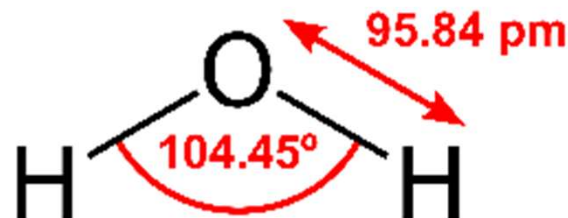




Since 1959



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

Sabu A, Vice Chancellor
Anil Ramachandran, Director, Research Directorate



Associate Editor

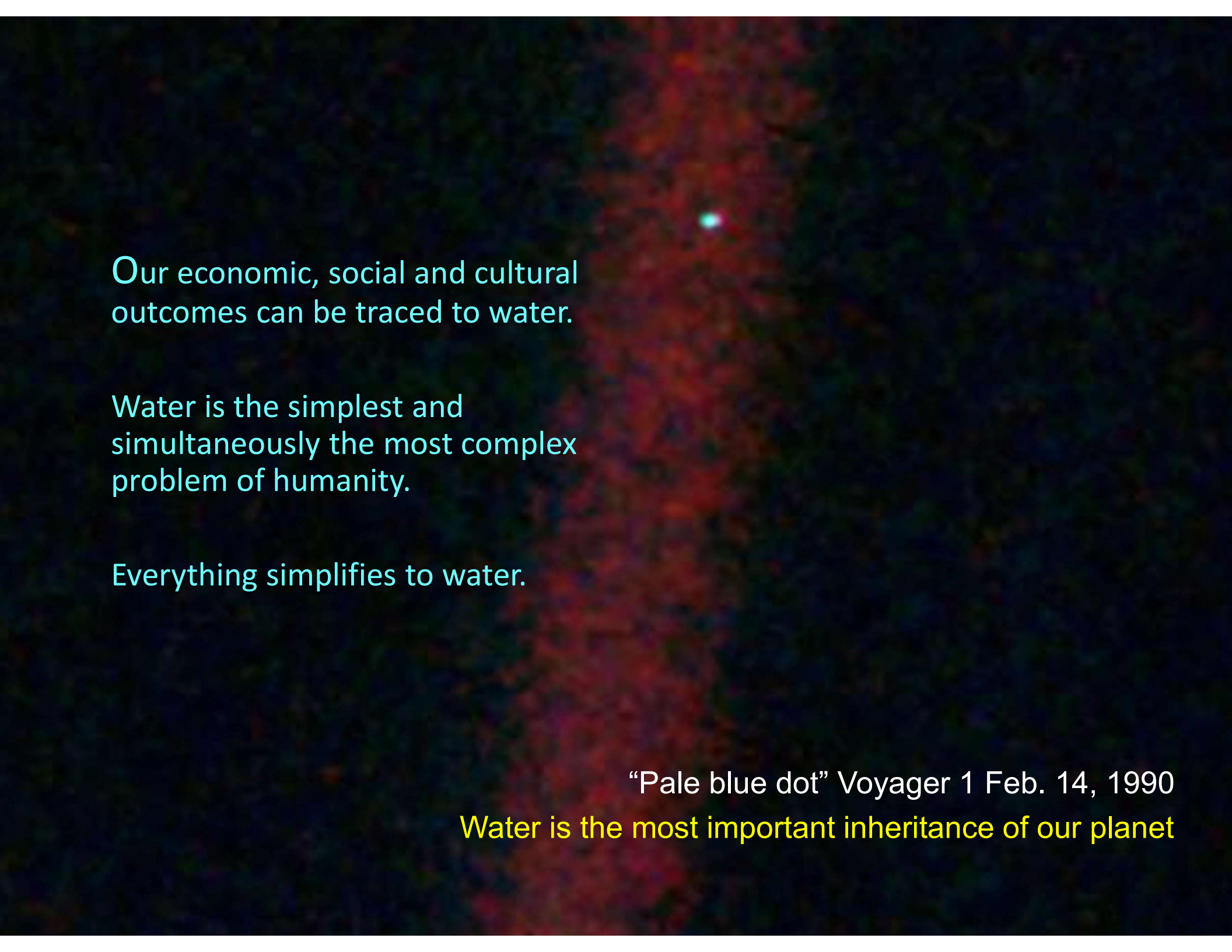
ACS
Sustainable
Chemistry & Engineering



International Centre for Clean Water



Public Lecture Series, Kannur University, July 12, 2022



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.

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

Water is the most important inheritance of our planet

Water is at the centre of action

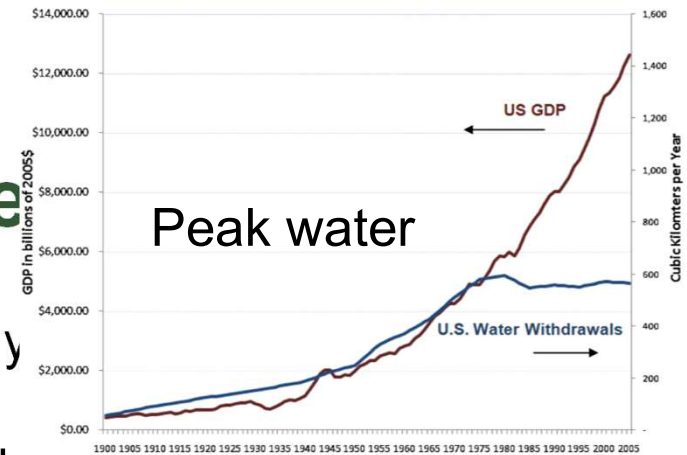


There is water in everything we do.

Water is big.... Are we safe

Per capita water availability – 1500 CM per y

That water and its benefits need to reach all.



Peter H. Gleick and Meena Palaniappan, PNAS, 2010, 107, 11155–11162

3Ss for water **Store – Sensitive – Smart**

Average annual rainfall 1085 mm, 85th in a list of 186 countries

Traditions of storage and conservation – we store just about 8%

Water is for all – for every living form

83% of freshwater species have declined globally in the last 50 years!

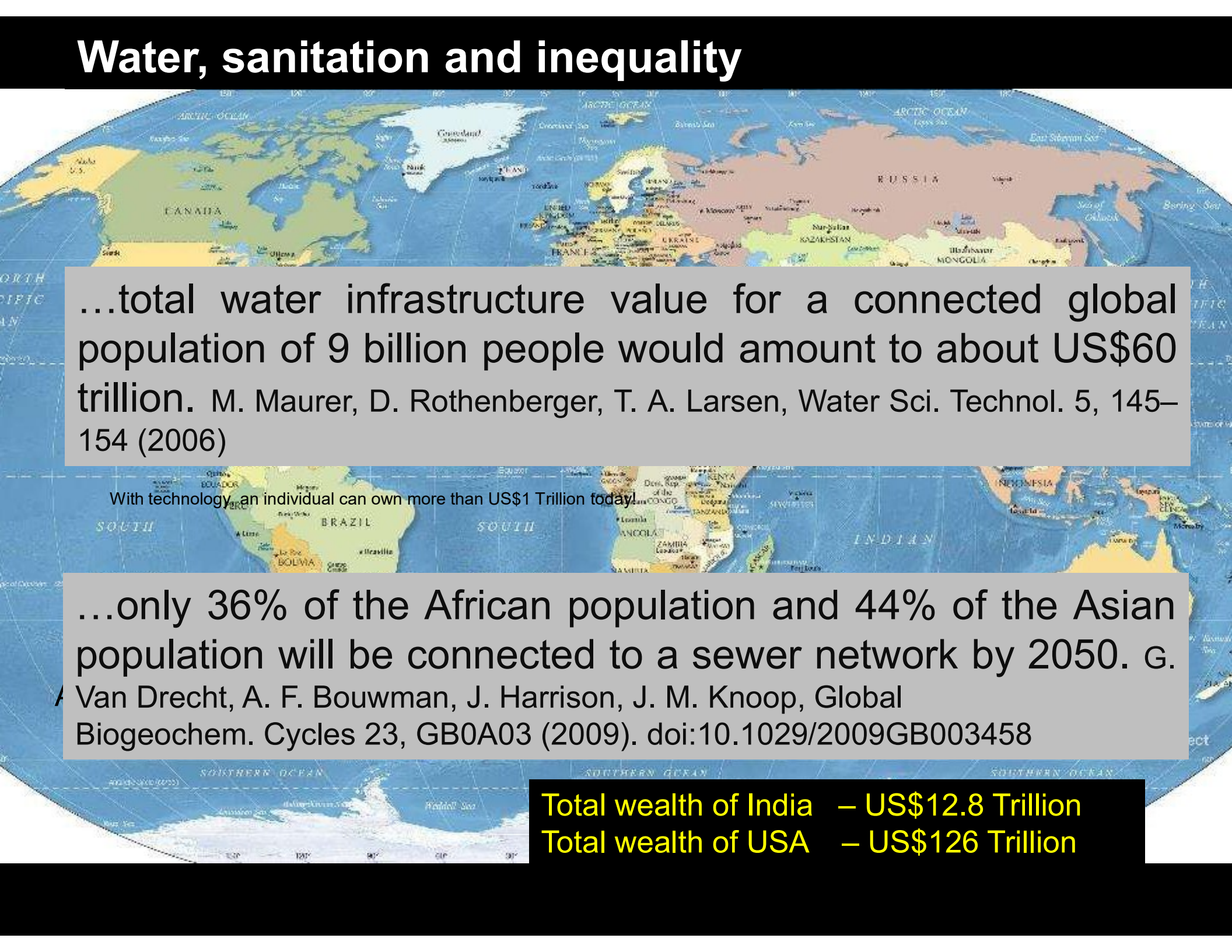
GDP can grow even by capping freshwater withdrawals

We must find technologies of relevance

Energy - food – clothing – construction – manufacturing -

Water is big in every scale – Gaps, opportunities, wealth, satisfaction

Water, sanitation and inequality

A world map with a color gradient from blue (low value) to red (high value). The highest values are concentrated in North America, Europe, and parts of Asia, while the lowest values are in sub-Saharan Africa and parts of South America.

...total water infrastructure value for a connected global population of 9 billion people would amount to about US\$60 trillion. M. Maurer, D. Rothenberger, T. A. Larsen, Water Sci. Technol. 5, 145–154 (2006)

With technology, an individual can own more than US\$1 Trillion today!

...only 36% of the African population and 44% of the Asian population will be connected to a sewer network by 2050. G. A. Van Drecht, A. F. Bouwman, J. Harrison, J. M. Knoop, Global Biogeochem. Cycles 23, GB0A03 (2009). doi:10.1029/2009GB003458

Total wealth of India – US\$12.8 Trillion
Total wealth of USA – US\$126 Trillion

Challenges

Every possible need

Arsenic
Fluoride
Uranium
Mercury
Chromium
Perchlorate
Nitrate
Pesticides
Antibiotics
Plastics
Detergents
.....

-45 °C, 15% RH

Every river is contaminated
50% of the microbial diversity is lost for ever

Grooten, M.; Almond, R. E. A. Living Planet Report - 2018:
Aiming Higher; WWF: Switzerland, 2018.

From S. Vishwanath

+45 °C, 99% RH

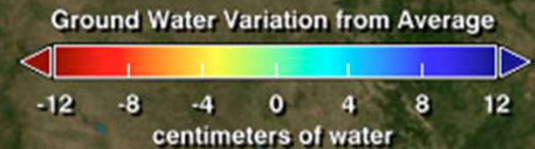
Indian agriculture

67% of agriculture run on GW

Total districts 742
Water stressed >300
256 with critical or overexploited ground water levels
'India is suffering from its worst water crisis in its history.'

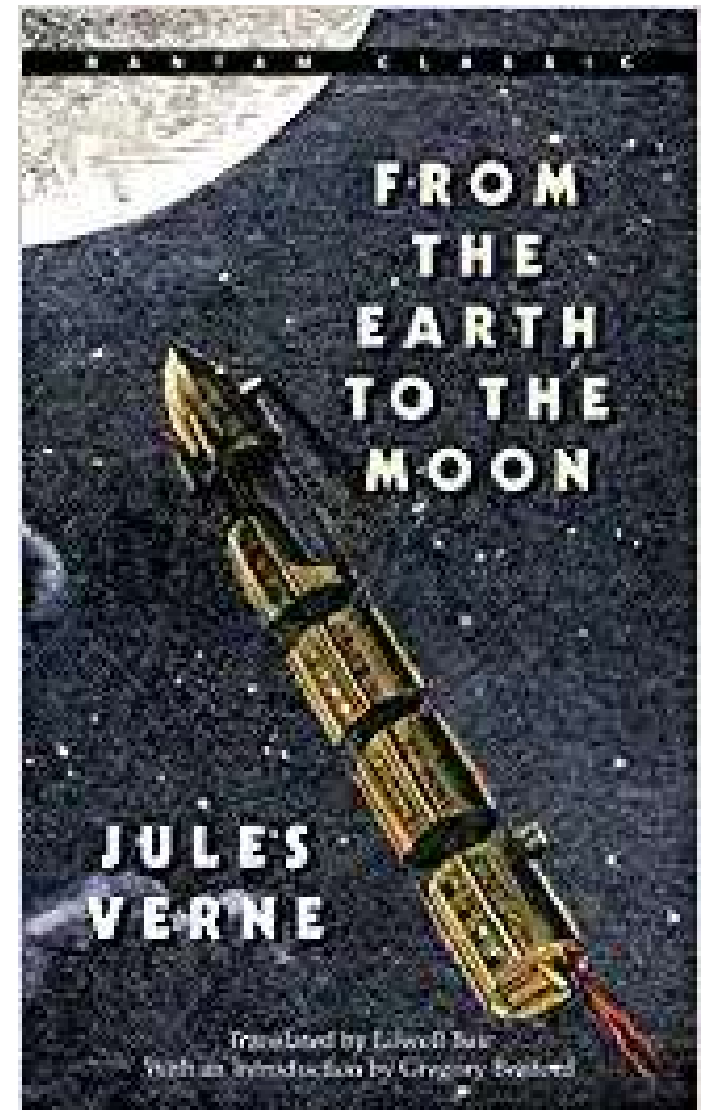
November 2002

November 2008



Data from NASA

Our dreams become reality with materials



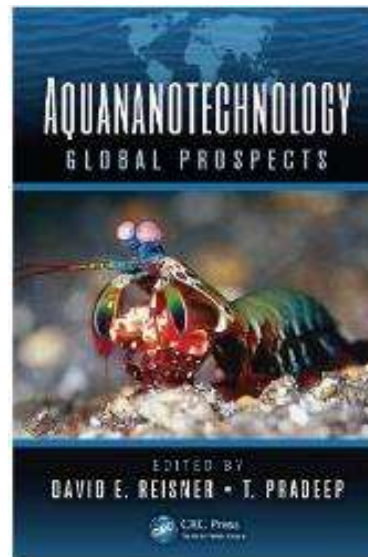
Water purification, history

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)

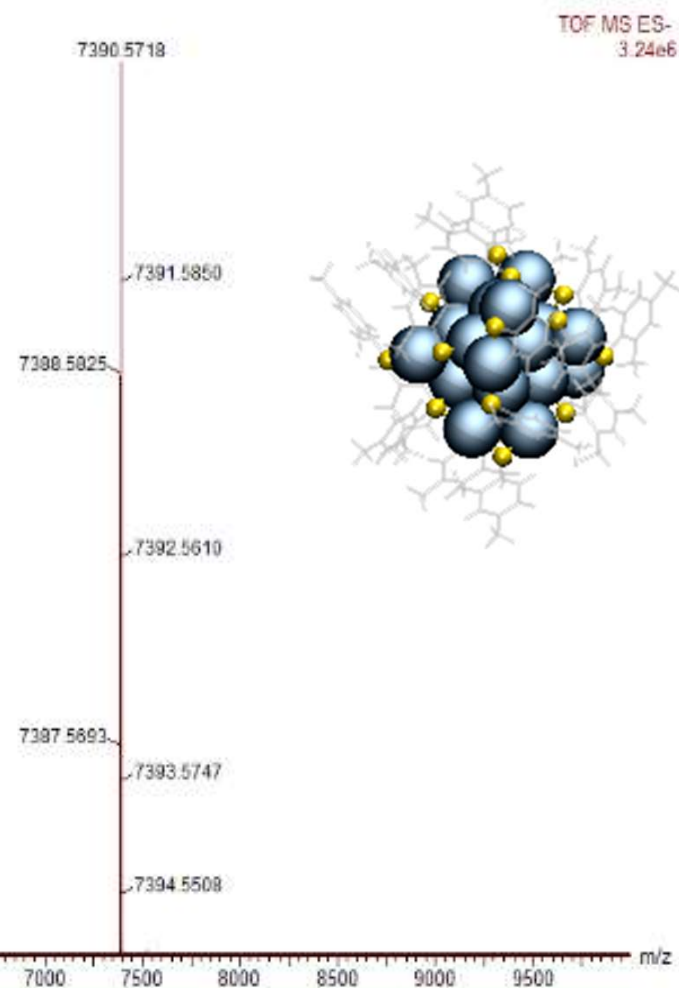
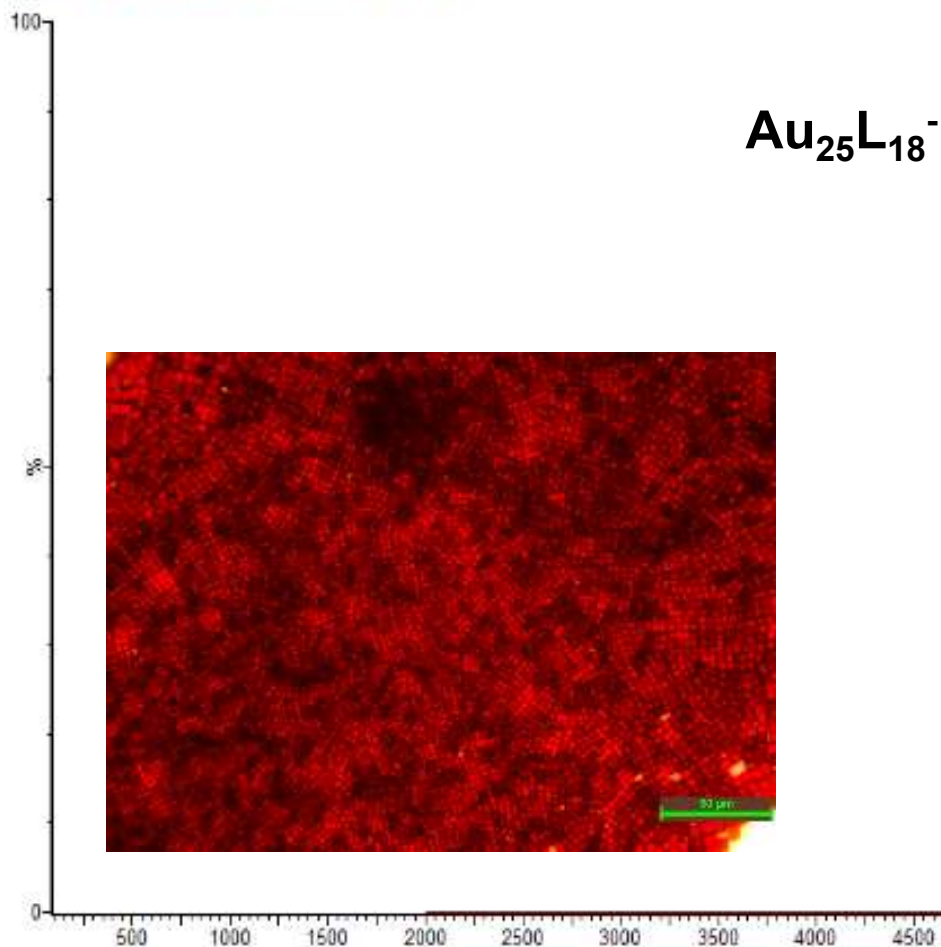
Affordable clean water is a problem of advanced materials

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.

