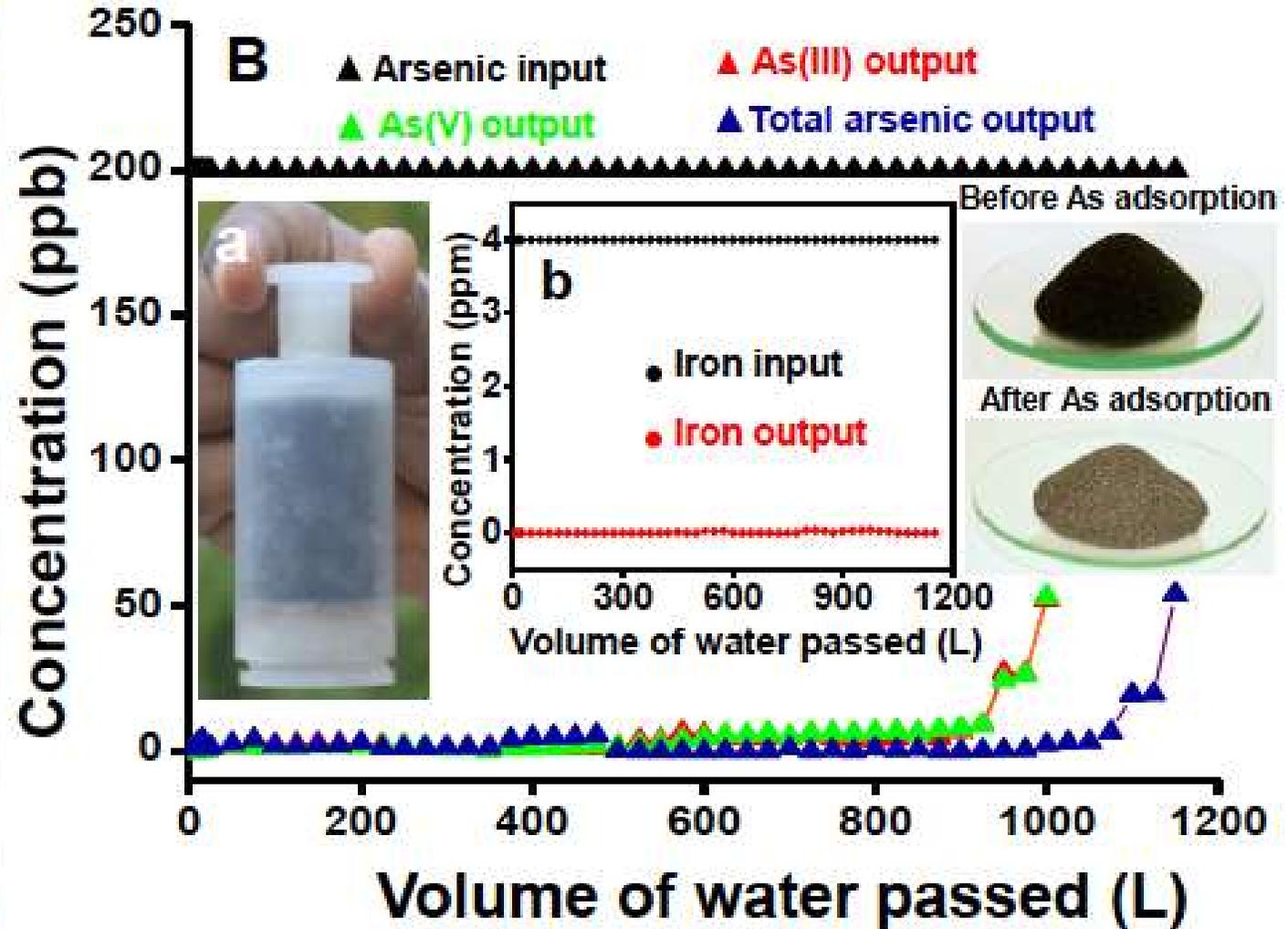
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

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*

Mechanism







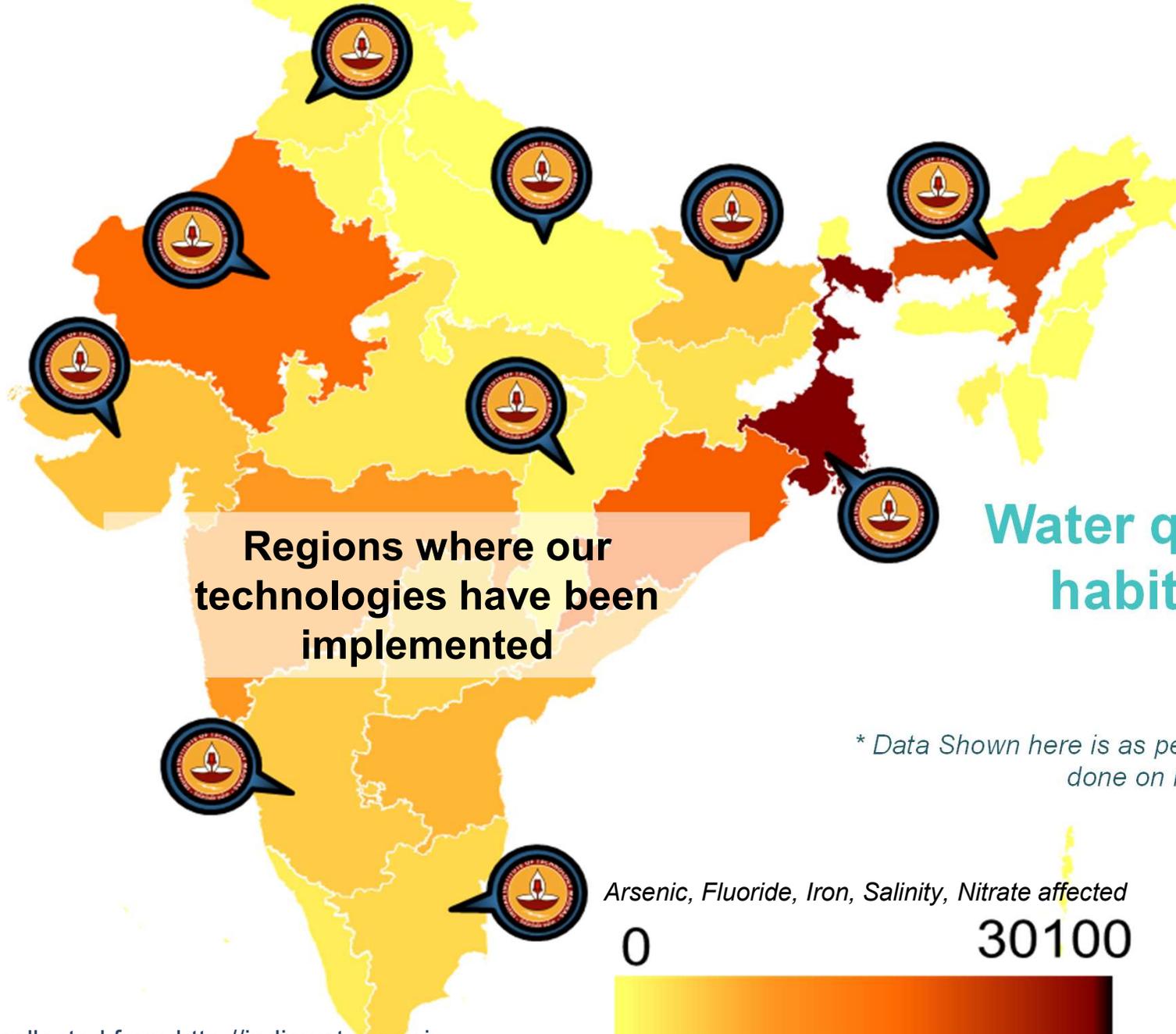
Changing the dynamics in the field



- 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

OUR REACH



Water quality affected habitations of India

* Data Shown here is as per laboratory testing results entry done on regular basis hence may change

Collected on 29.05.2018

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)

Seeing how the new adsorbents are changing the dynamics at the ground level (type 1 of our efforts)



Name of the scheme: Mahilan Wala (TW9144), District: Amritsar
Population: 2610, Daily demand@70 LPCD: 188 kLD, OHSR Capacity:
100 kL

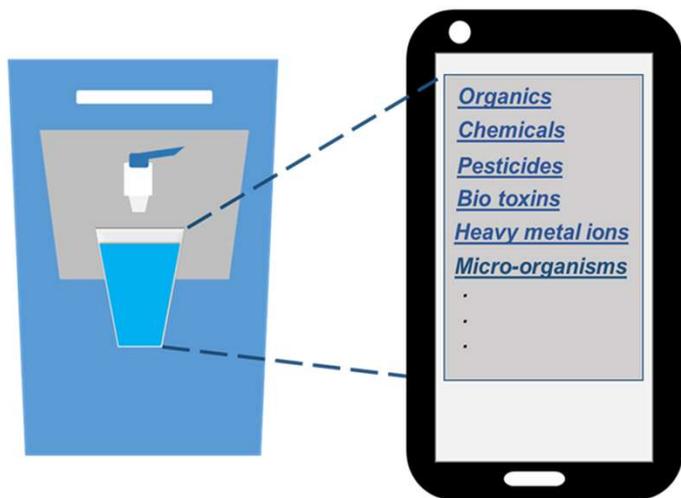
Cleanwater at 2.1 paise per litre!

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

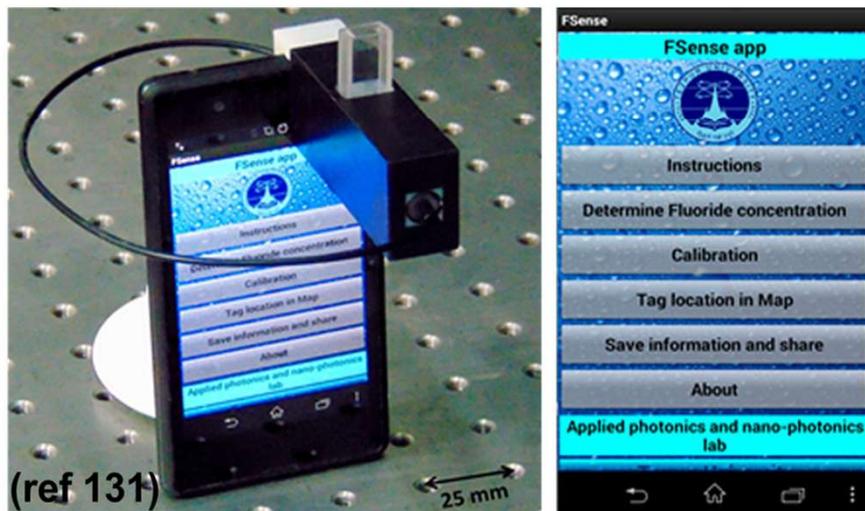
Sr.No	Design population	1,071	Plant capacity/70 LPCD
	Item/Description	Cost / Quantity	Remarks
1	Cost of Replacement of Iron removal media	56400	After minimum two years if Iron concentration is more than 5 ppm. But iron concentration is more than 5 ppm at only two to three places. Therefore media may 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	
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

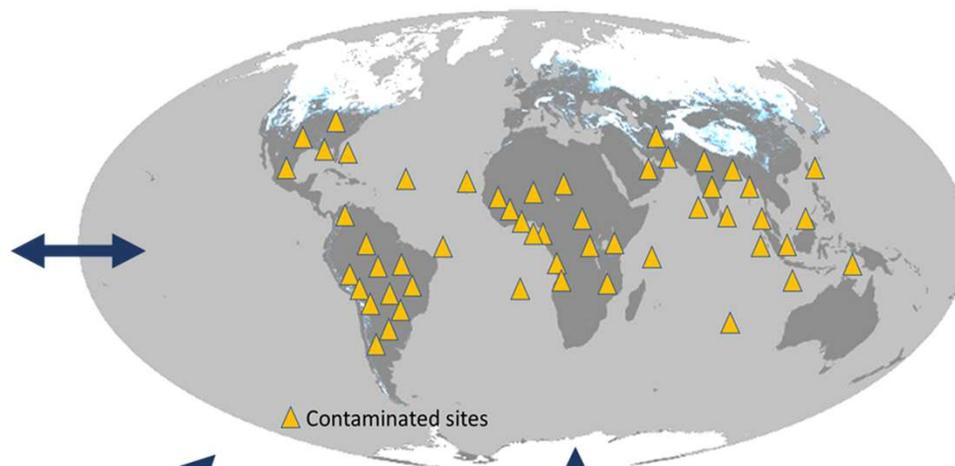
Smart Water Purifiers linked to IoT



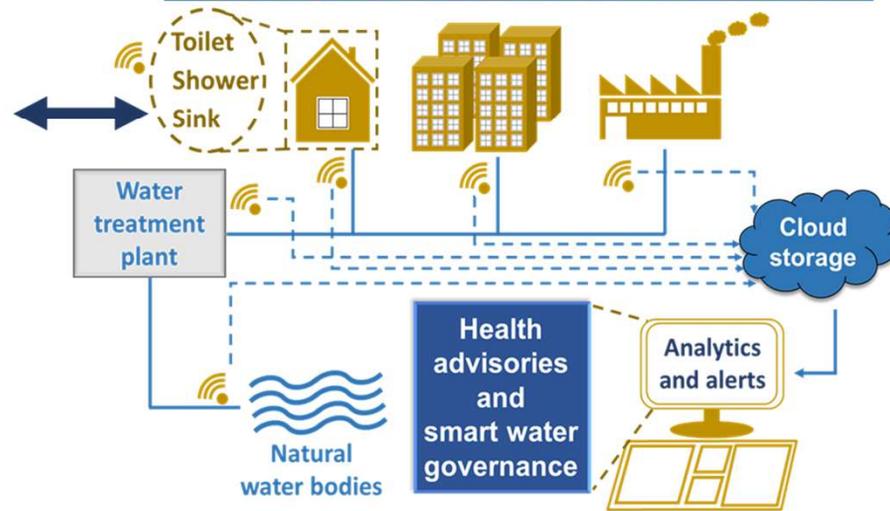
Cost-effective sensor accessory for point-of-use applications



