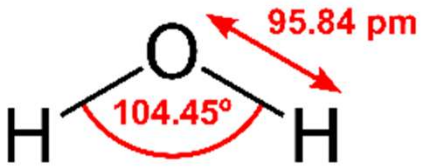
Since 1959



Affordable clean water using advanced materials

T. Pradeep
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Dr. Noelia Barrabés

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.

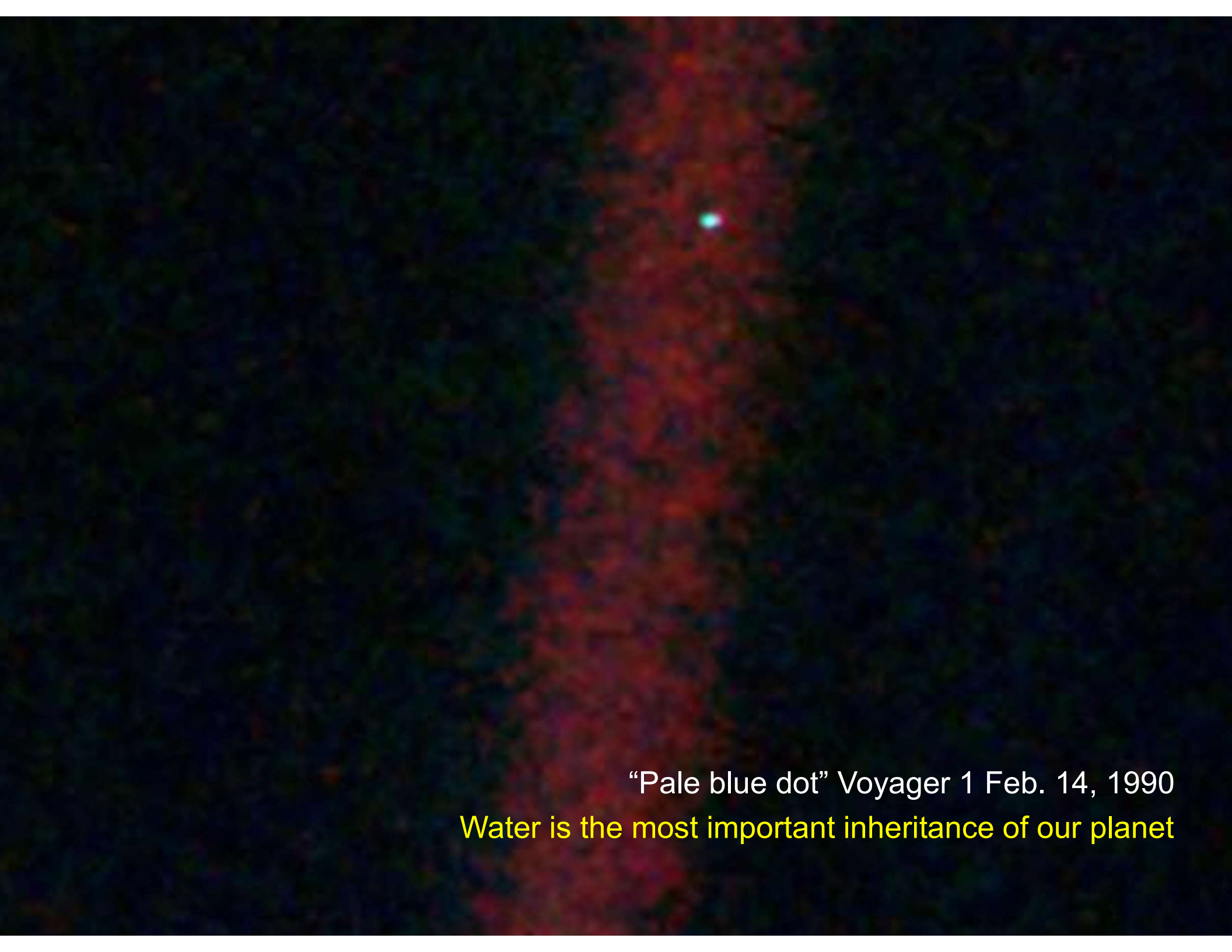
Associate Editor

ACS Sustainable Chemistry & Engineering

Professor-in-charge

