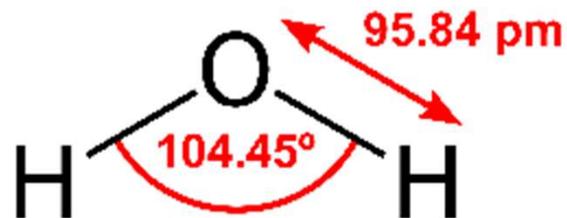




Since 1959



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.

Vinod K. Shahi and colleagues

Professor-in-charge



International Centre for Clean Water

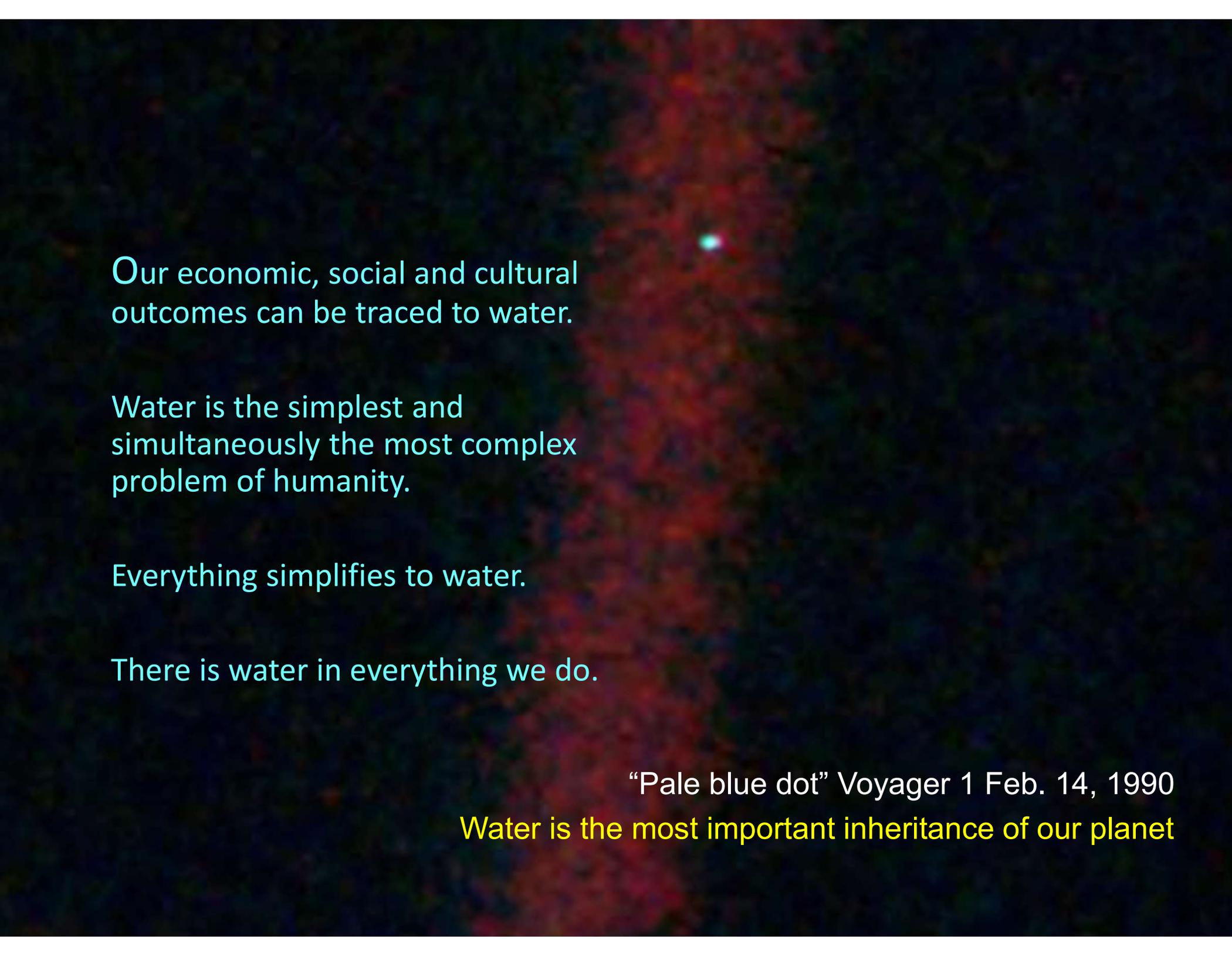


Associate Editor

ACS
Sustainable
Chemistry & Engineering



THEMATIC UNIT OF EXCELLENCE



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

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

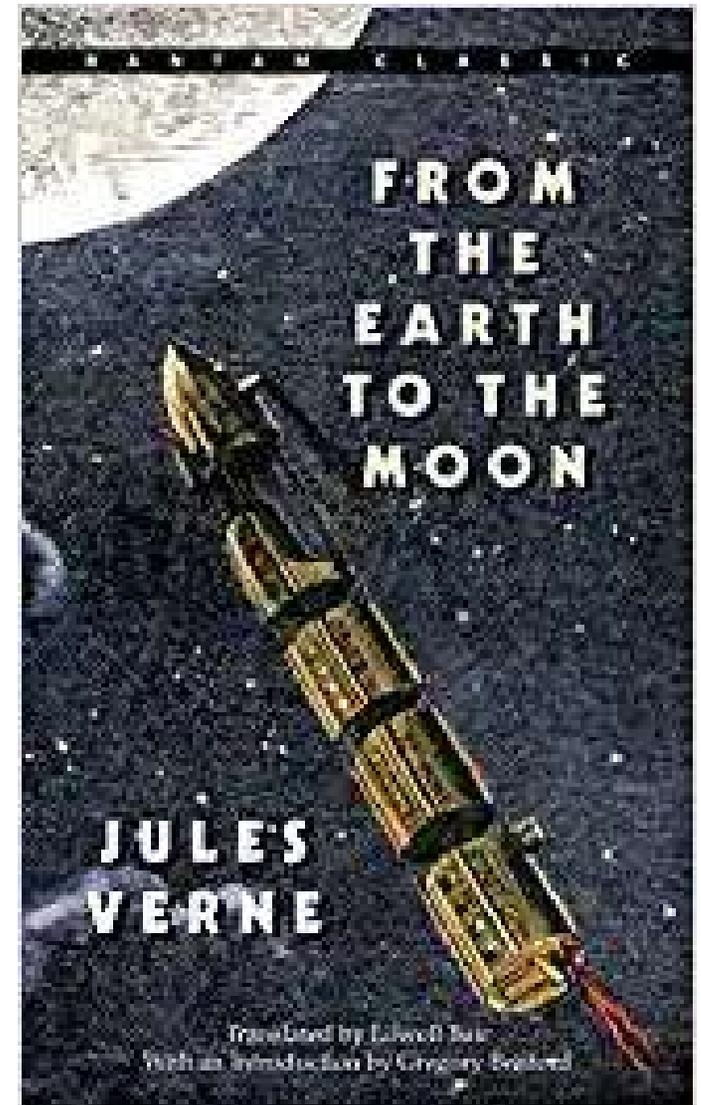
Everything simplifies to water.

There is water in everything we do.

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

Water is the most important inheritance of our planet

Our dreams become reality with materials



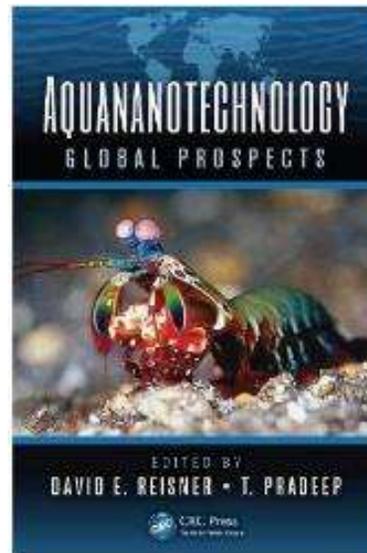
Water purification, history

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)

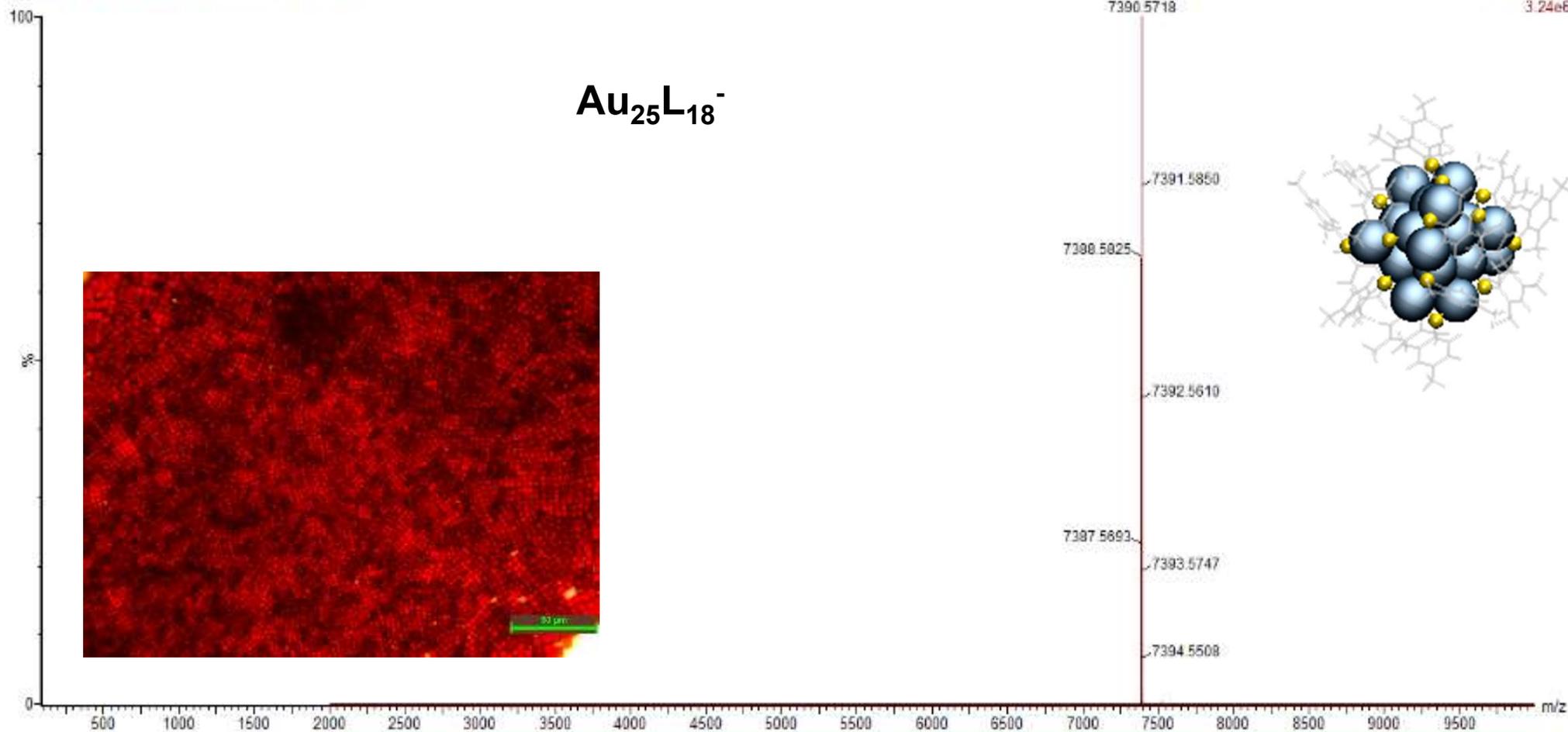
Affordable clean water is a problem of advanced materials

- 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)