Nanomaterials can solve real problems



ACS Sustainable Chemistry & Engineering Editorial, December 2016

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

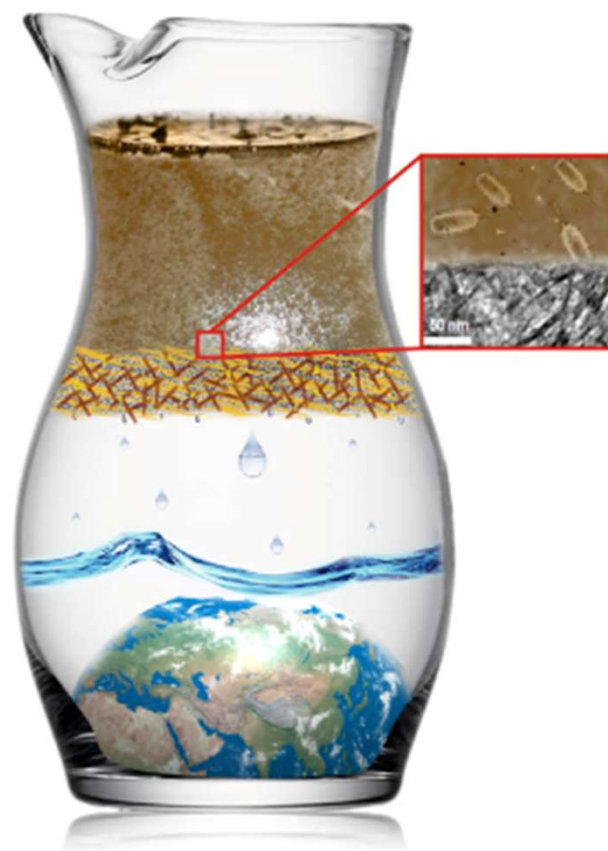
Mohan Udhaya Sankar¹, Sahaja Aigal¹, Shihabudheen M. Maliyekkal¹, Amrita Chaudhary, Anshup, Avula Anil Kumar, Kamalesh Chaudhari, and Thalappil Pradeep²

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 proper forms. These nanocomposites can be used as a water purifier. The ability to release silver ions at ambient temperature for water purification is a significant advantage.

hybrid | green |

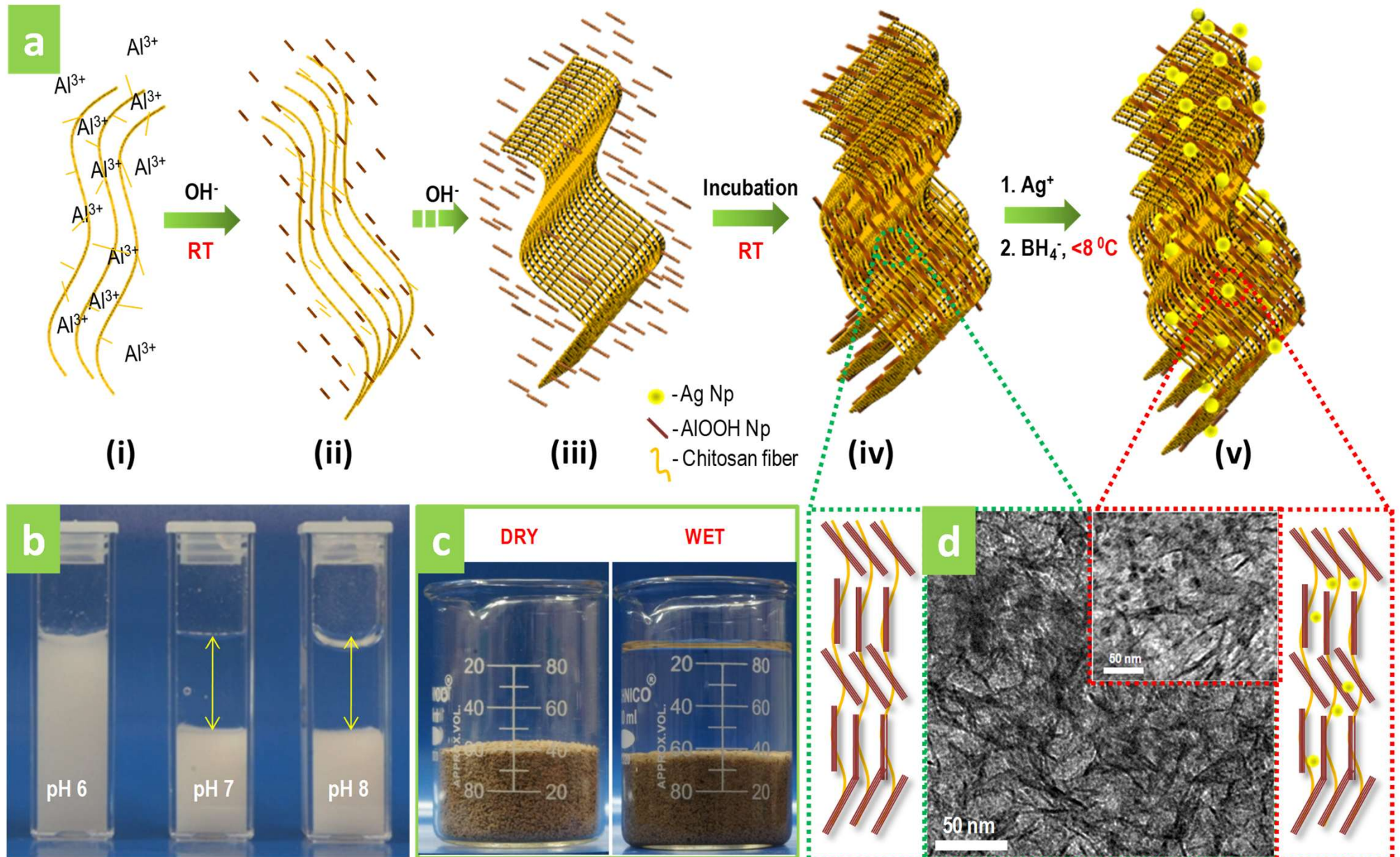


release into water are not available; and (c) continued retention of the nanoparticles in the matrix is difficult.

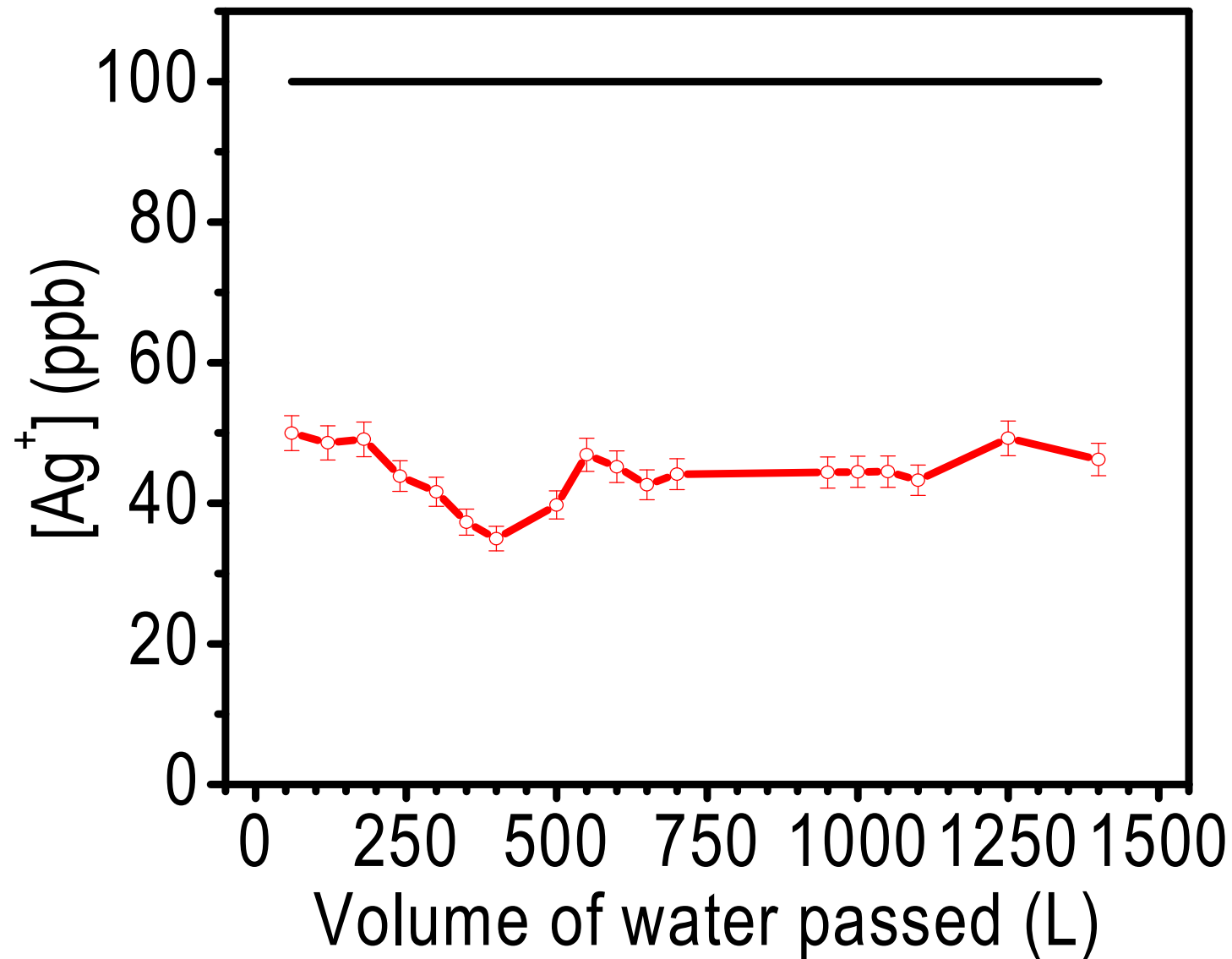
In this work, we demonstrate a unique family of nanocrystalline metal oxyhydroxide-chitosan granular composite materials prepared at near room temperature through an aqueous route. The degree of crystallinity in the composition is attributed to abundant -OH functional groups on chitosan, which help in 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 absence 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

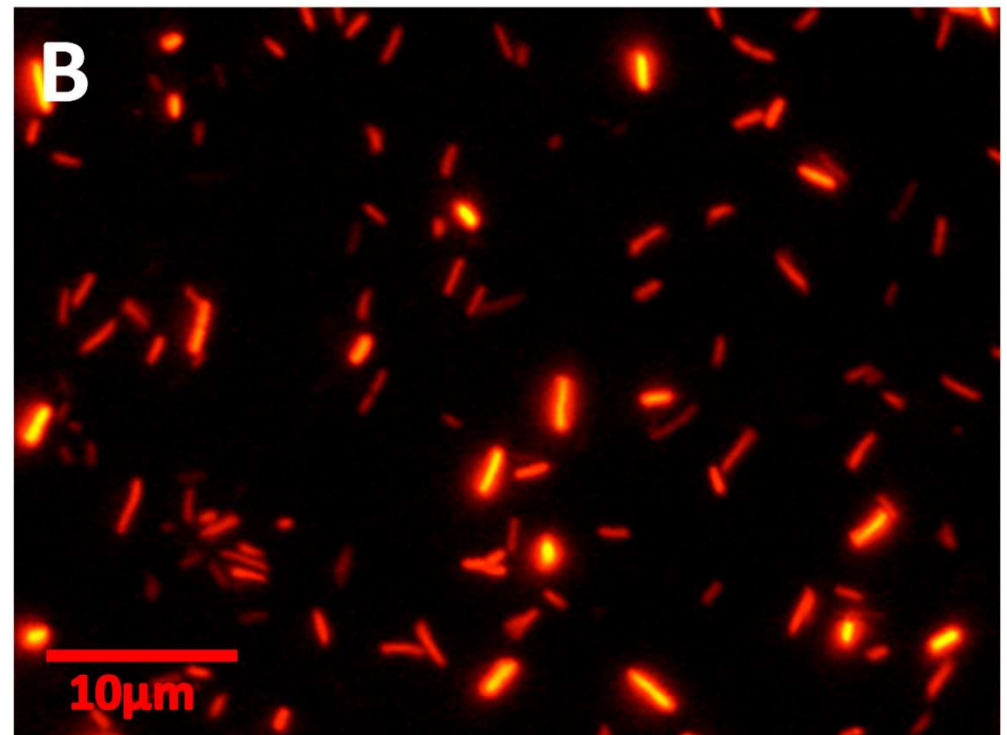
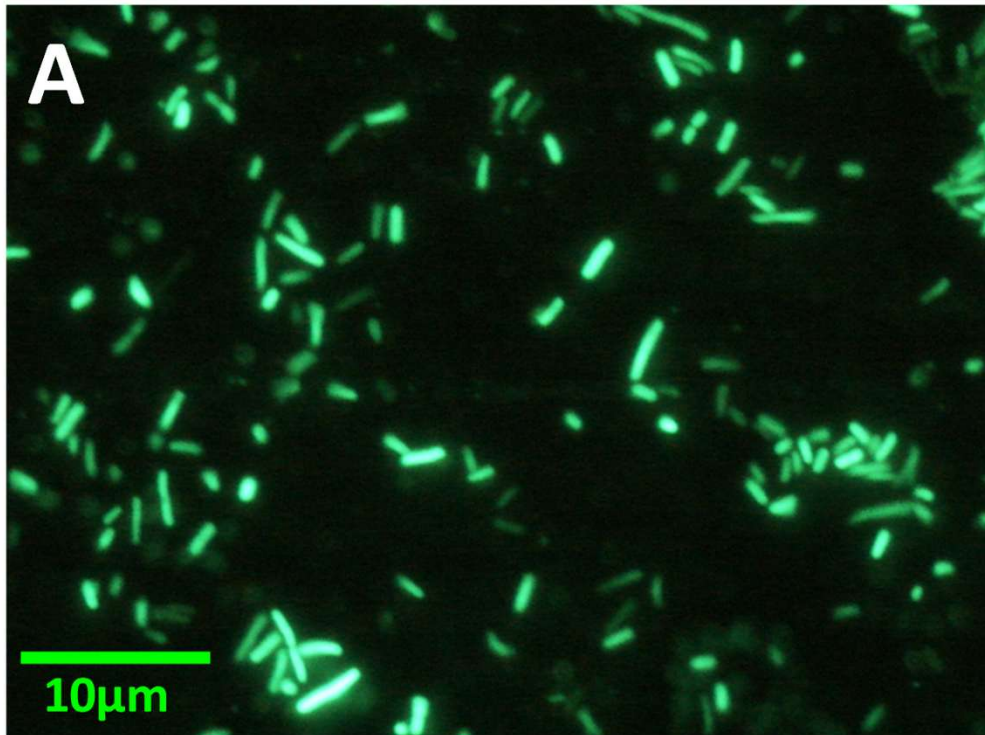
New materials

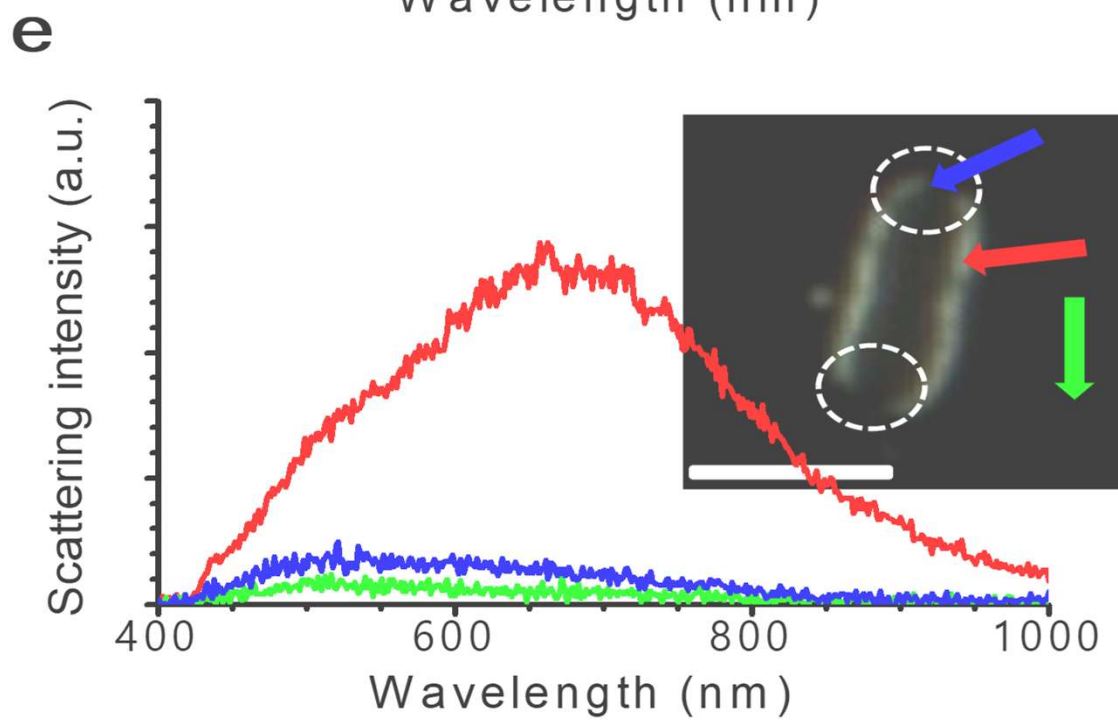
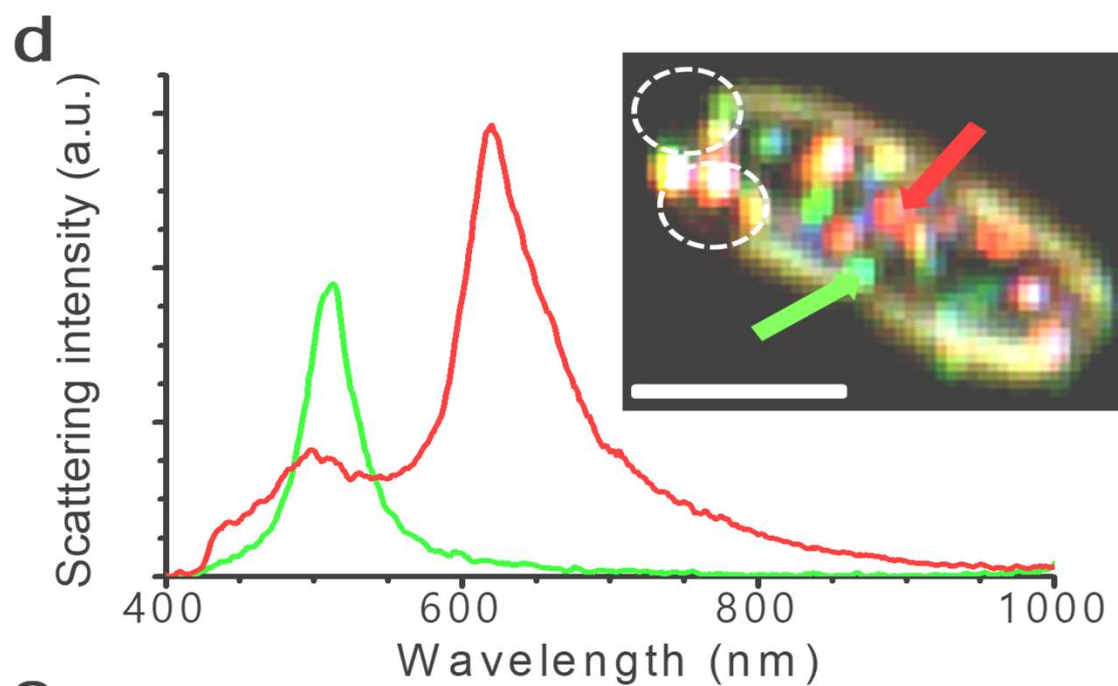
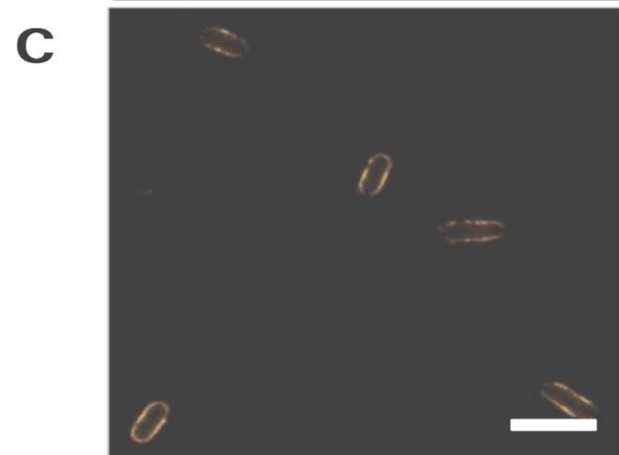
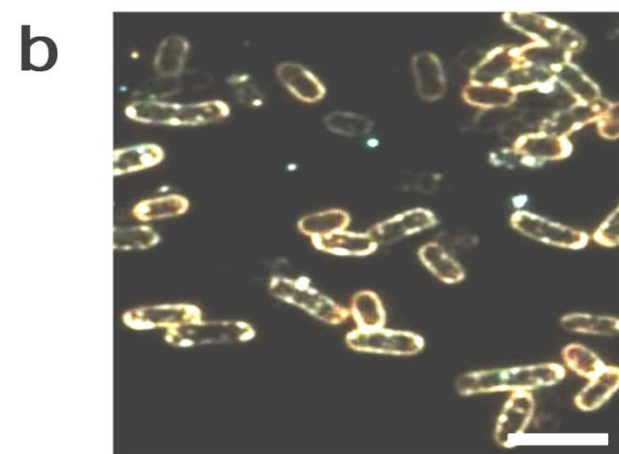
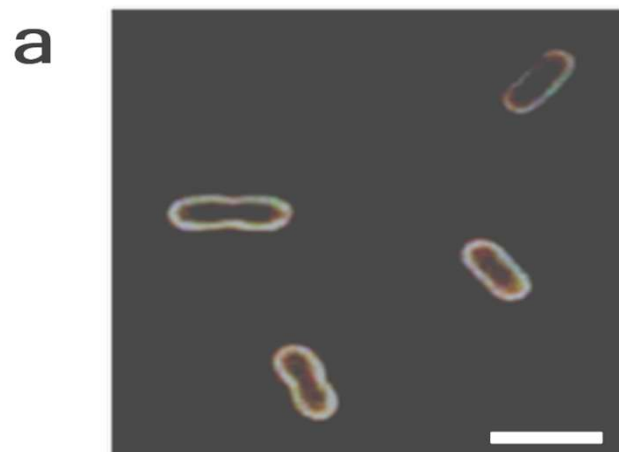