Global Map of Water Health

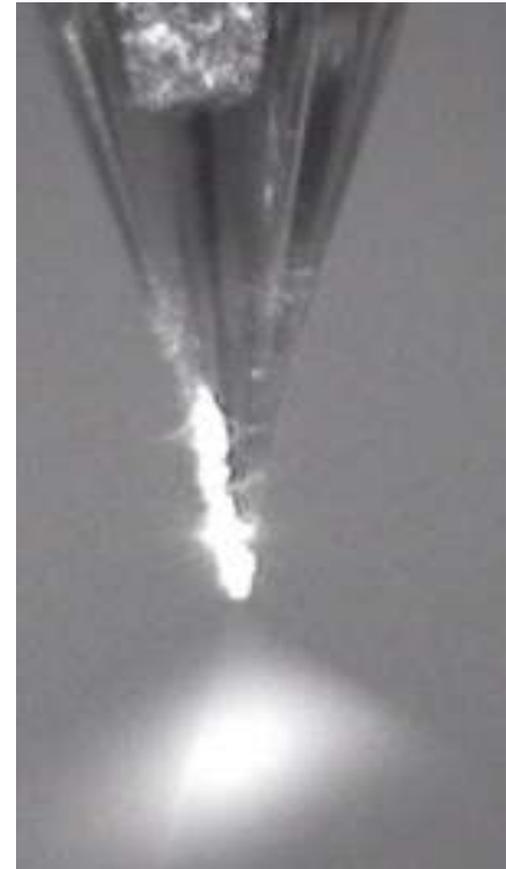
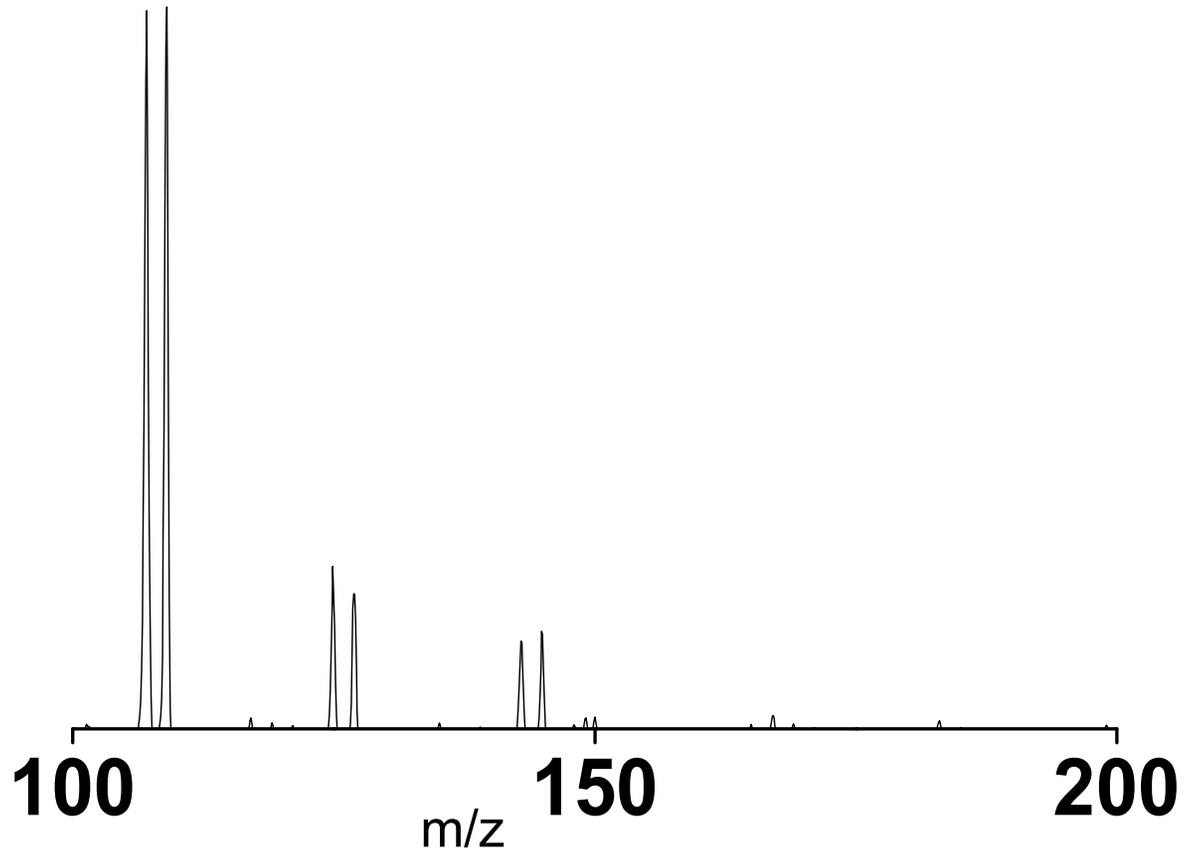


IoT-enabled sensing for households and distribution networks

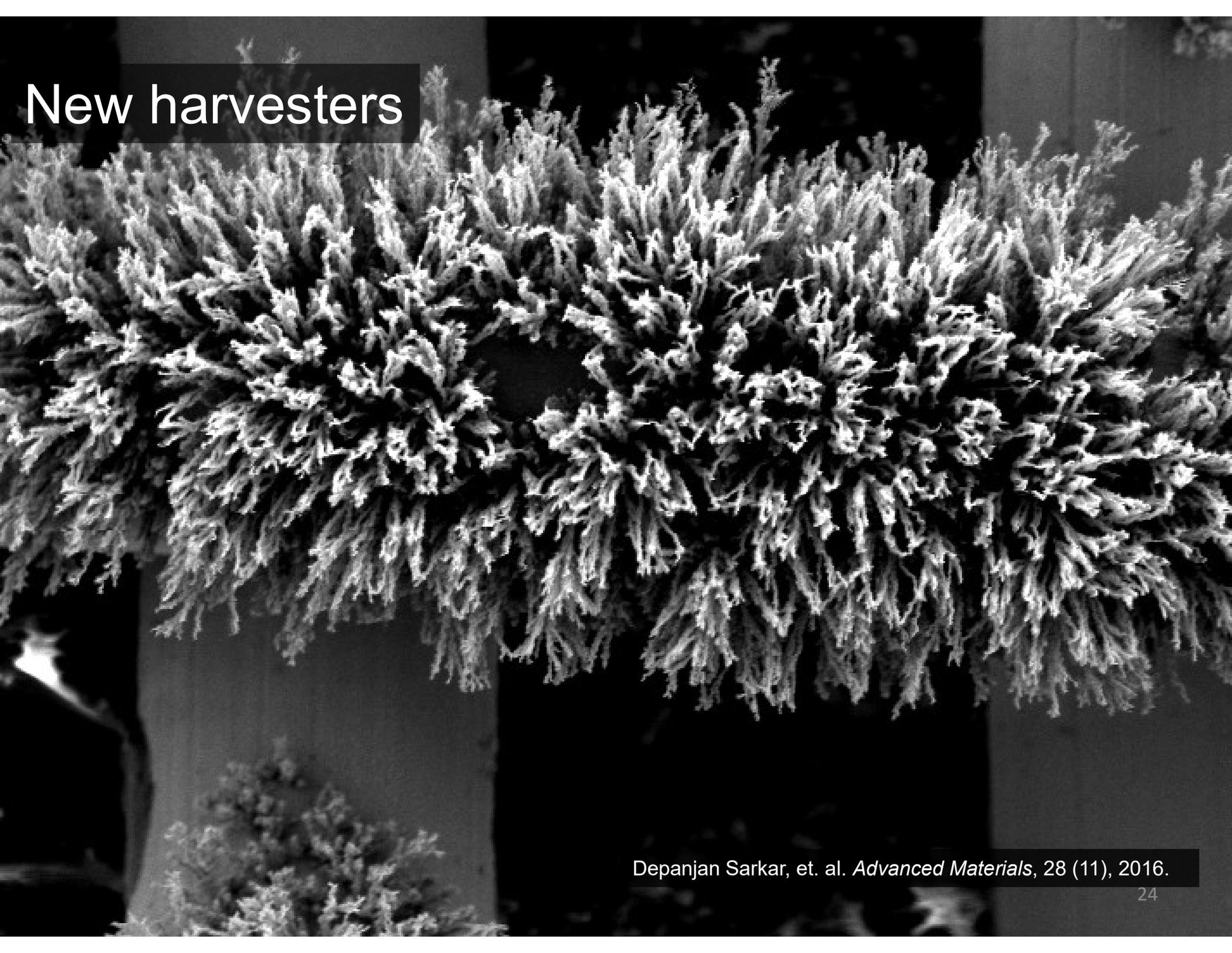




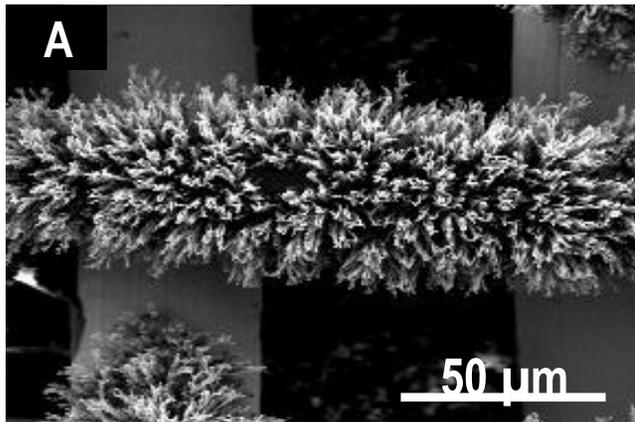
Atmospheric water harvesting



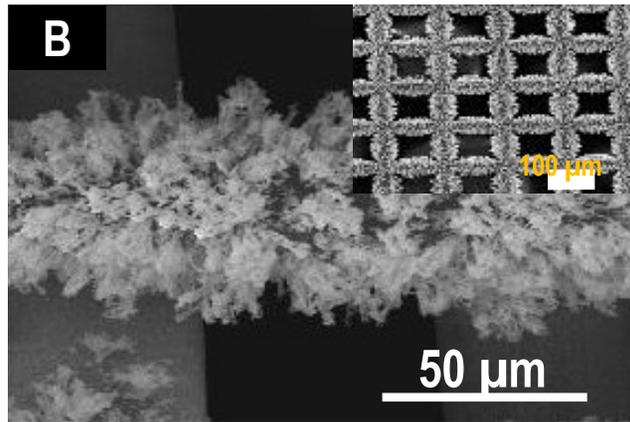
New harvesters



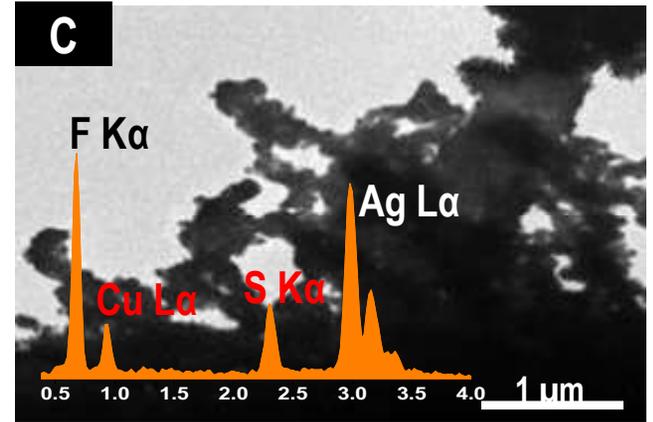
Depanjan Sarkar, et. al. *Advanced Materials*, 28 (11), 2016.



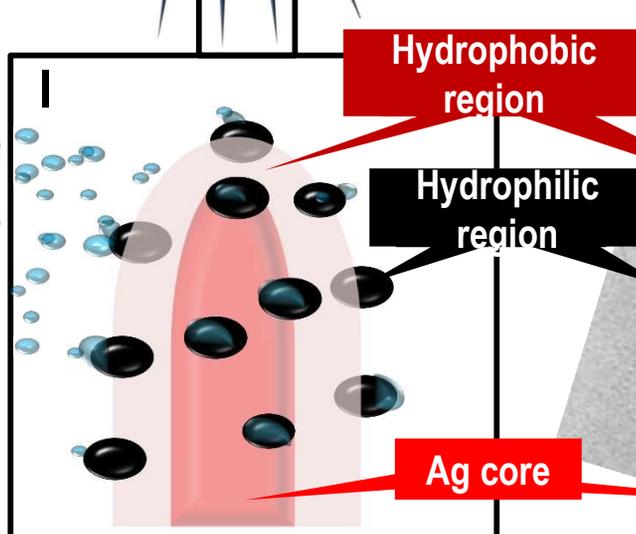
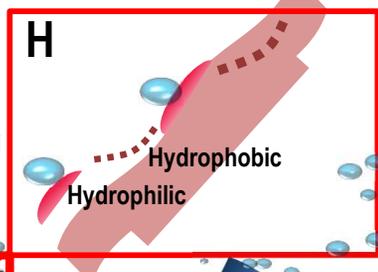
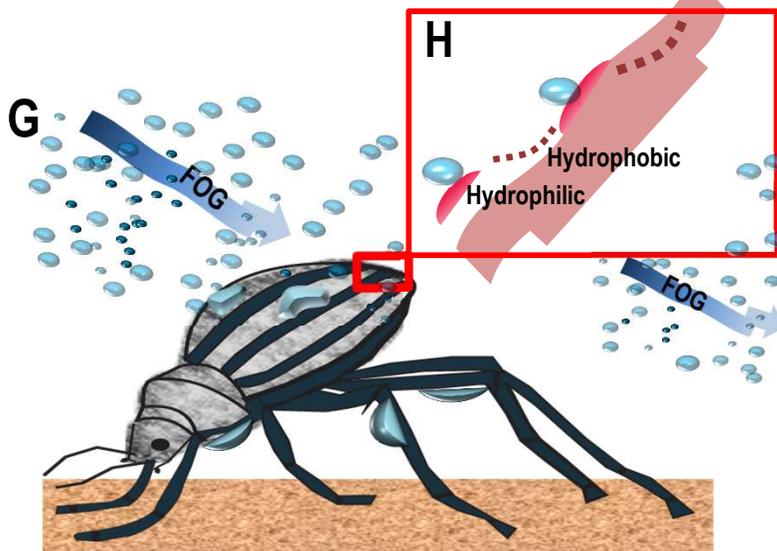
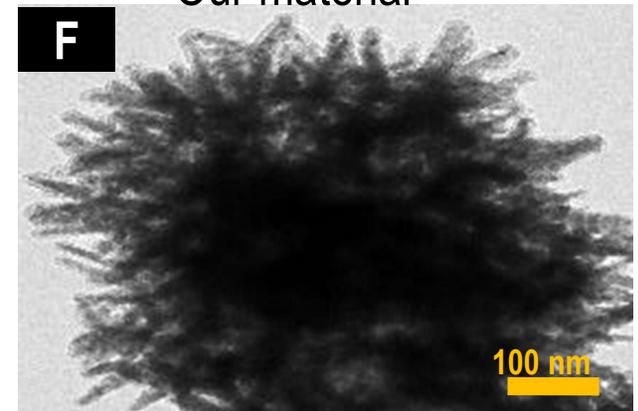
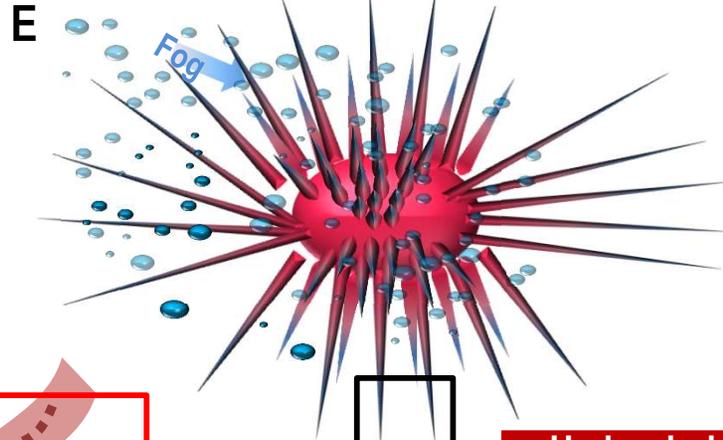
Nature