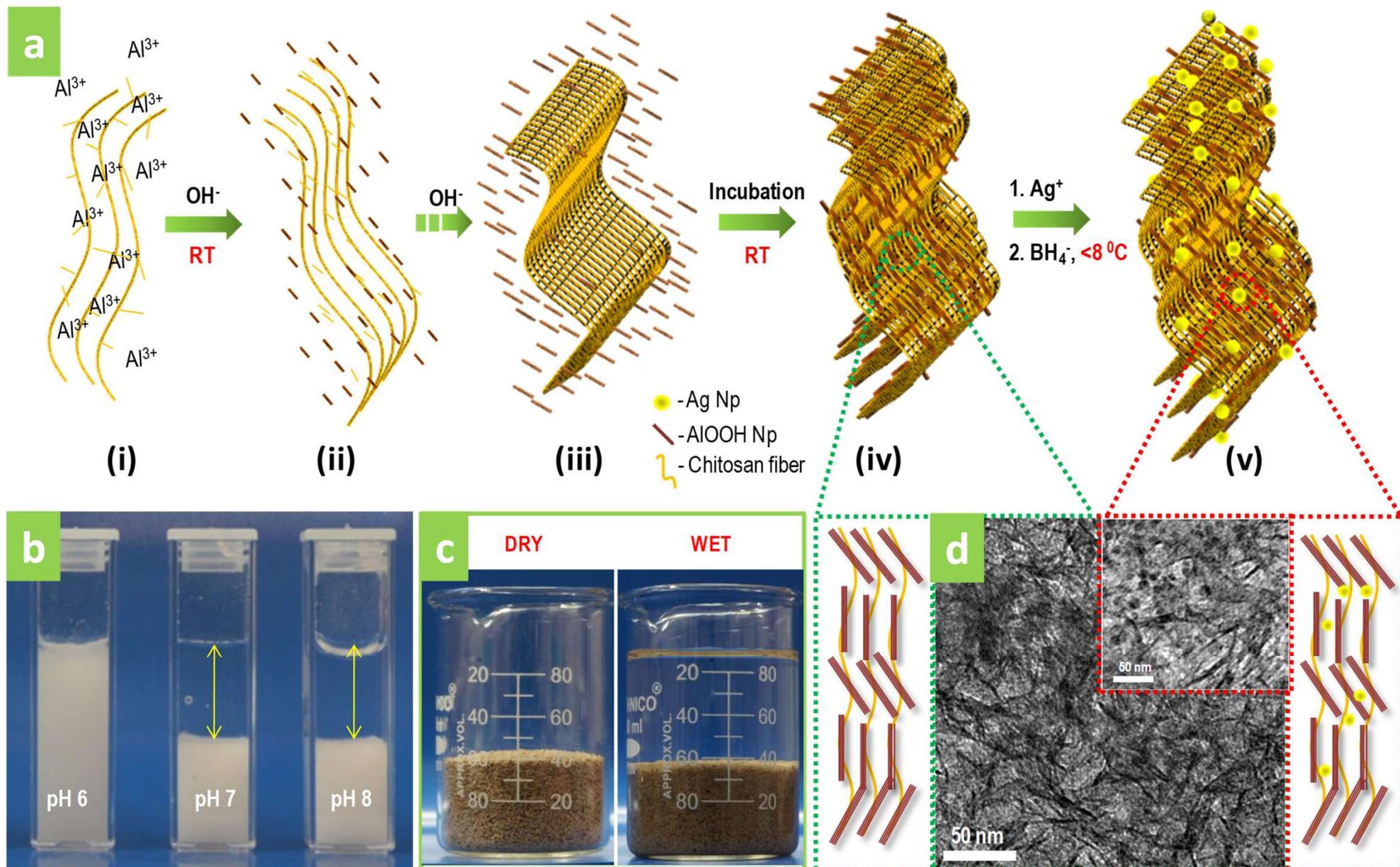


Nanomaterials can solve real problems

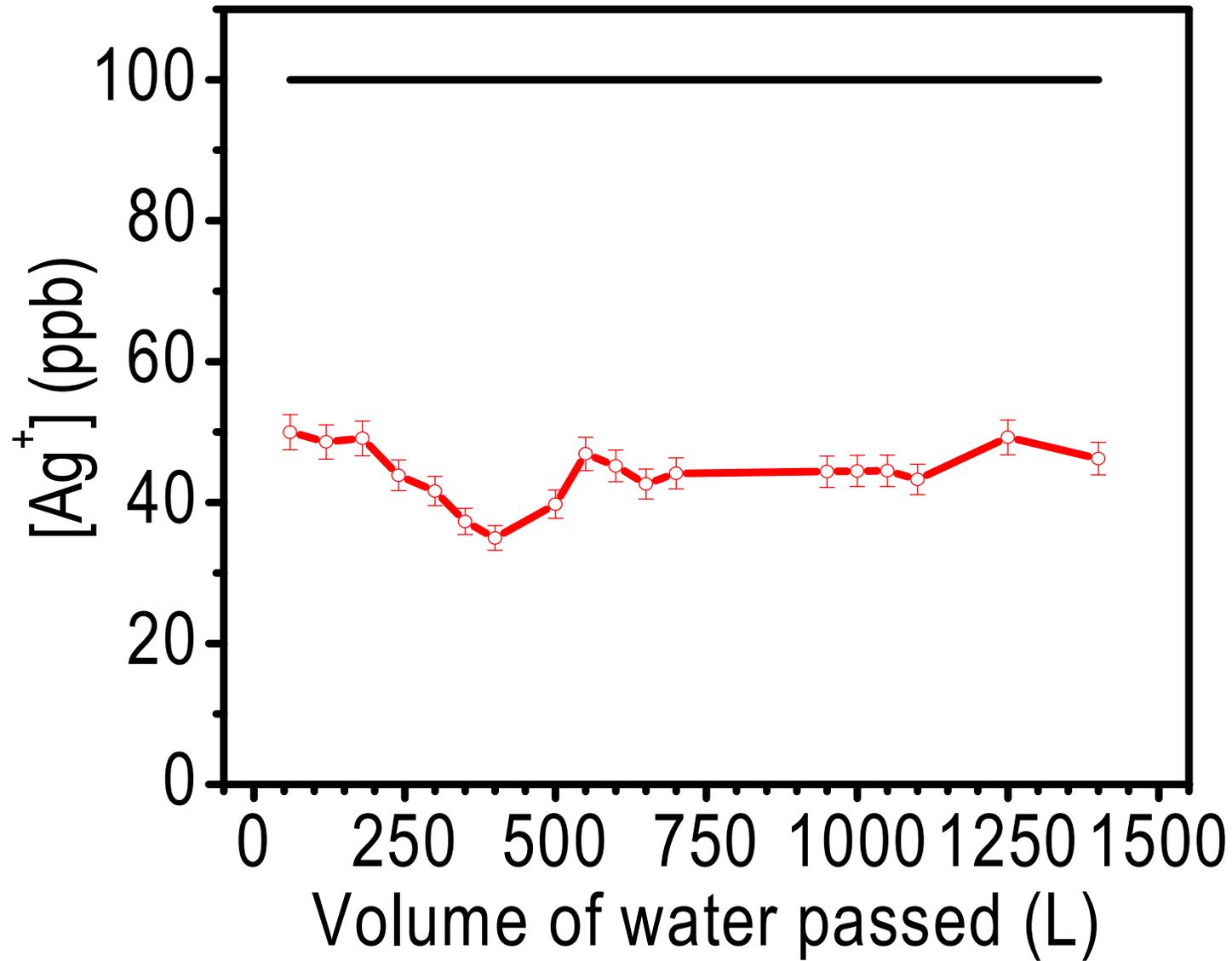


ACS Sustainable Chemistry & Engineering Editorial, December 2016

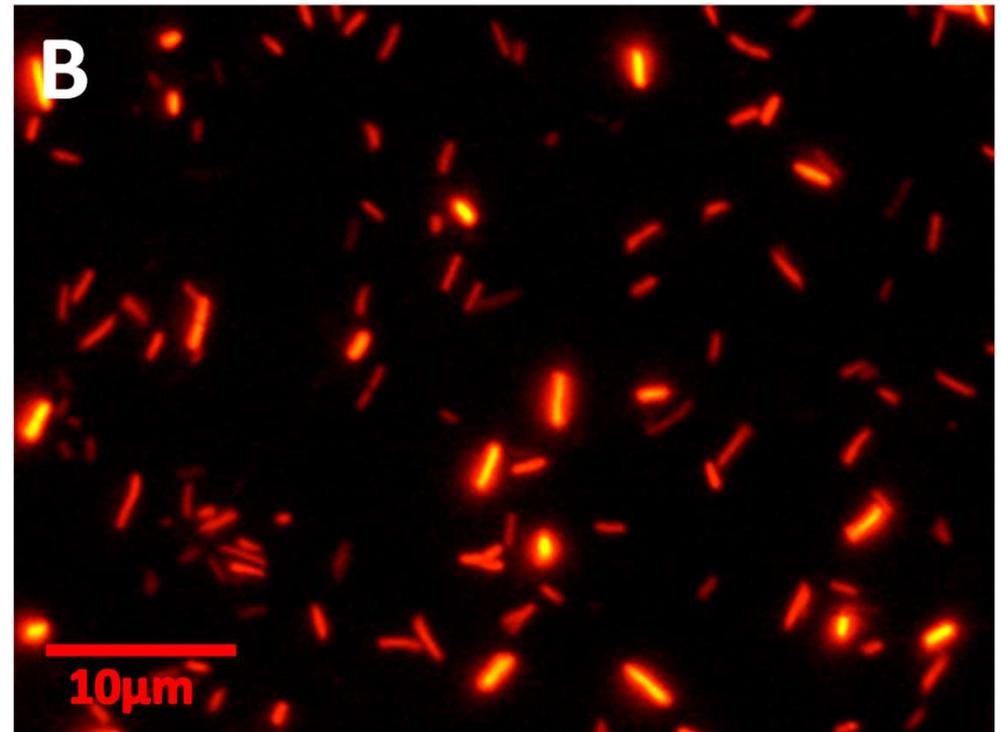
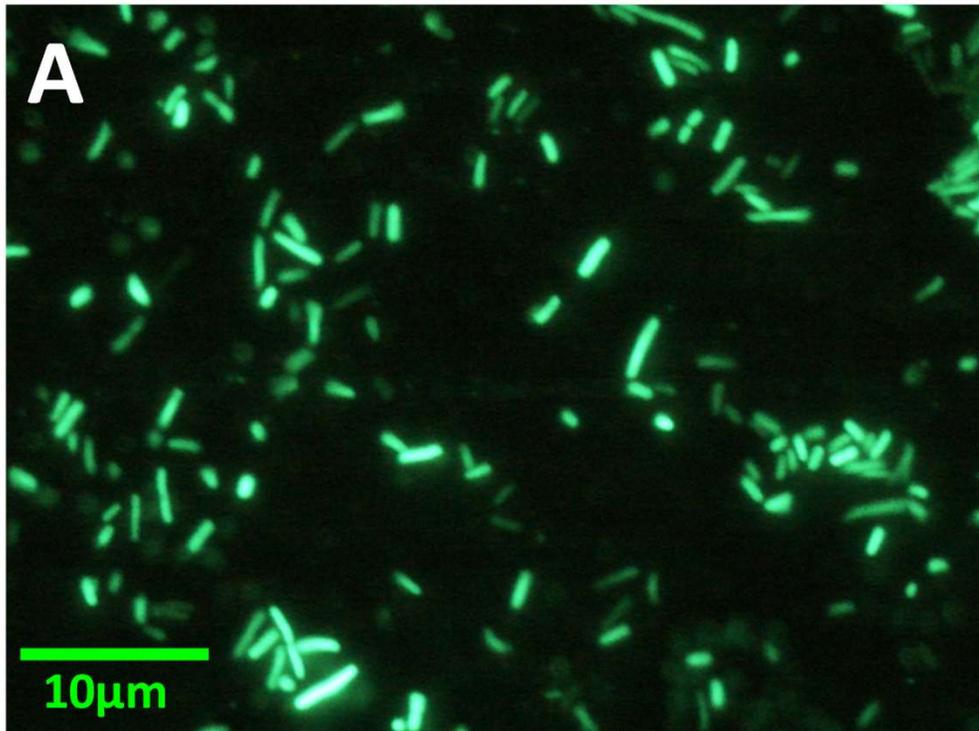
New materials

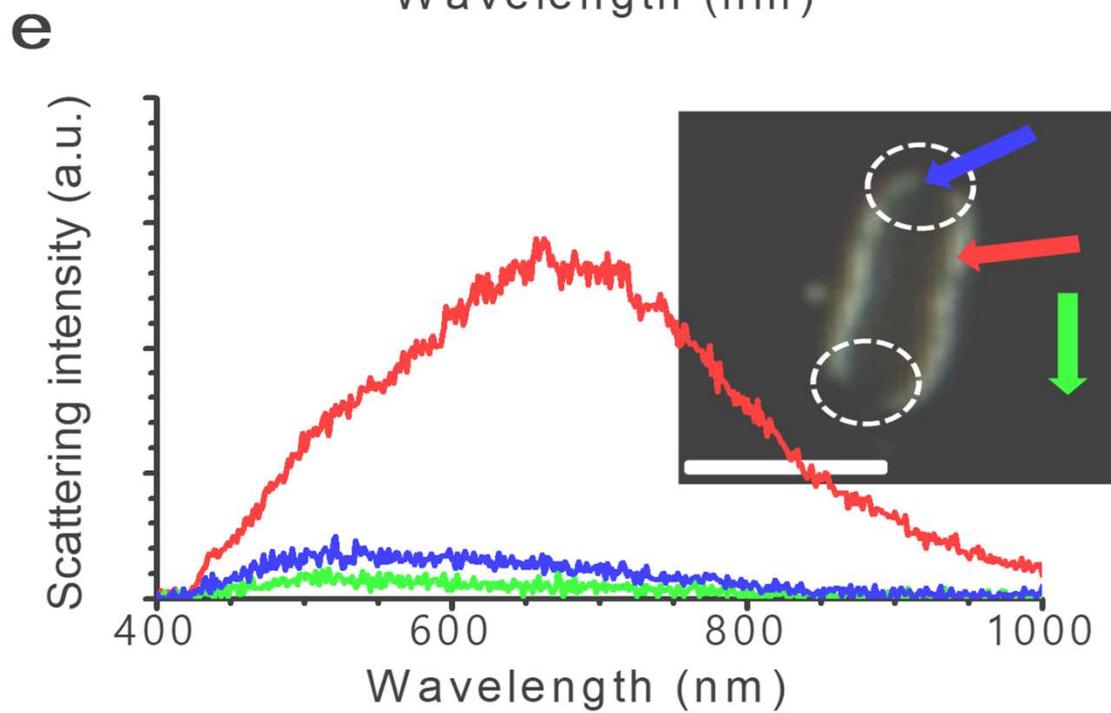
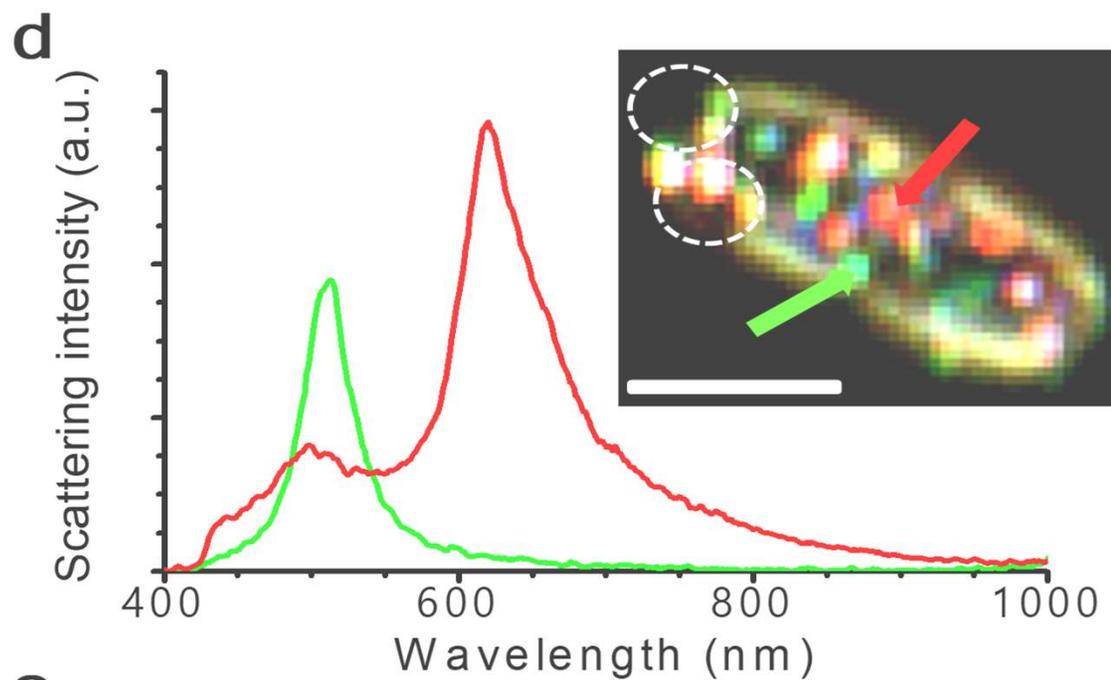
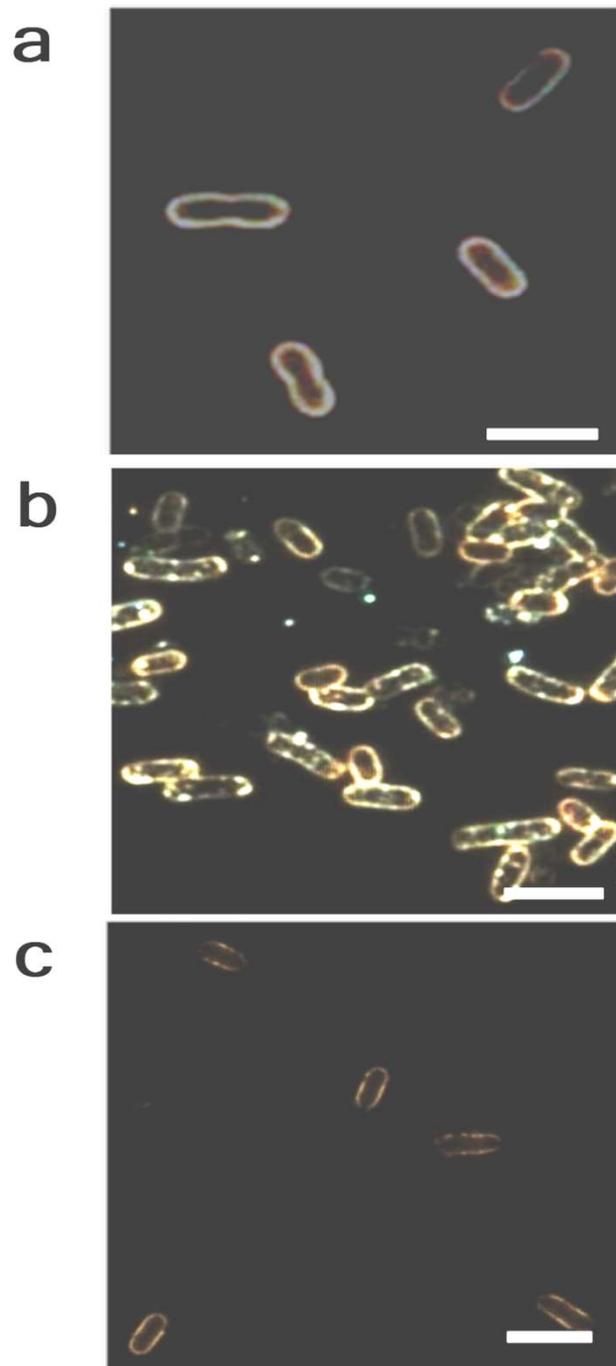


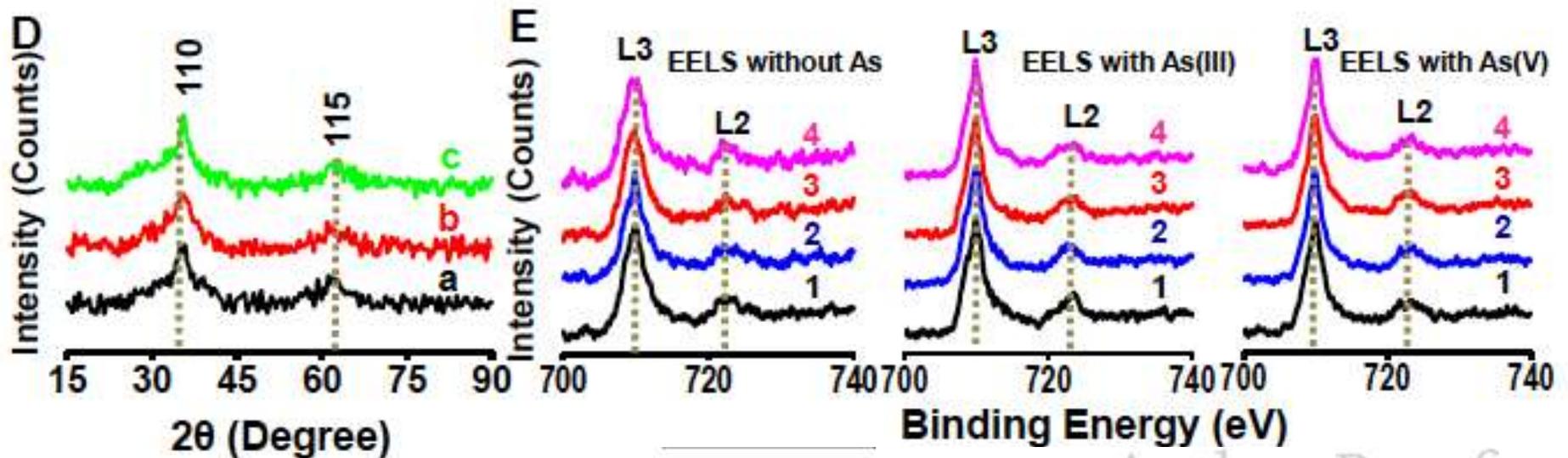
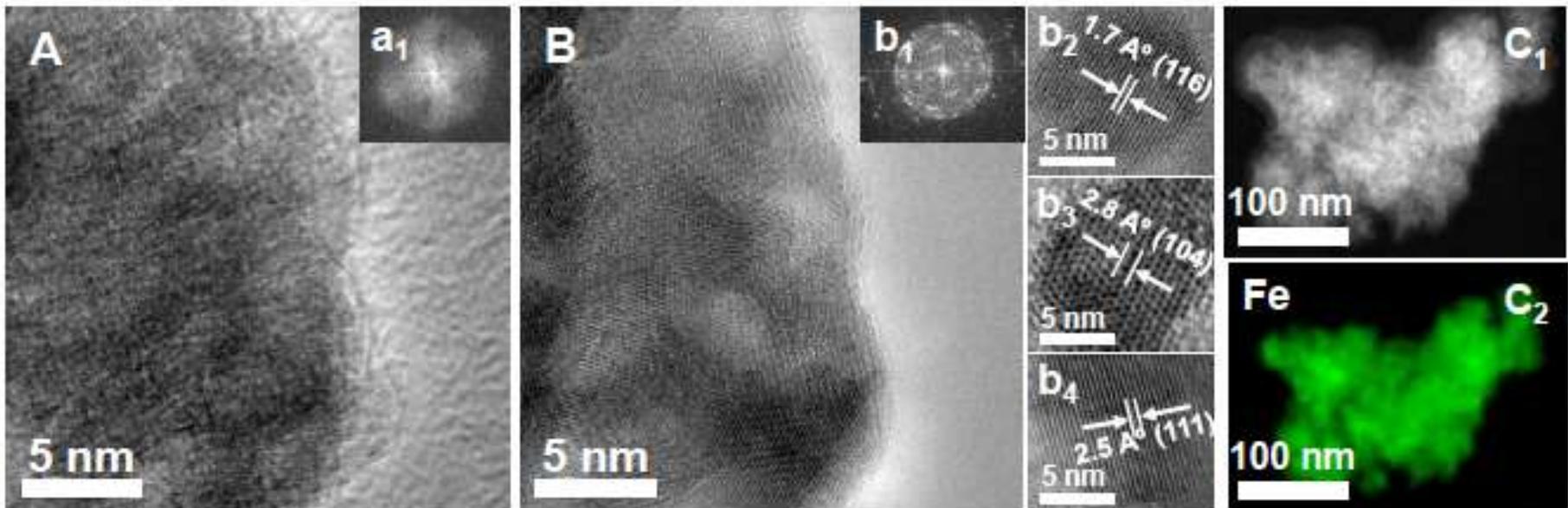
What is special?