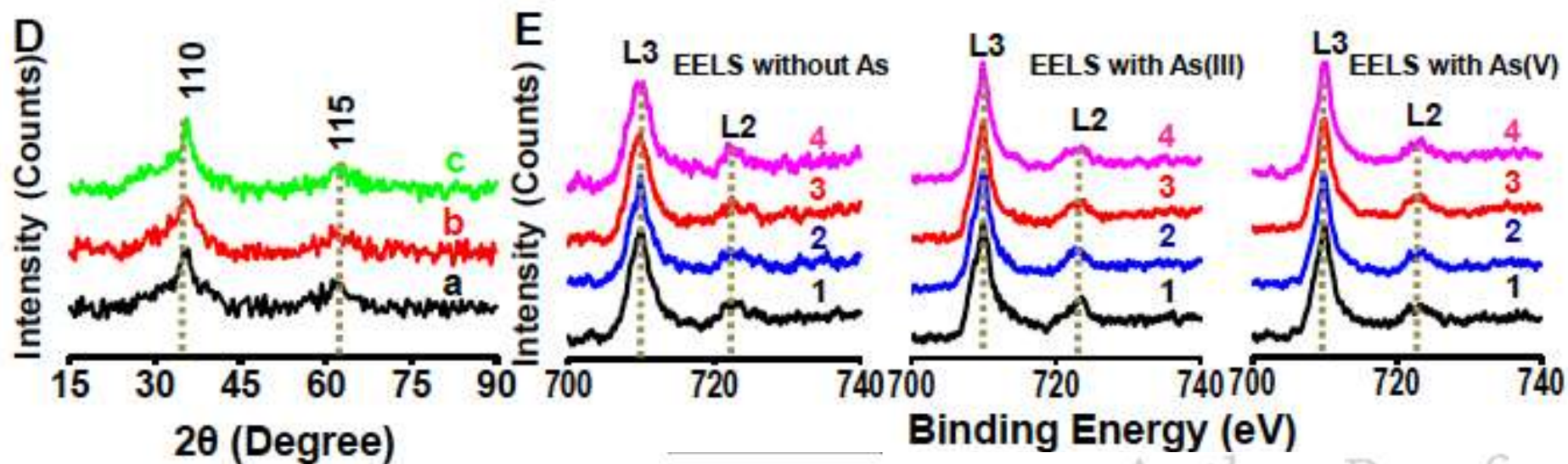
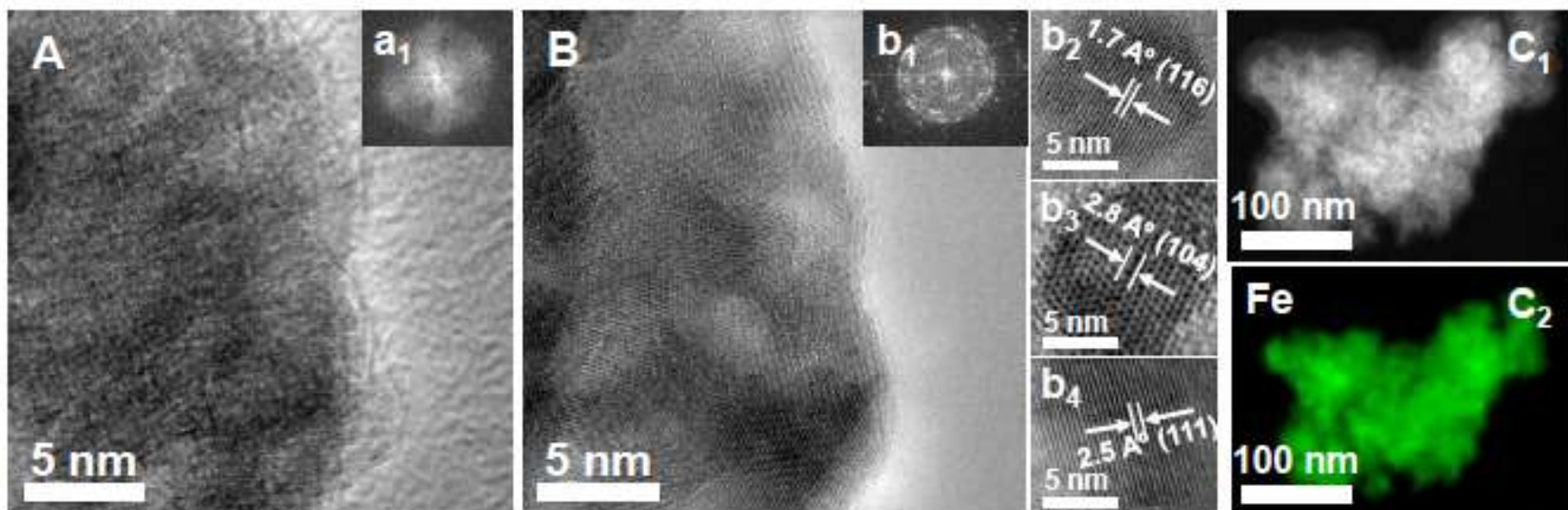
What is special?



Live/dead staining experiments







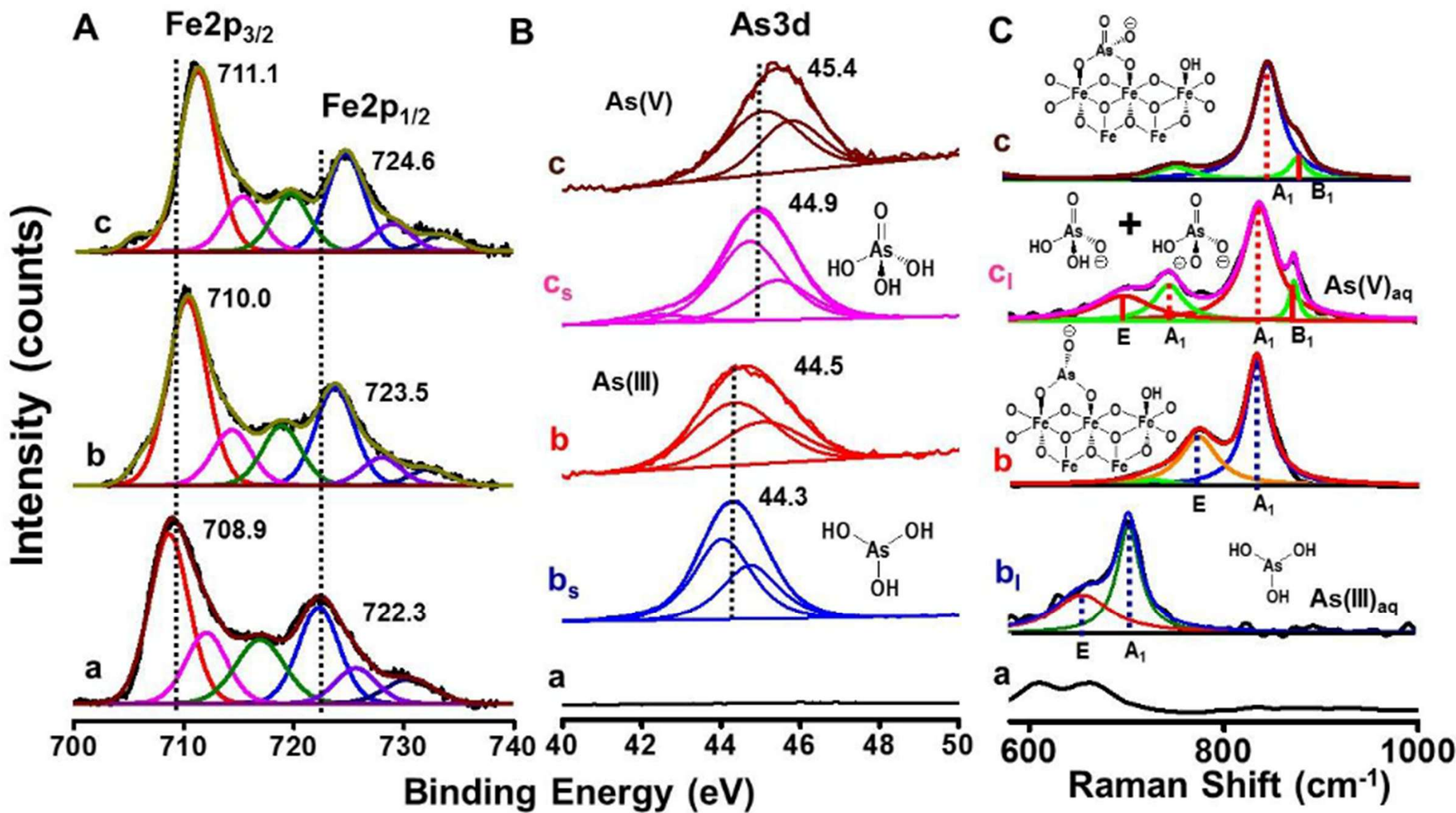
www.advmat.de

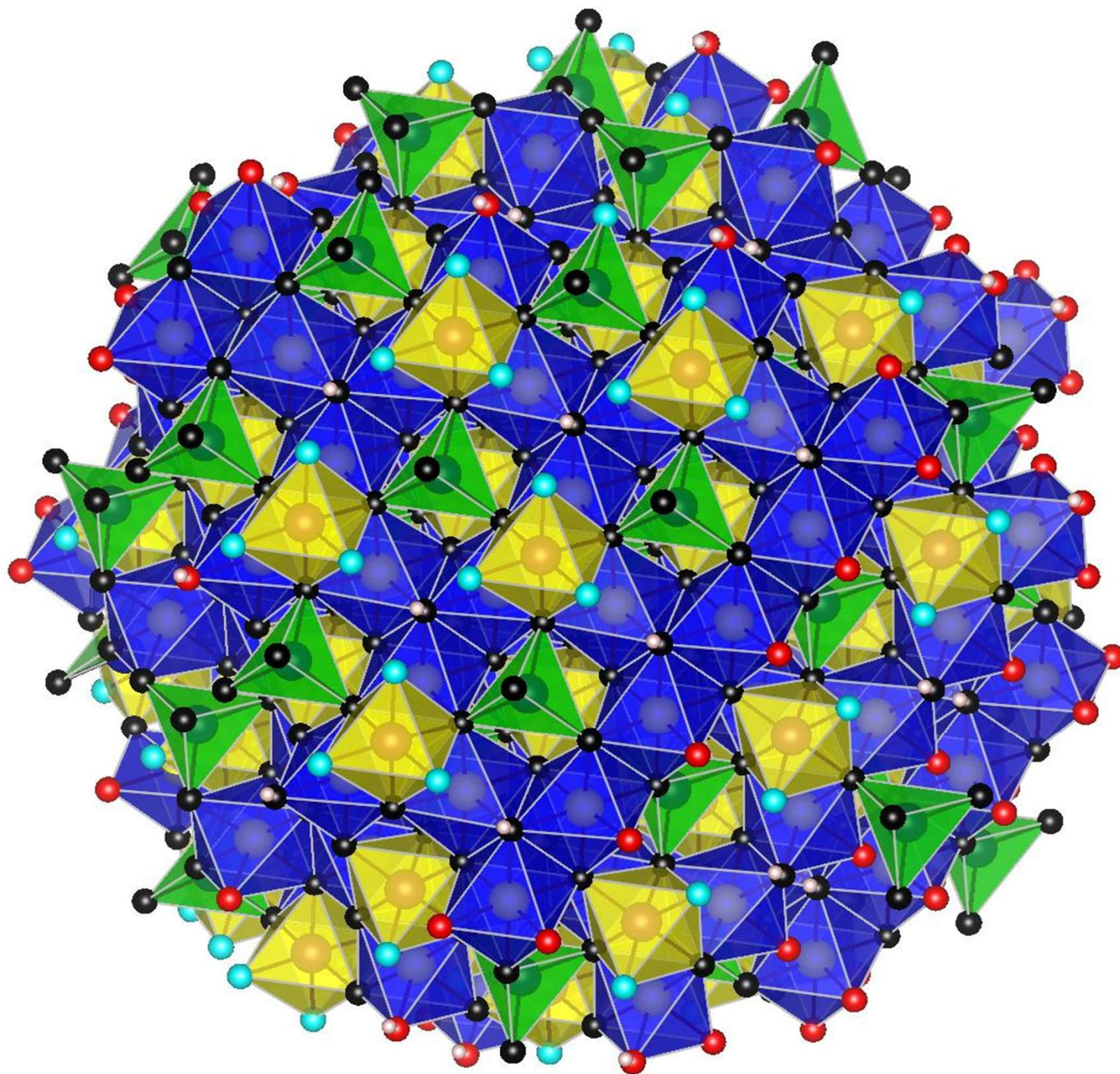
Author Pr ⁶ ADVANCED MATERIALS

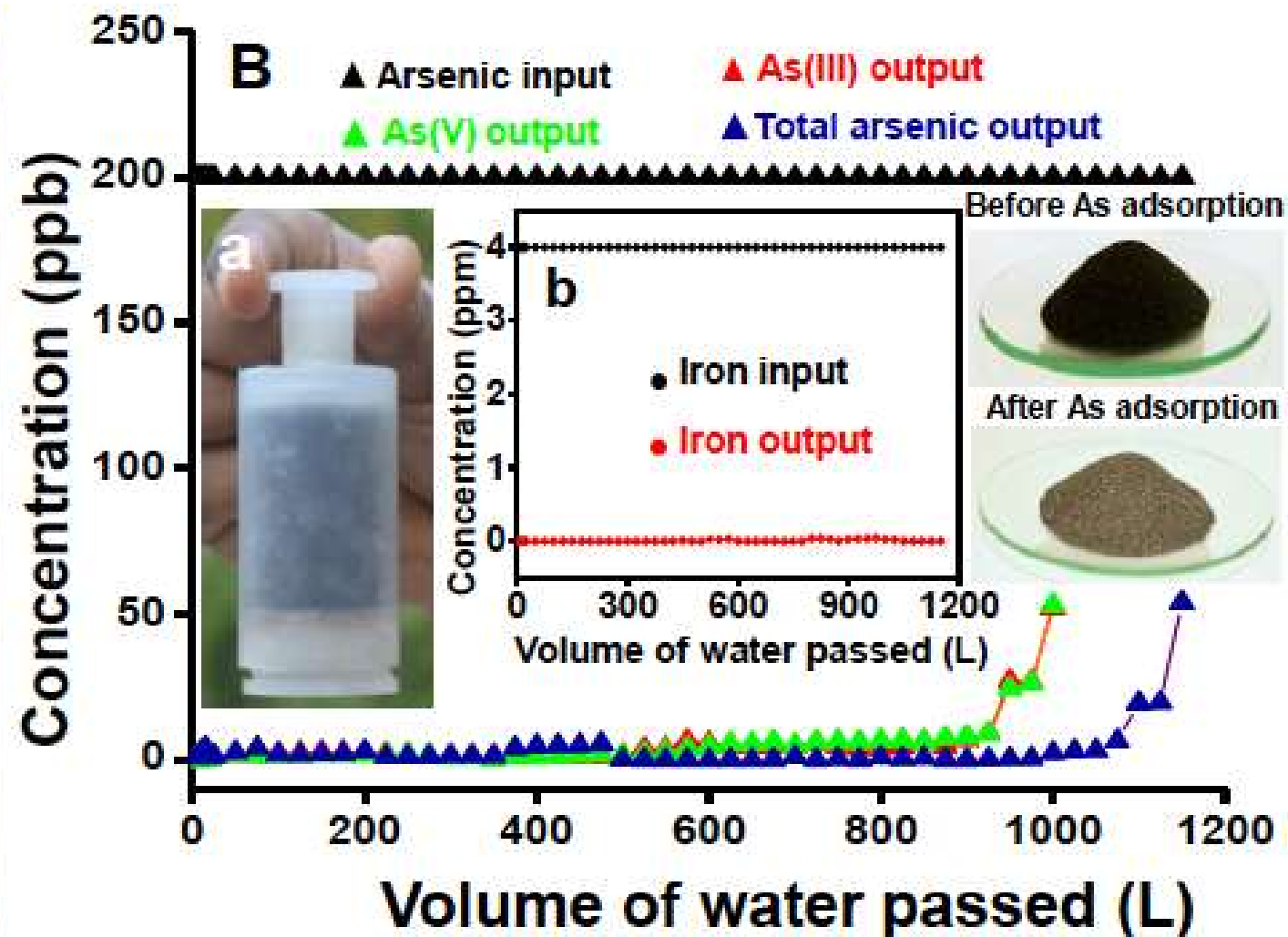
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

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









Population Map Of India-2001



Changing the dynamics in the field



Existing plant in 40 cents

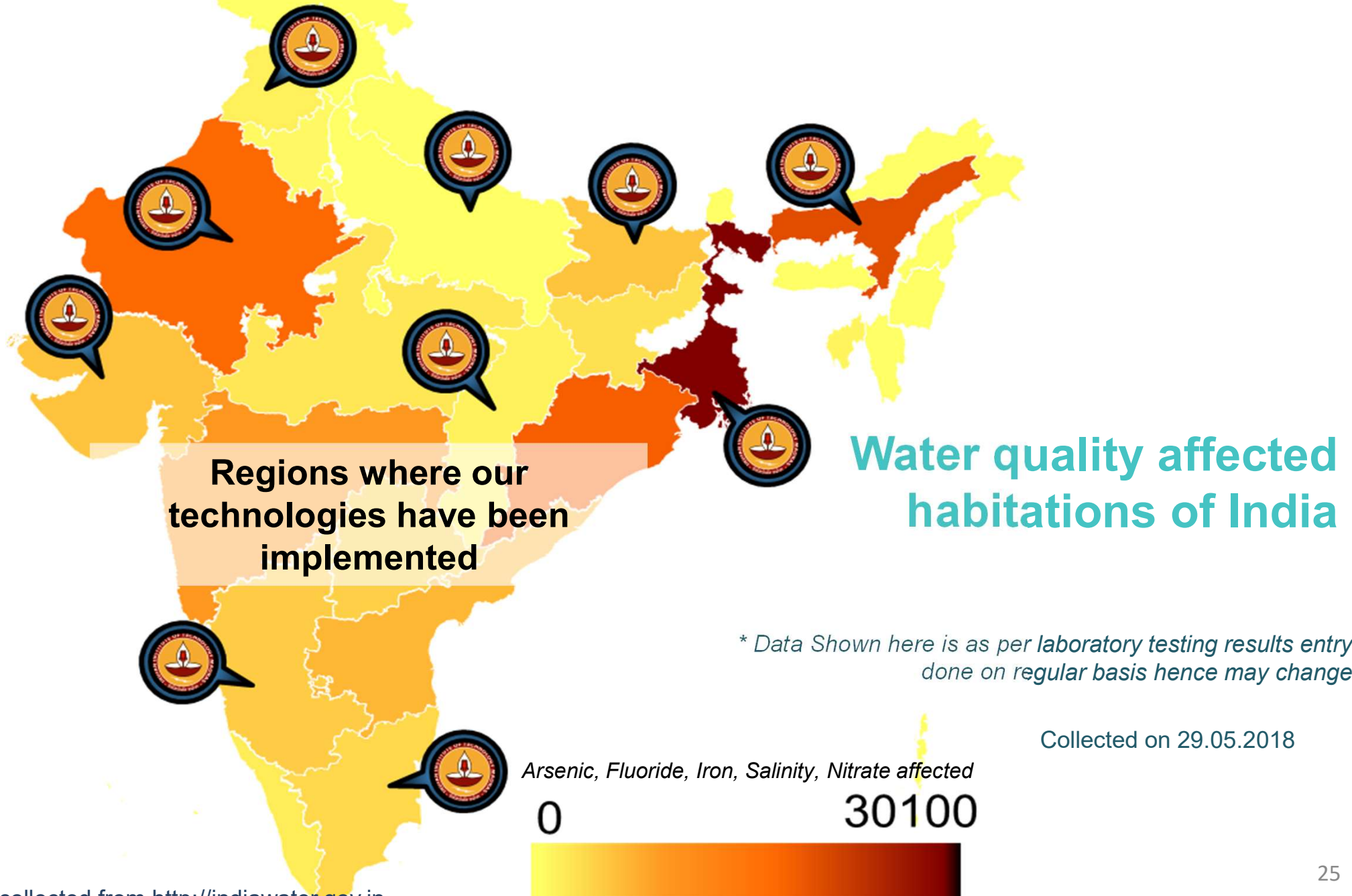
- Existing unit for iron and arsenic removal – 20 m³/h
- Uses activated alumina and iron oxide (old generation of adsorbents)



New plant in 3 cents

- 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



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

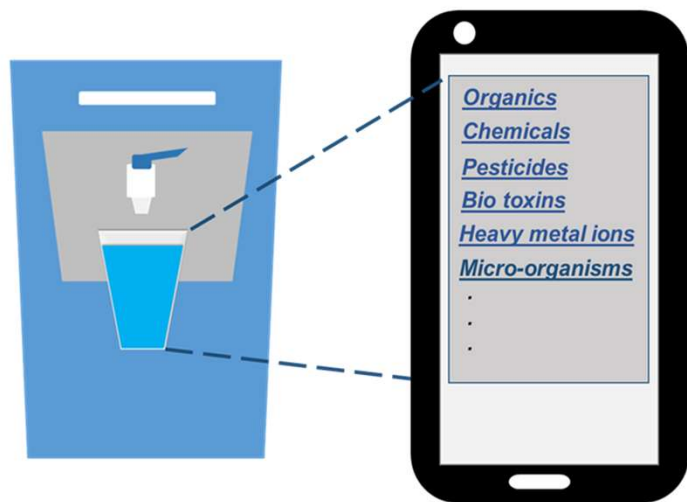
Cleanwater at 2.1 paise per litre!