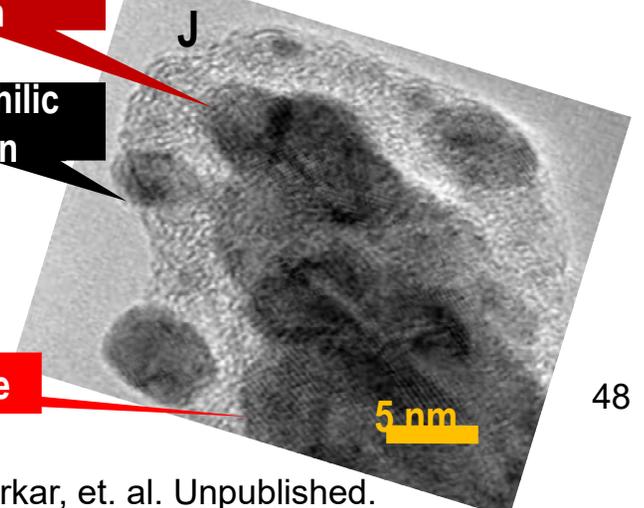
Schematic

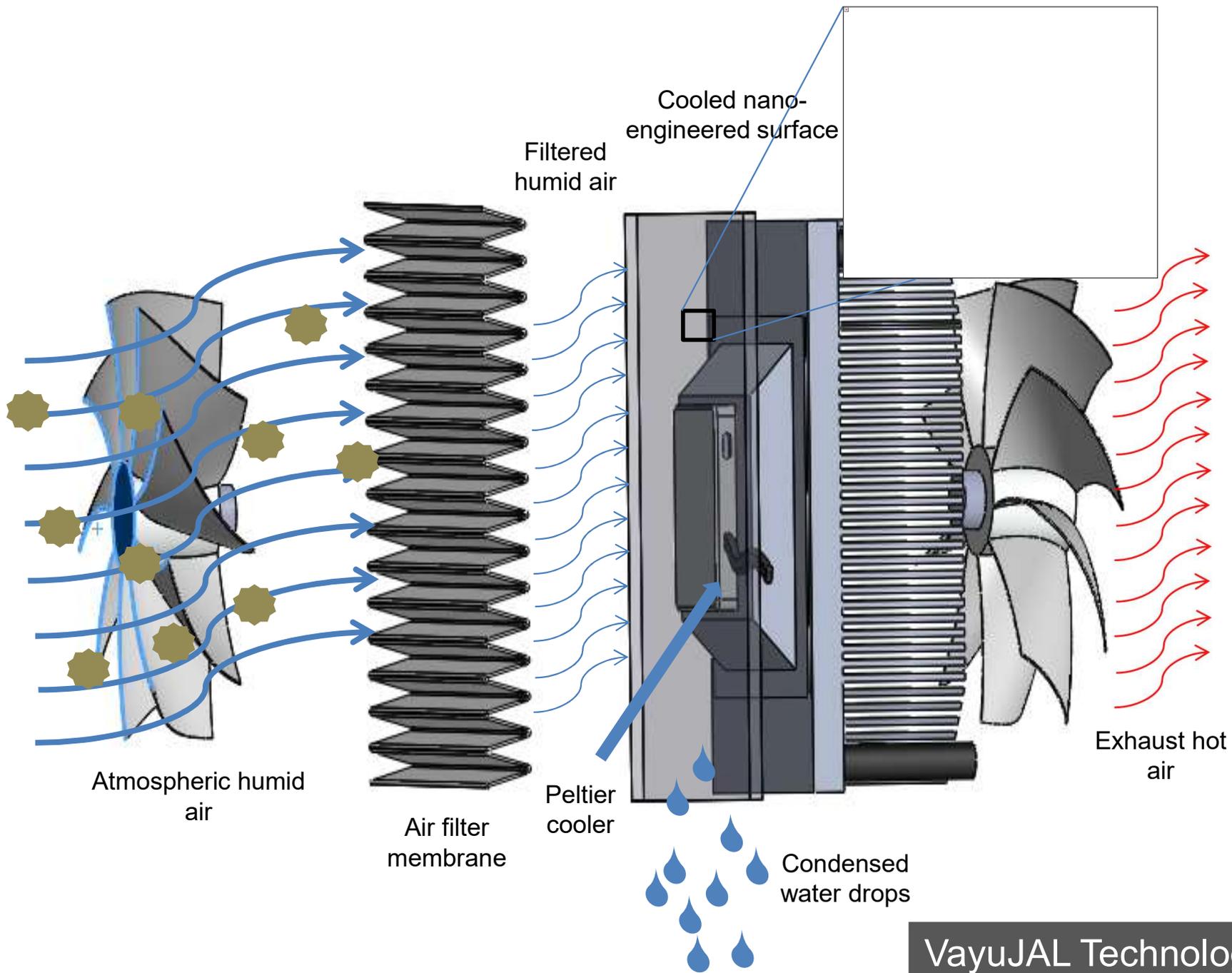


Our material



Combination of cactus and Namib desert beetle effect





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

Products in the field



35 LPD 120 LPD

400 LPD

1000 LPD

2000 LPD

(LPD: Litres per day)



THE HINDU

CHENNAI
A time



SHRBY ARTICL

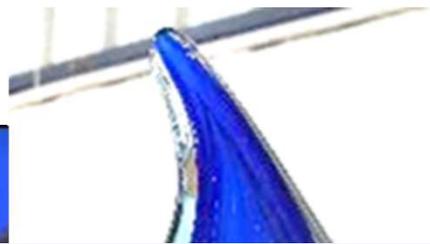
by Sw



If there
scorest
Then the answ
Ramesh Kum
togethe
clean th
about
-Fac

A
studies of the
environmental
concerns like
from being
water crisis
in that area
in which
dependence
the air
the air
water at
economy
benefit
atmospheric
water crisis

Mandir celebrated their golden jubilee reunion
an atmospheric water generator (AWG) to their
potable water with the moisture in the air.



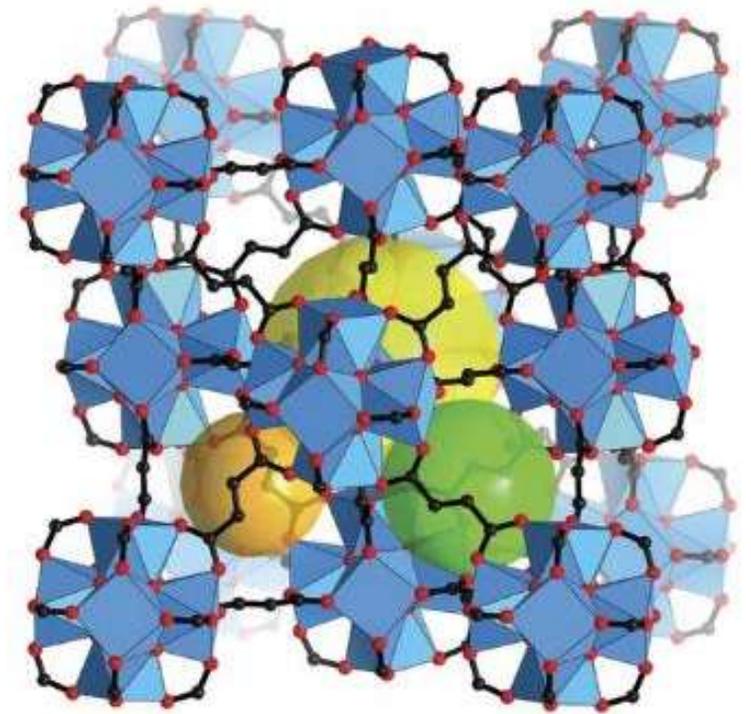
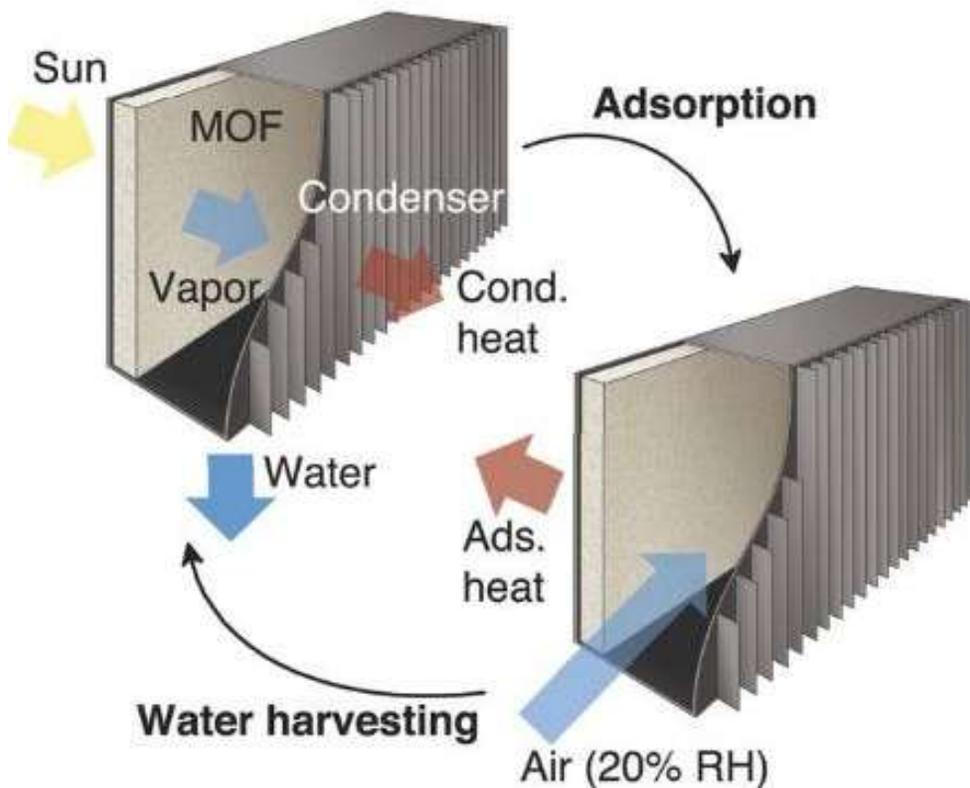
'VAYUJAL MISSION OF IIT-MADRAS IS SIGNIFICANT'



PROF. K. VIJAYRAGHAVAN
Principal Scientific Advisor
Govt of India

Sustainable atmospheric water harvesting

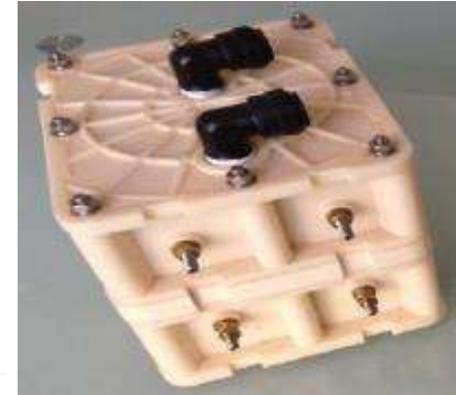
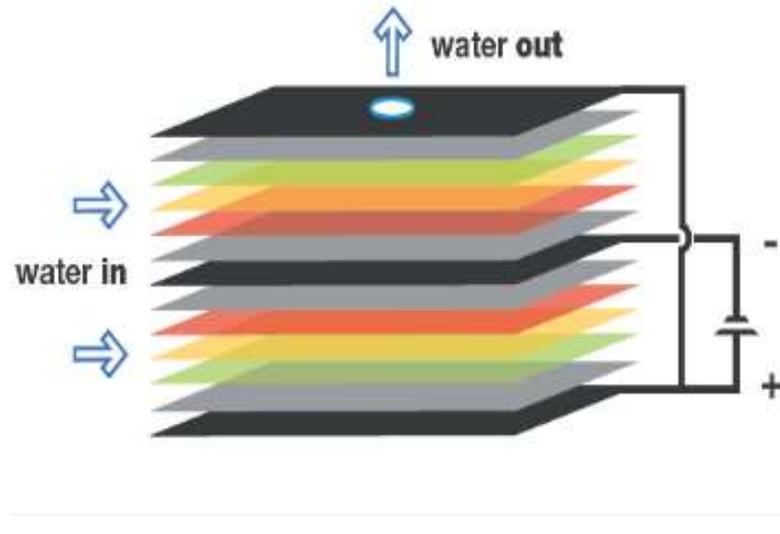
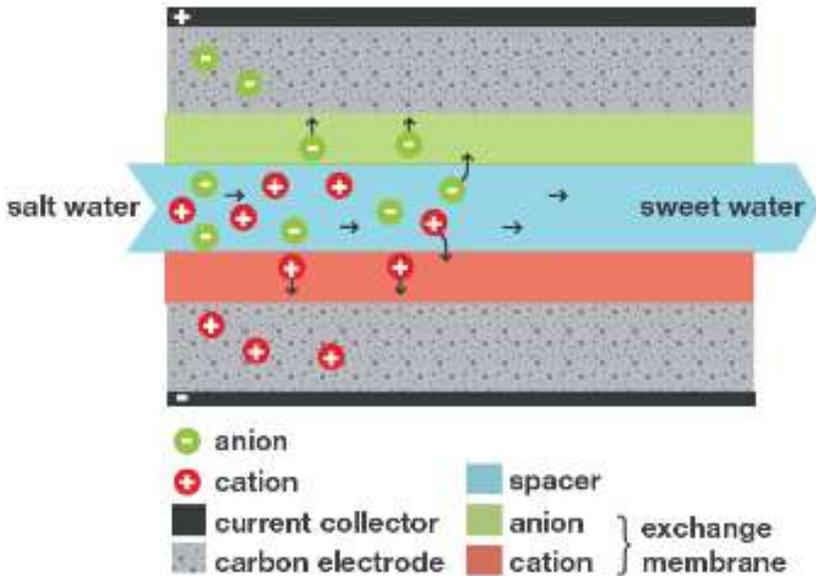
Solar- heat-enabled atmospheric water capture at a relative humidity as low as 20%