Live/dead staining experiments







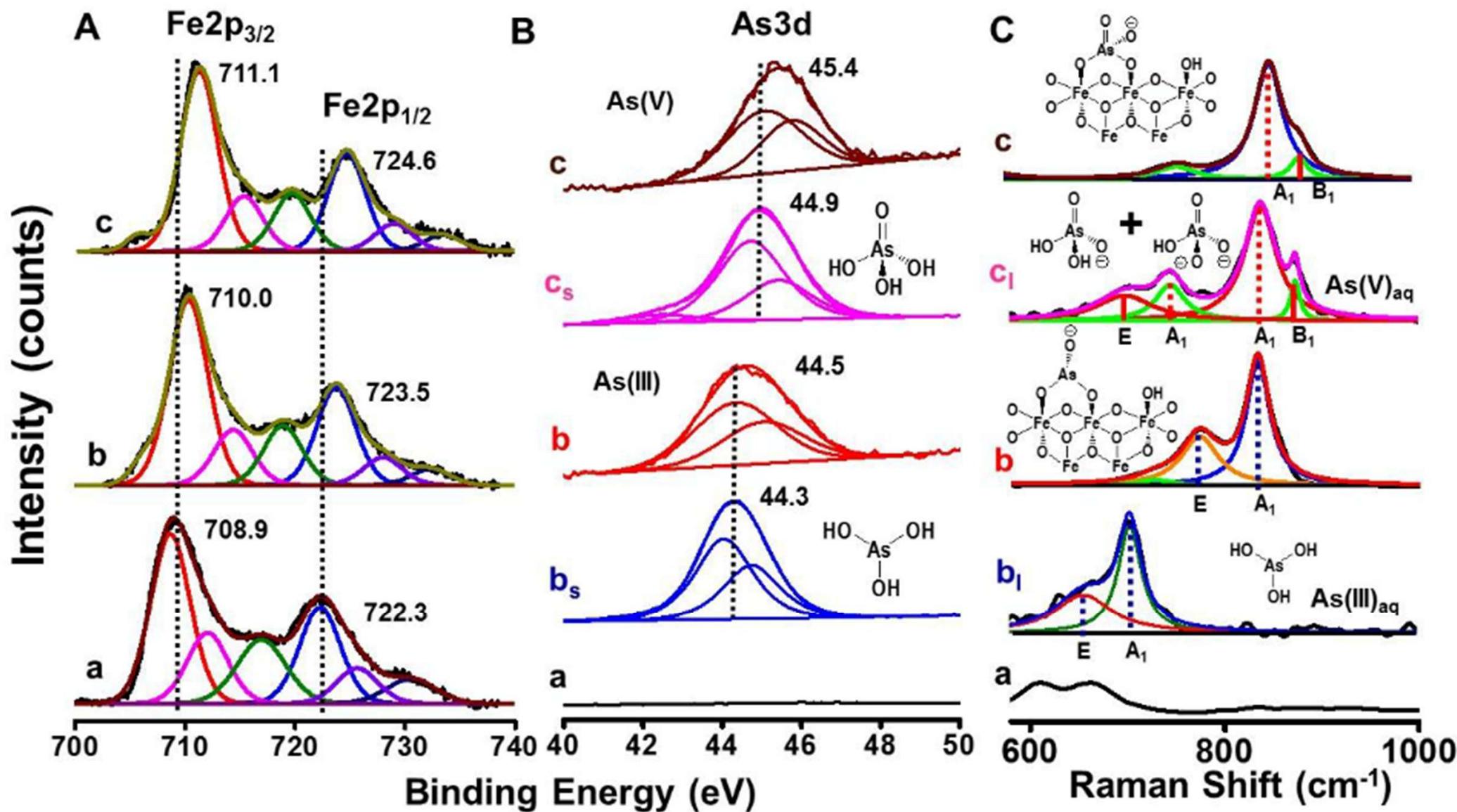
www.advmat.de

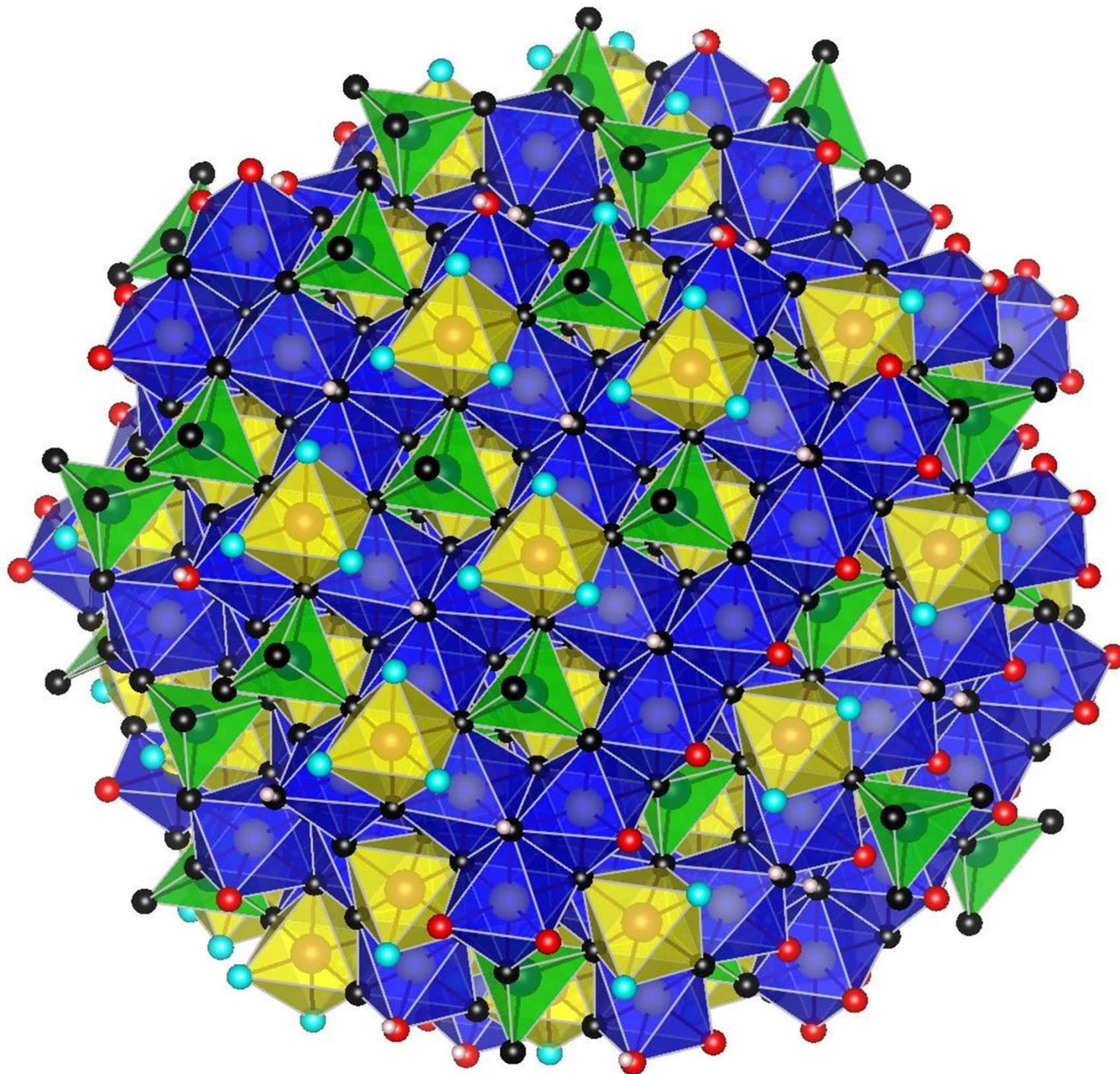
Author Pr **ADVANCED MATERIALS**

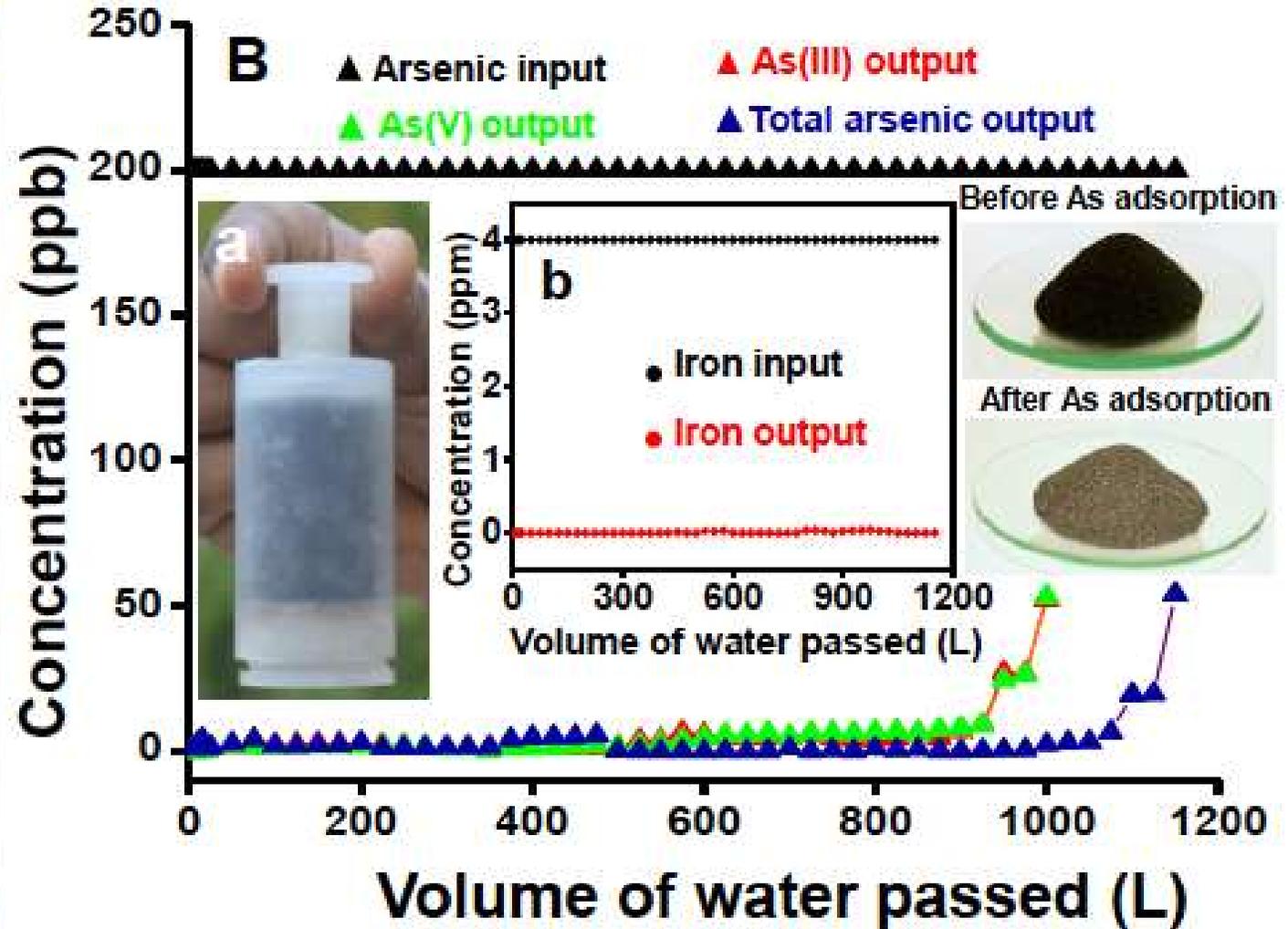
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

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*

Mechanism









Changing the dynamics in the field



Existing plant in 40 cents

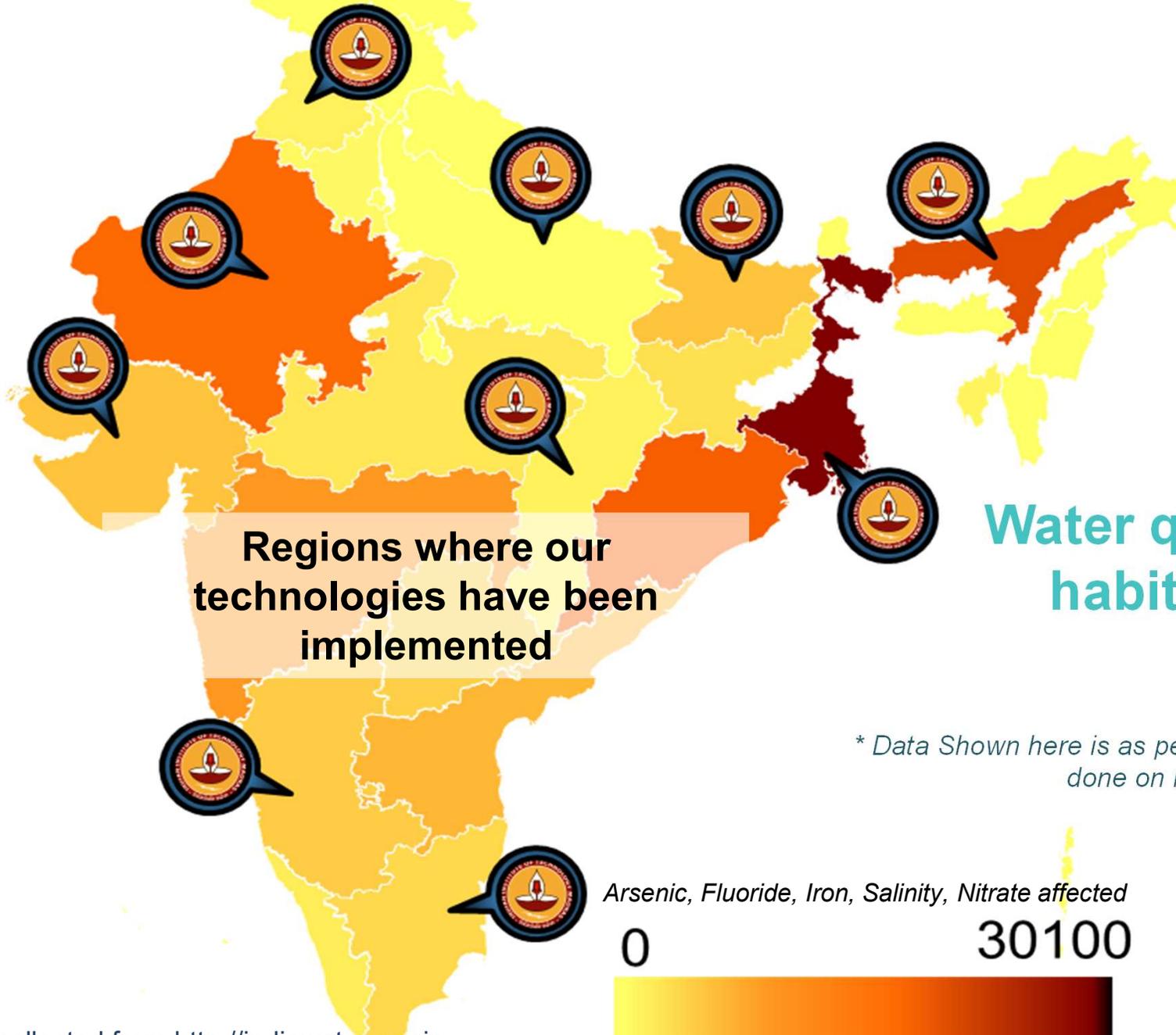
- Existing unit for iron and arsenic removal – 20 m³/h
- Uses activated alumina and iron oxide (old generation of adsorbents)



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



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

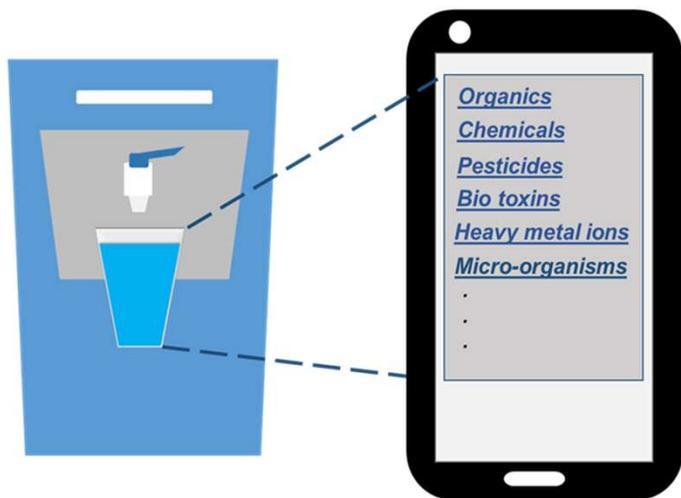
Cleanwater at 2.1 paise per litre!

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

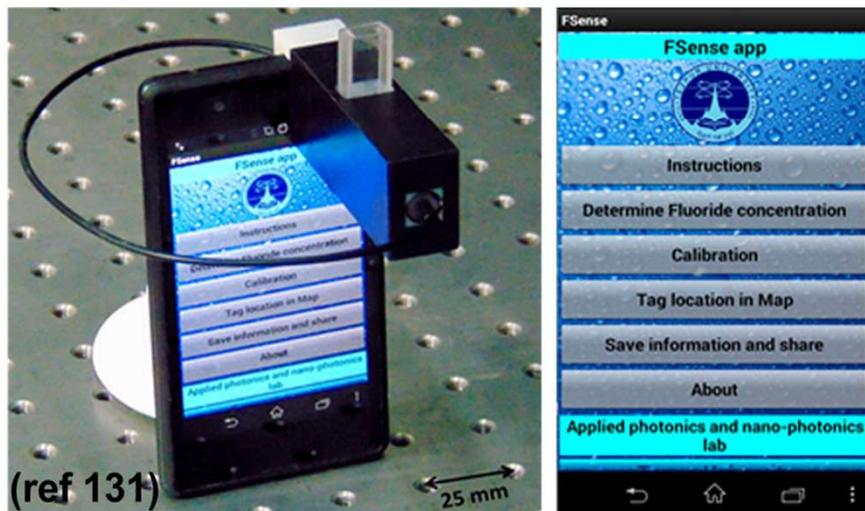
Sr.No	Design population	1,071	Plant capacity/70 LPCD
	Item/Description	Cost / Quantity	Remarks
1	Cost of Replacement of Iron removal media	56400	After minimum two years if Iron concentration is more than 5 ppm. But iron concentration is more than 5 ppm at only two to three places. Therefore media may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

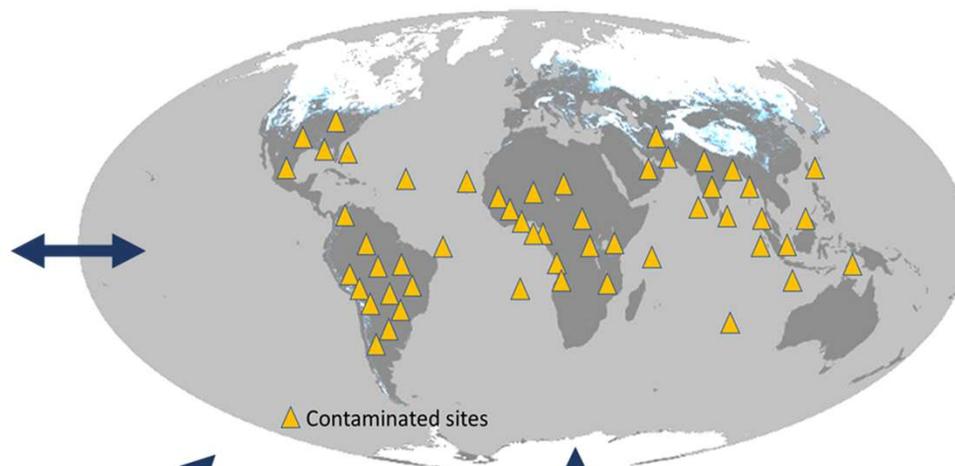
Smart Water Purifiers linked to IoT



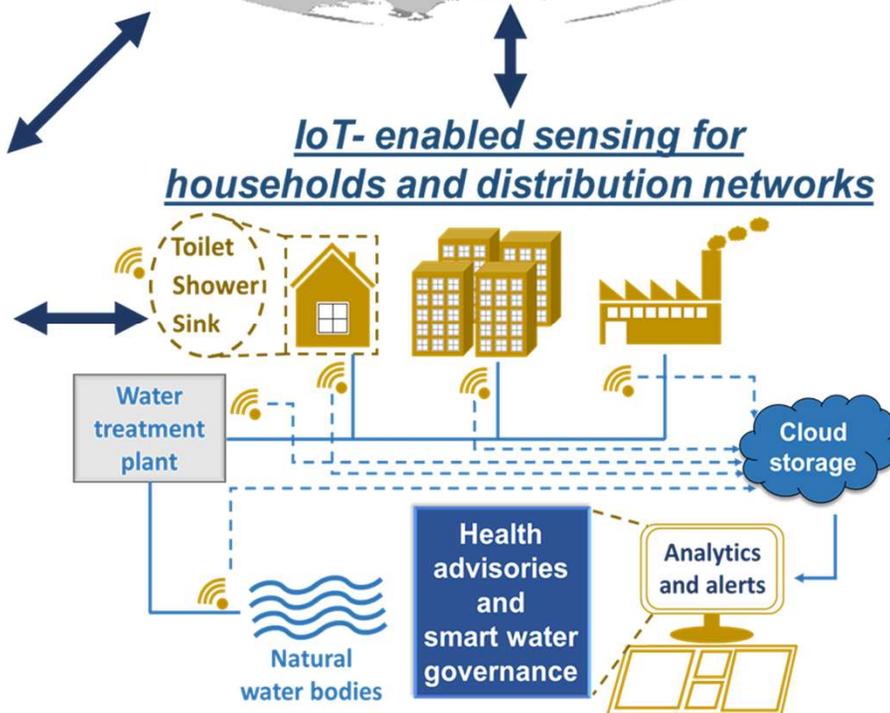
Cost-effective sensor accessory for point-of-use applications