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

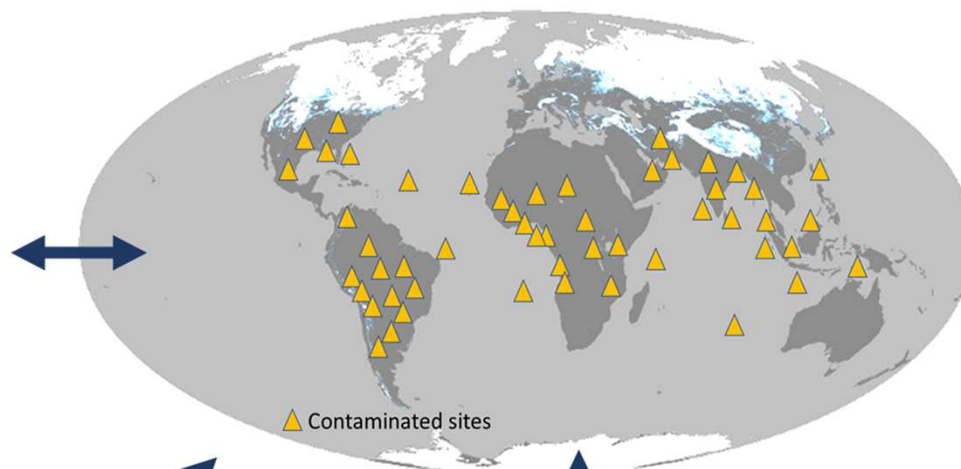
	Design population	1,071	Plant capacity/70 LPCD
Sr.No	Item/Description	Cost / Quantity	Remarks
1	Cost of Replacement of Iron removal media	56400	After minimum two years if Iron concentration is more than 5 ppm. But iron concentration is more than 5 ppm at only two to three places. Therefore media may 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 liter of water	2.1 Paise per ltr	
		1.36	Rs. per head per day
9	Cost of replacement of media	<u>40.80</u>	=Media replacement cost per year/365/Design population per head per month for 70 LPCD water

Smart water purifiers and big data

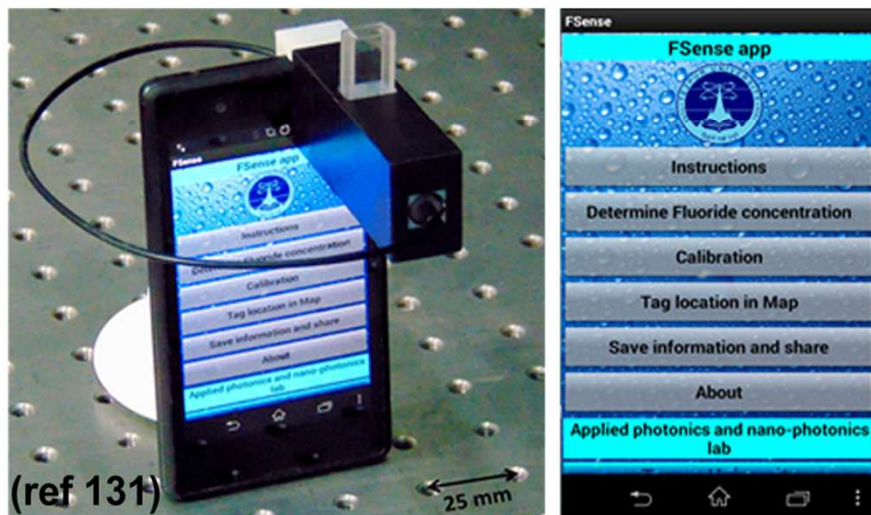
Smart Water Purifiers linked to IoT



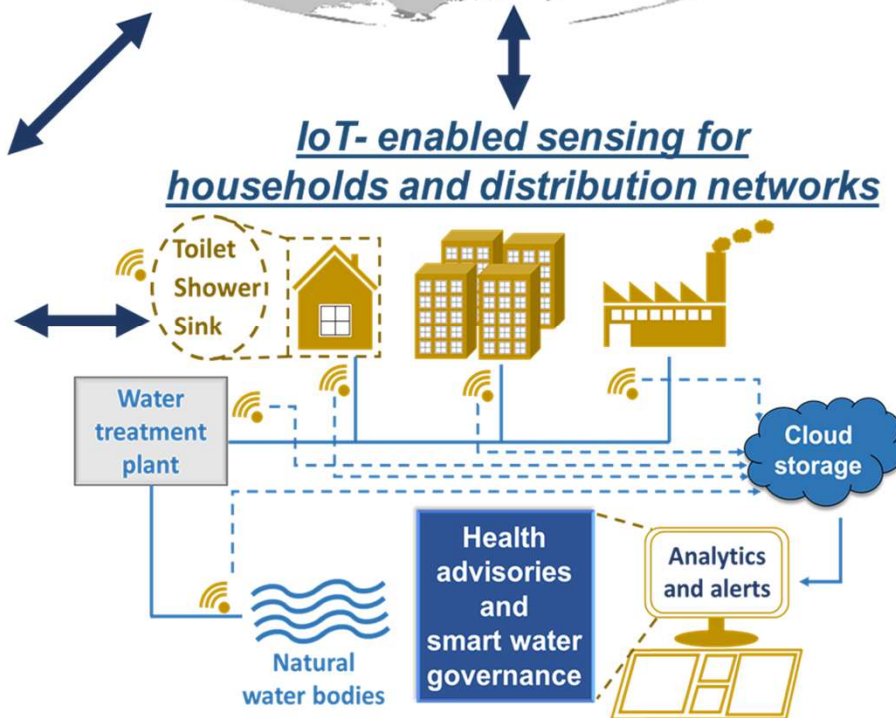
Global Map of Water Health



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



IoT-enabled sensing for households and distribution networks



Waste management

Adsorbents conform to toxicity characteristic leaching procedure

Elemental waste goes back to local environment

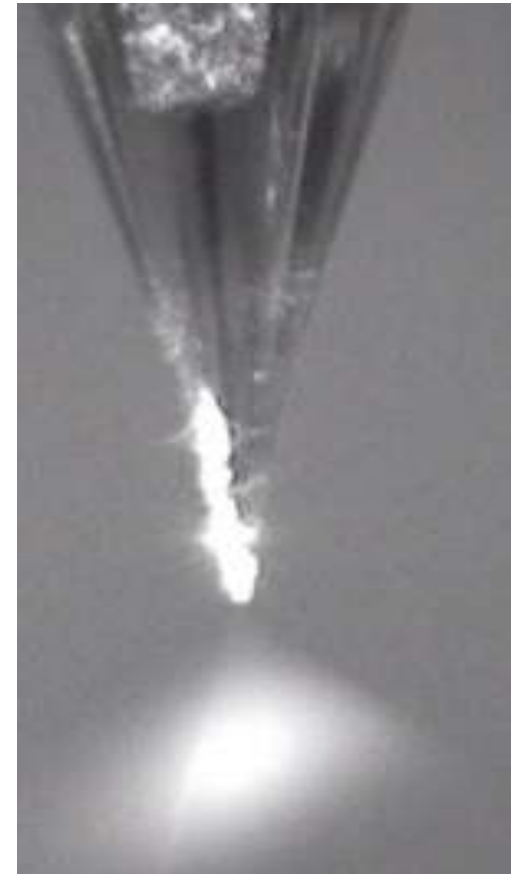
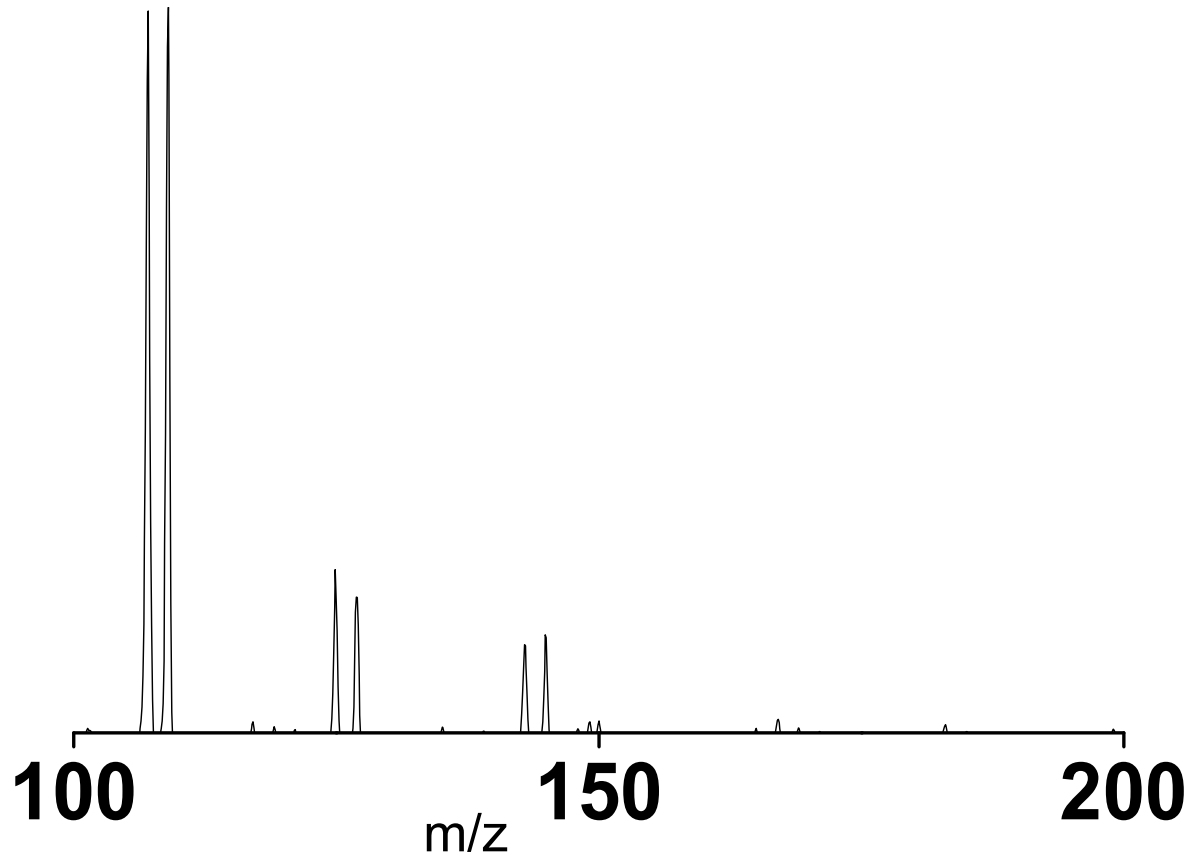
Safe disposal of arsenic (or any other) laden waste

Additional protection could be considered, if necessary

Exploring viable uses



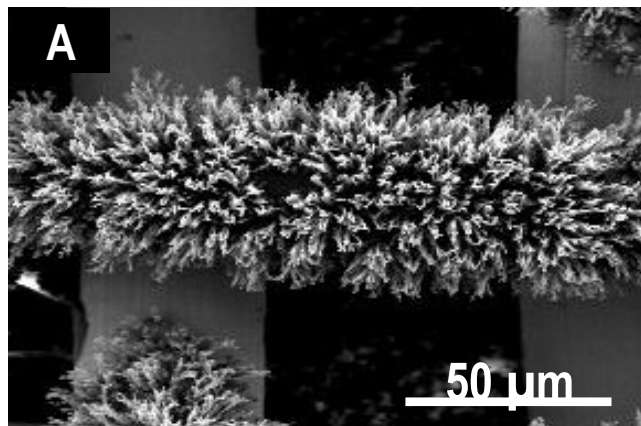
Atmospheric water harvesting



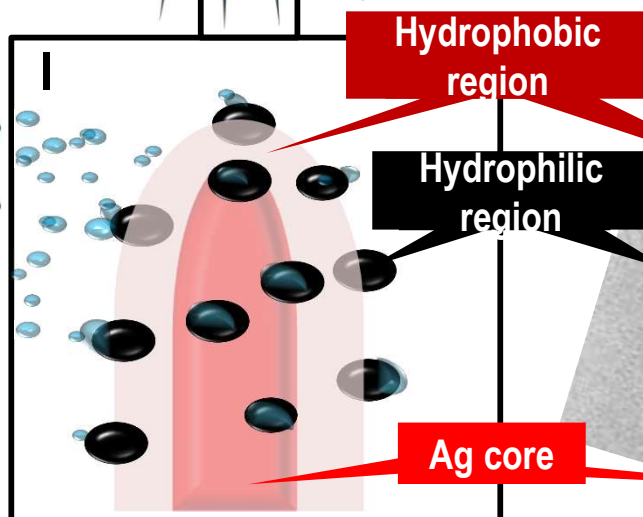
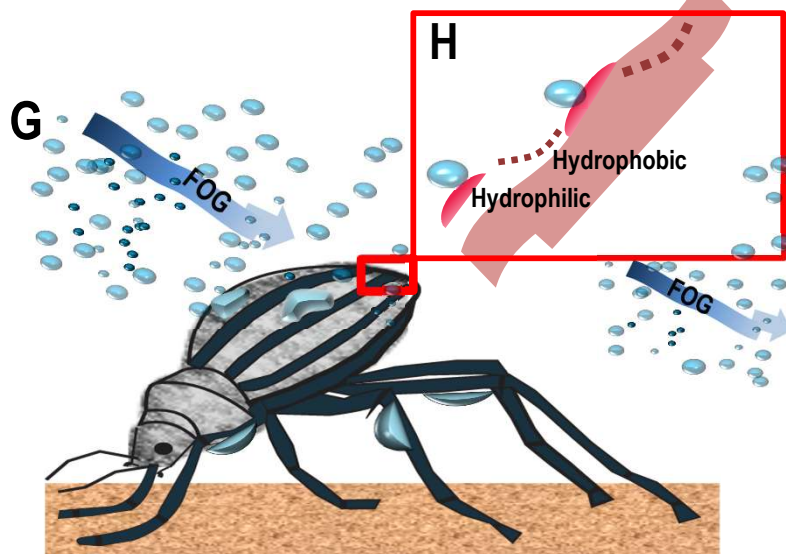
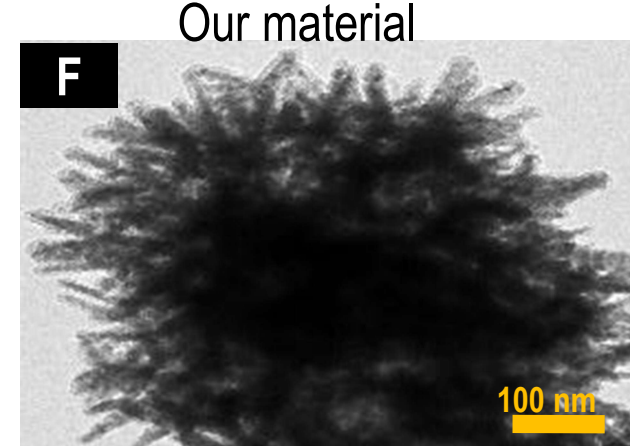
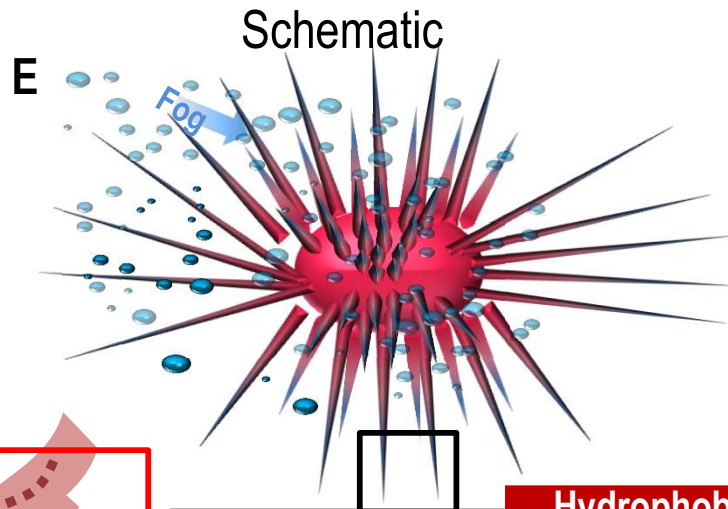
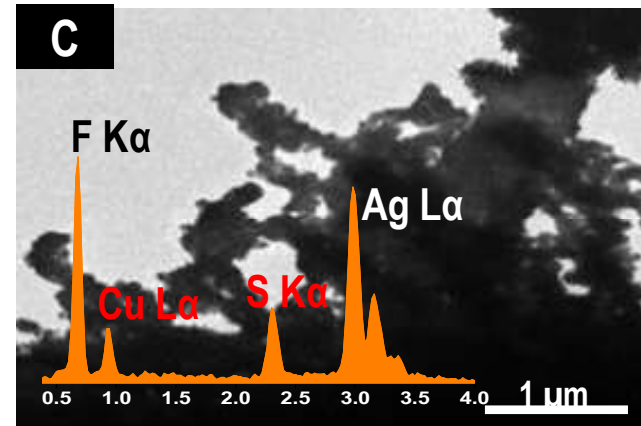
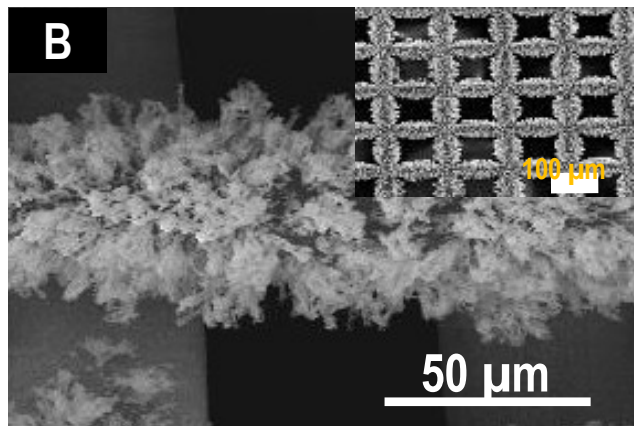
New harvesters



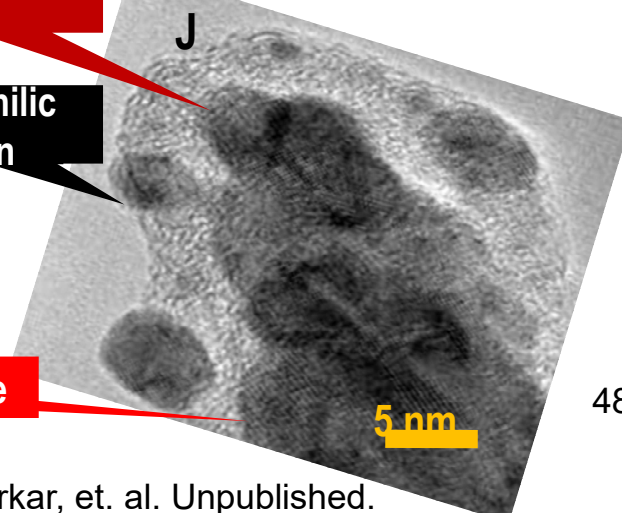
Depanjan Sarkar, et. al. *Advanced Materials*, 28 (11), 2016.