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

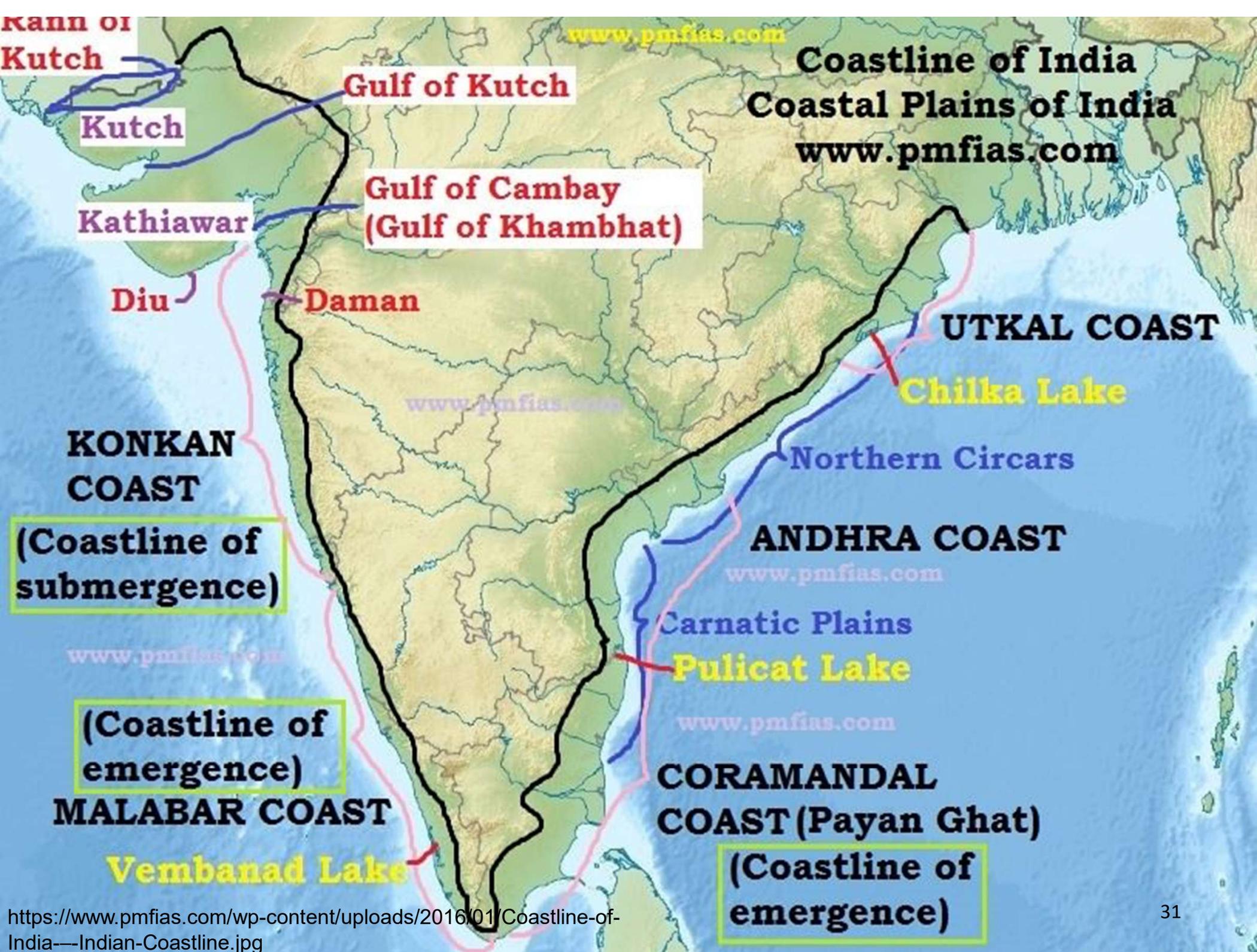
Kim Hyunho, et al. *Science*, 356 (6336) 2017

Capacitive Desalination (CDI)



Our new company

Soujit Sengupta, Rabiul Islam and others



Kann of Kutch

www.pmfias.com

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

Gulf of Kutch

Kutch

Gulf of Cambay
(Gulf of Khambhat)

Kathiawar

Diu

Daman

UTKAL COAST

Chilka Lake

KONKAN COAST

Northern Circars

(Coastline of submergence)

ANDHRA COAST

www.pmfias.com

www.pmfias.com

Carnatic Plains

Pulicat Lake

(Coastline of emergence)

www.pmfias.com

MALABAR COAST

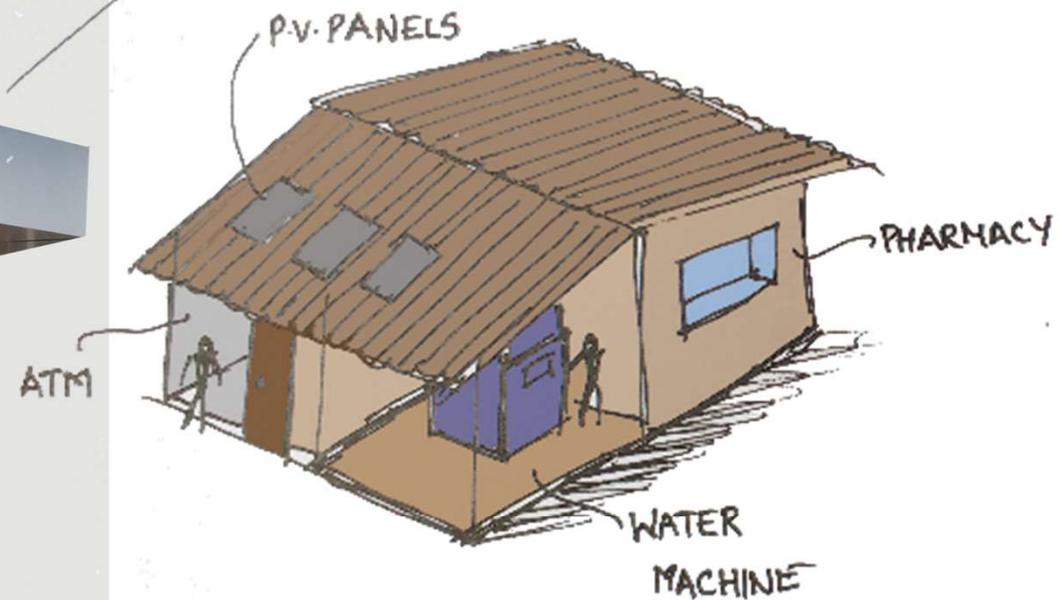
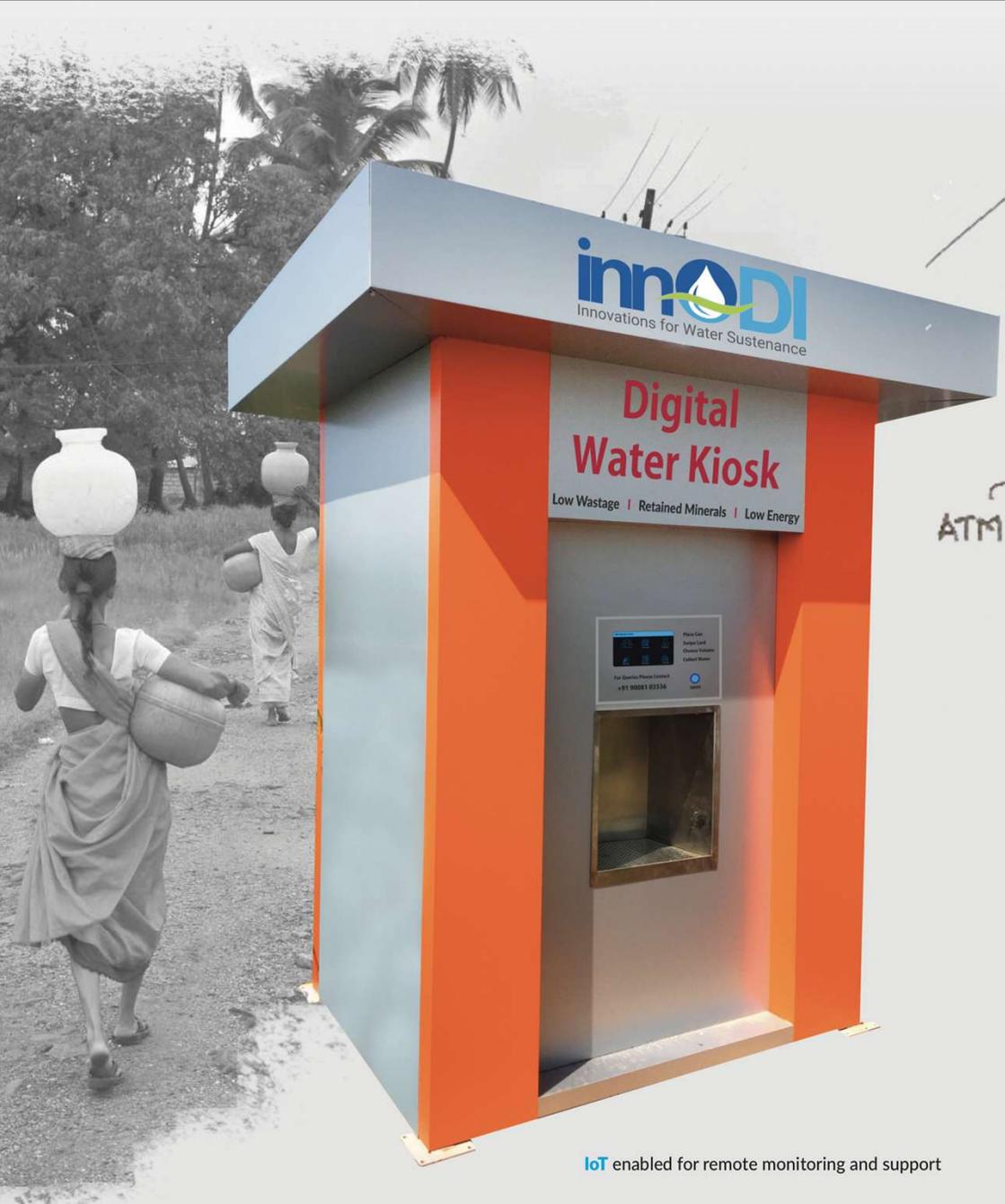
CORAMANDAL COAST (Payan Ghat)

Vembanad Lake

(Coastline of emergence)

DIGITAL WATER KIOSK

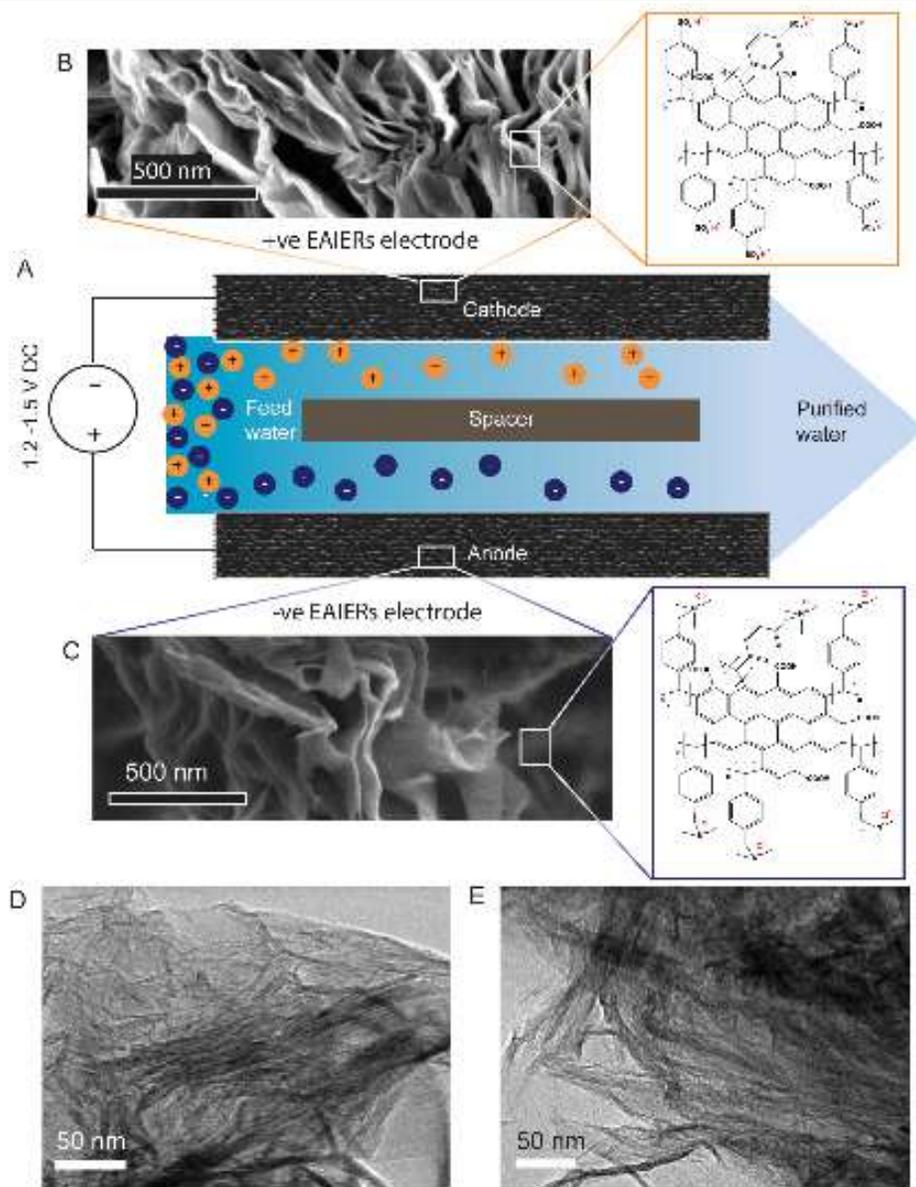
for community drinking using CDI Technology



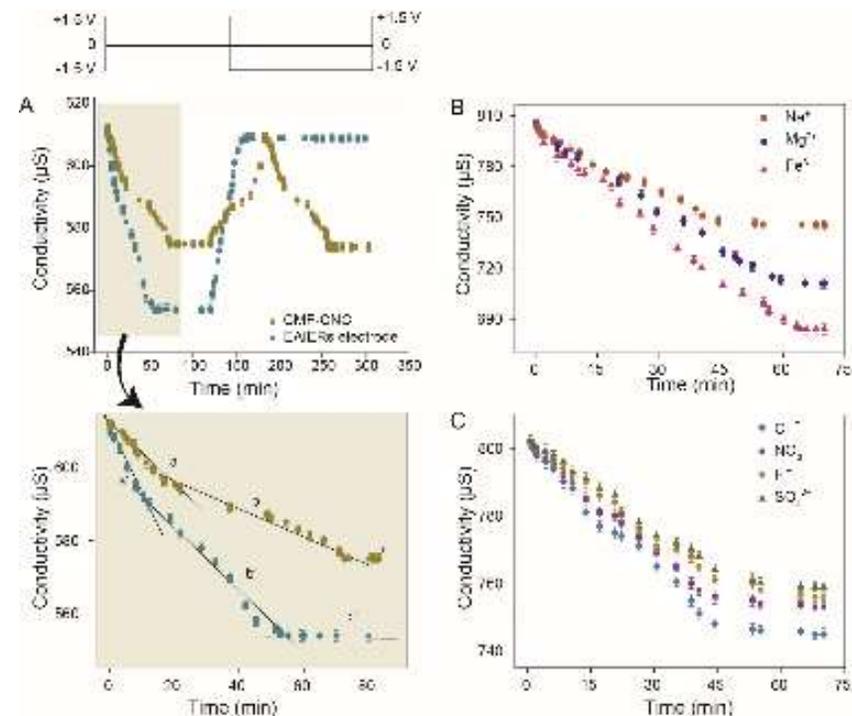
Products under implementation

Vijay Sampath and Tullio Servida

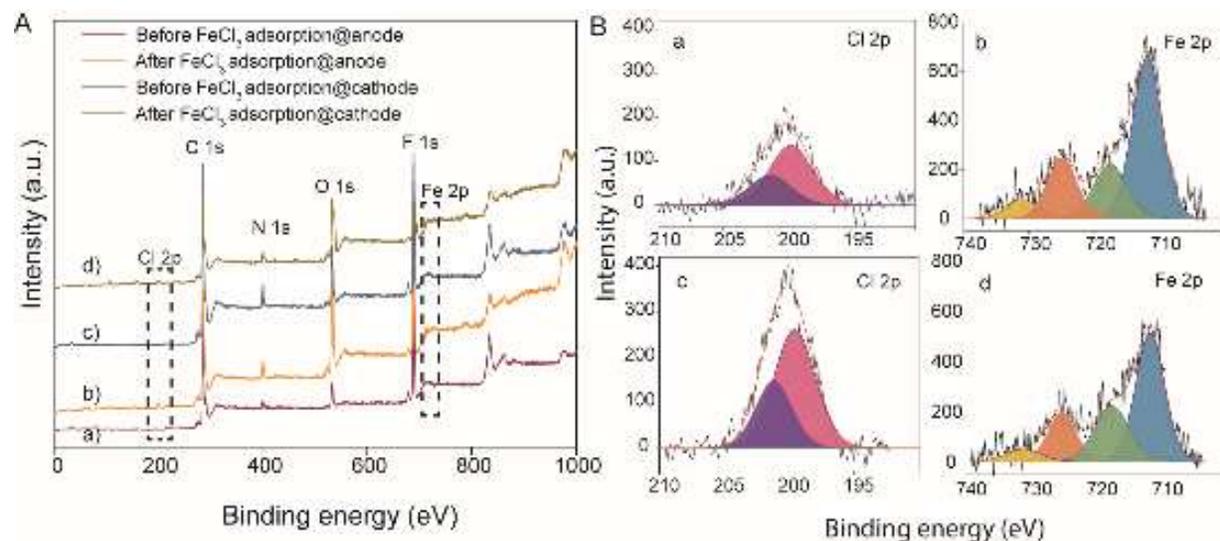
A Covalently Integrated Reduced Graphene Oxide -Ion Exchange Resin Electrode for Efficient CDI