Global Map of Water Health



IoT-enabled sensing for households and distribution networks



Waste management

Adsorbents conform to toxicity characteristic leaching procedure

Elemental waste goes back to local environment

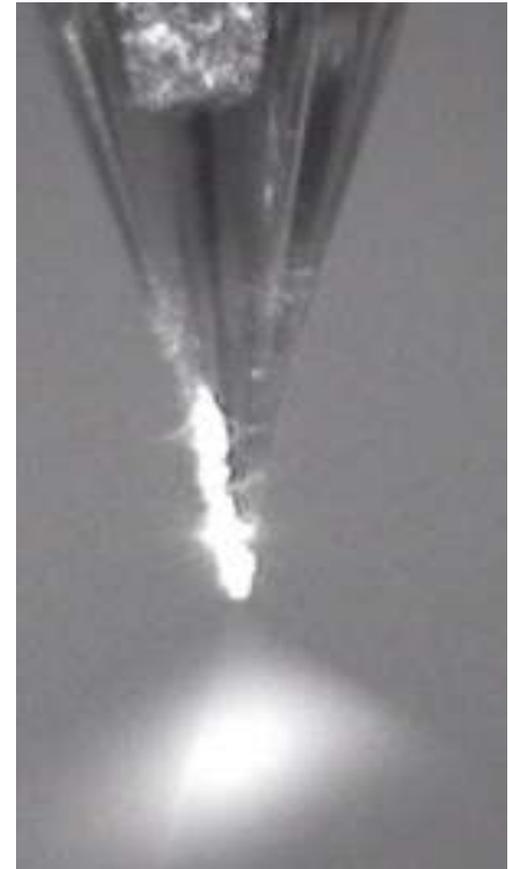
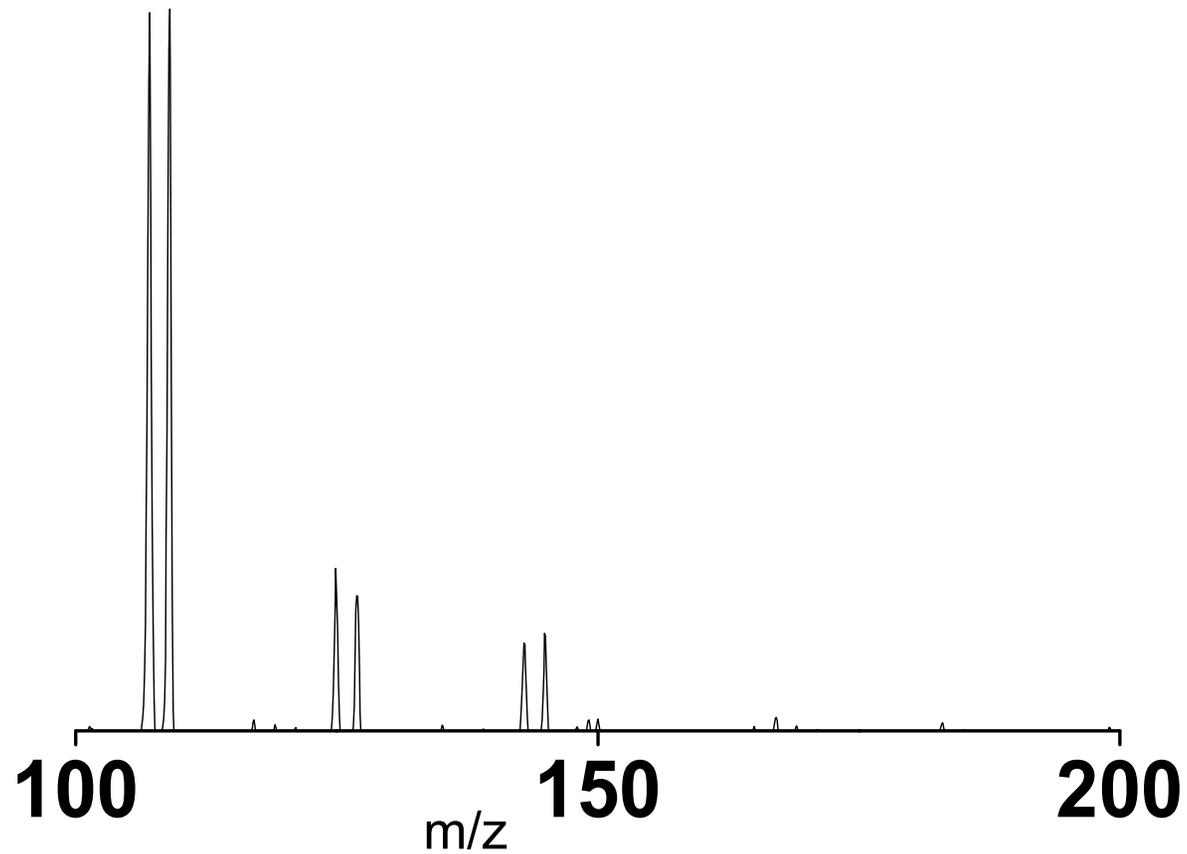
Safe disposal of arsenic (or any other) laden waste

Additional protection could be considered, if necessary

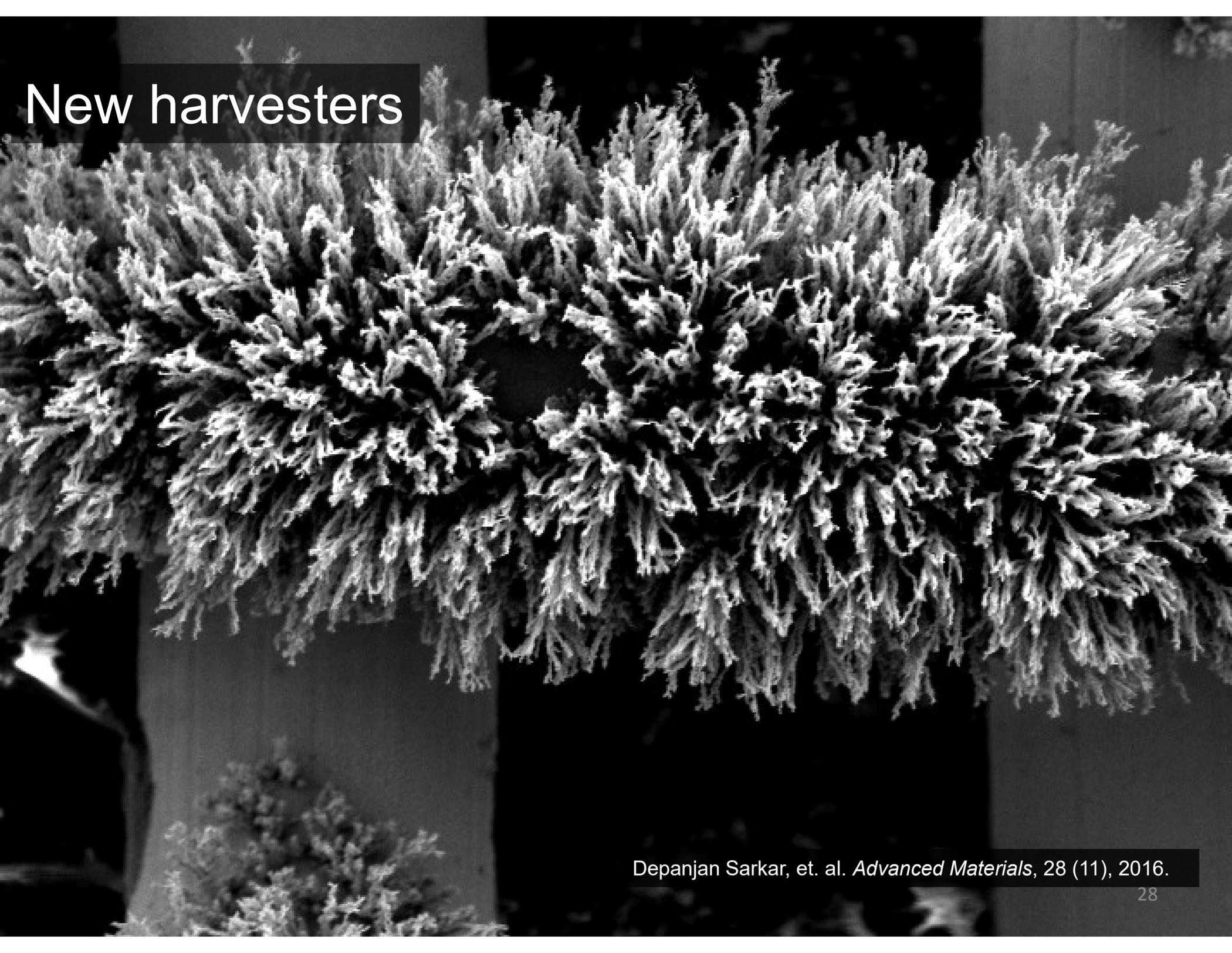
Exploring viable uses



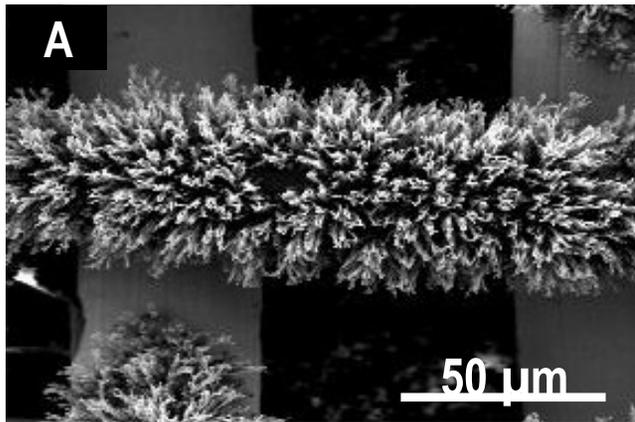
Atmospheric water harvesting



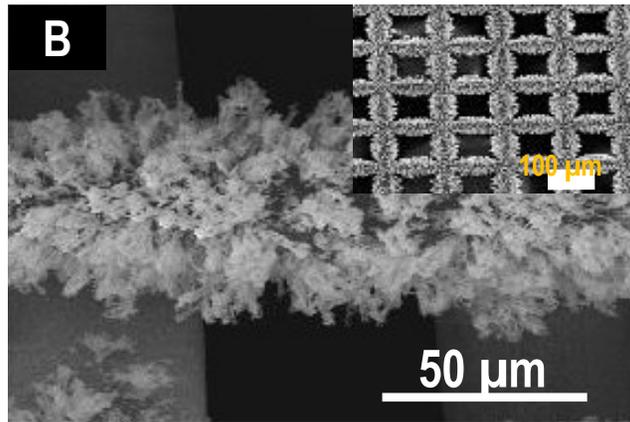
New harvesters



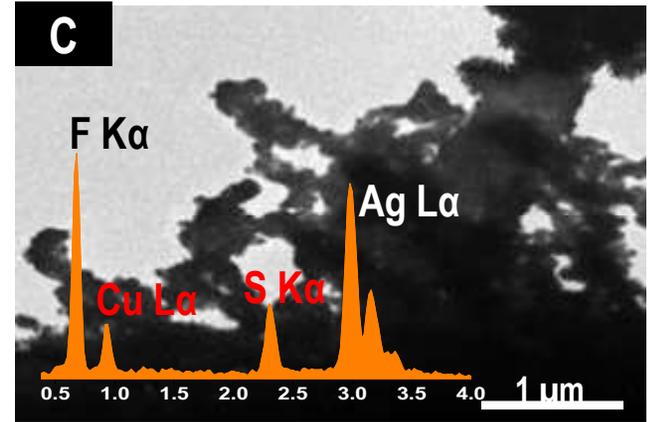
Depanjan Sarkar, et. al. *Advanced Materials*, 28 (11), 2016.



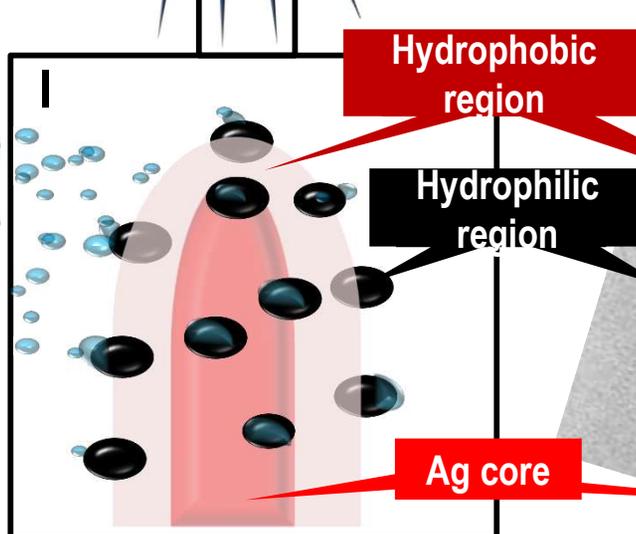
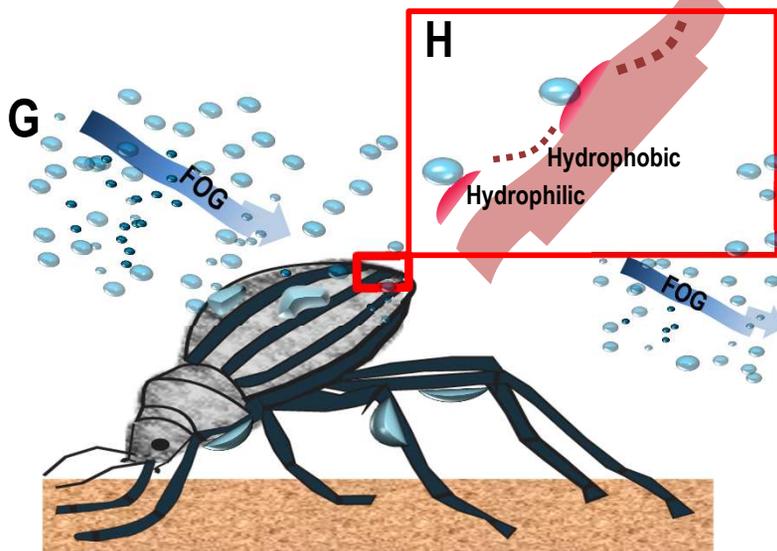
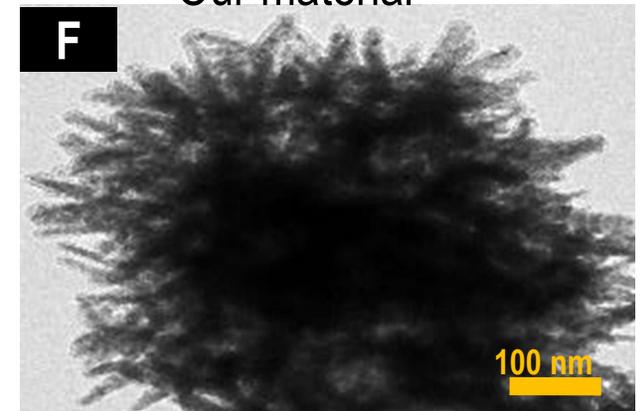
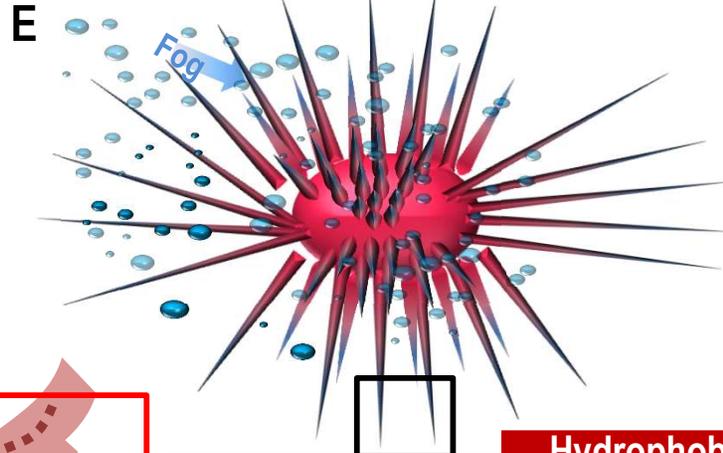
Nature