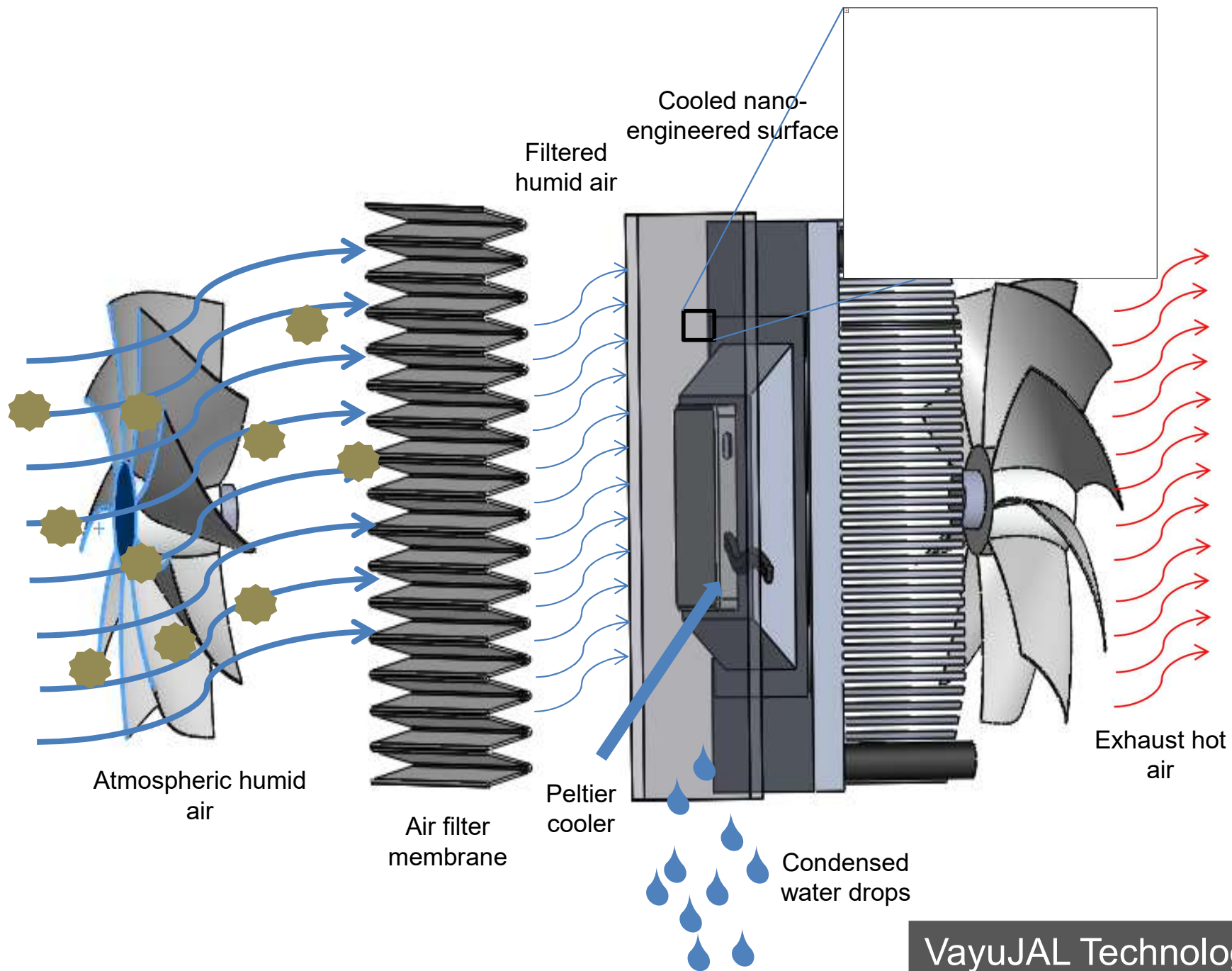


Nature



Combination of cactus and Namib desert beetle effect





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

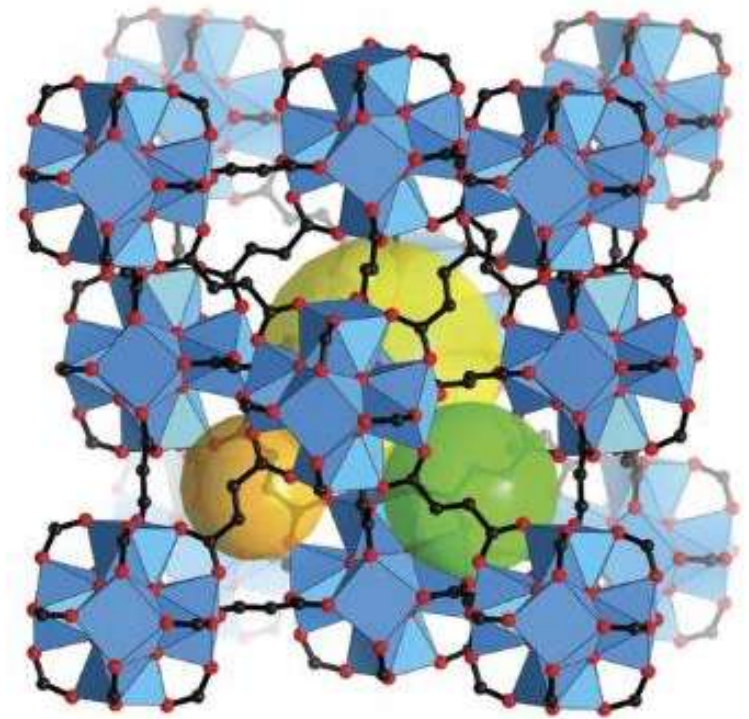
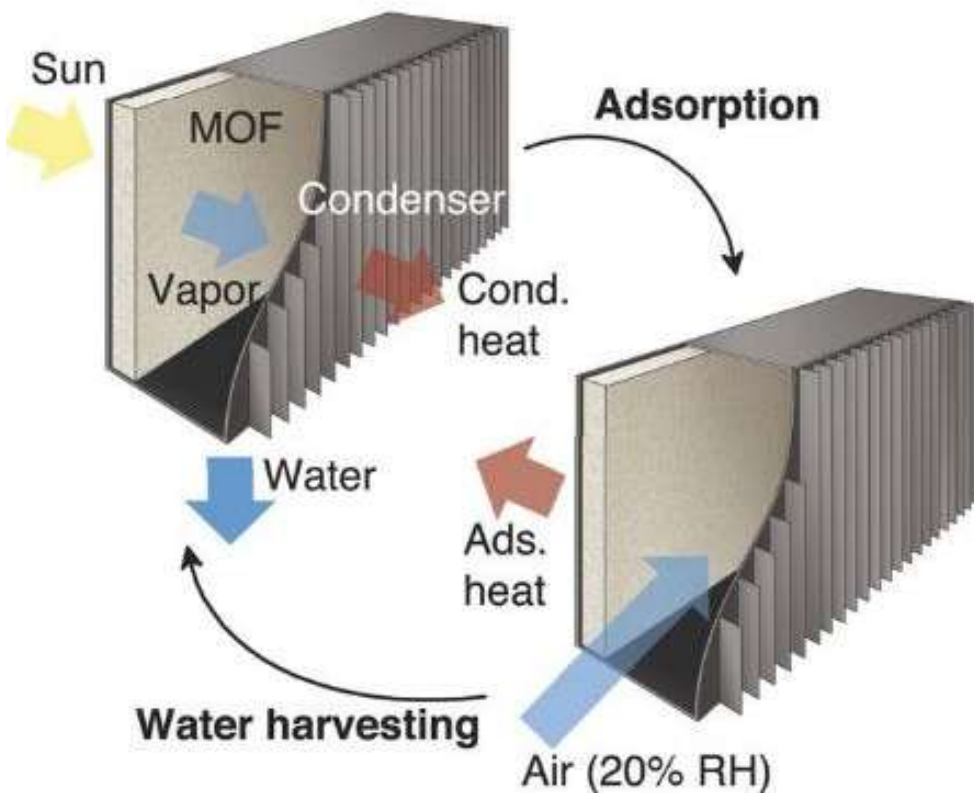
Products in the field



(LPD: Litres per day)

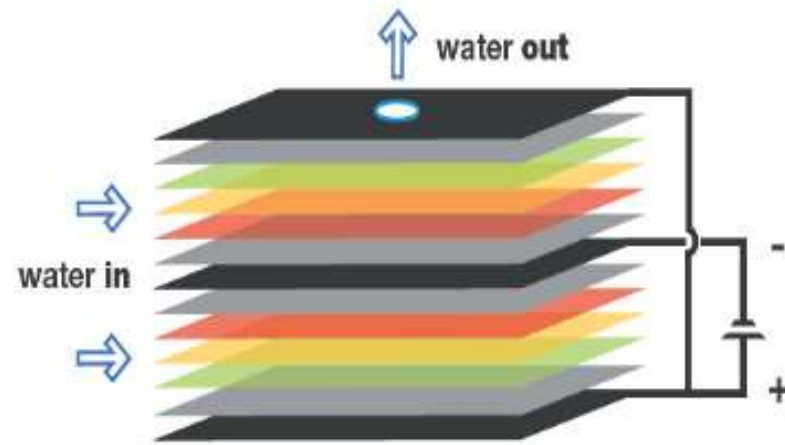
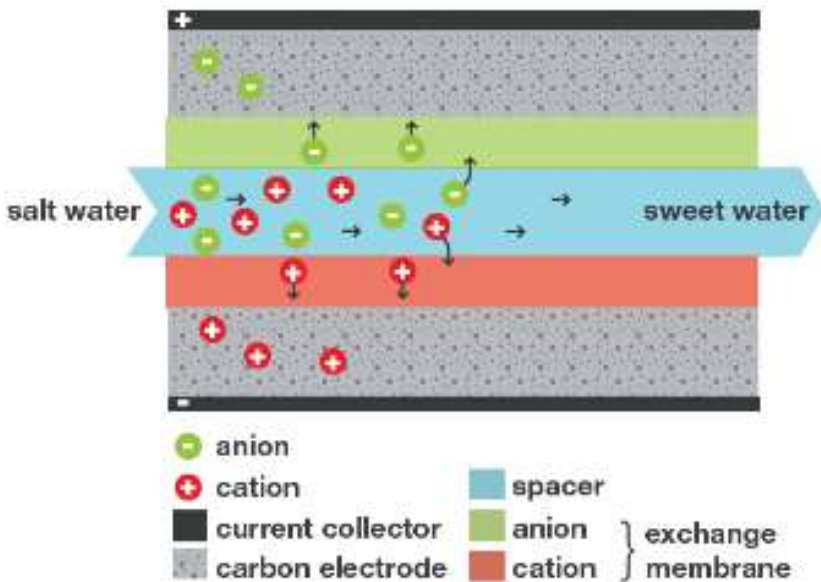
Sustainable atmospheric water harvesting

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



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

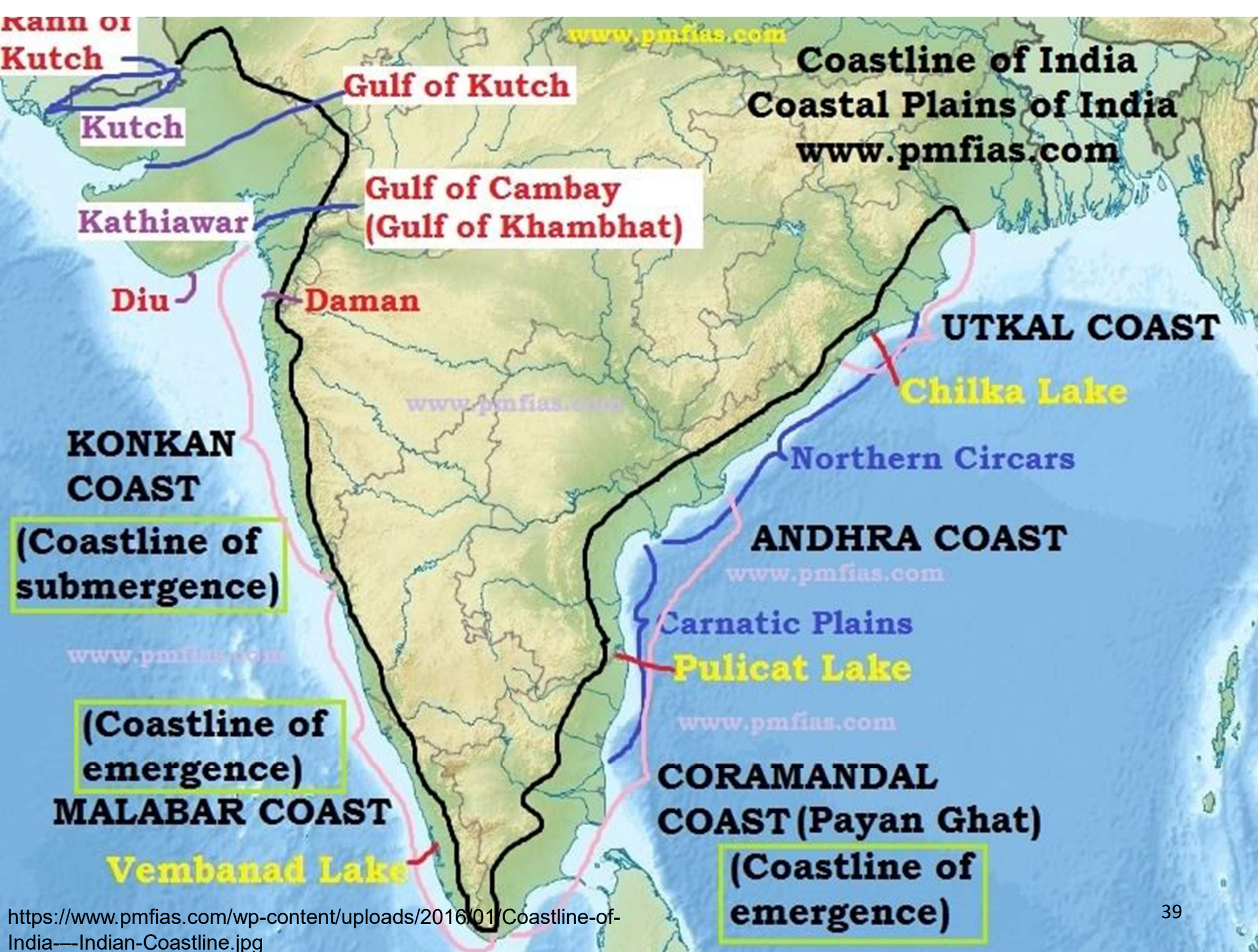
Capacitive Desalination (CDI)