International Centre for Clean Water

Technische Universität Wien, December 12, 2022


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

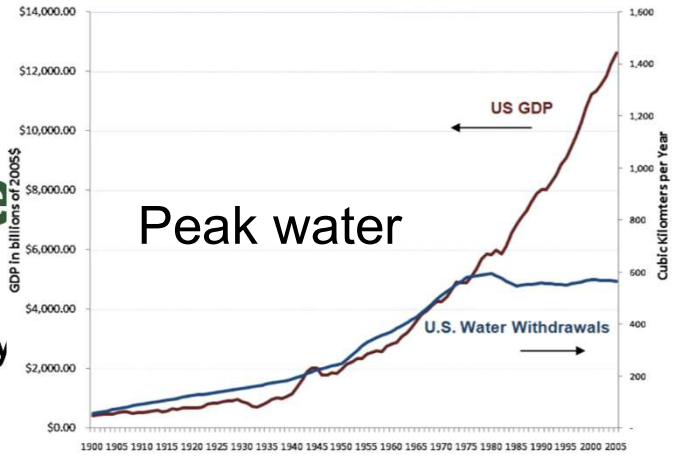
Water is at the entre of action

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!

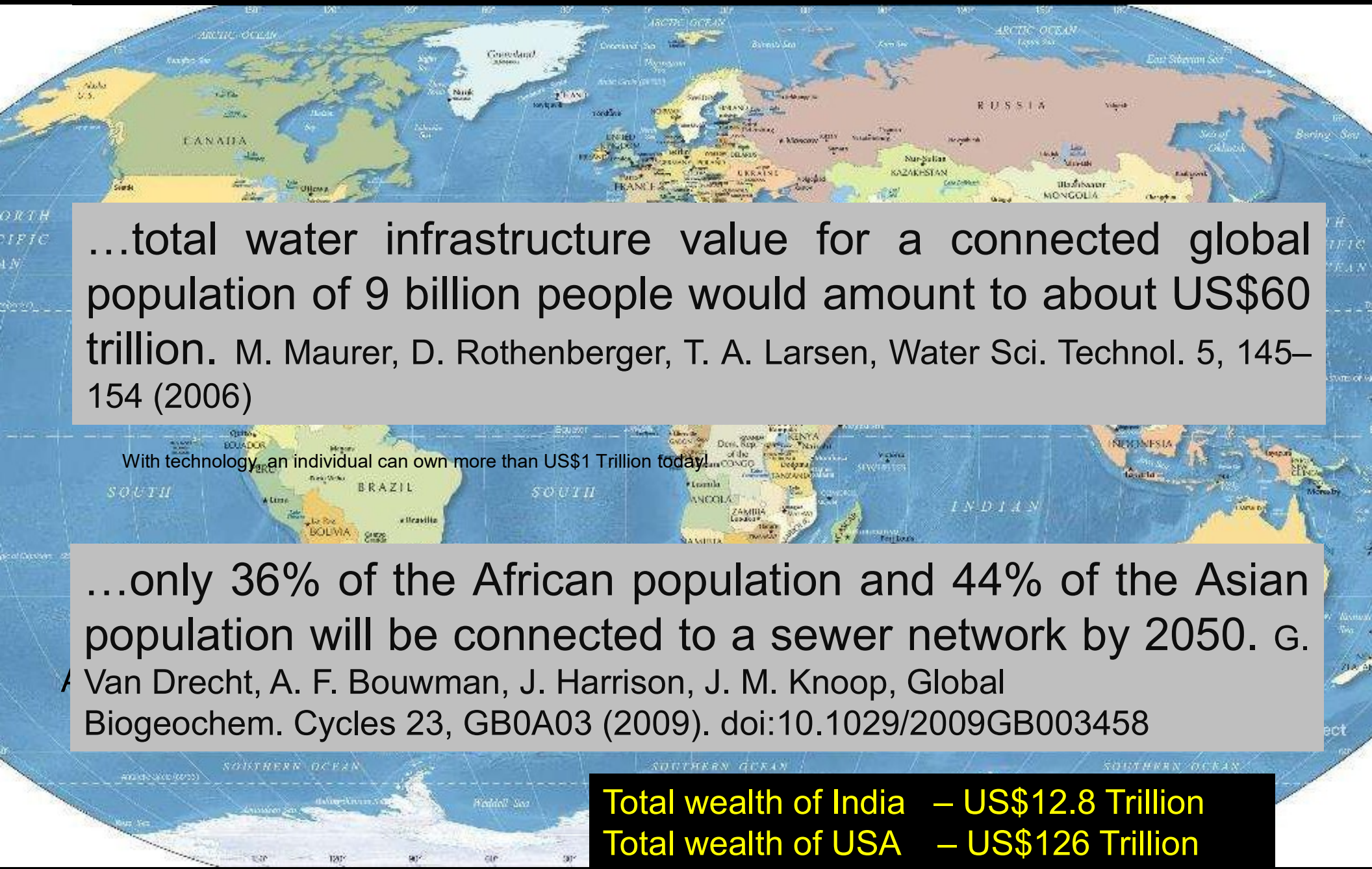
GDP can grow even by capping freshwater withdrawals