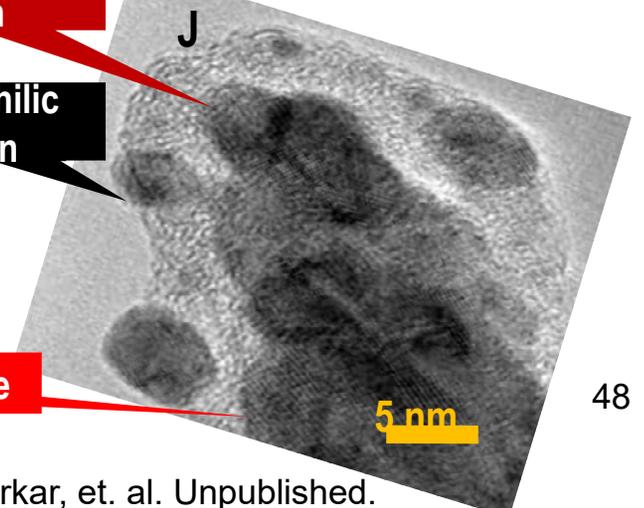
Schematic

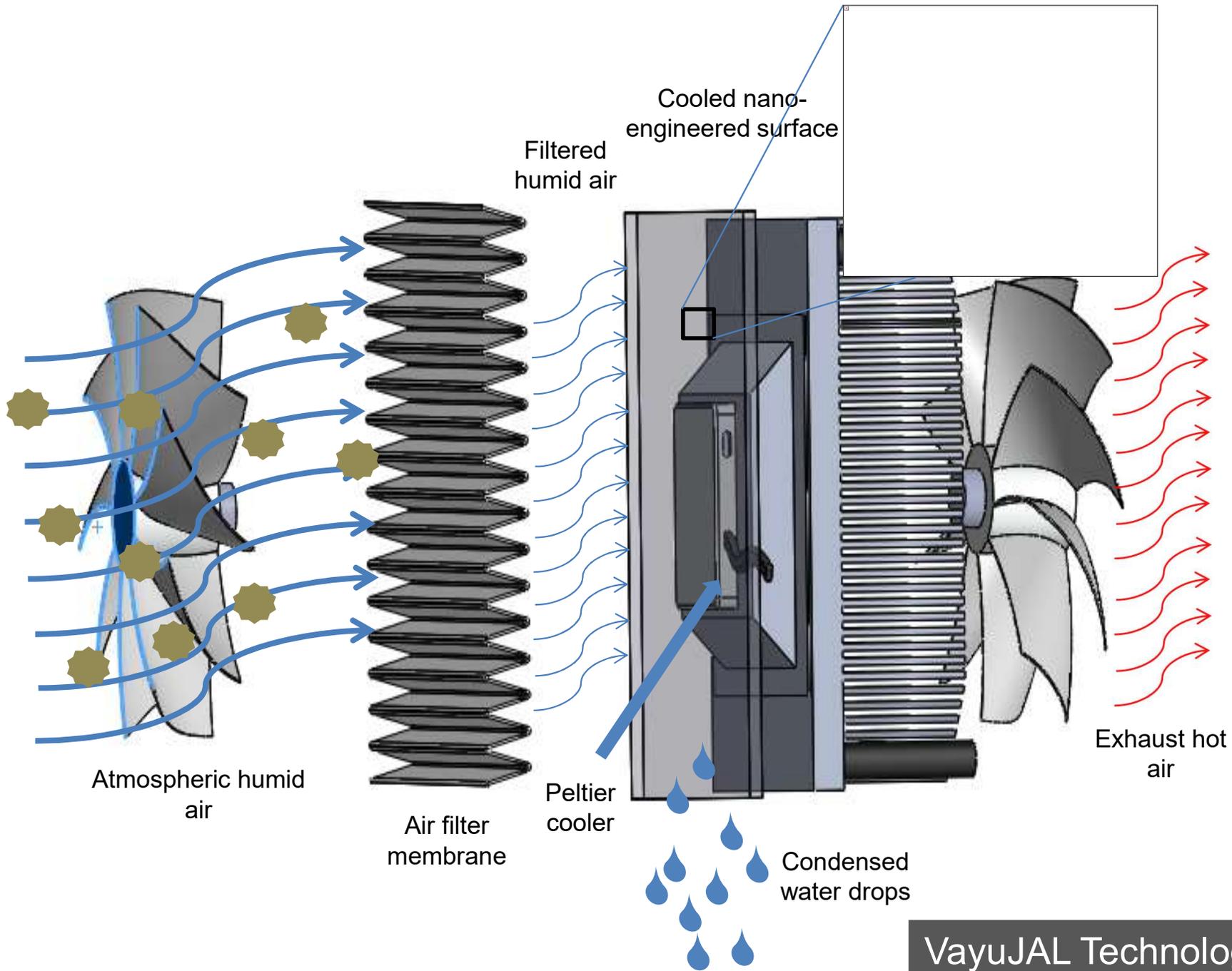


Our material



Combination of cactus and Namib desert beetle effect





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

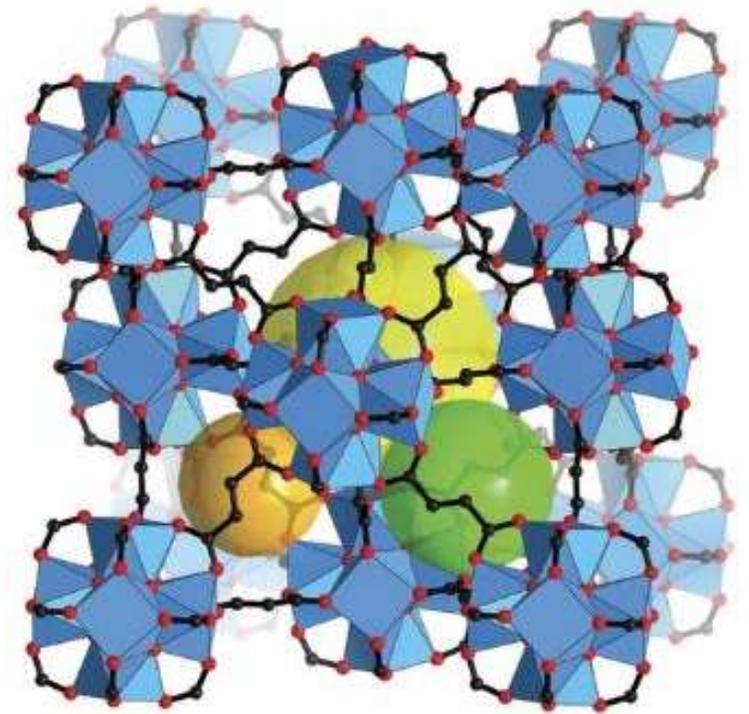
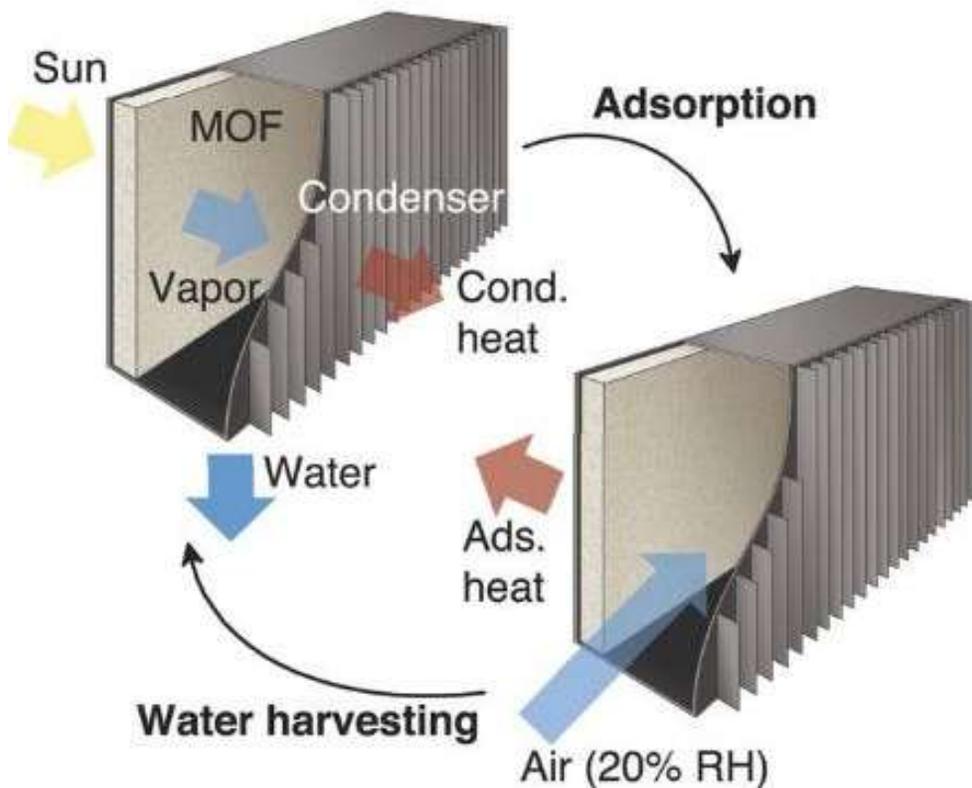
Products in the field



(LPD: Litres per day)

Sustainable atmospheric water harvesting

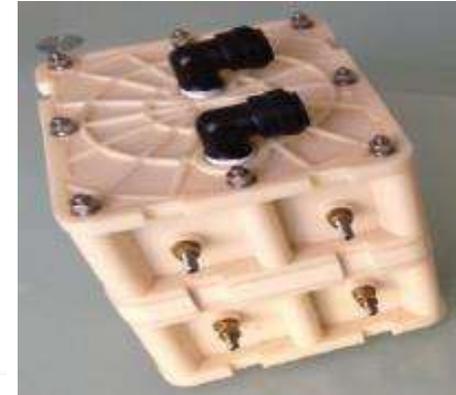
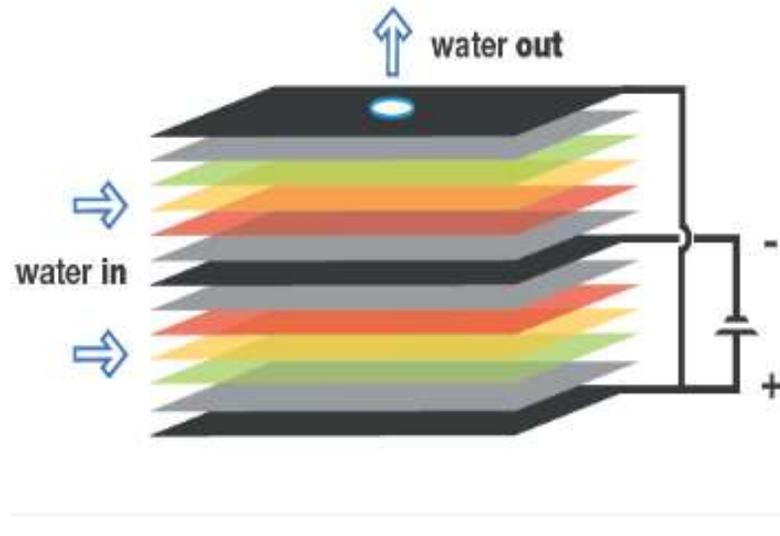
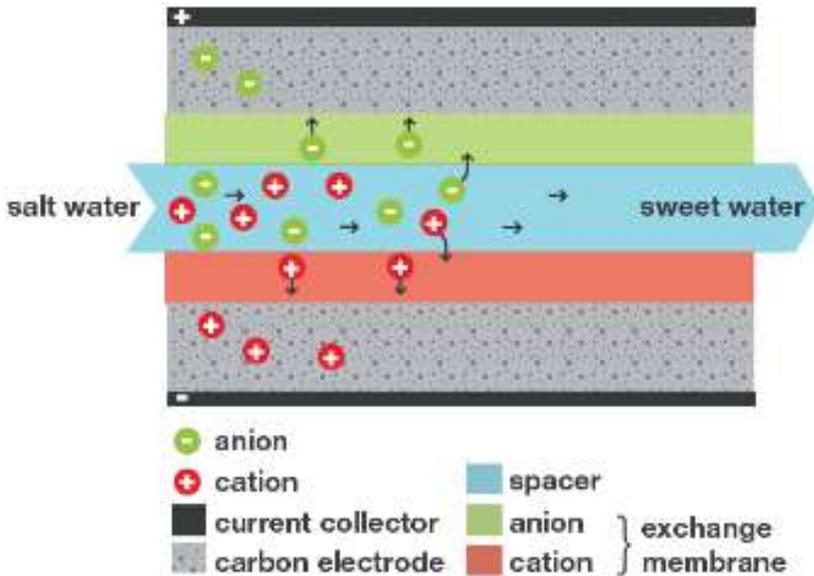
Solar- heat-enabled atmospheric water capture at a relative humidity as low as 20%



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

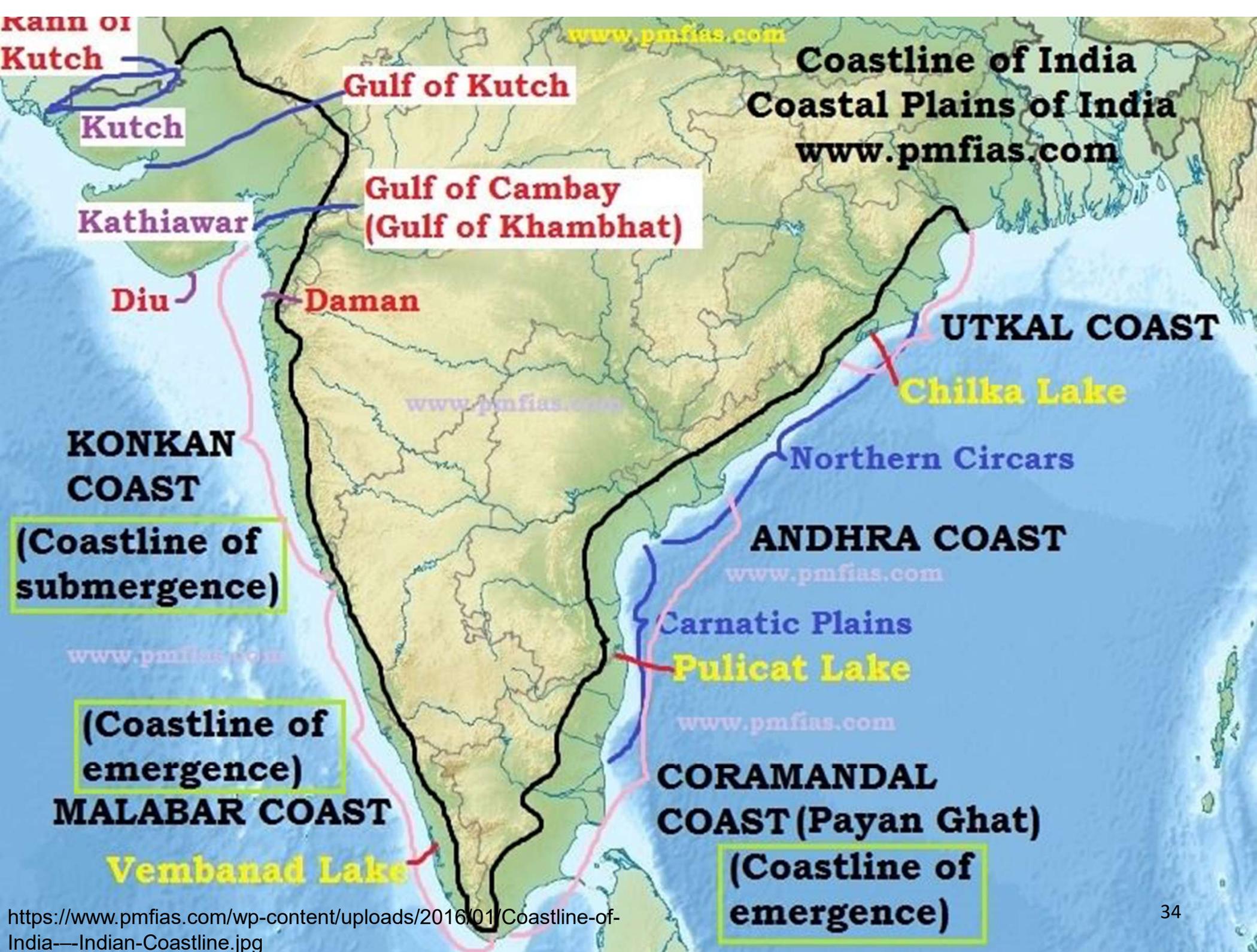
Kim Hyunho, et al. *Science*, 356 (6336) 2017

Capacitive Desalination (CDI)



Our new company

Soujit Sengupta, Rabiul Islam and others



Kann of Kutch

www.pmfias.com

Gulf of Kutch

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

Kutch

Gulf of Cambay (Gulf of Khambhat)

Kathiawar

Diu

Daman

UTKAL COAST

Chilka Lake

www.pmfias.com

Northern Circars

KONKAN COAST

ANDHRA COAST

www.pmfias.com

(Coastline of submergence)

Carnatic Plains

www.pmfias.com

Pulicat Lake

www.pmfias.com

(Coastline of emergence)

CORAMANDAL COAST (Payan Ghat)

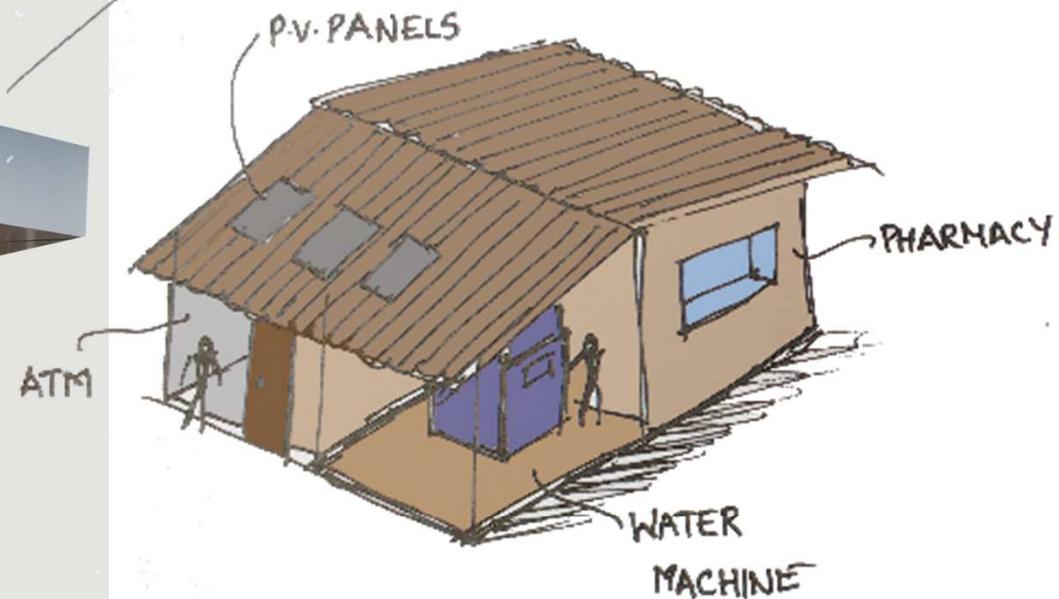
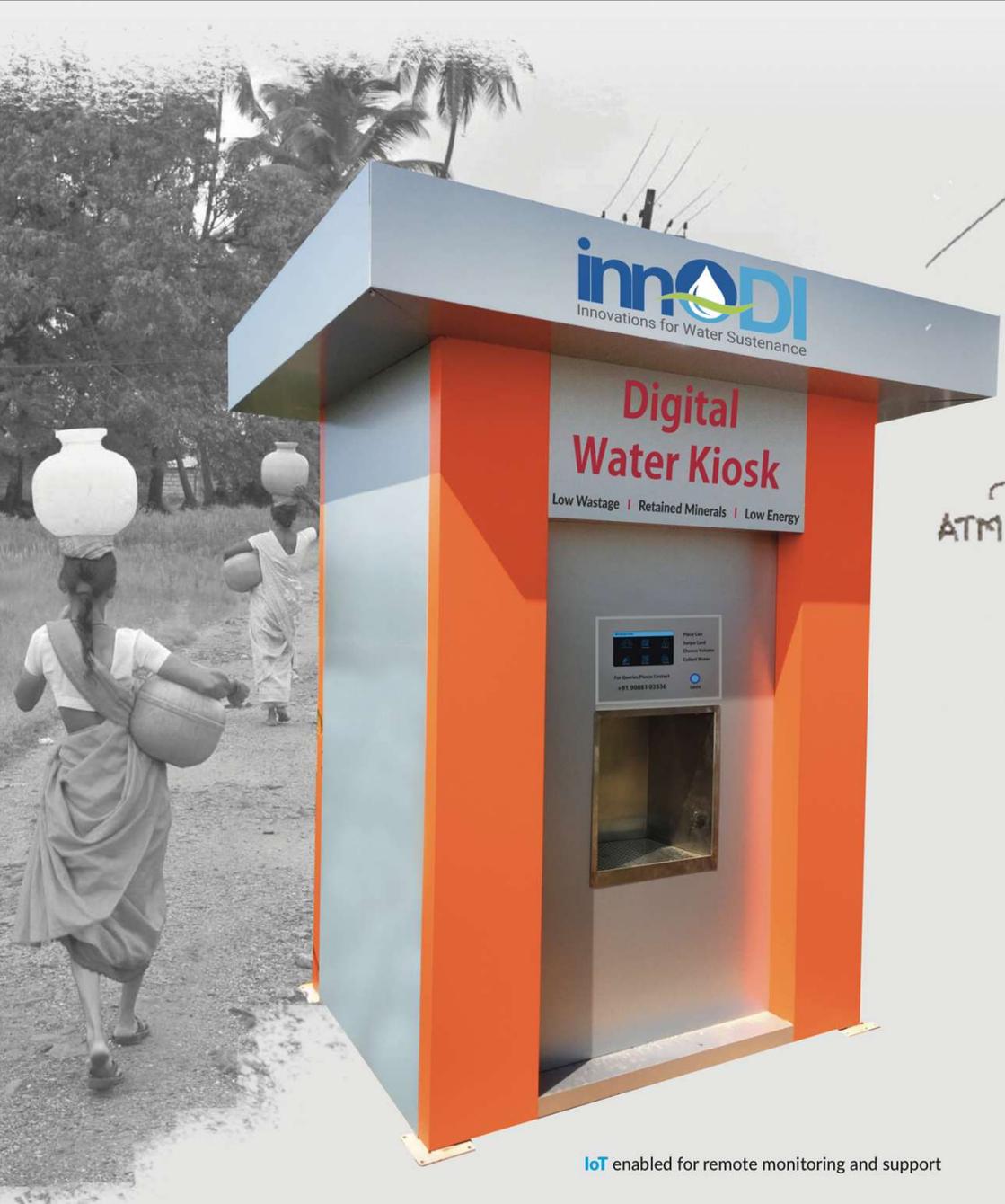
MALABAR COAST