imoDI

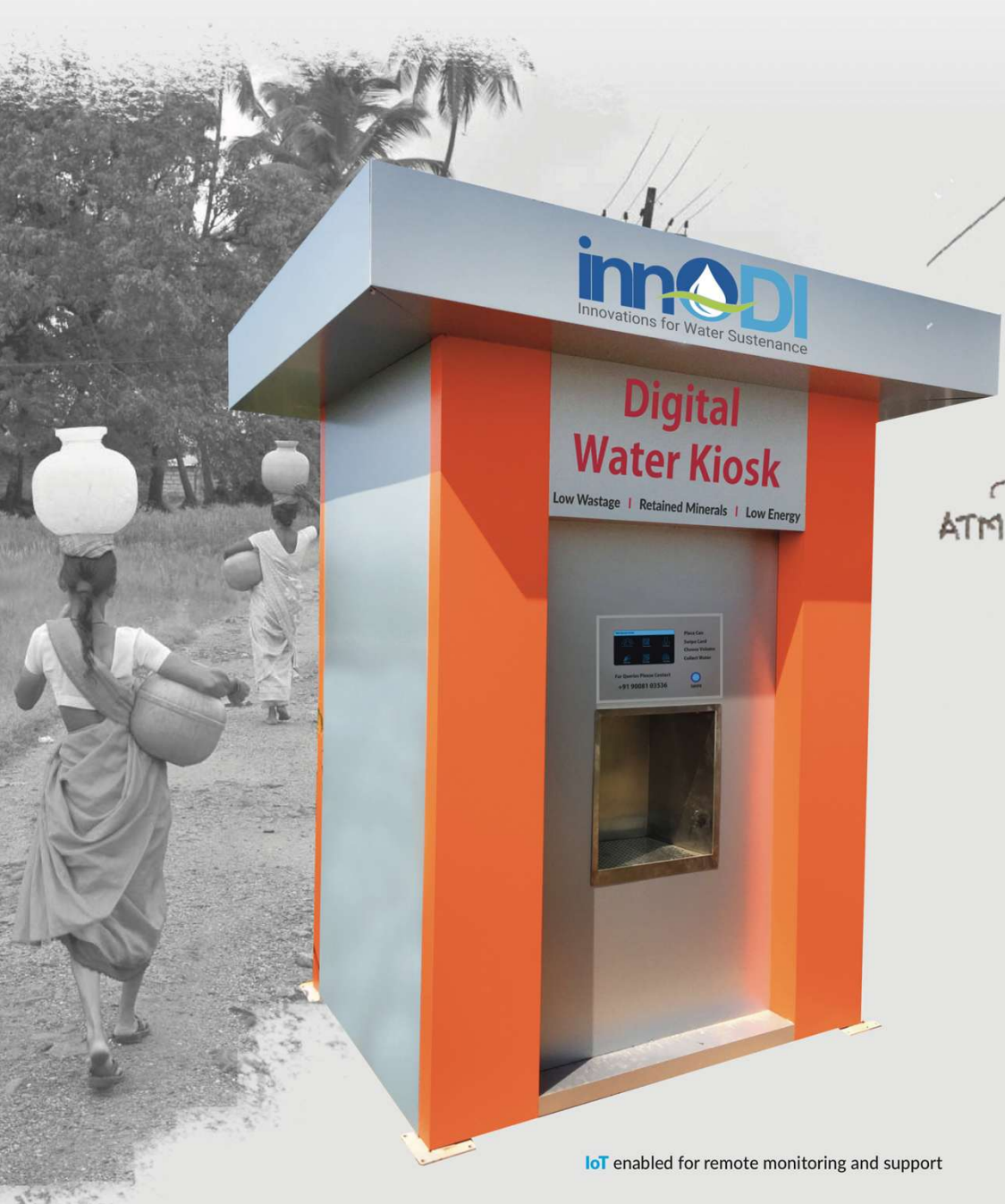
Our new company

Soujit Sengupta, Rabiul Islam and others

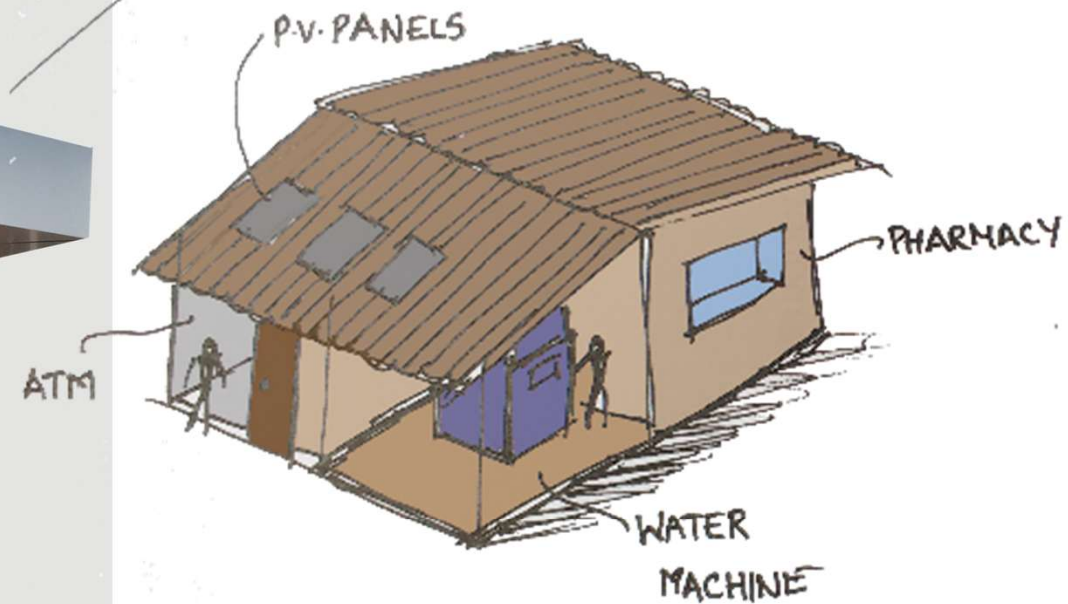


DIGITAL WATER KIOSK

for community drinking using CDI Technology



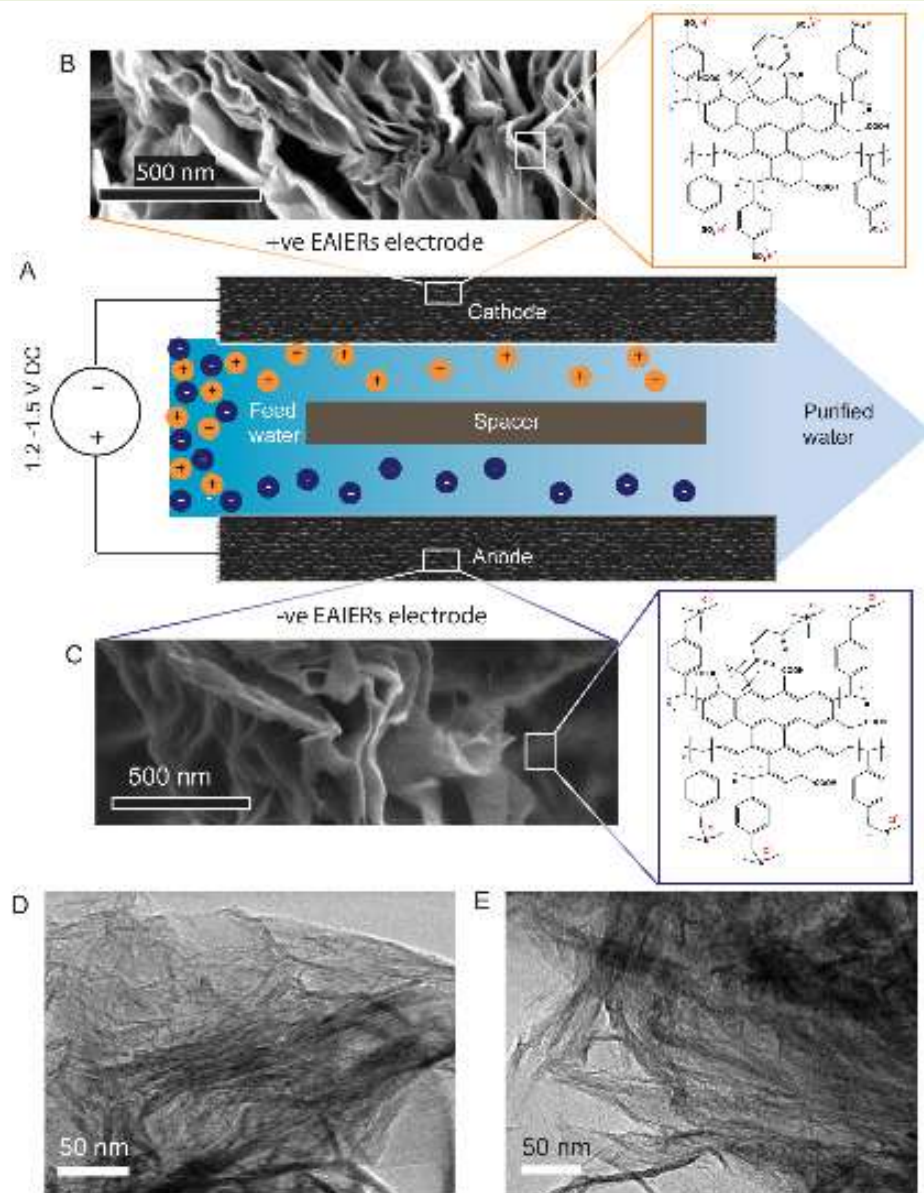
IoT enabled for remote monitoring and support



Products under implementation

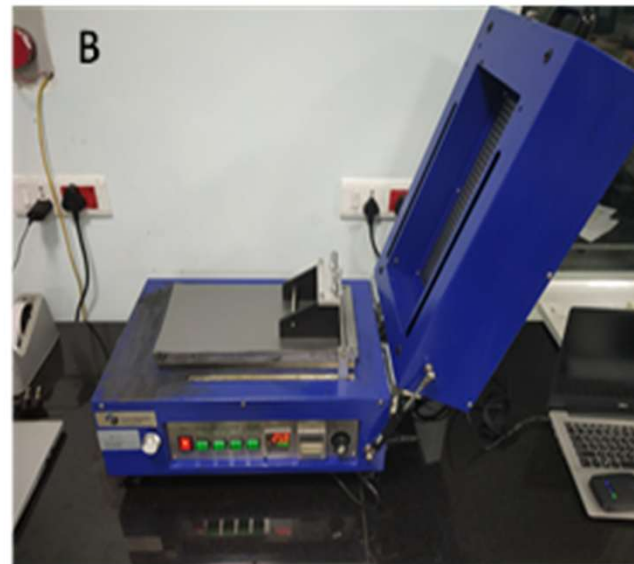
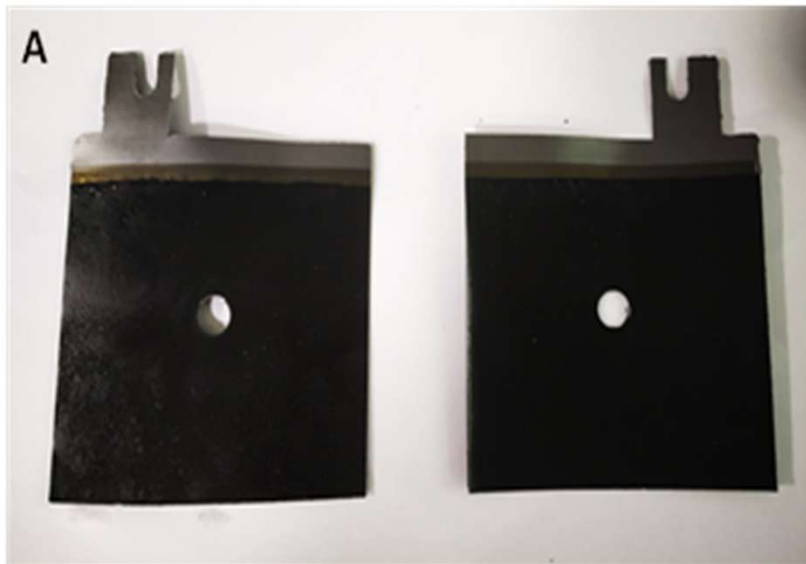
Vijay Sampath and Tullio Servida

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

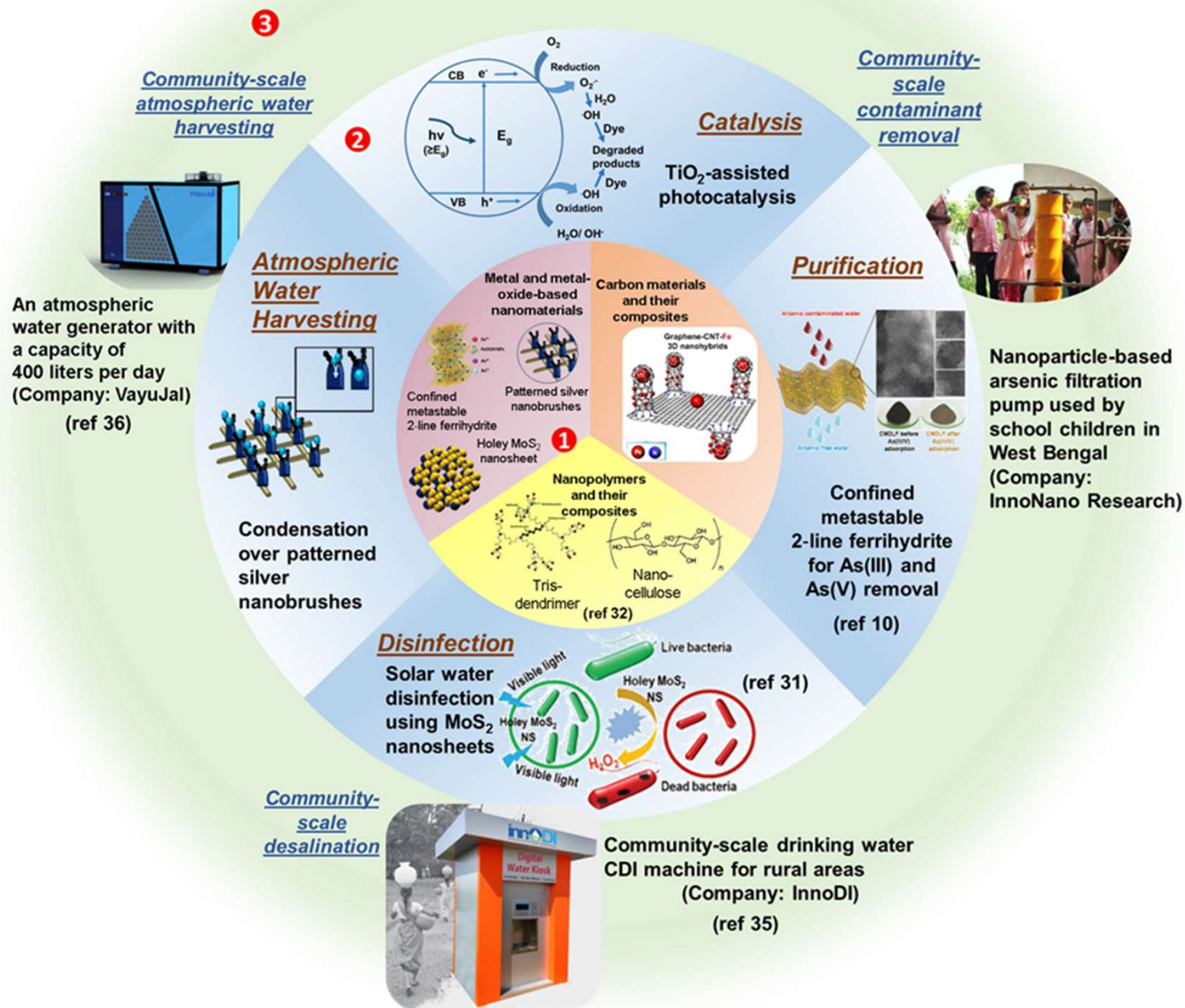


Rabiul et al., *Adv. Mater. Interfaces* **2021**, 8, 2001998

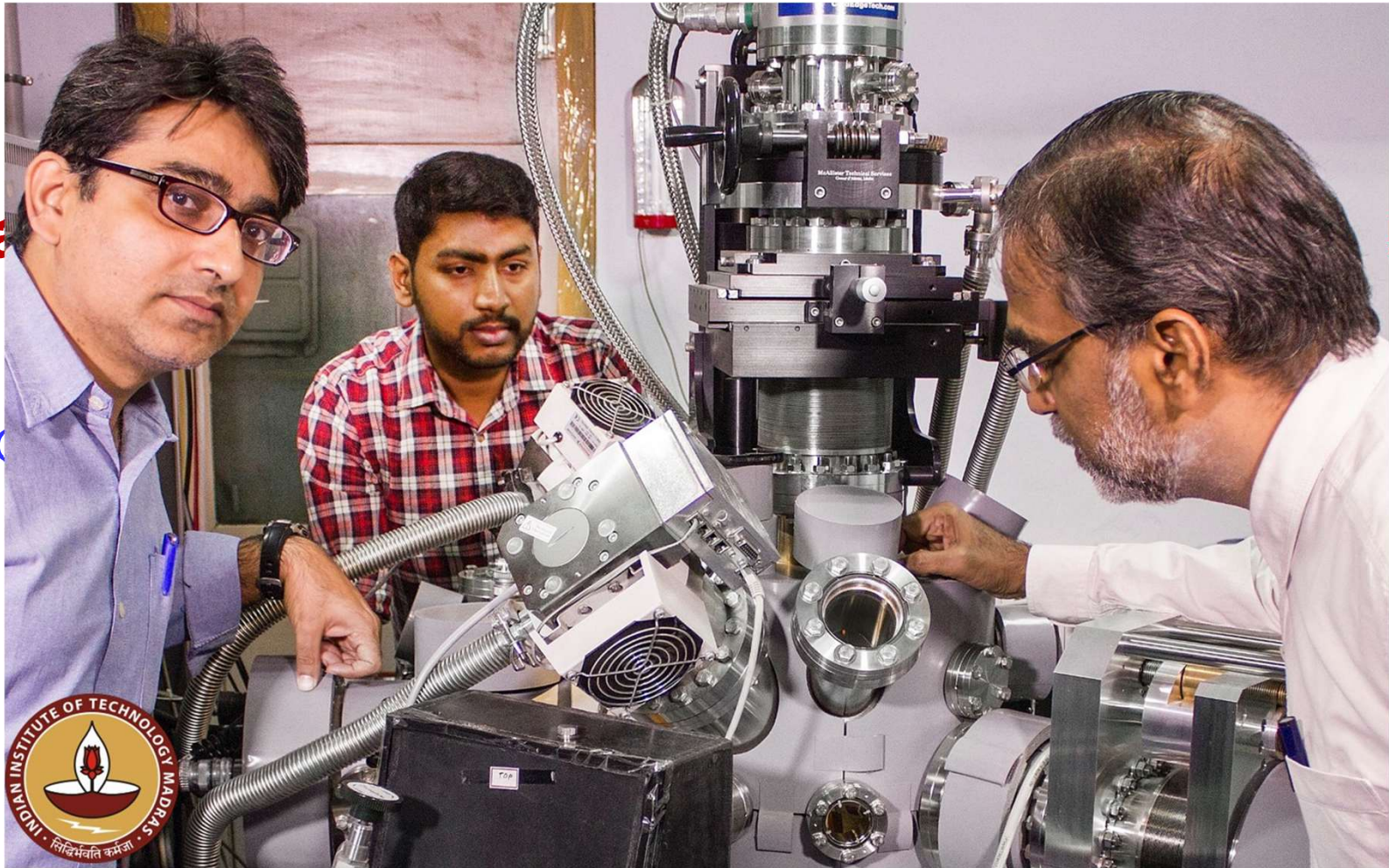
Various stages of electrode preparation



Evolution of materials to products

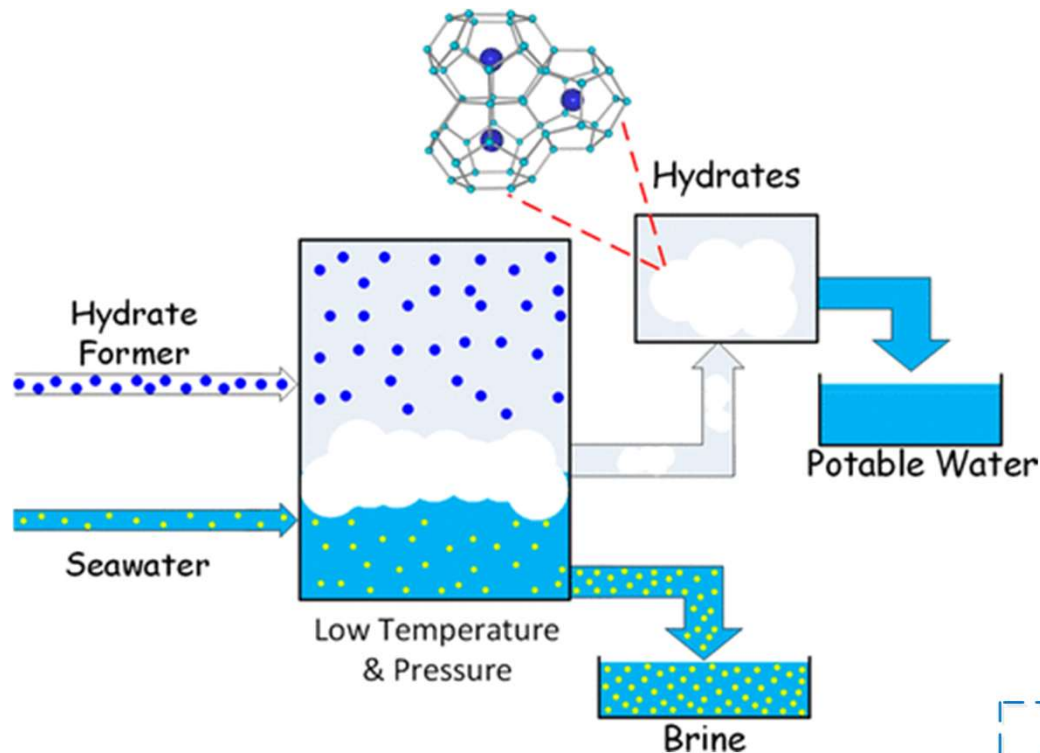


New phenomena



With Rajnish Kumar

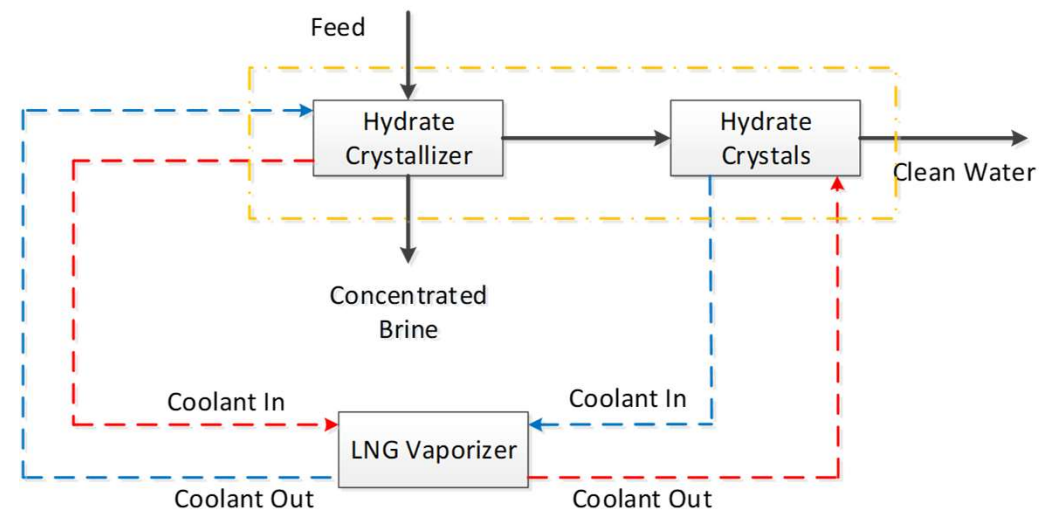
Hydrate-based desalination (HyDesal)