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



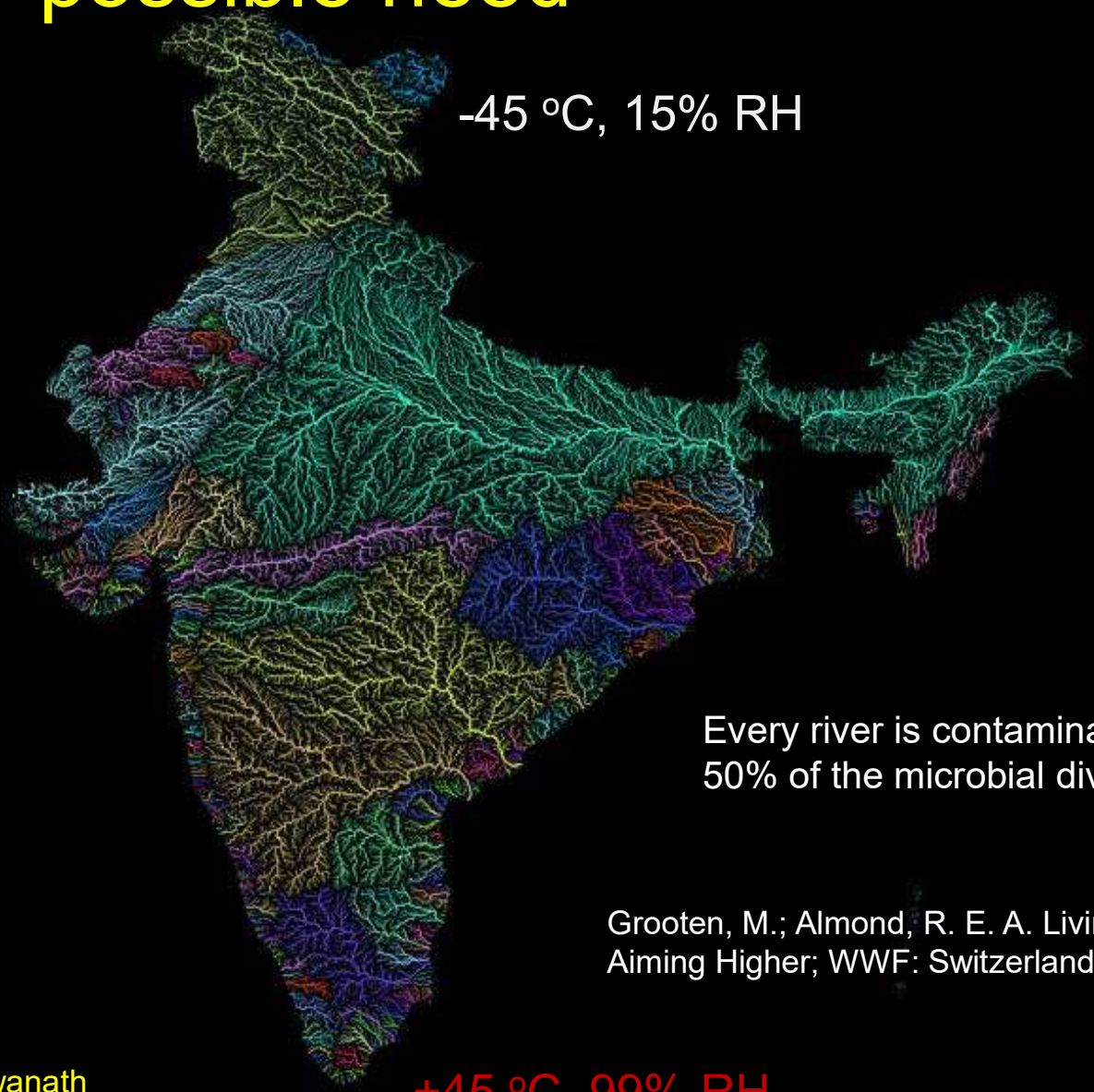
…total water infrastructure value for a connected global population of 9 billion people would amount to about US$60 trillion. M. Maurer, D. Rothenberger, T. A. Larsen, Water Sci. Technol. 5, 145–154 (2006)

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. 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
…..