(Coastline of emergence)

Vembanad Lake

DIGITAL WATER KIOSK

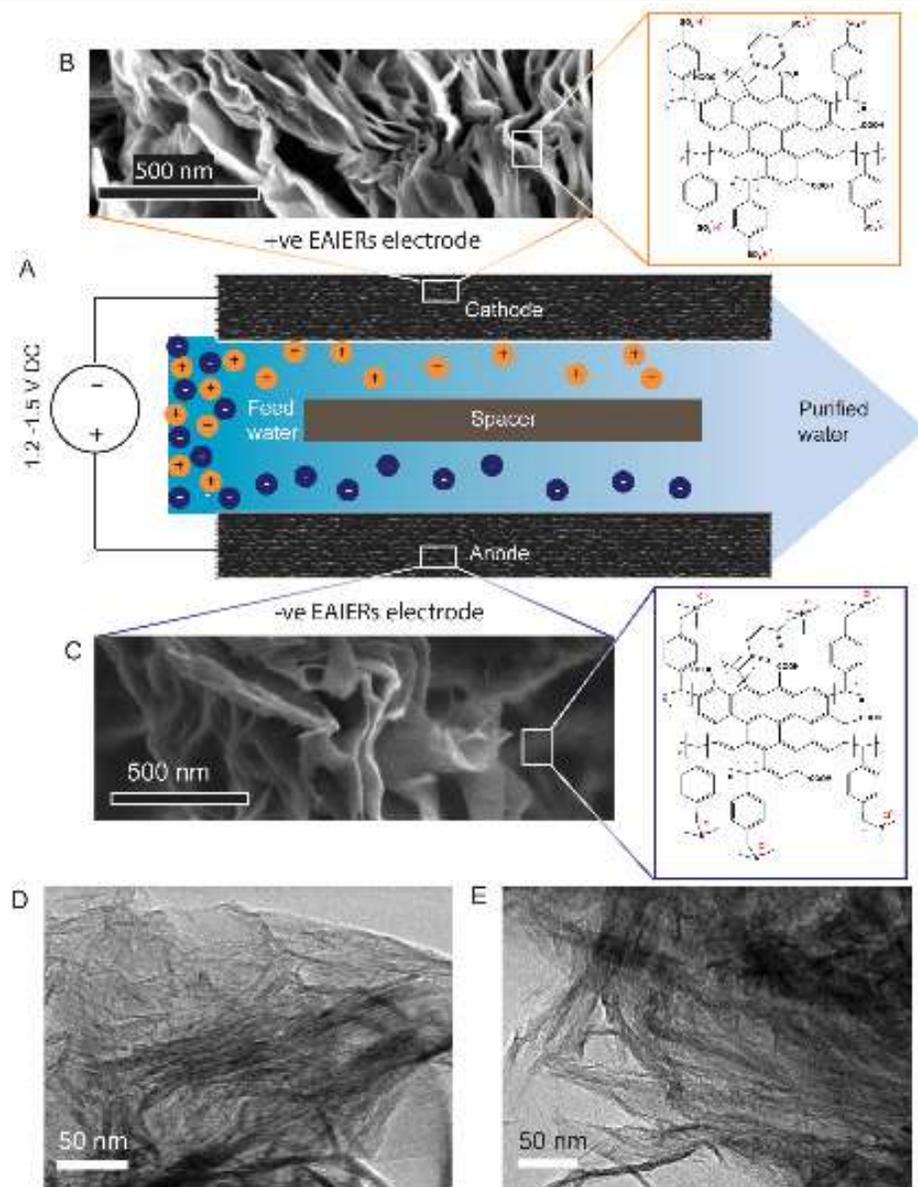
for community drinking using CDI Technology



Products under implementation

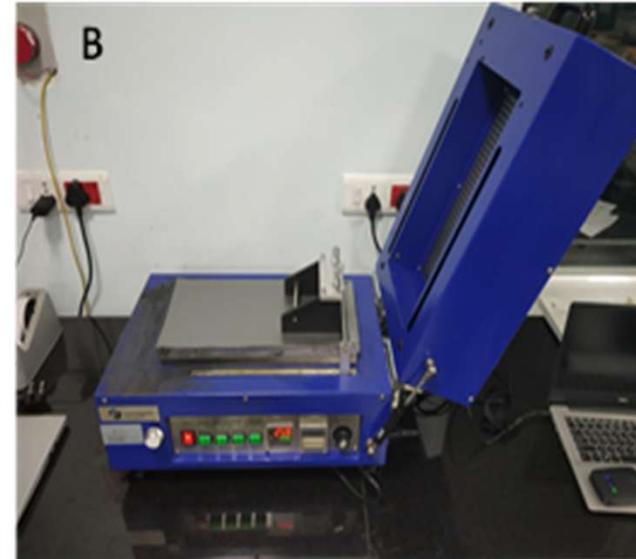
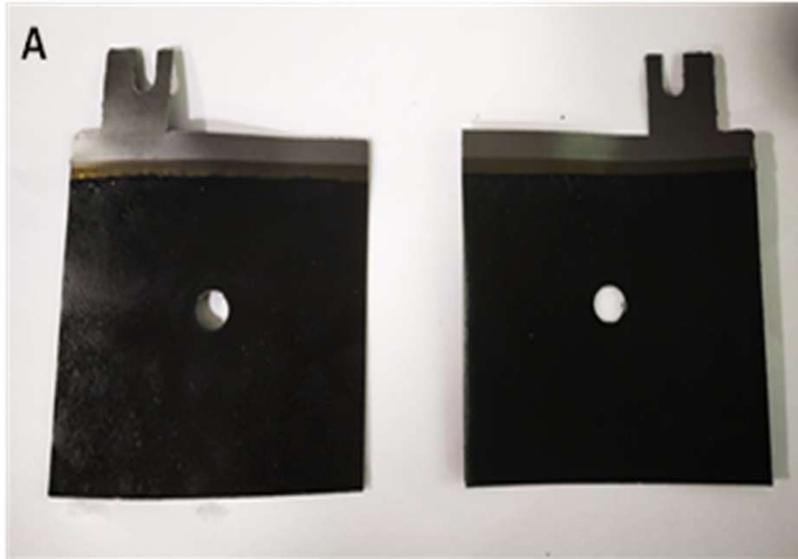
Vijay Sampath and Tullio Servida

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

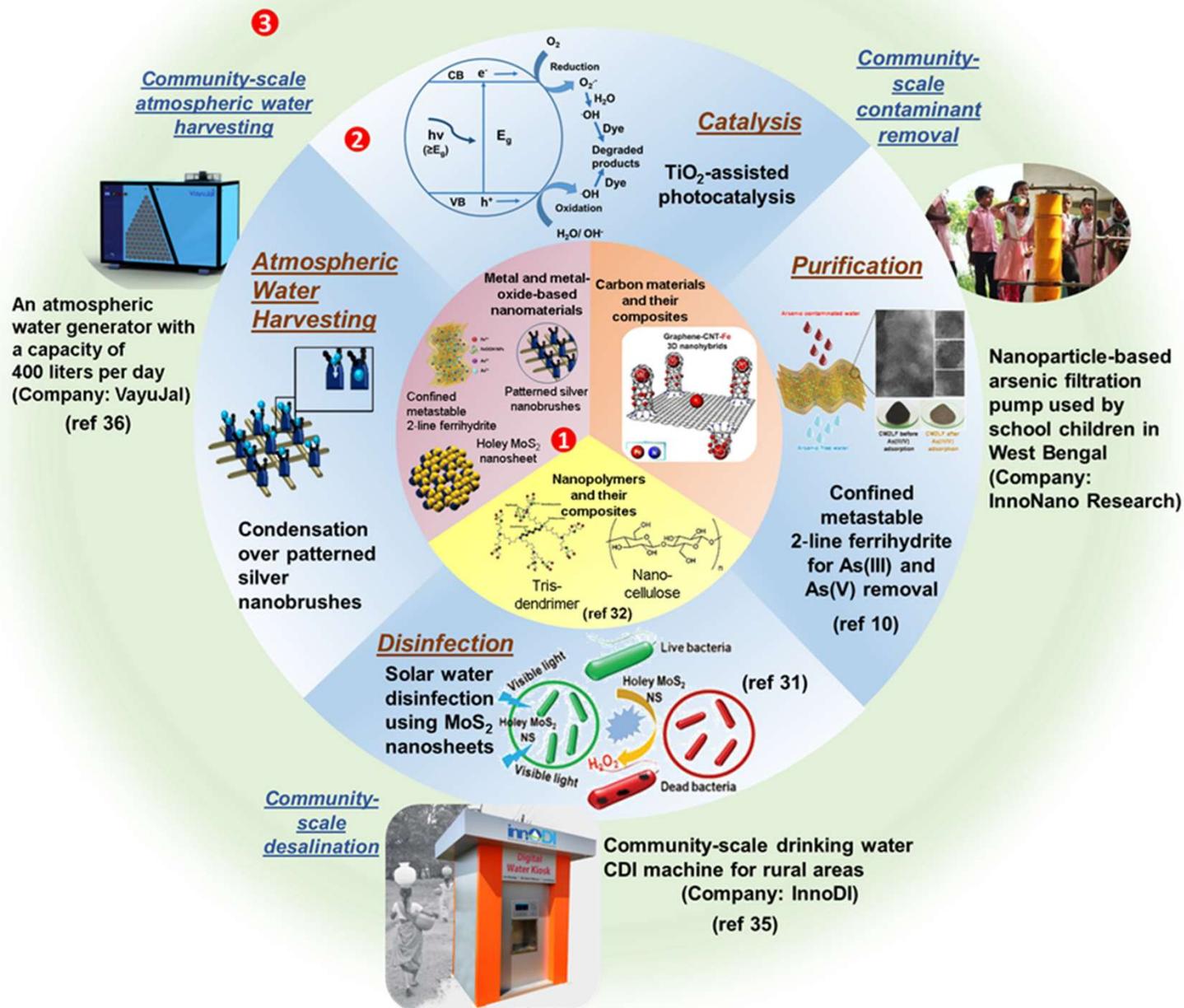


Rabiul *et al.*, *Adv. Mater. Interfaces* **2021**, *8*, 2001998

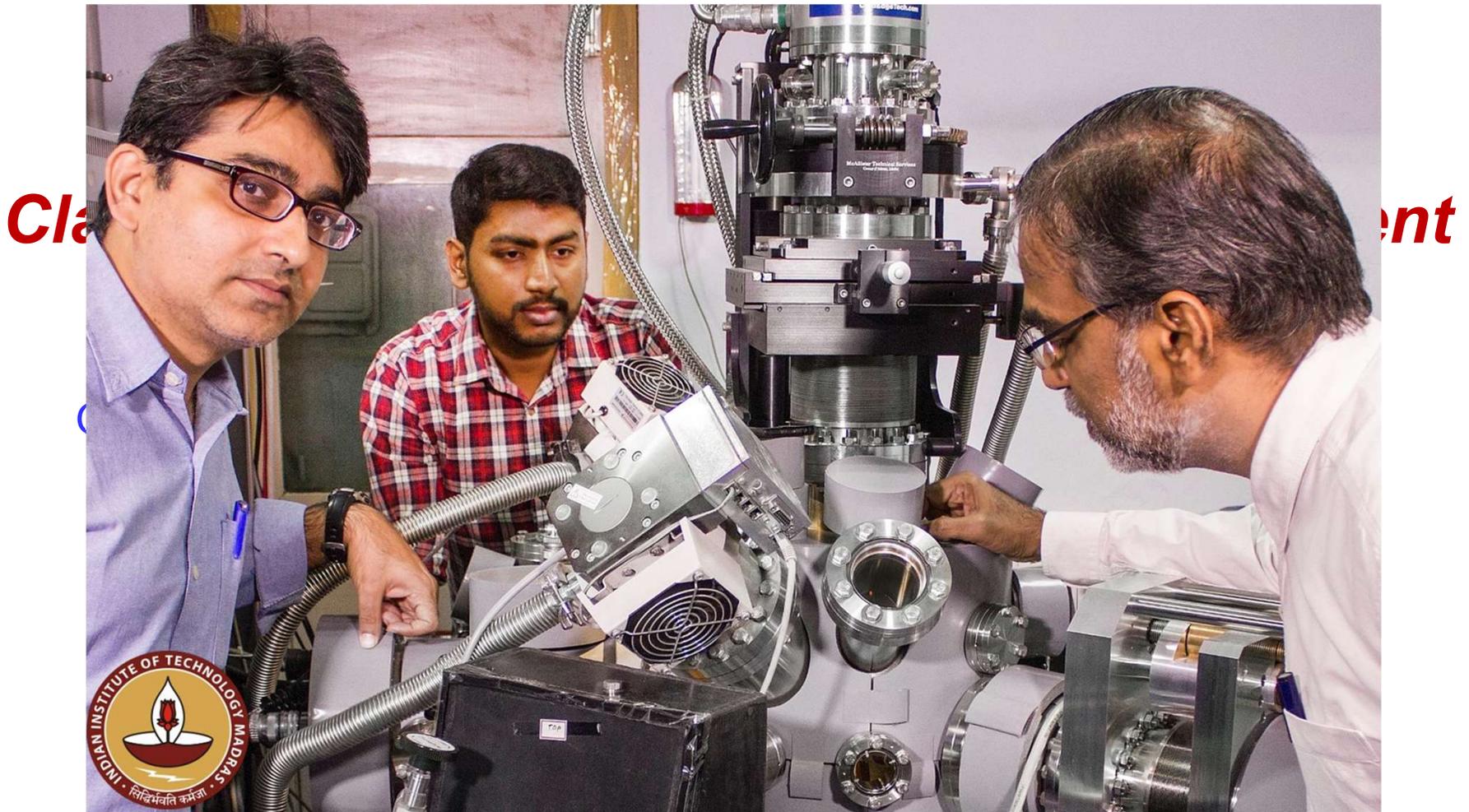
Various stages of electrode preparation



Evolution of materials to products

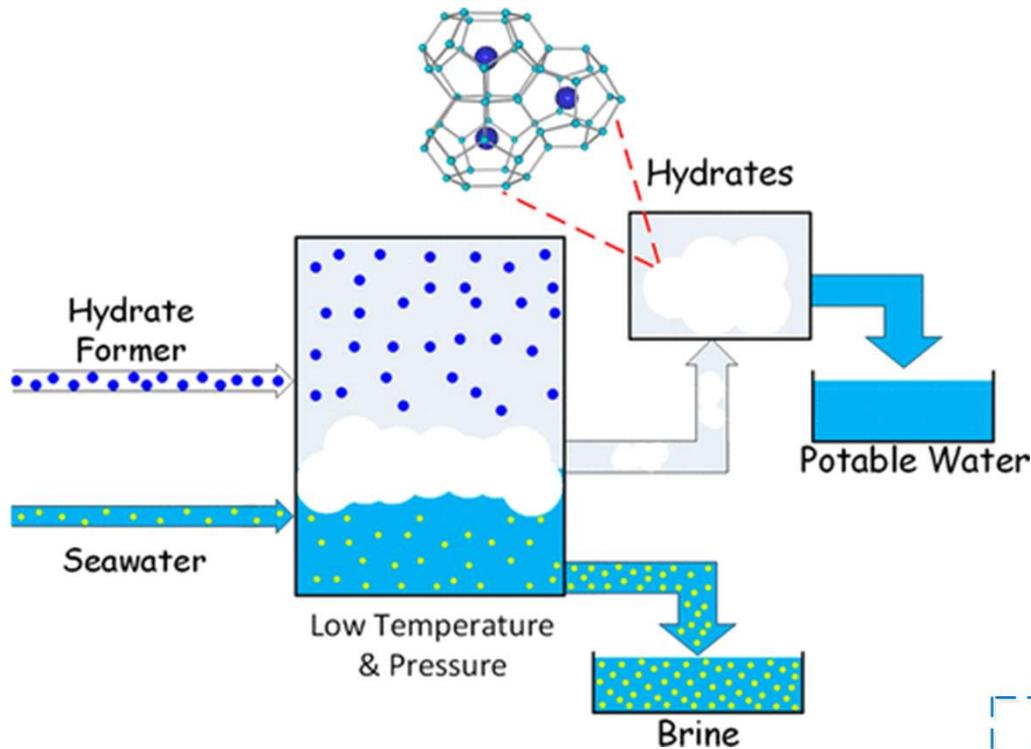


New phenomena



With Rajnish Kumar

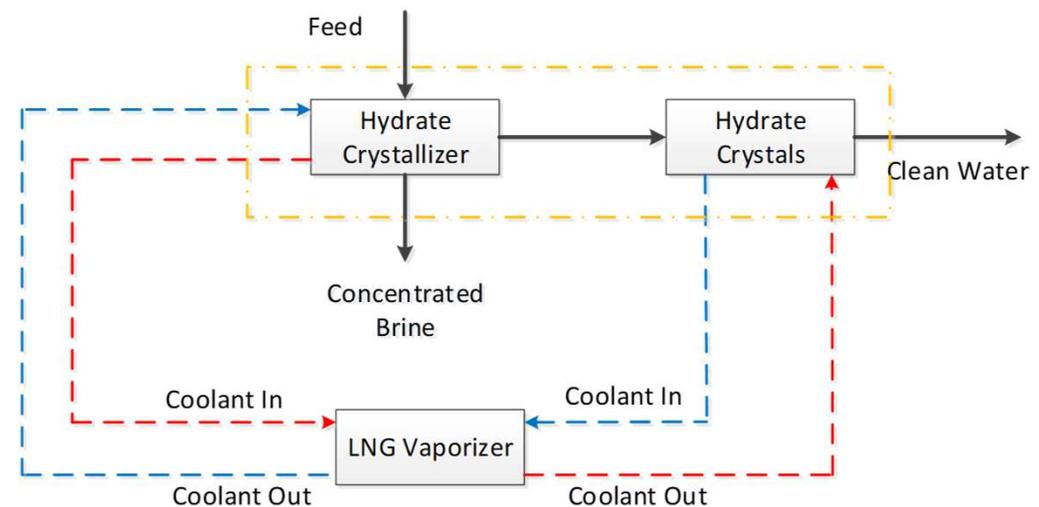
Hydrate-based desalination (HyDesal)