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

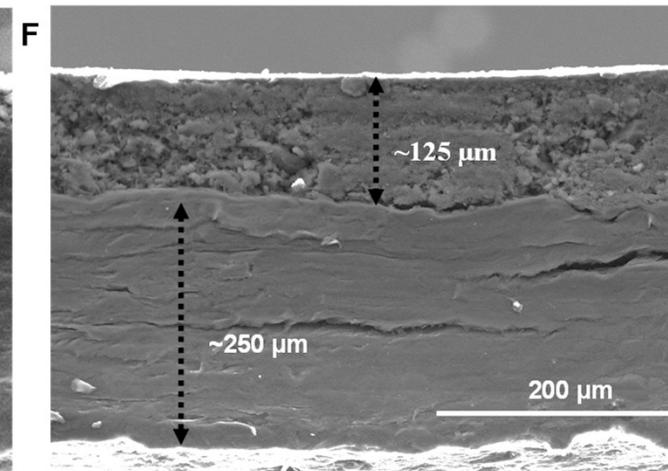
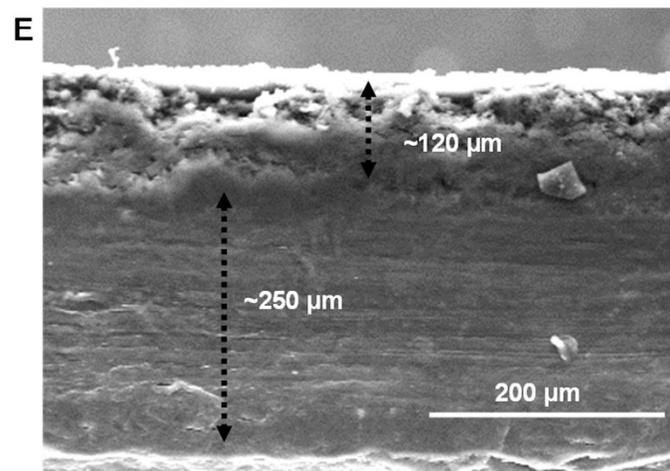
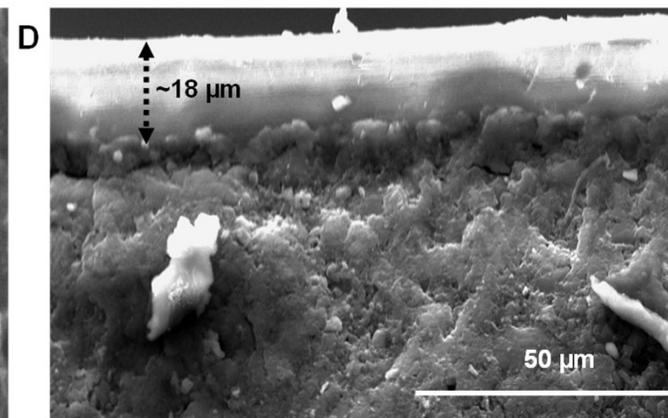
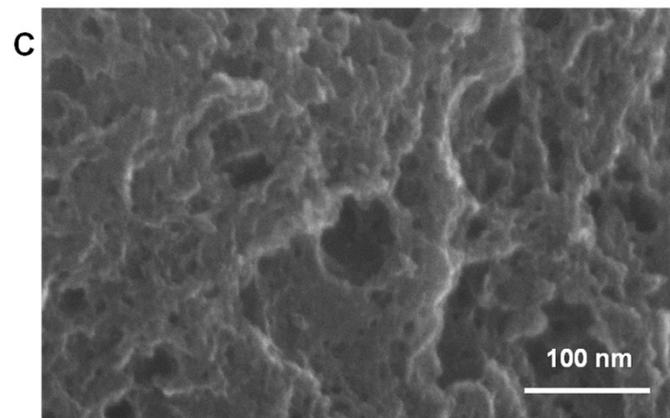
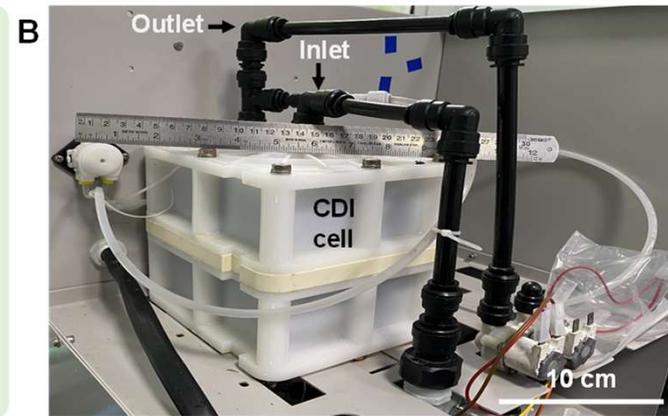
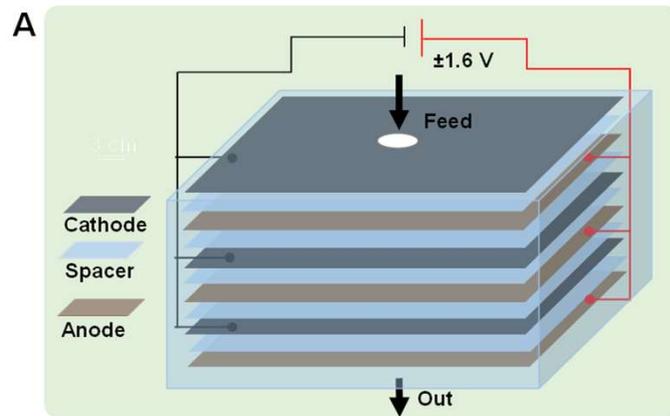


A) Comparison of CDI performance between covalently integrated EAIERs (rGO-PS functionalized) electrode and melamine-functionalized carbon nanocellulose (CMF-CNC) derived electrode in 610 μS NaCl solutions. Electrosorption kinetics for both the integrated EAIERs and CMF-CNC electrodes are shown in the expanded views below. Three distinct regimes of adsorption are shown, marked with a, b, and c, and a', b', and c' for CMF-CNF and EAIERs electrode, respectively. Variation in the potential of the electrodes with time is shown on top of the (A). CDI performances of EAIERs electrodes using different B) cations and C) anions with solution conductivity of 802 μS . The operating potential was maintained at 1.5 V during the measurements.

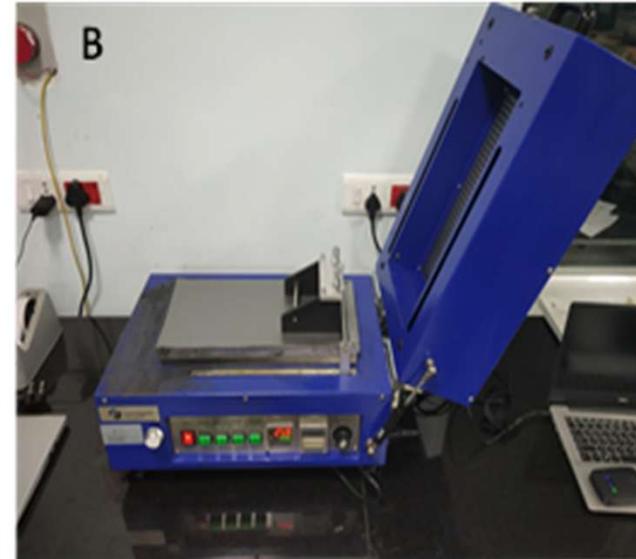
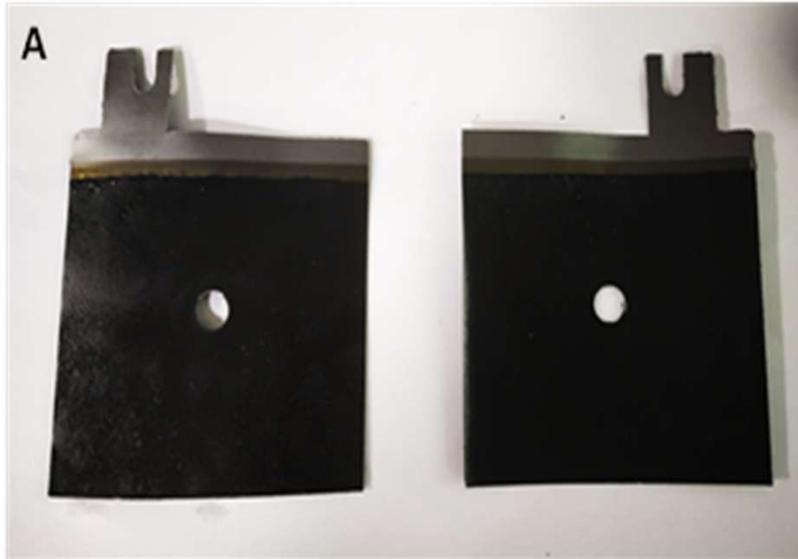


A) XPS survey spectra of the material after single adsorption, a) anode and c) cathode (before adsorption); b) anode and d) cathode (after FeCl_3 adsorption), and B) deconvoluted XPS spectra of a) Cl 2p, b) Fe 2p of the cathode and c) Cl 2p, d) Fe 2p of anode after adsorption of FeCl_3 . Peaks appearing at 717.35 eV (green) and 731.34 eV (yellow) are the satellite peaks of Fe 2p_{3/2} (blue) and 2p_{1/2} (brown), respectively.