Water dissociated from hydrate is pure

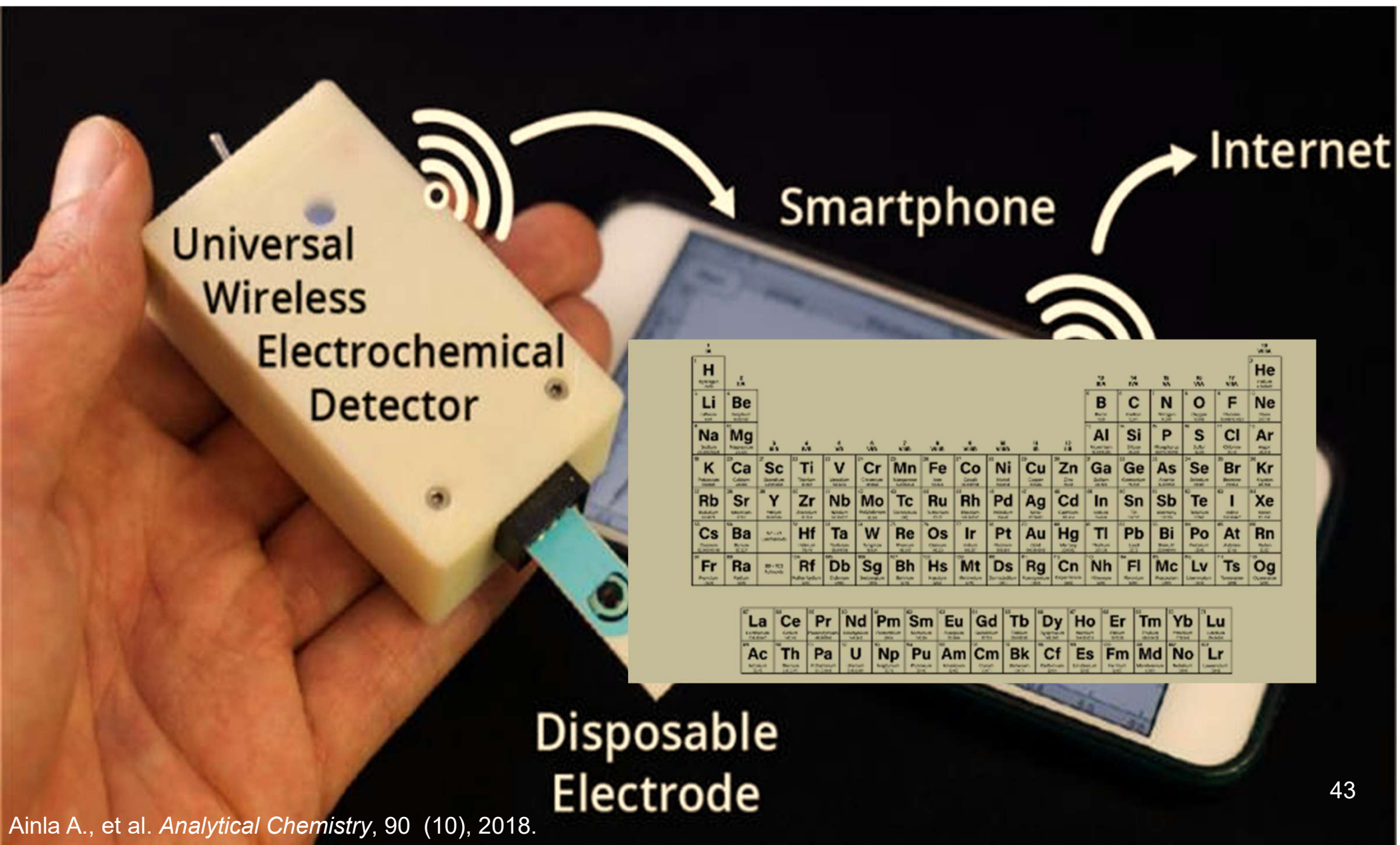
HyDesal process advantages

- ✓ 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

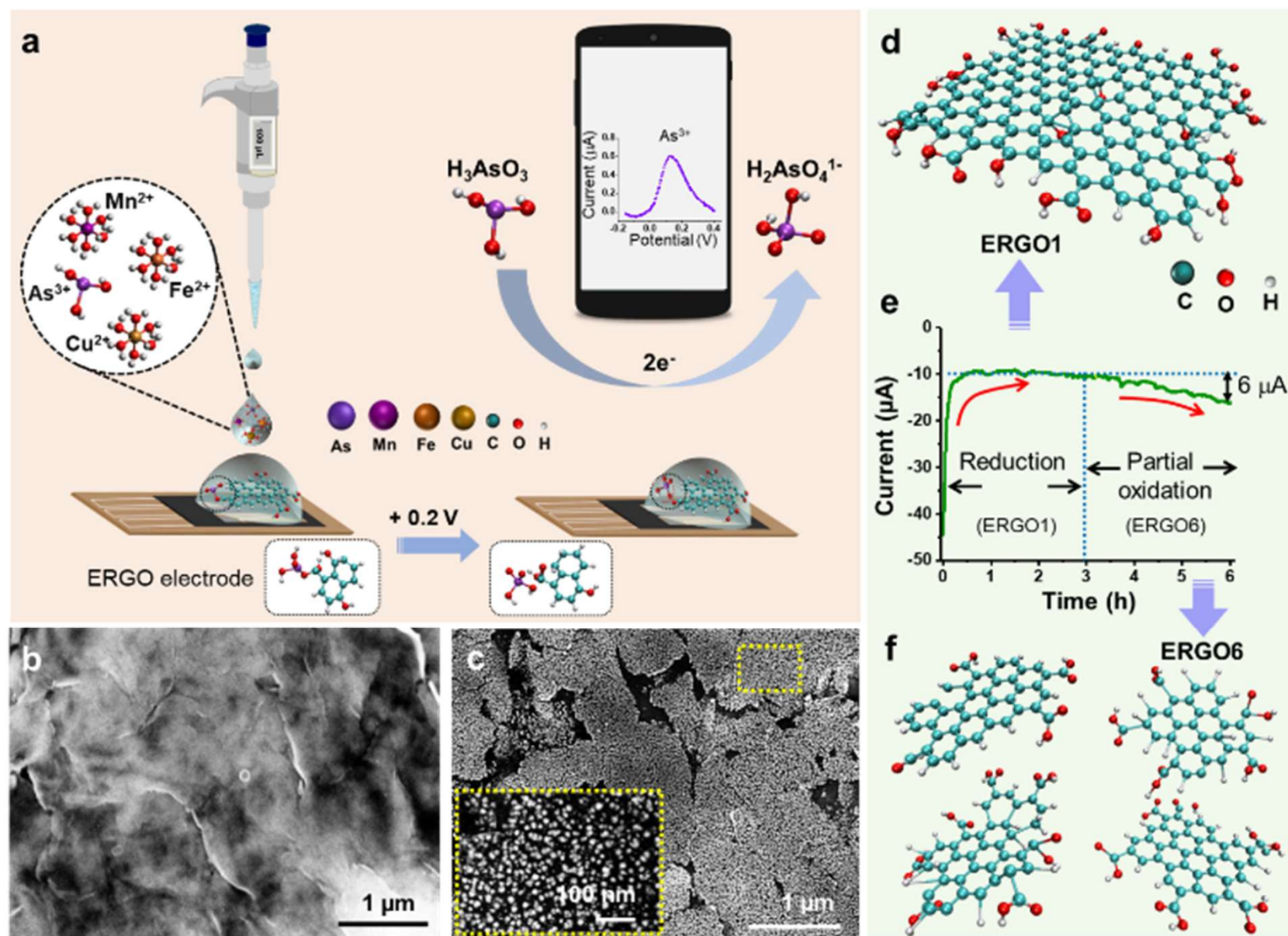


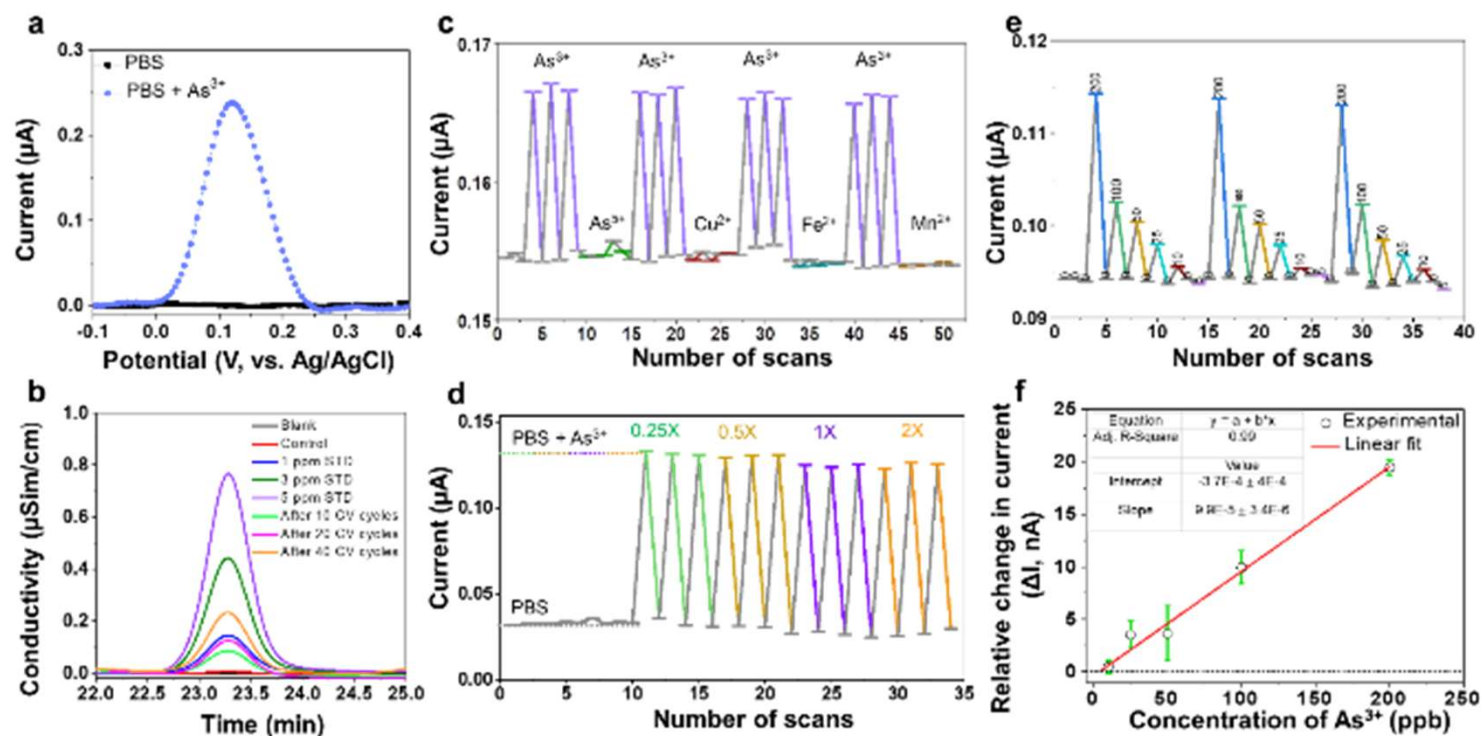
Cold Energy in LNG terminals can be harvested to produce water

Analytical devices

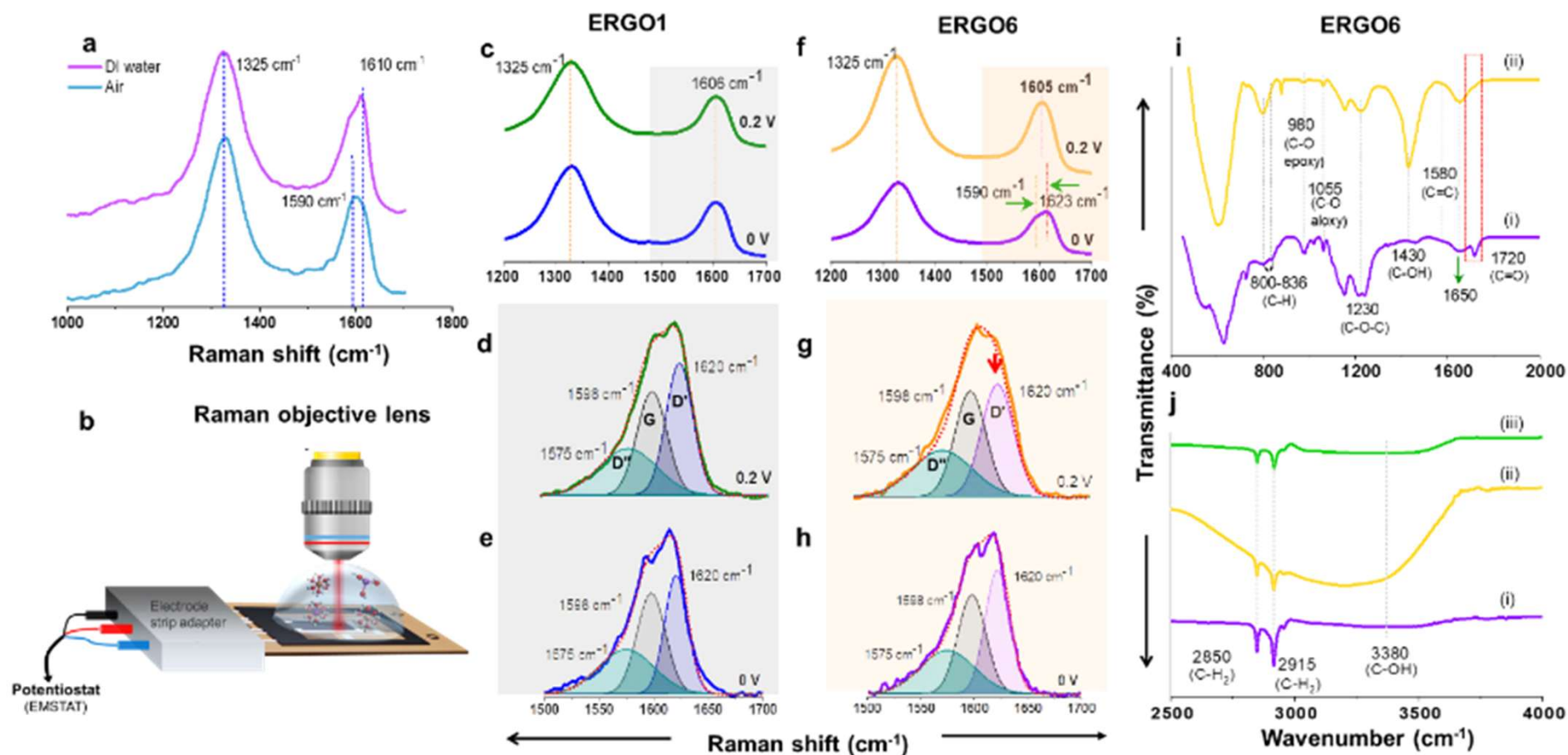


Practical graphene-based arsenite sensor at 10 ppb



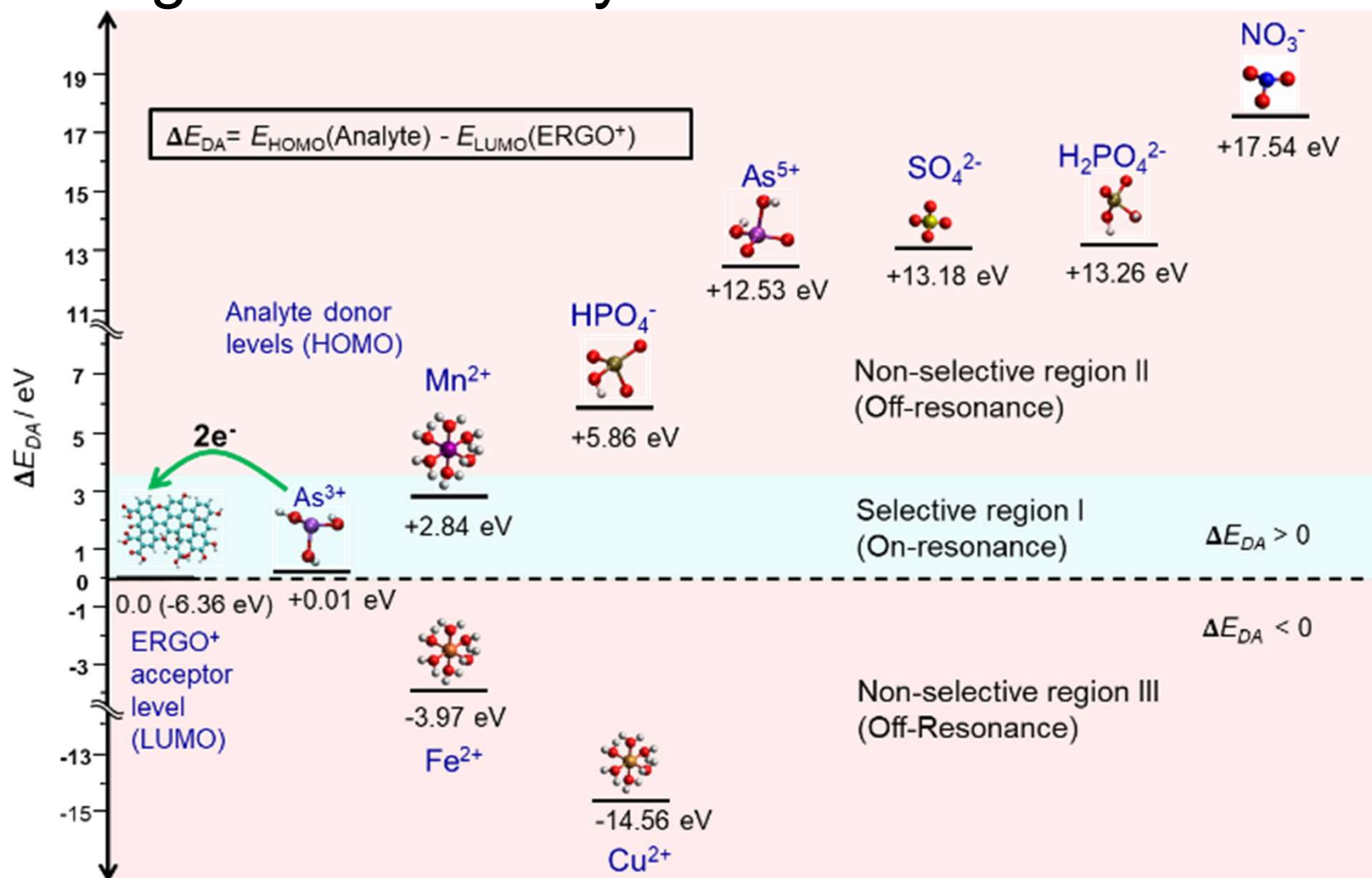


(a) LSV response of ERGO6 without and with 1 ppm As^{3+} , (b) Chronograms obtained from ion chromatography (IC) measurement with the solutions obtained after different number of CV cycles and same measurement with standard (STD) As^{5+} solutions of different concentrations. (c) CA measurement with different concentrations of As^{3+} . (d) Calibration curve showing linearity down to 10 ppb. (e) Interference study performed with several heavy metal ions with ERGO6 electrode. Concentration of As^{3+} was fixed at 200 ppb, while 1 ppm was maintained for interfering ions. (f) Investigation of CA current response of 1 ppm As^{3+} spiked in PBS with different ionic conductivity. We prepared PBS solutions of different conductivity by changing their ionic concentrations and used them further as electrolytes during CA measurements.



(a) Raman spectra of ERGO6 without (air) and with DI water. (b) Schematic depicts spectro-electrochemical (SPEC) measurement set-up. During SPEC measurements, the Raman objective was focused at the surface of ERGO6 strips with and without As³⁺ containing DI water on it and a DC potential of 0.2 V was applied to the electrode. (c) Raman spectra of ERGO1 in presence of As³⁺ without and with the application of potential (+ 0.2 V). Gaussian peak fitting was performed on the G bands of Raman spectra of ERGO1 (d) with, and (e) without the application of potential. (f) Raman spectra of ERGO6 in presence of As³⁺ without and with application of +0.2 V. Gaussian peak fitting was performed on the G bands of the Raman spectra of ERGO6 (g) with and (h) without the application of potential. Decrease in the intensity of D' is marked with a downward arrow. FTIR spectra of ERGO6 (i) without (purple trace) and with As³⁺ (yellow trace), (j) FTIR spectra of the same strip without As³⁺ (purple trace), with As³⁺ (yellow trace), and after electrochemical oxidation (green trace) to show the changes in OH deformation peak at higher wavenumber.