Water dissociated from hydrate is pure

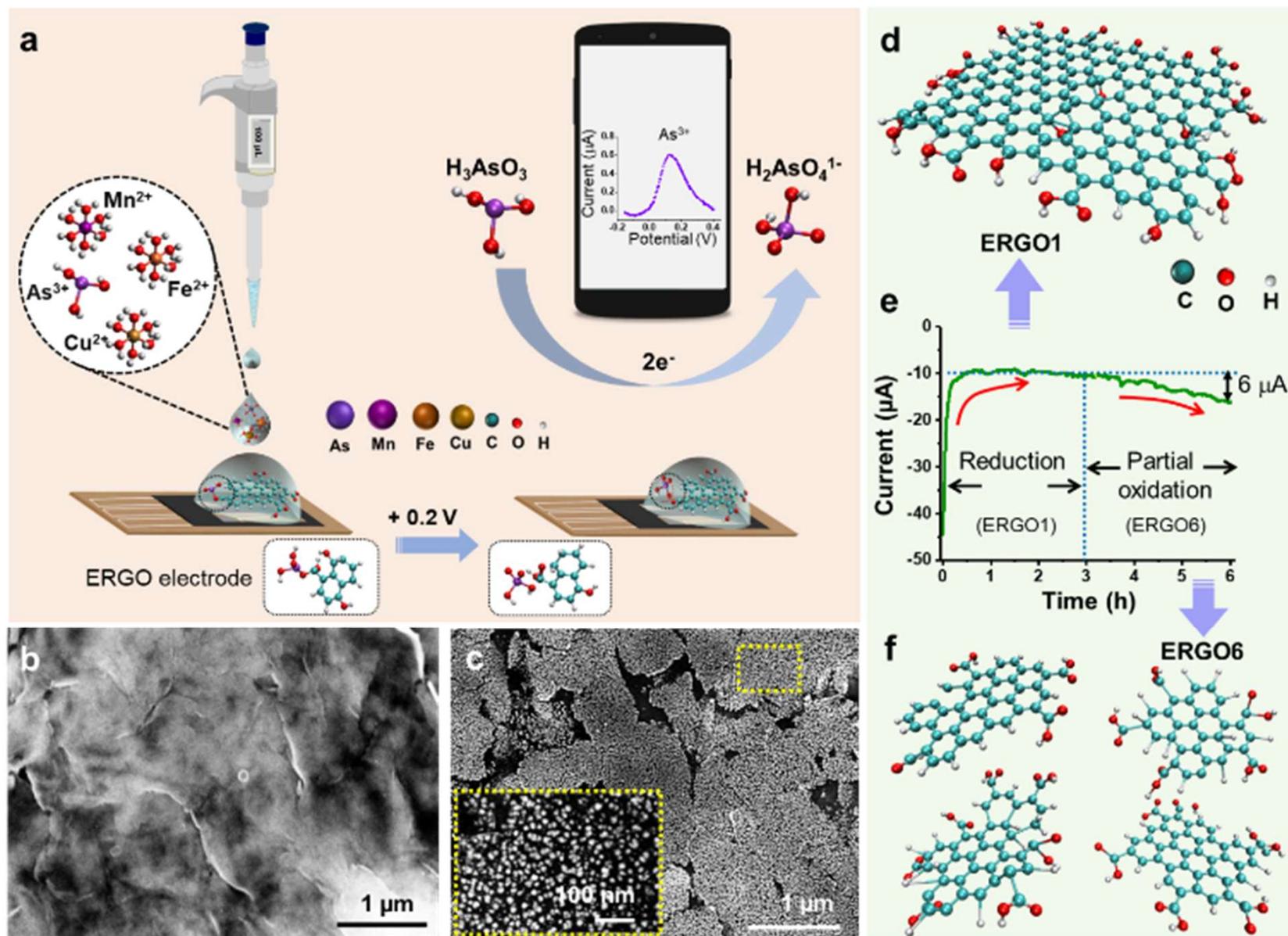
HyDesal process advantages

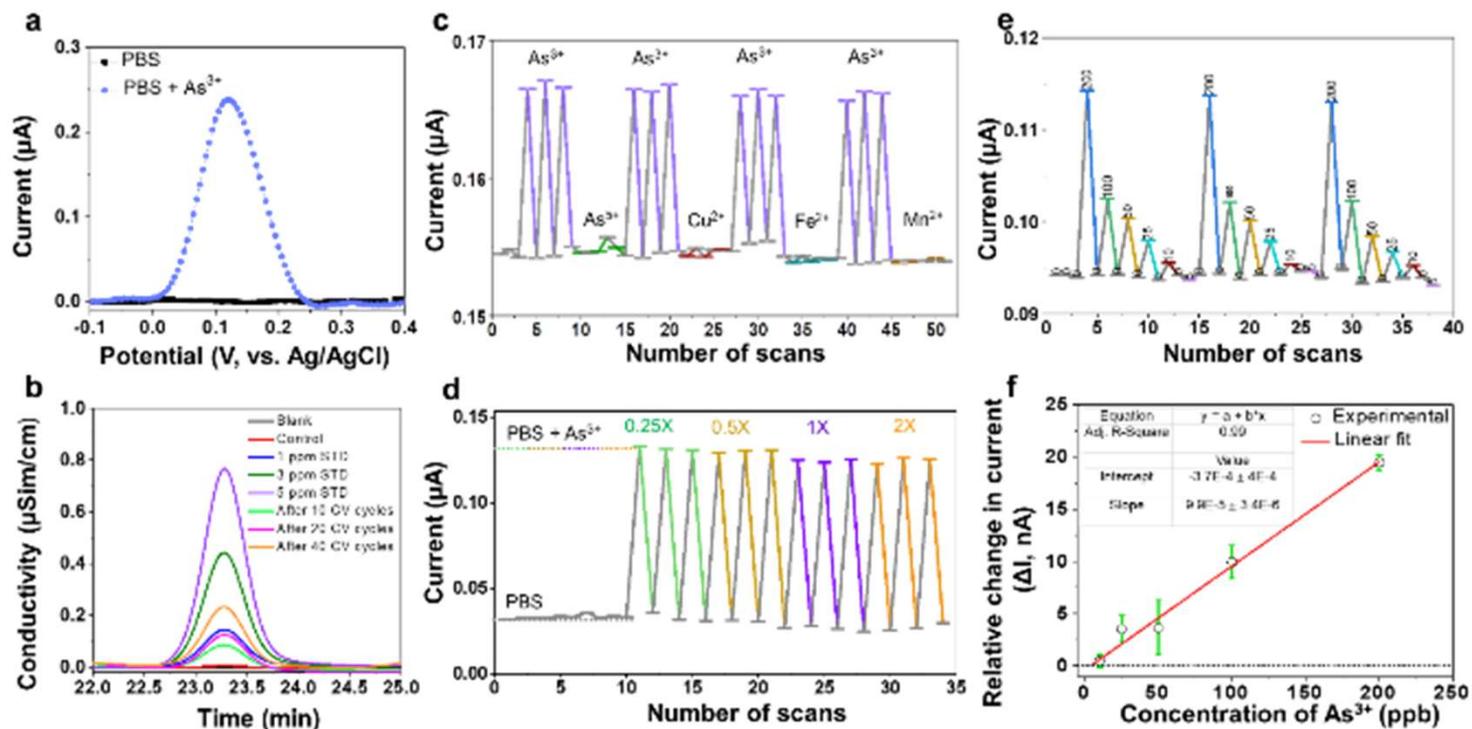
- ✓ Salts get occluded
- ✓ No chemical reaction, recovery of water is very easy
- ✓ Hydrates consist of 85% water and rest guest gas
- ✓ Not sensitive to impurities or salt concentration



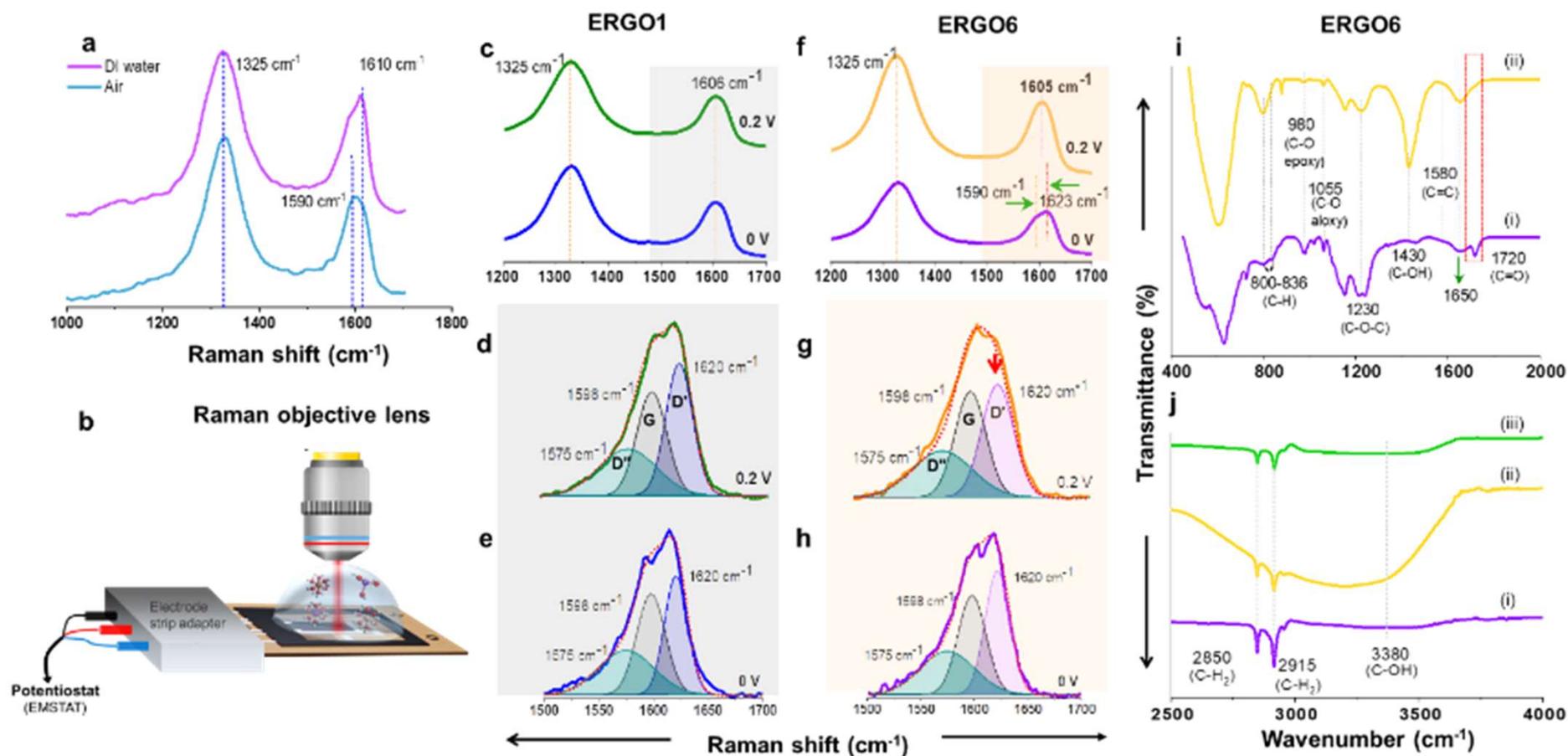
Cold Energy in LNG terminals can be harvested to produce water

Practical graphene-based arsenite sensor at 10 ppb



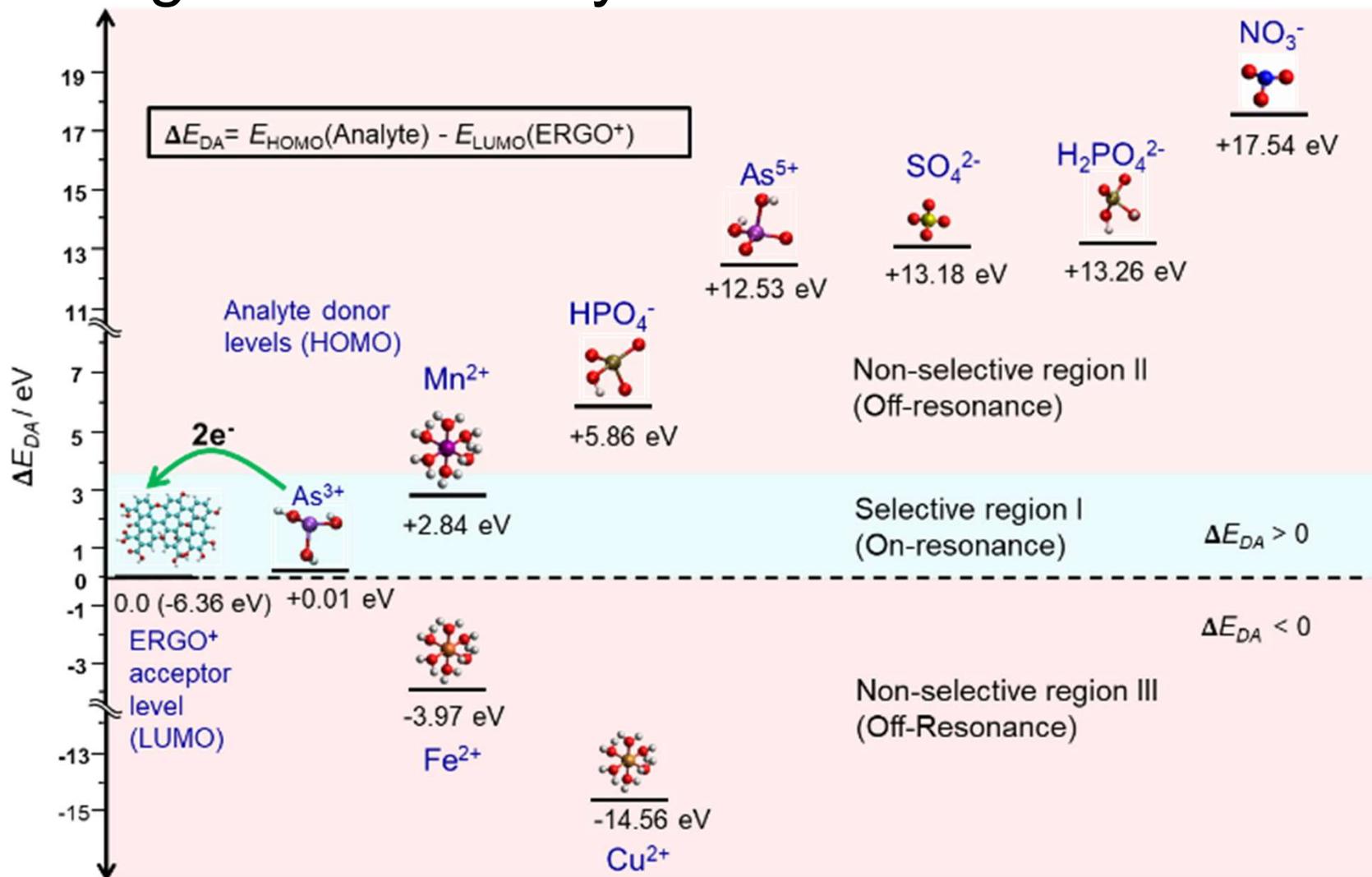


(a) LSV response of ERGO6 without and with 1 ppm As^{3+} , (b) Chronograms obtained from ion chromatography (IC) measurement with the solutions obtained after different number of CV cycles and same measurement with standard (STD) As^{5+} solutions of different concentrations. (c) CA measurement with 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 As^{3+} 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 As^{3+} 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 As^{3+} 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 As^{3+} (yellow trace), (j) FTIR spectra of the same strip without As^{3+} (purple trace), with As^{3+} (yellow trace), and after electrochemical oxidation (green trace) to show the changes in OH deformation peak at higher wavenumber.

Origin of selectivity



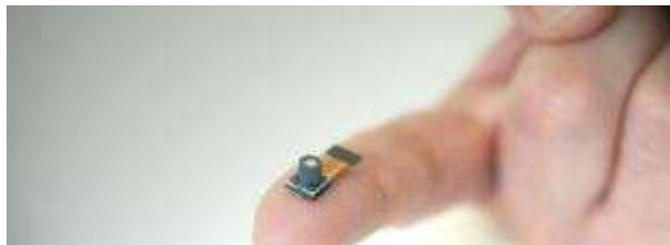
Sensors and new opportunities



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



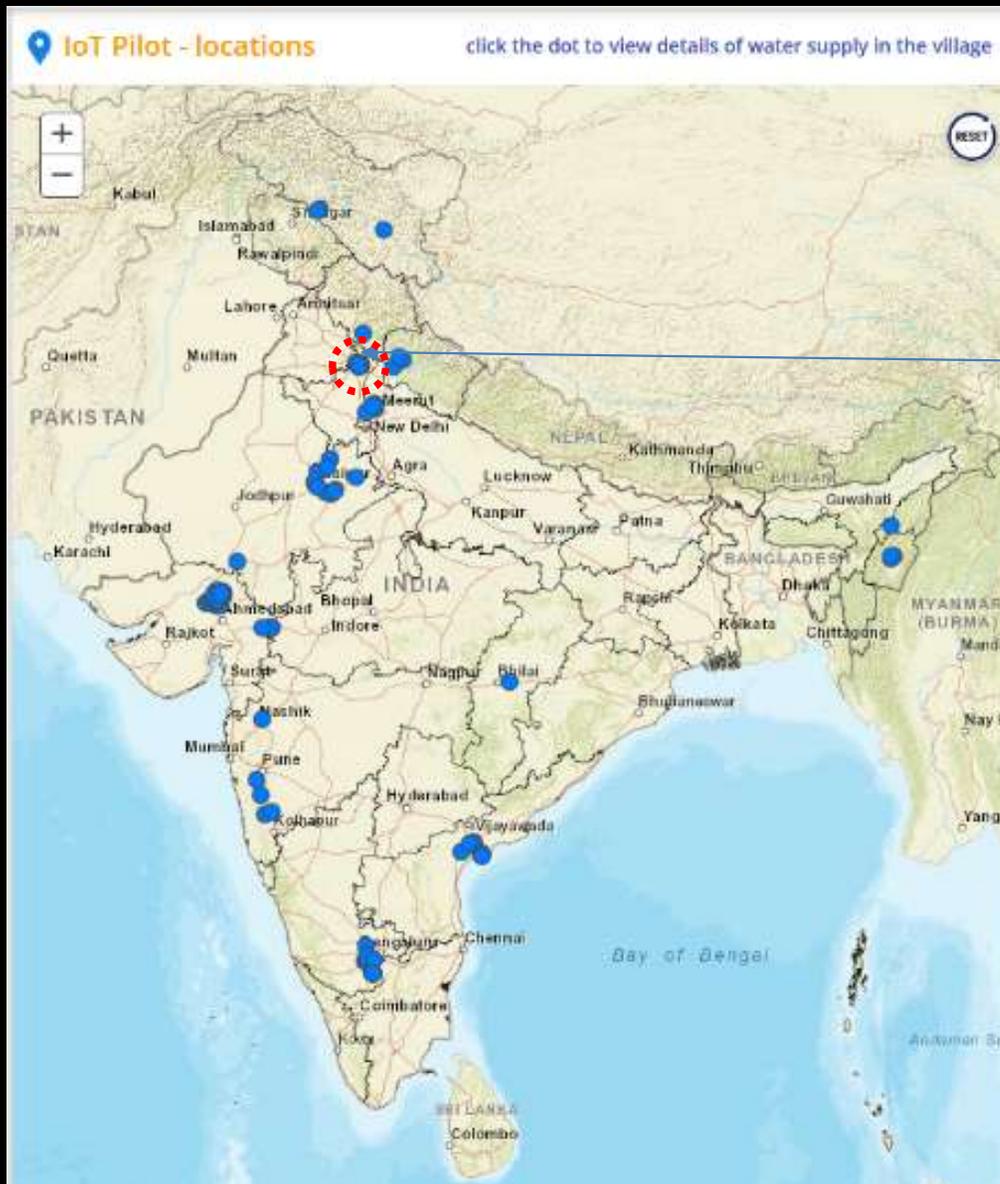
**Ultra compact Low Cost
Spectral Sensor Module**
~ **Billions units (? 2027)**