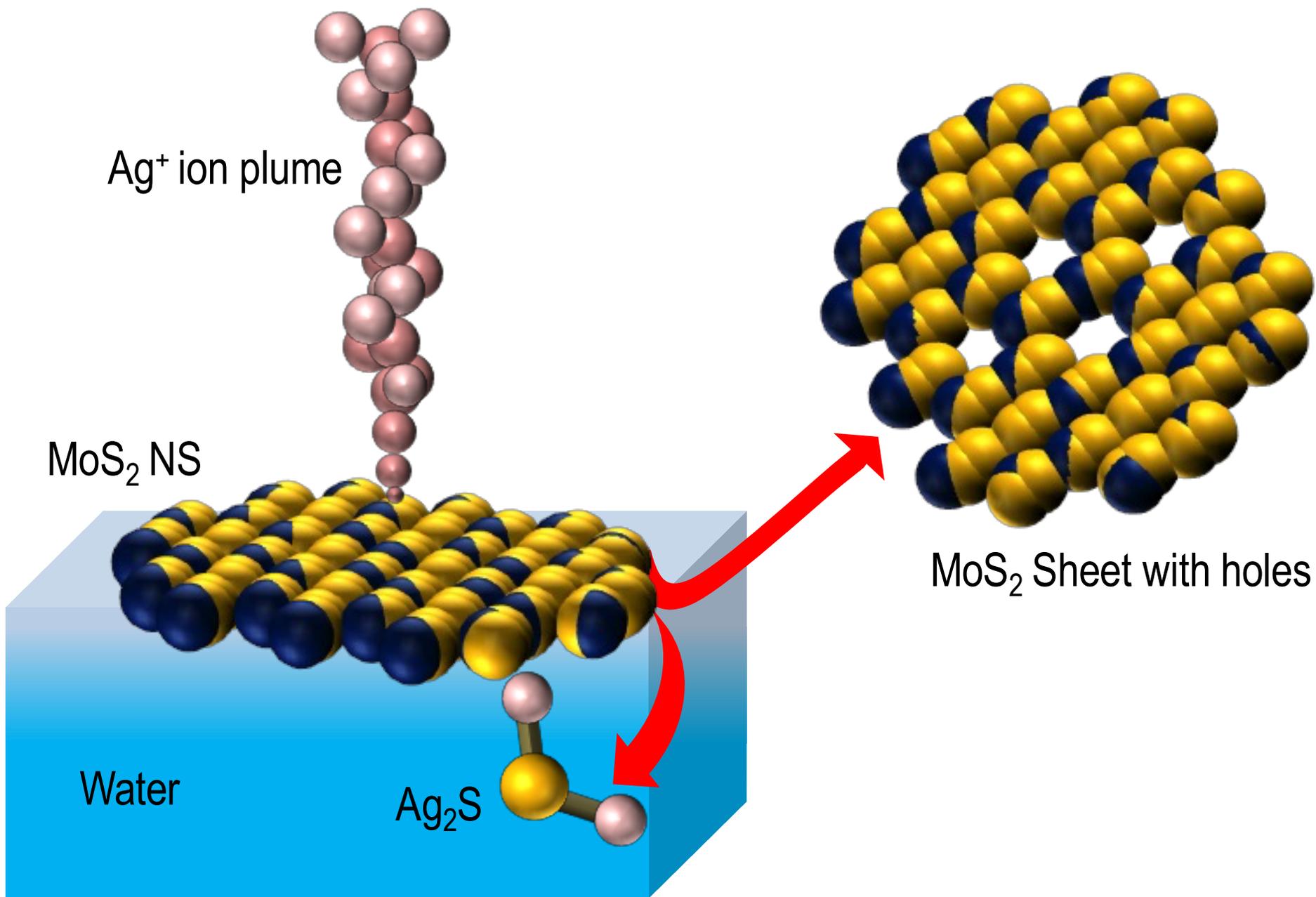
Industrial development

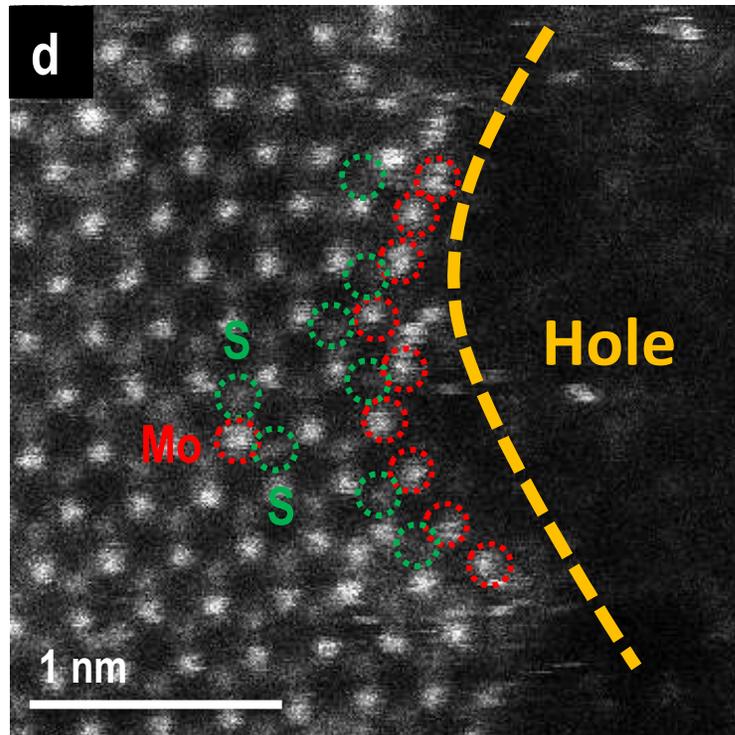
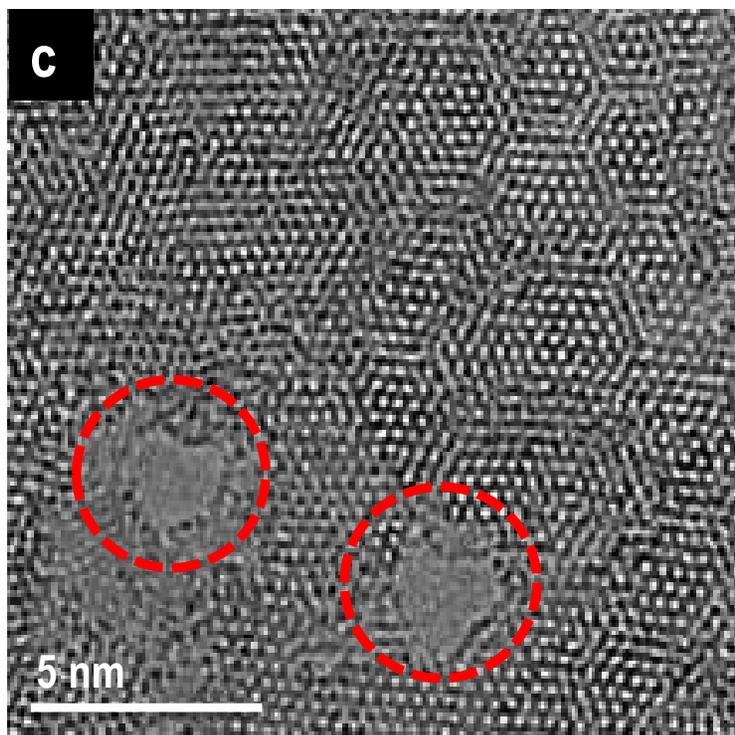
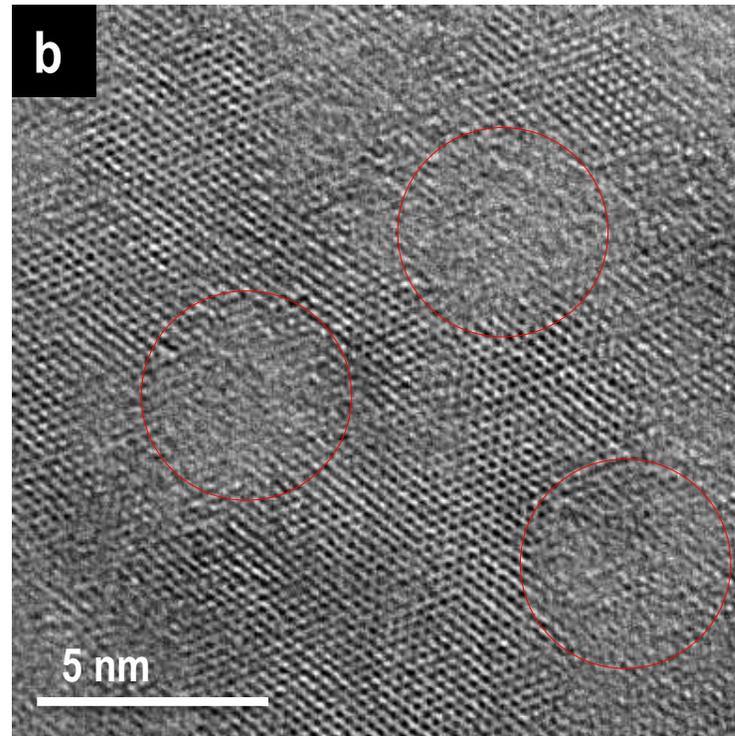
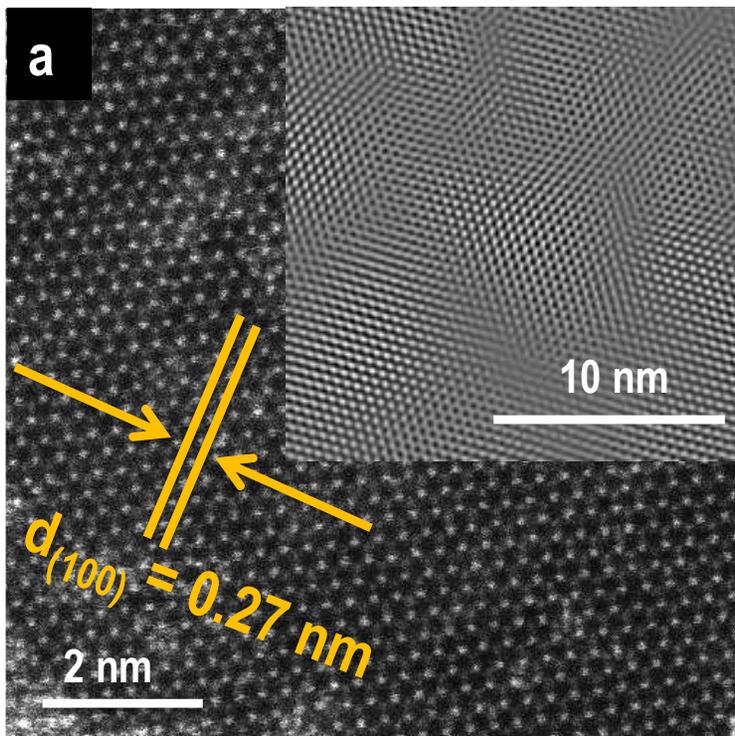


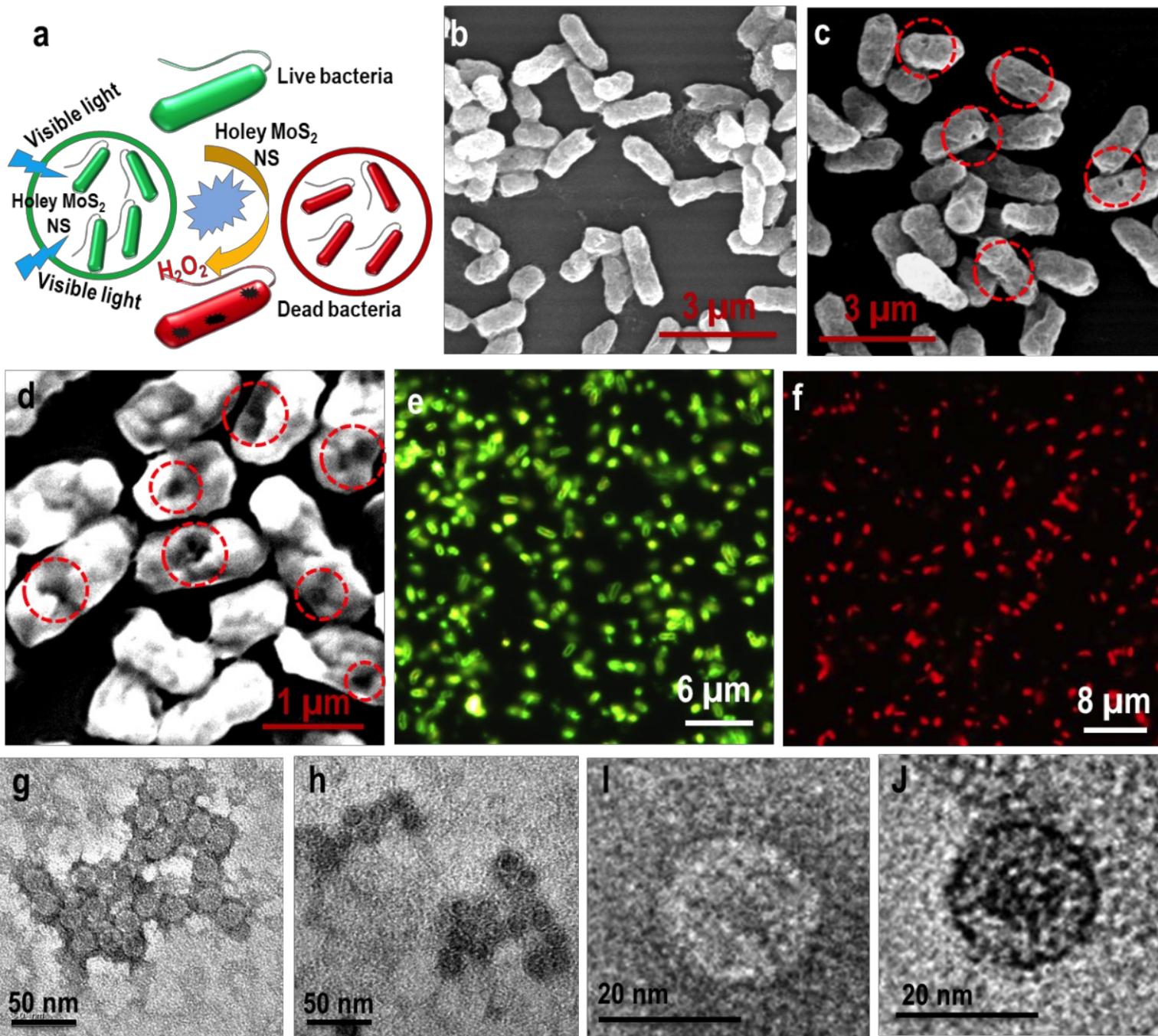
Various stages of electrode preparation



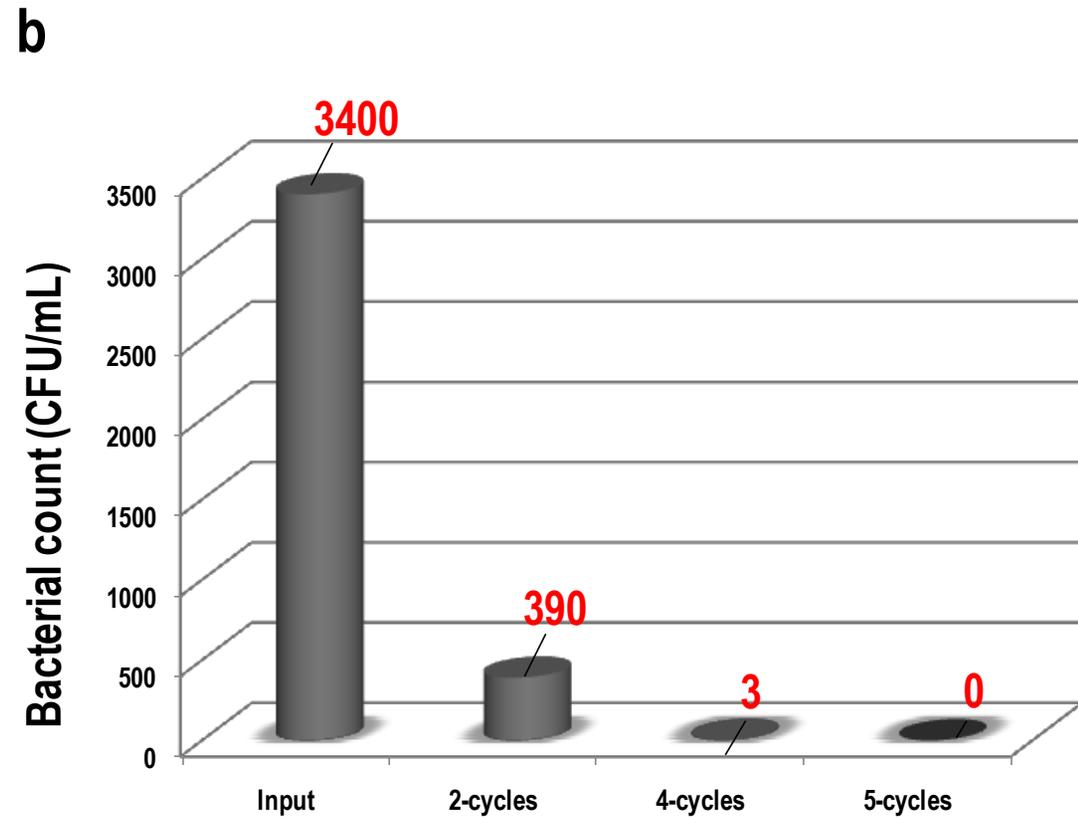
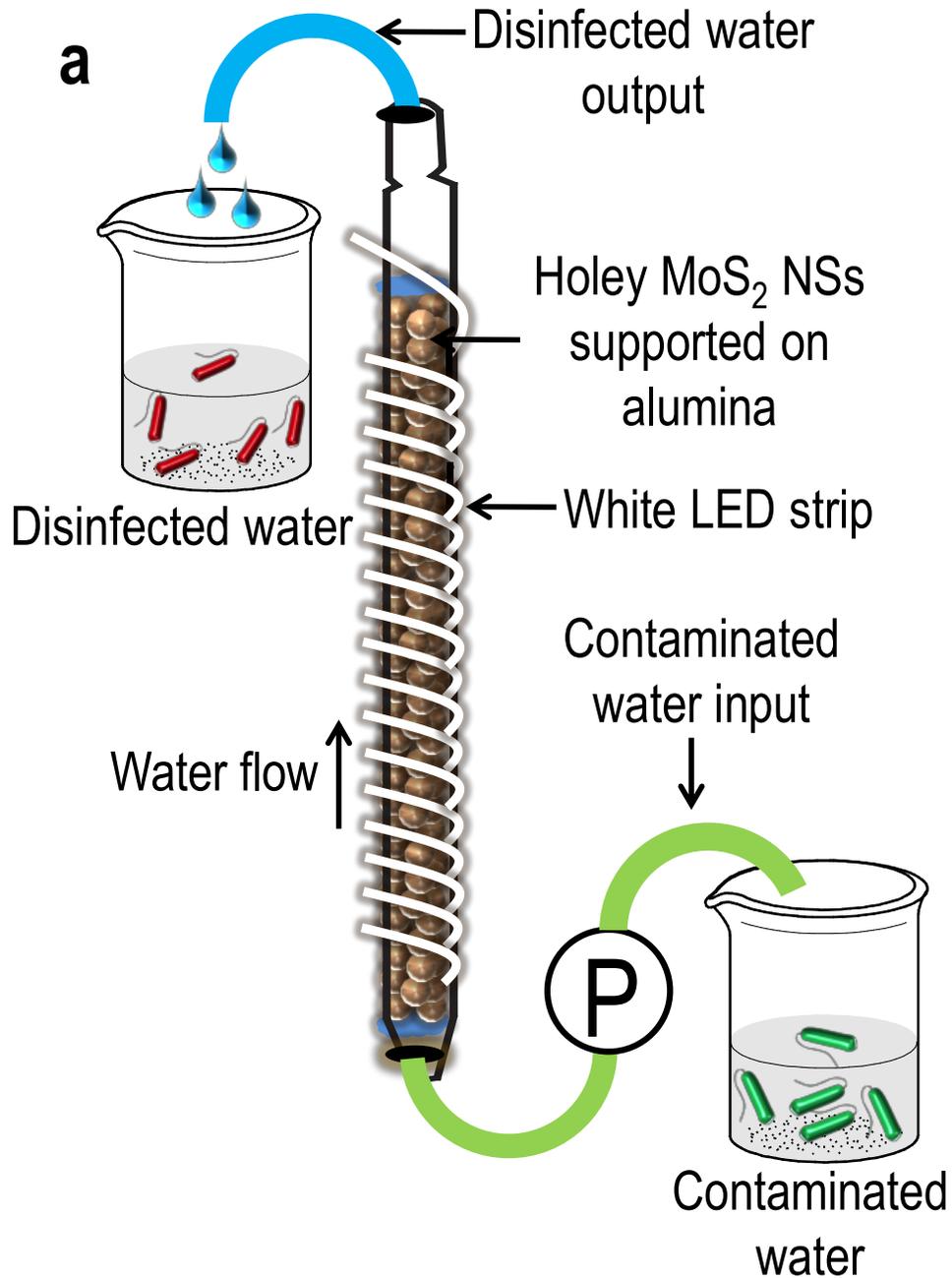
2D materials, nanopores