Origin of selectivity



Sensors and new opportunities



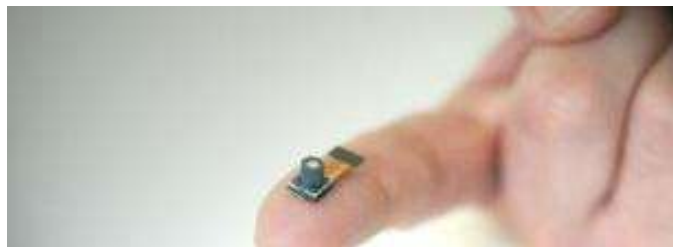
Analog/Grating
Equipment

\$ 5~6 Billion (2017)

a few **100k units** (2017)



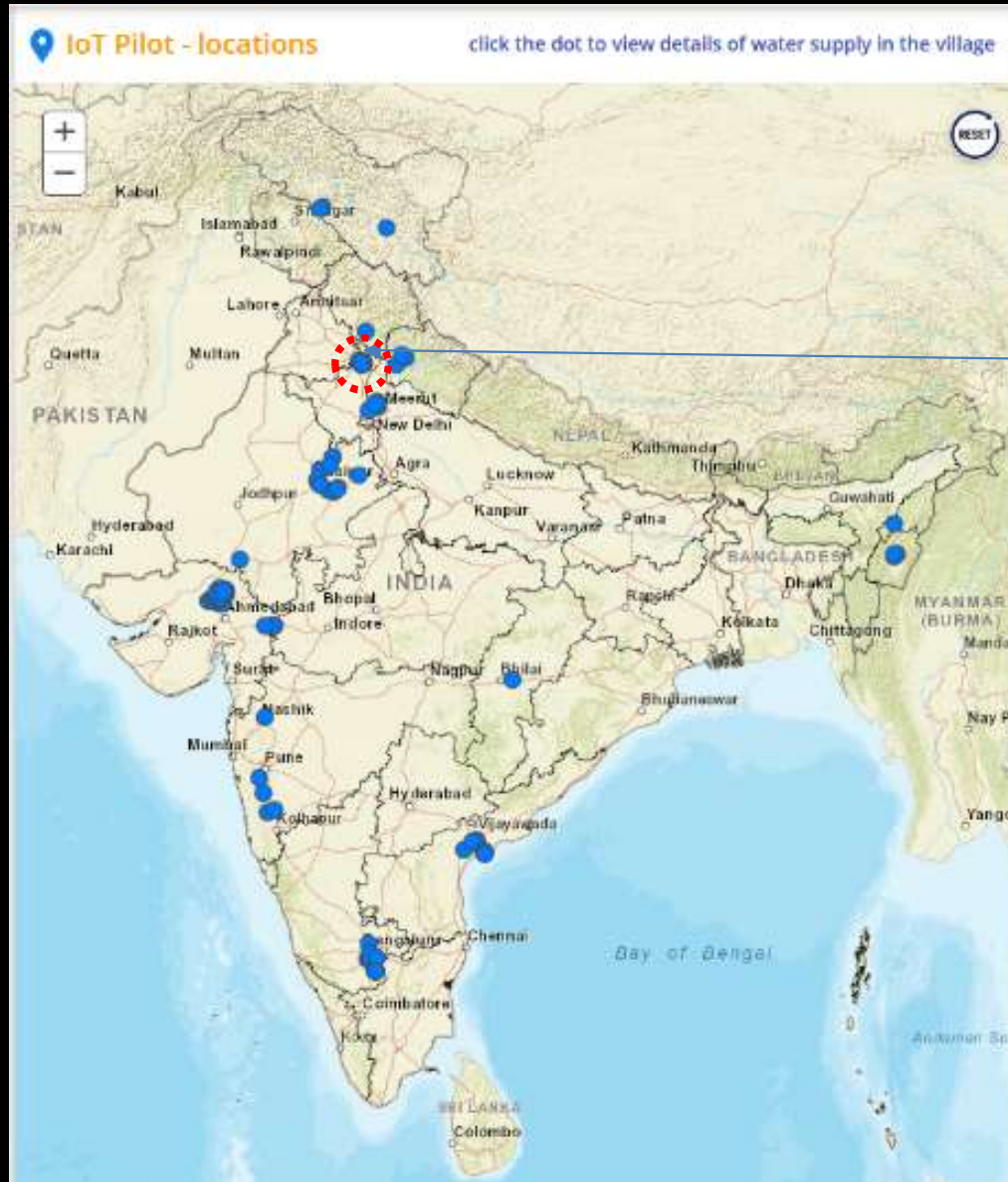
**Ultra compact Low Cost
Spectral Sensor Module**
~ **Billions units** (? 2027)



Water quality measurement – In the pipeline

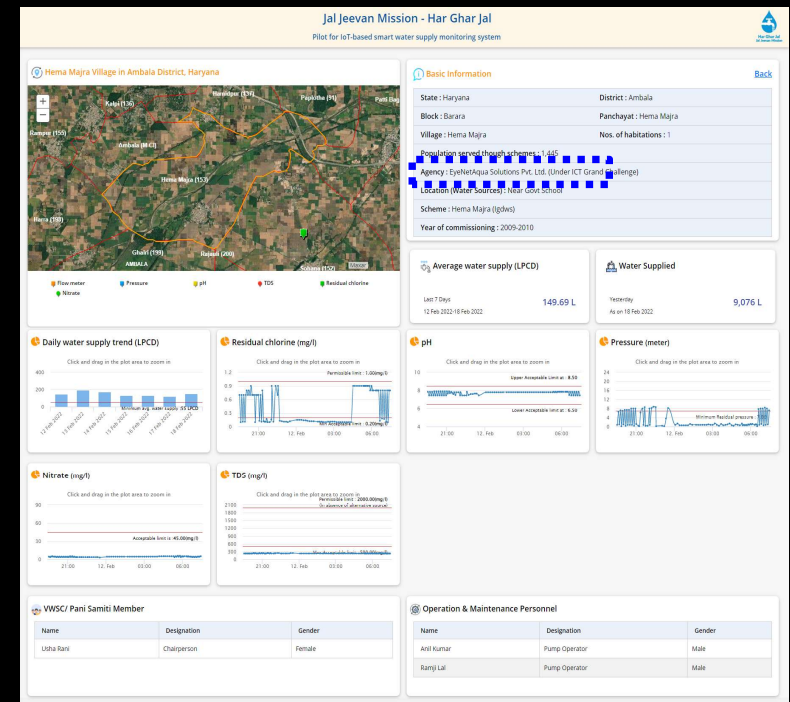
nano λ

India's water is being monitored



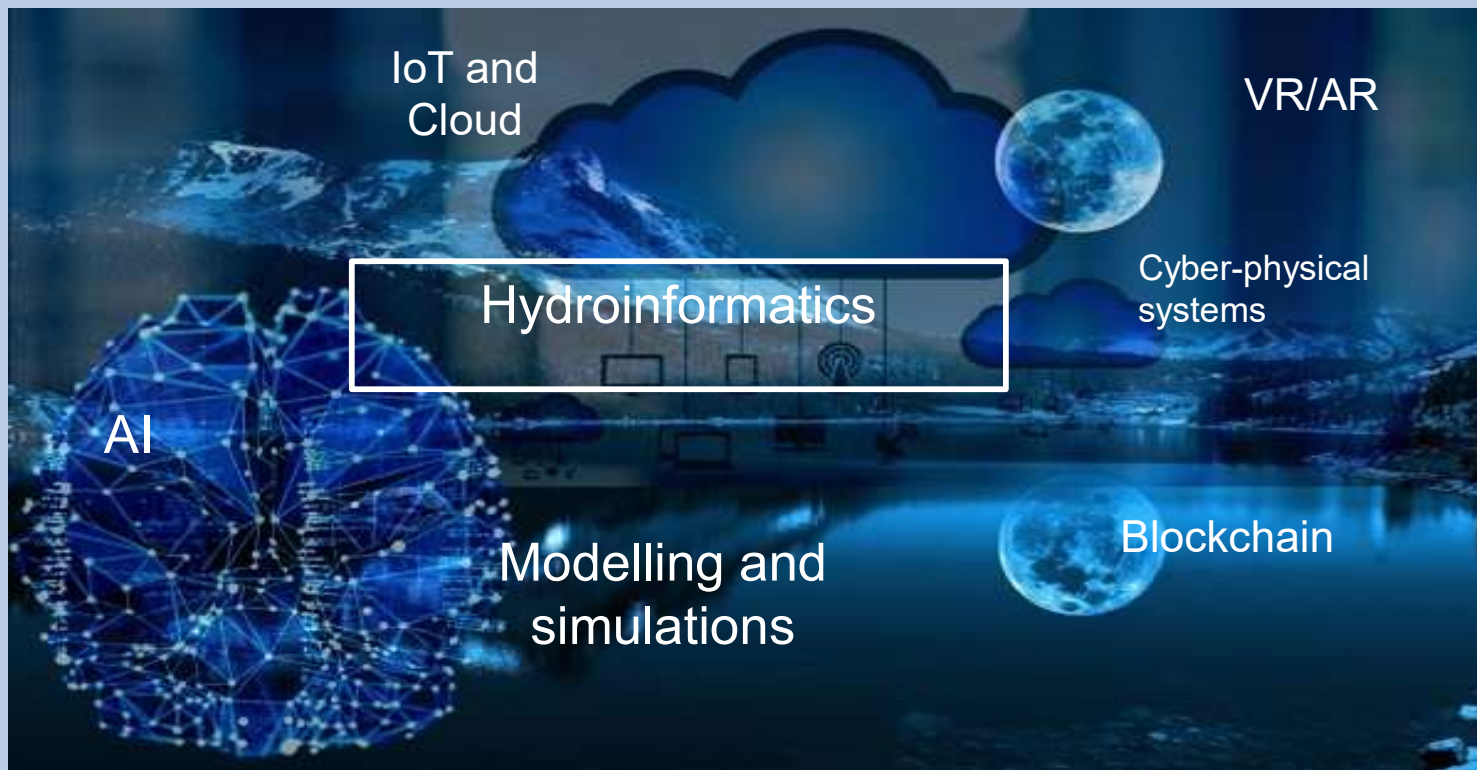
IITM/IISc

Installations made by four companies



Hydroinformatics

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

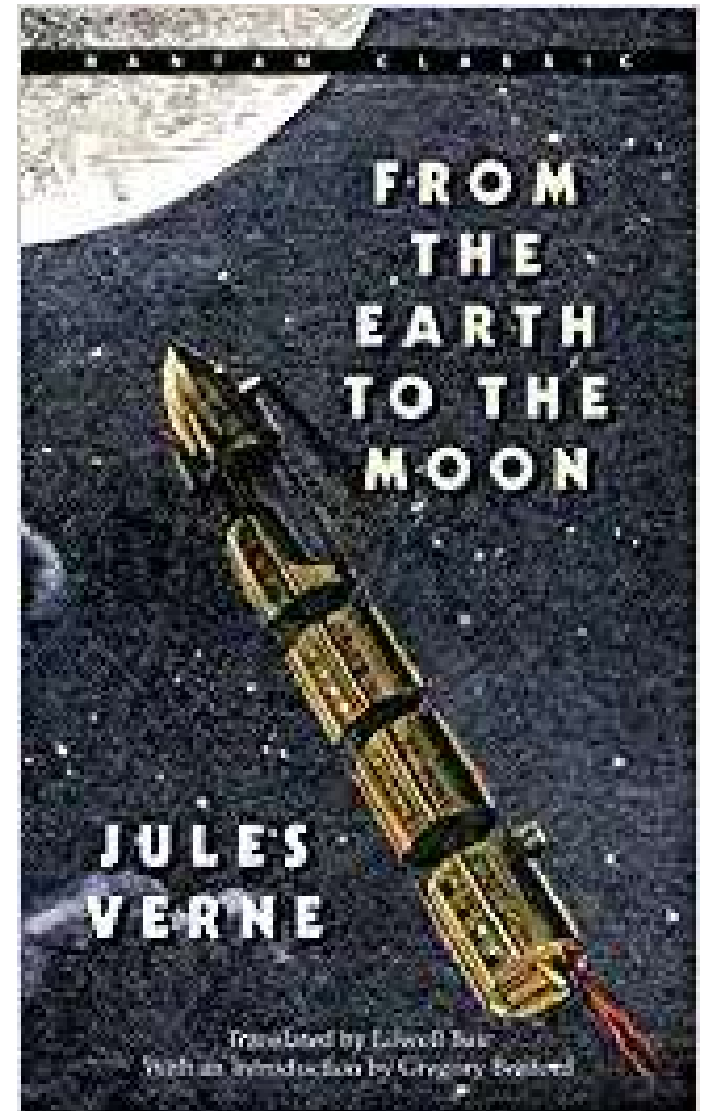
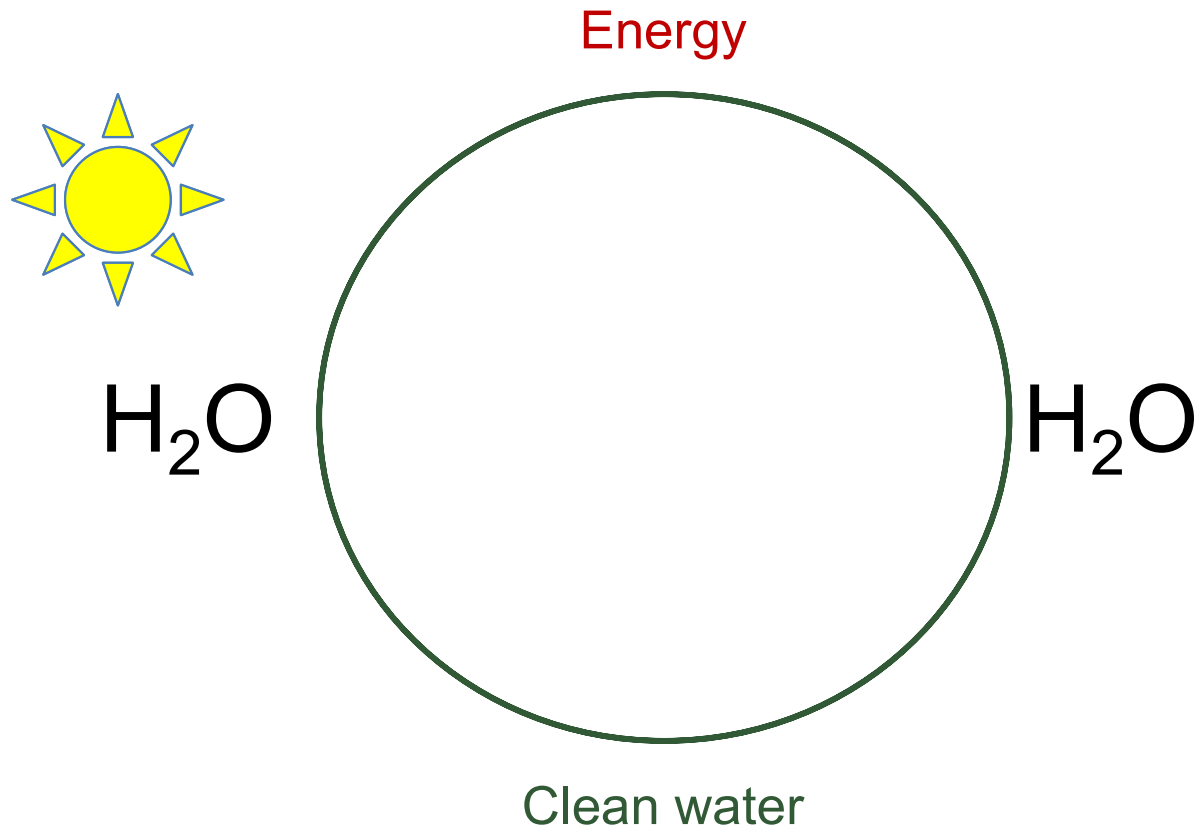


Digital water or water 4.0 will revolutionize water management.



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 per cubic meter, 0.9 paise per litre!

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

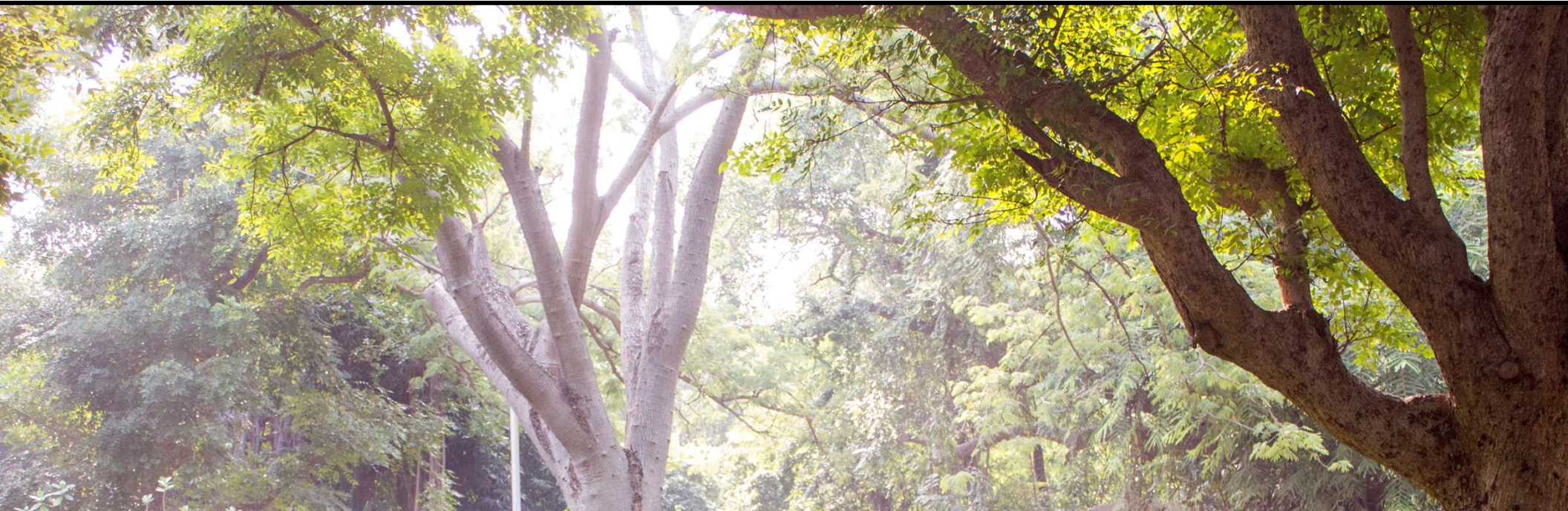
That world will need water literacy



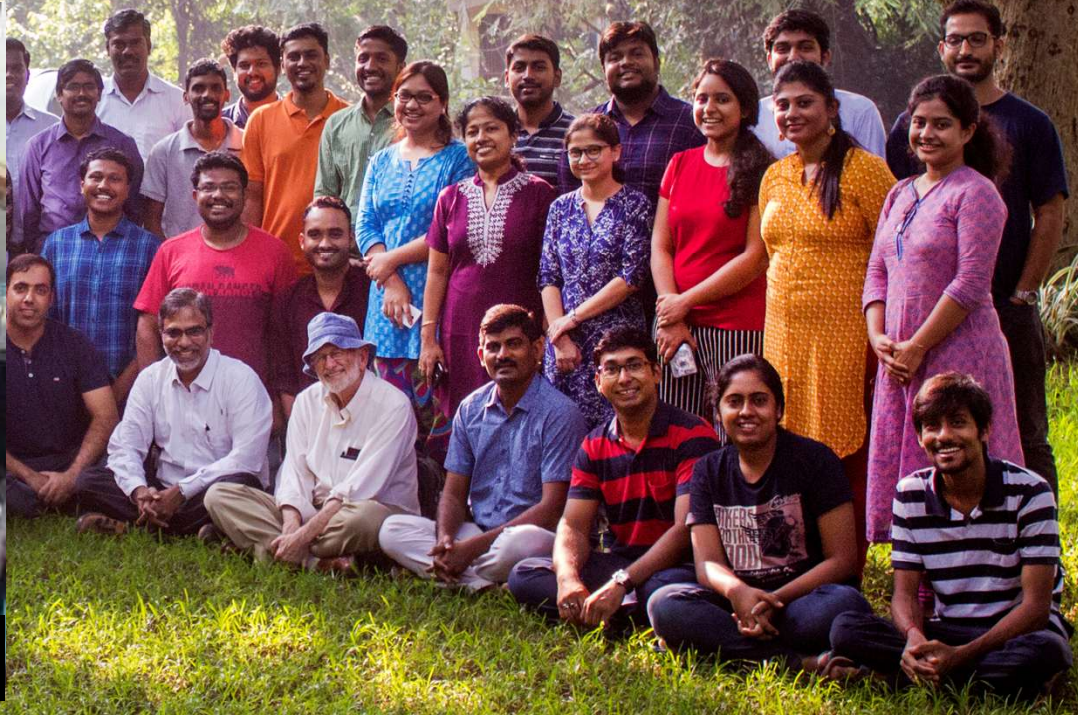
International Centre for Clean Water



IIT Madras Research Park



The AMRIT Team, 2013



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:





Indian Institute of Technology Madras



Associate Editor

ACS
Sustainable
Chemistry & Engineering

Bhaskar Ramamurthi/V. Kamakoti

Thank you all