Water quality measurement – In the pipeline

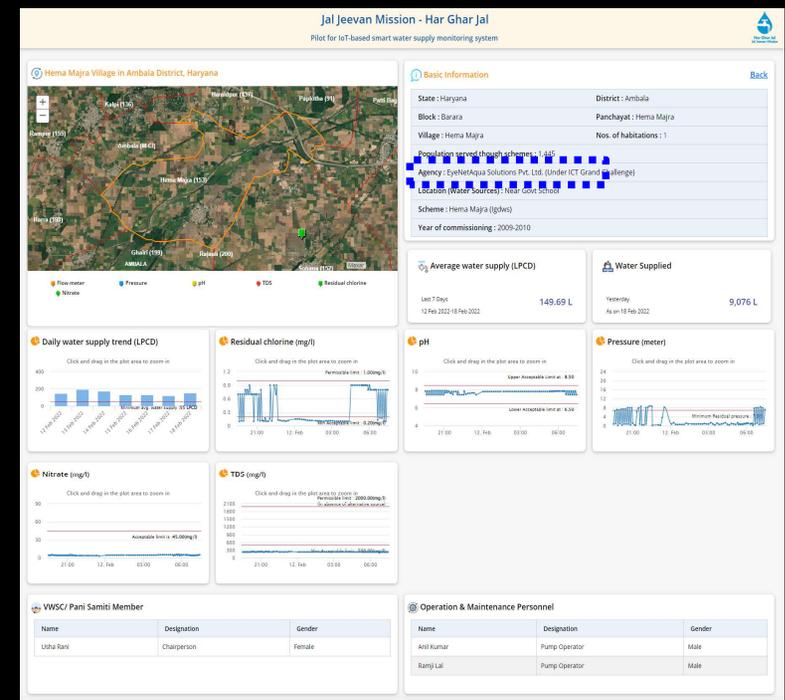
nano λ

India's water is being monitored



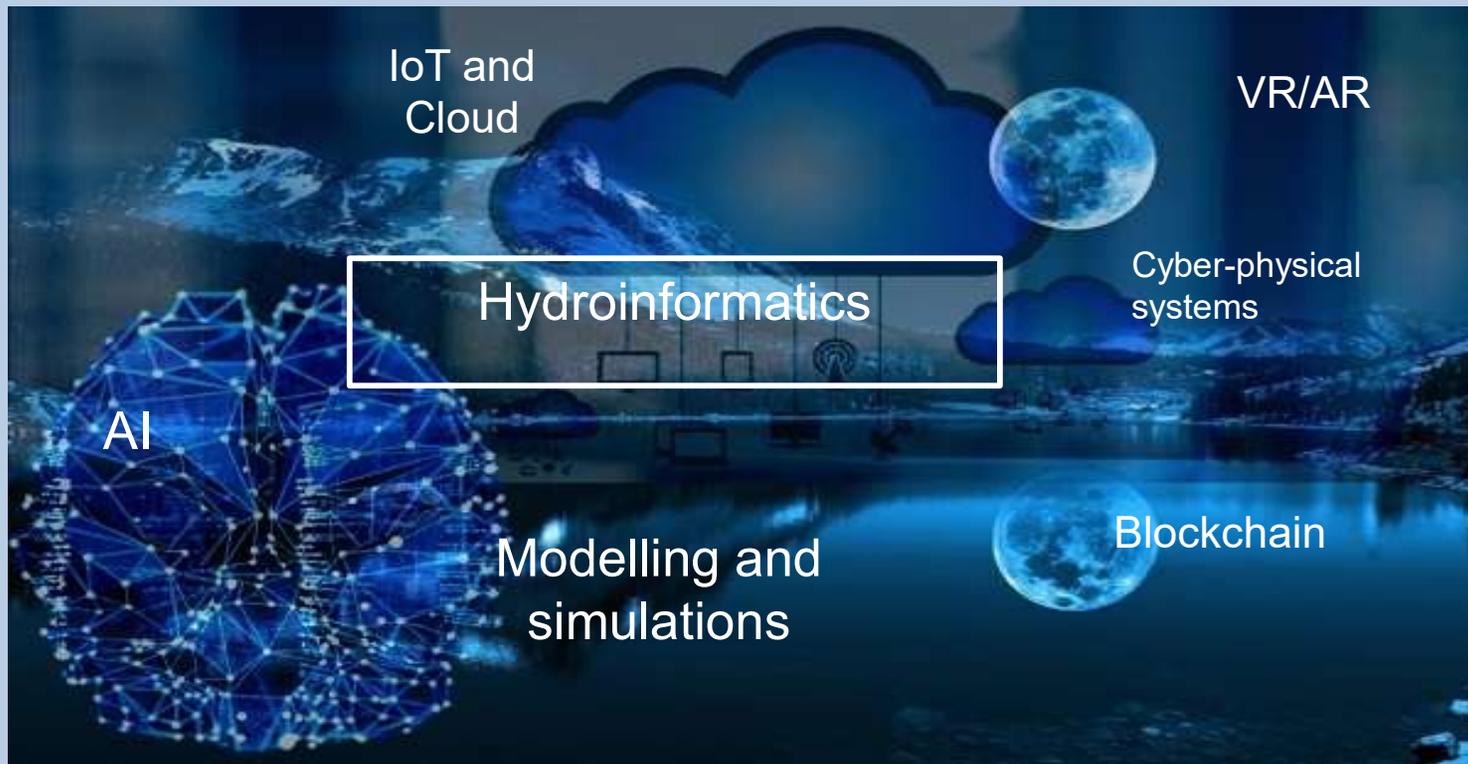
IITM/IISc

Installations made by four companies



Hydroinformatics

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

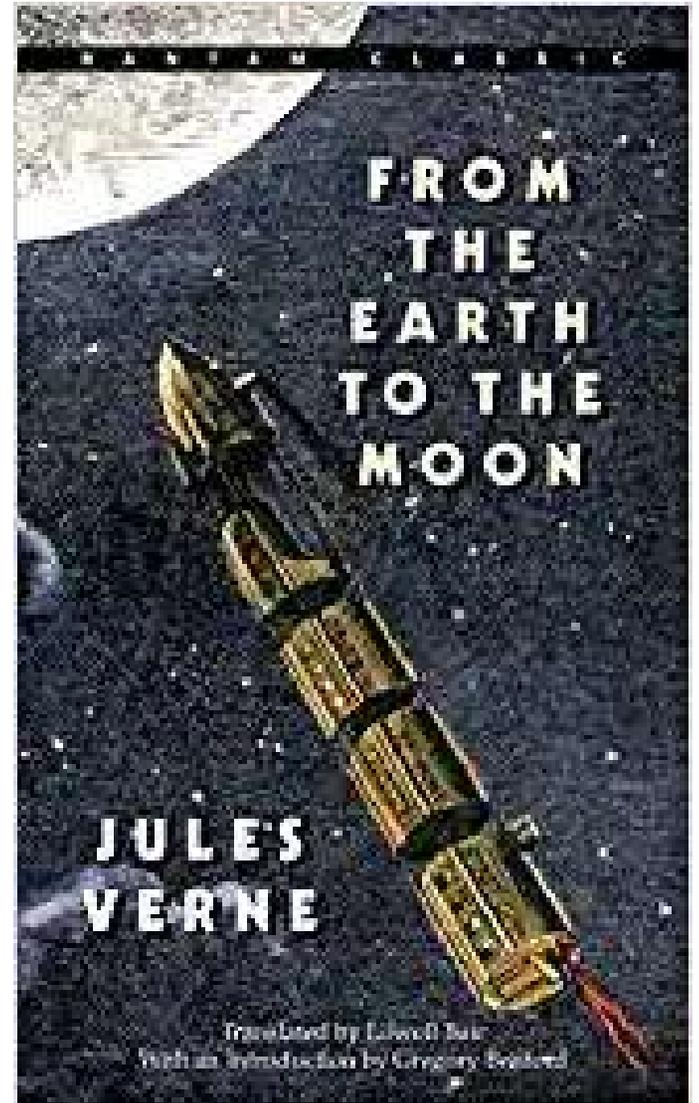
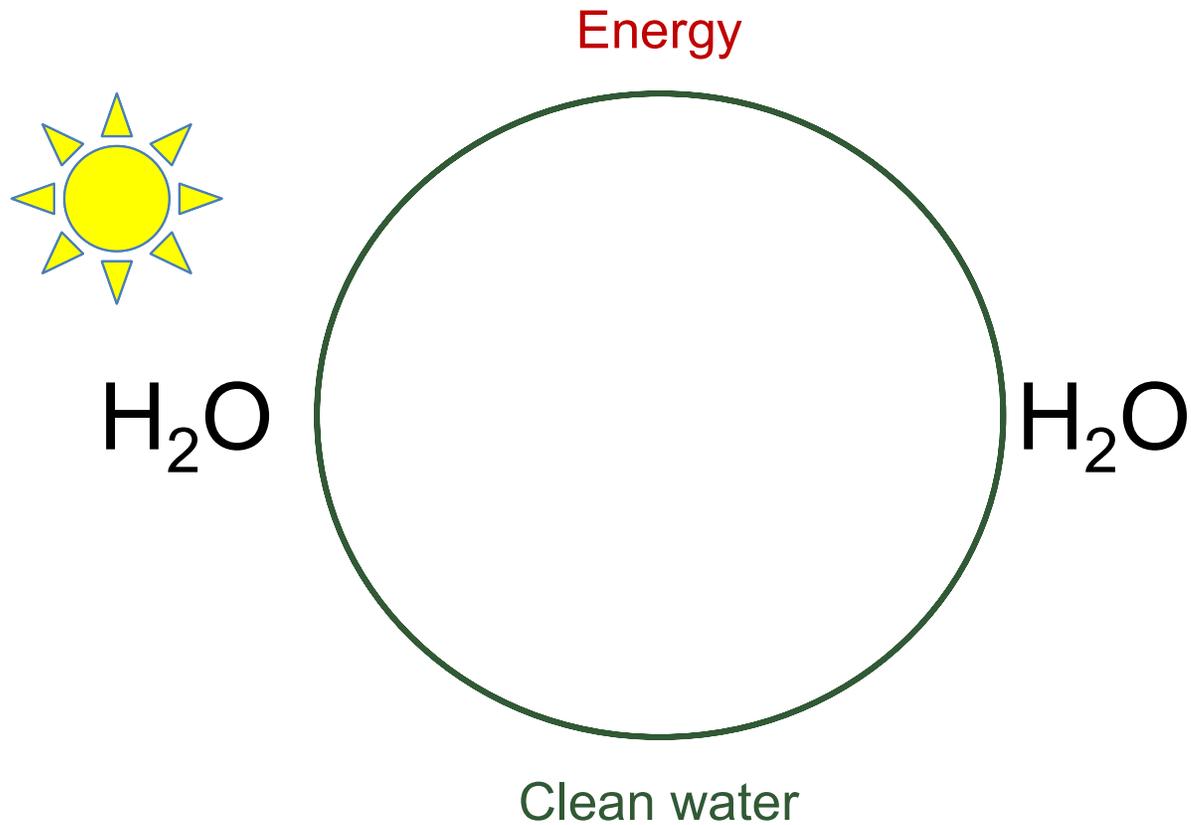


Digital water or water 4.0 will revolutionize water management.



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.

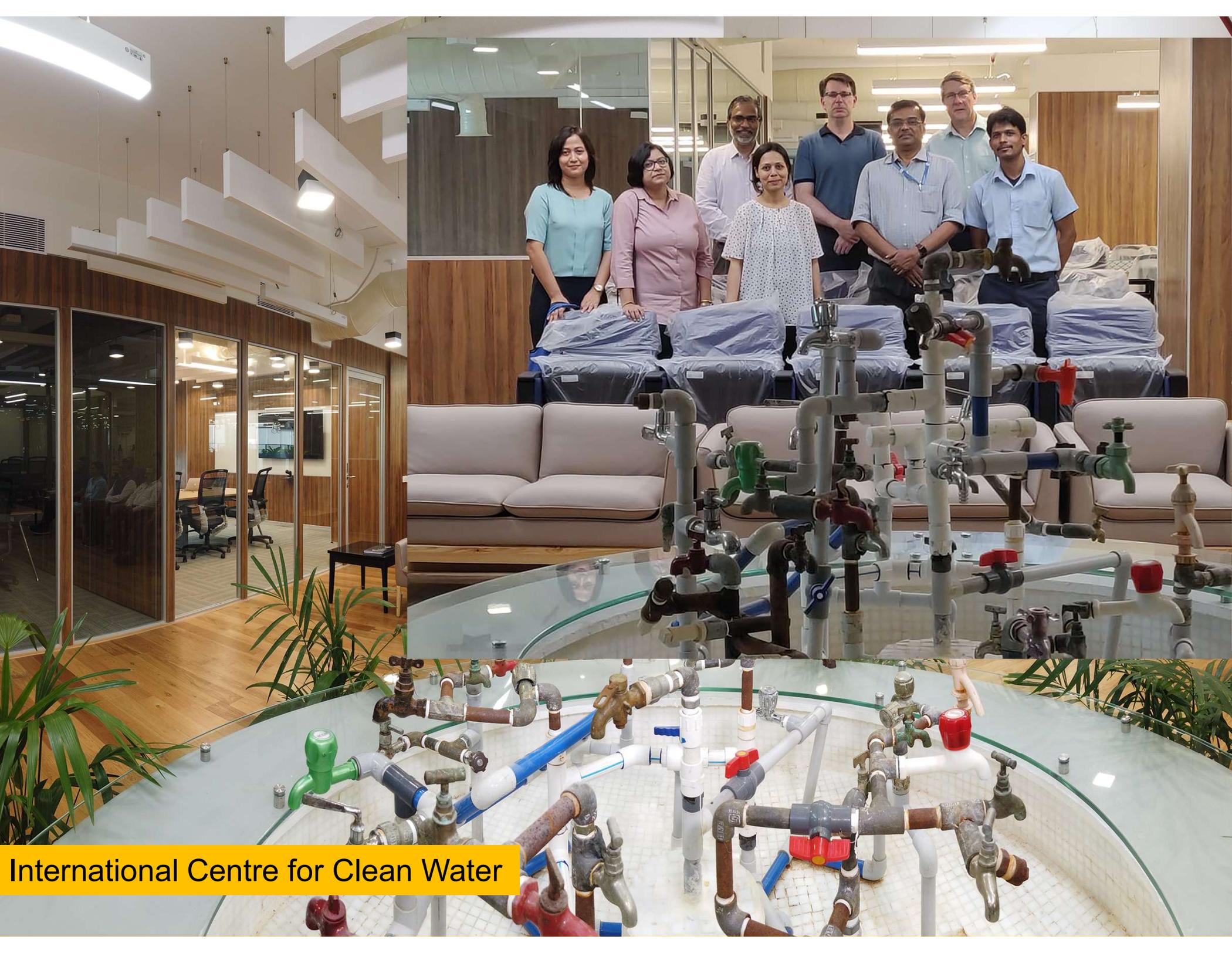
Desalination needs 2.4 kWh or 8.84 million joules for 1 CM of water.

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.

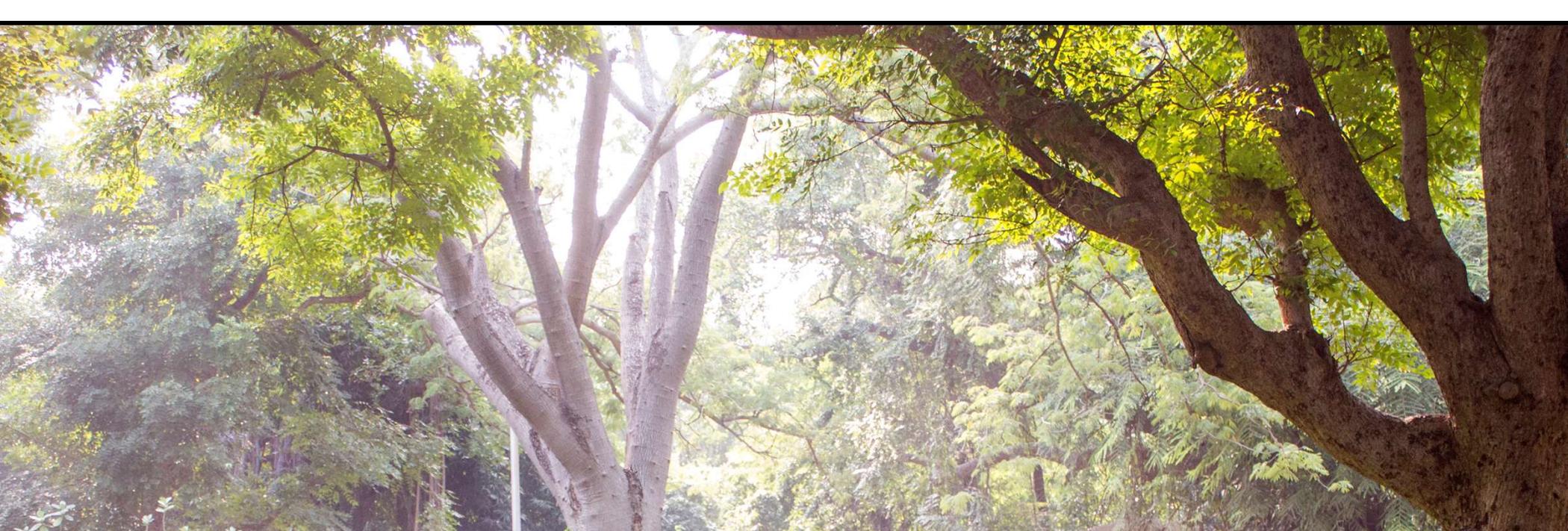
That world will need water literacy



International Centre for Clean Water



IIT Madras Research Park



The AMRIT Team, 2013



Group during 2018, along with Prof. Graham Cooks

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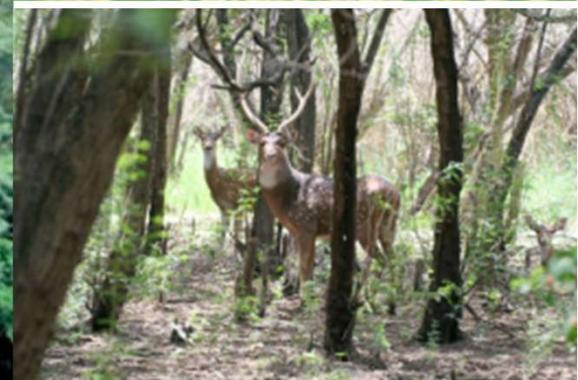
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Start-ups and partners:





Indian Institute of Technology Madras



Associate Editor



Bhaskar Ramamurthi/V. Kamakoti

Thank you all