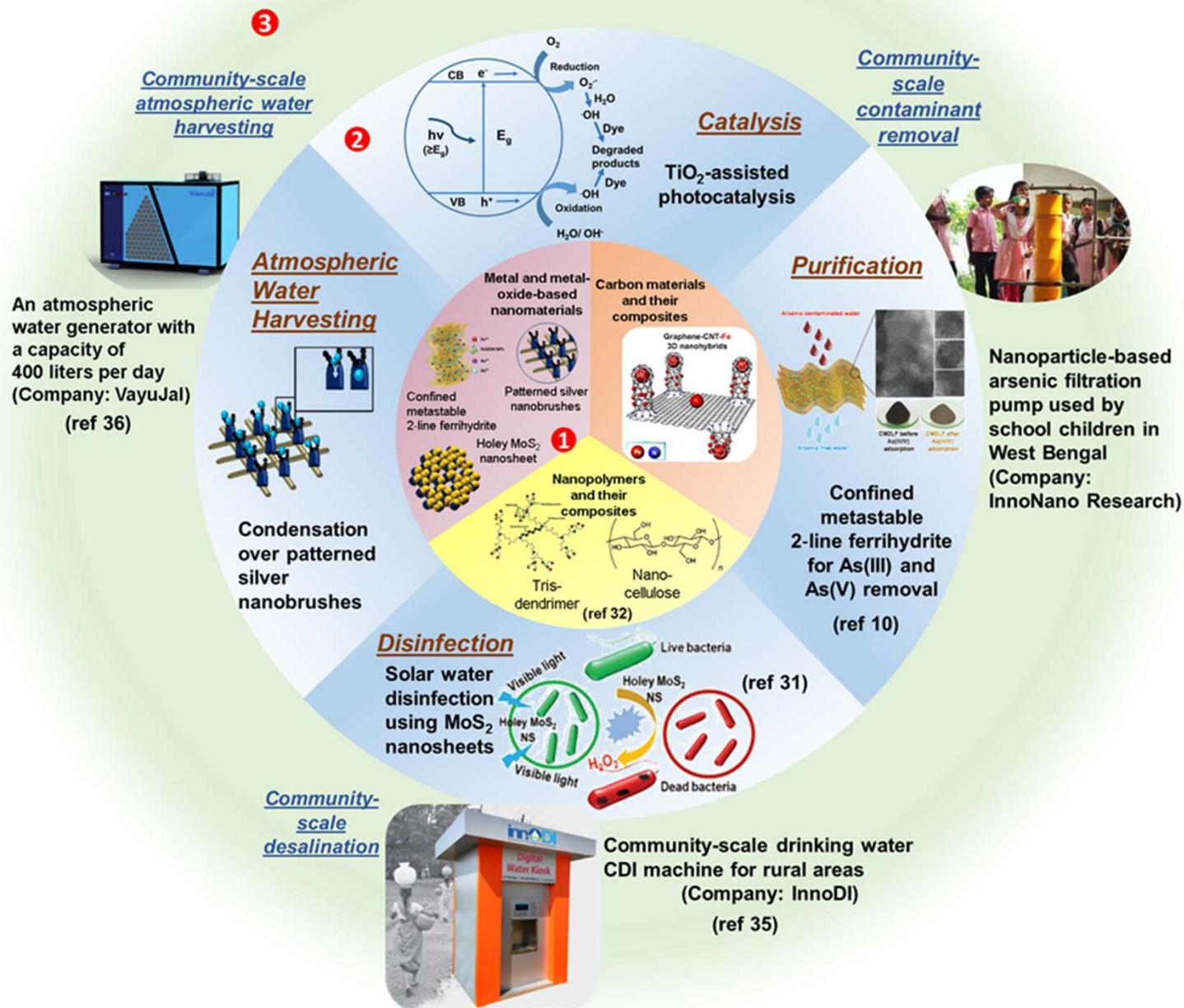




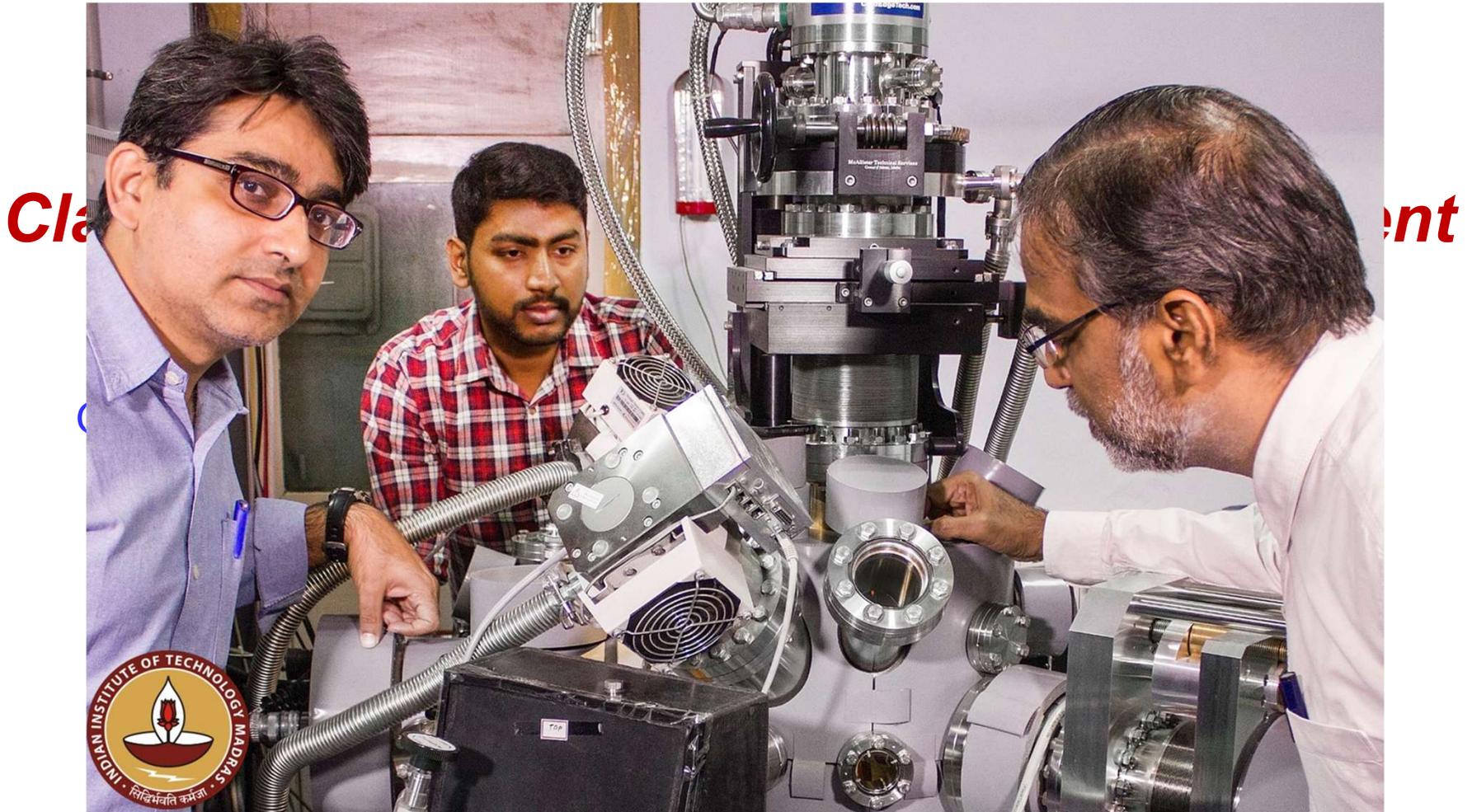
Prototype



Evolution of materials to products

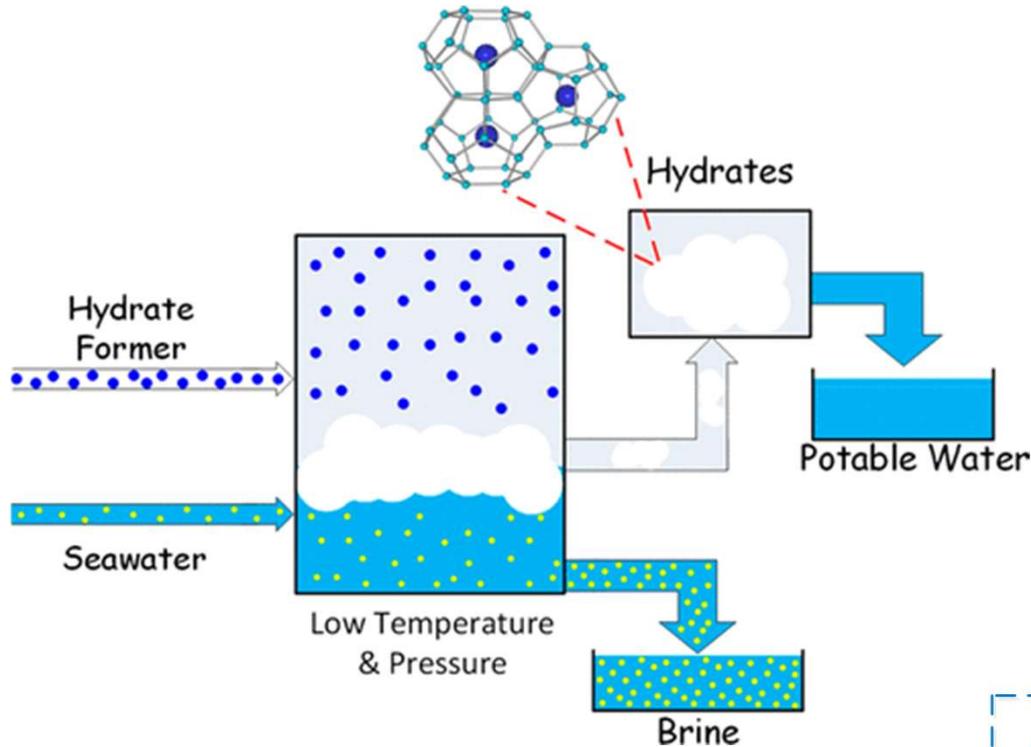


New phenomena



With Rajnish Kumar

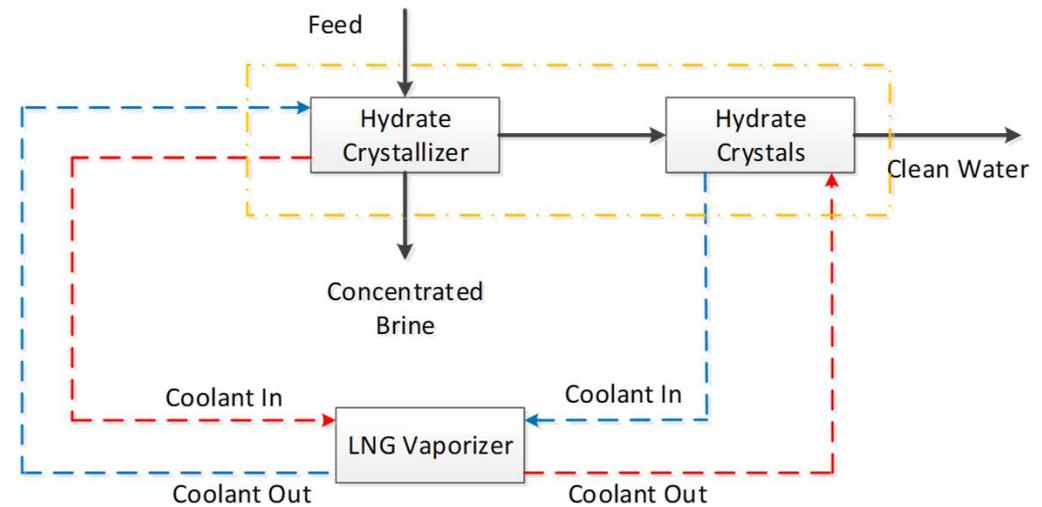
Hydrate-based desalination (HyDesal)



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

Analytical devices

Universal
Wireless
Electrochemical
Detector

Smartphone

Internet

Disposable
Electrode

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		

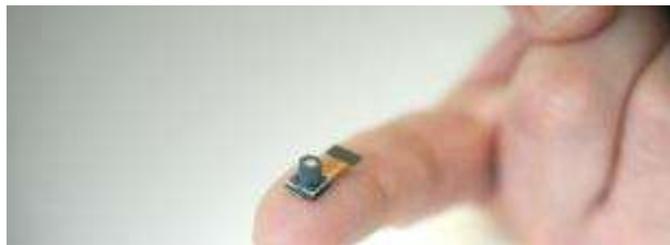
Sensors and new opportunities



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



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

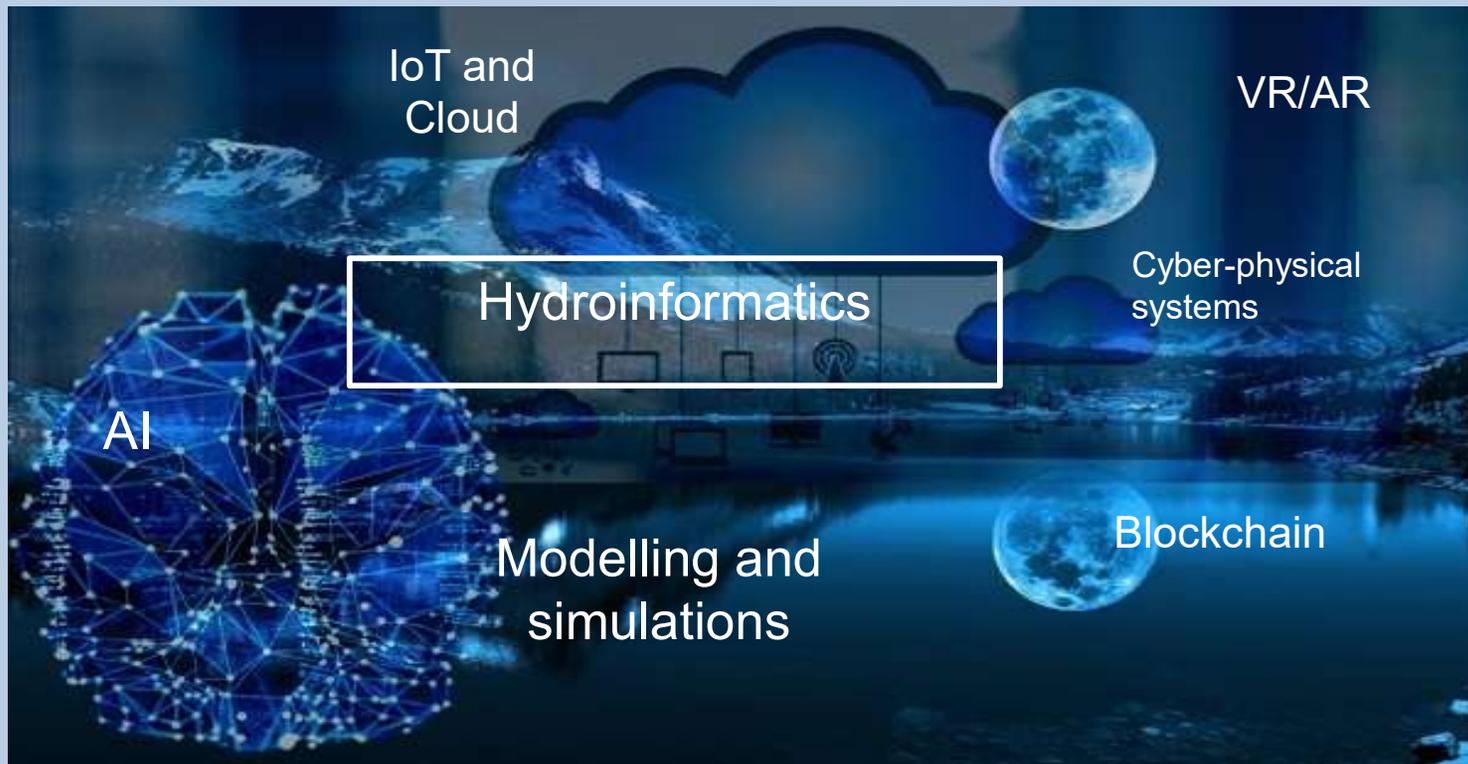


Water quality measurement – In the pipeline

nano λ

Hydroinformatics

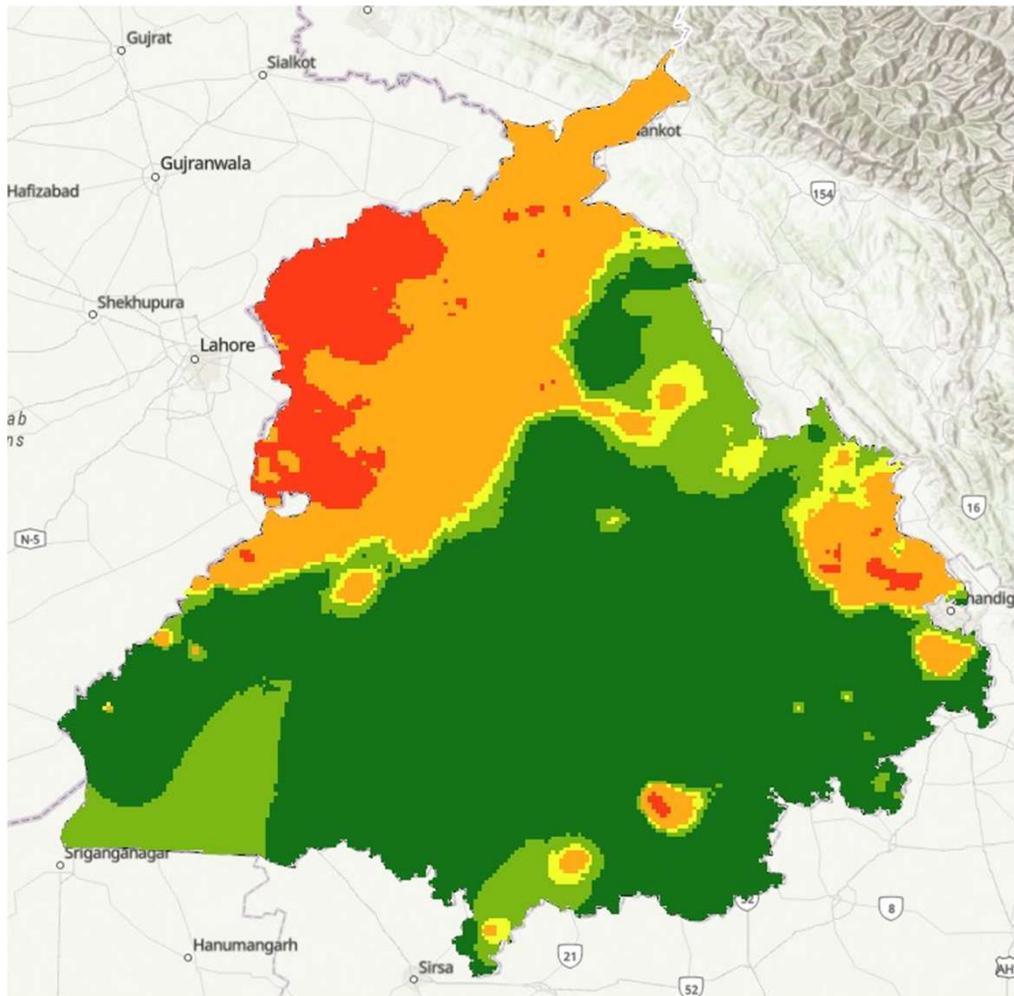
Application of computing technologies for efficient, sustainable and equitable water management.



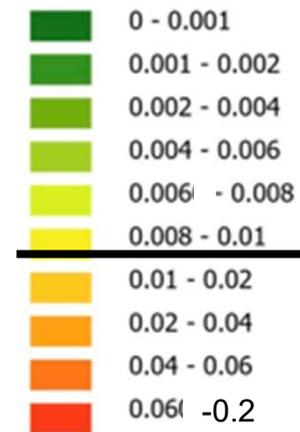
Digital water or water 4.0 will revolutionize water management.

Average of arsenic at 7000 locations

2017-2020

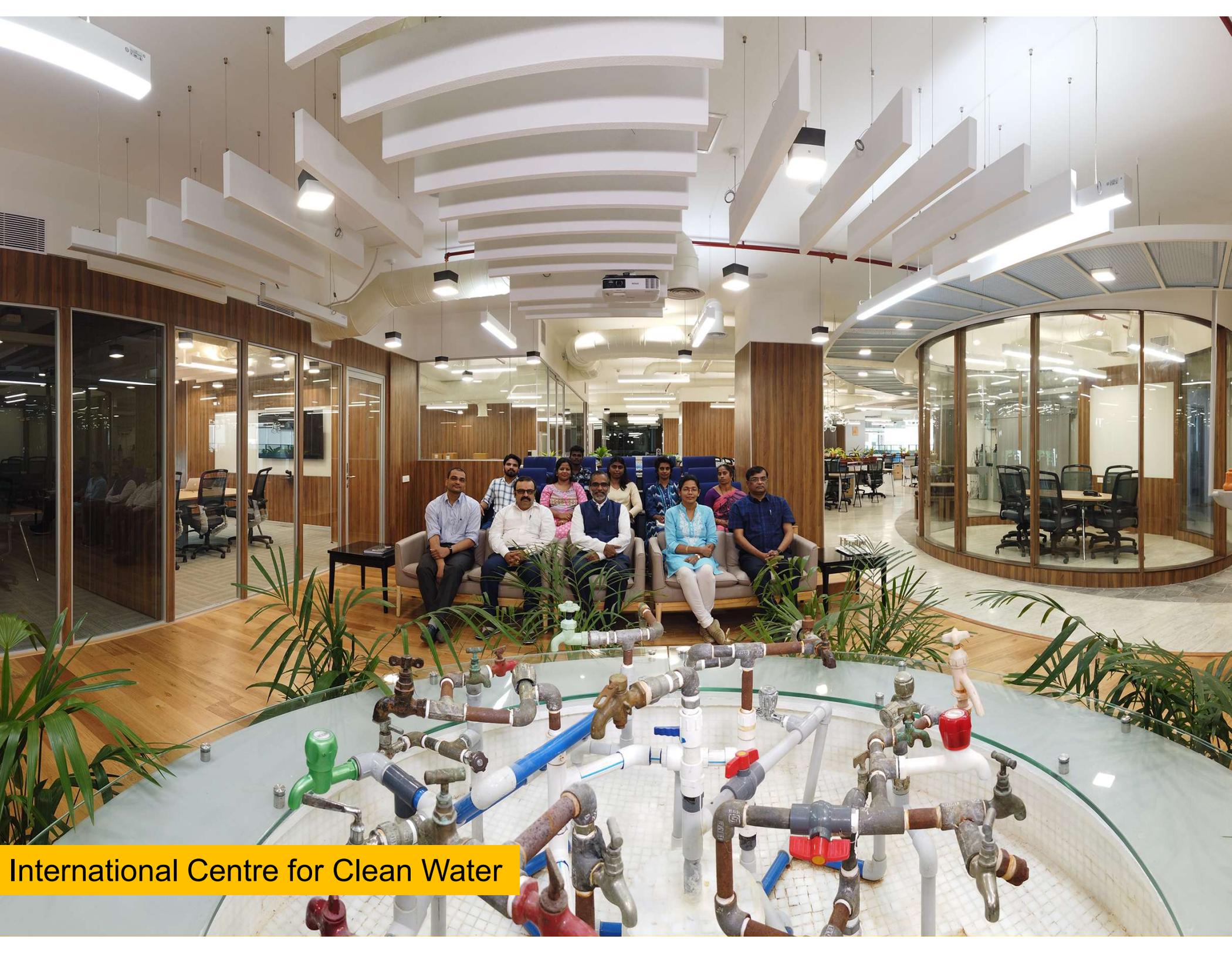


Arsenic in mg/L





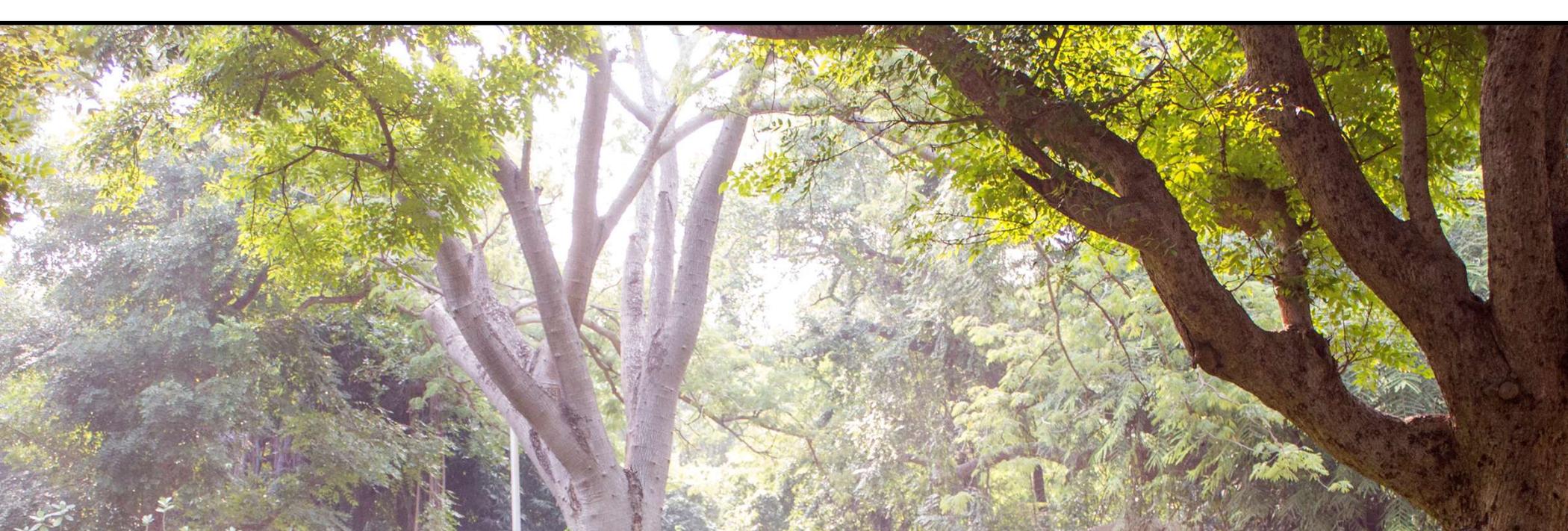
Policy



International Centre for Clean Water



IIT Madras Research Park



The AMRIT Team, 2013



Group during 2018, along with Prof. Graham Cooks

People: 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, 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

Funding: Department of Science and Technology, Government of India

Start-ups and partners:



Our collaborators



Ministry of Drinking Water and Sanitation, Govt. of India

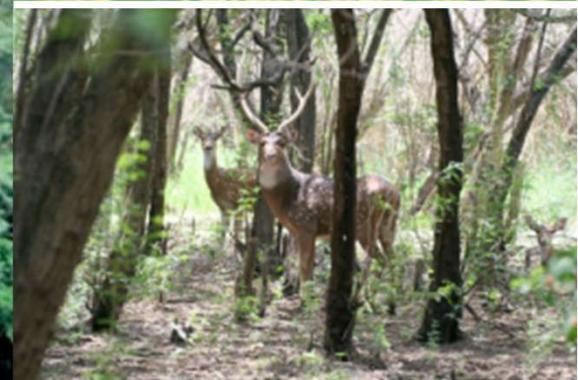


IndianOil





Indian Institute of Technology Madras



Associate Editor



Bhaskar Ramamurthi/V. Kamakoti

Thank you all