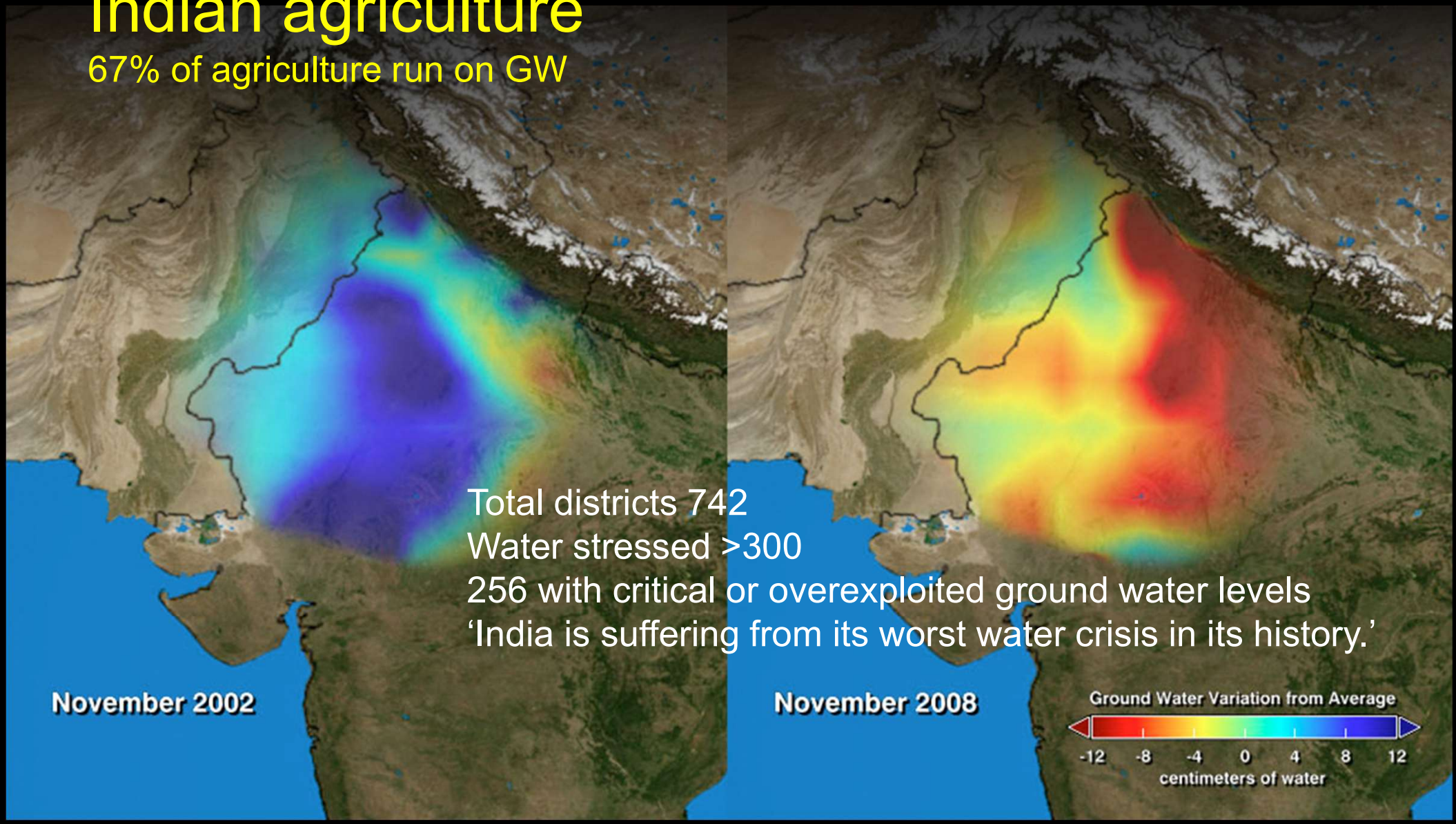
Every river is contaminated
50% of the microbial diversity is lost for ever

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

From S. Vishwanath

Indian agriculture

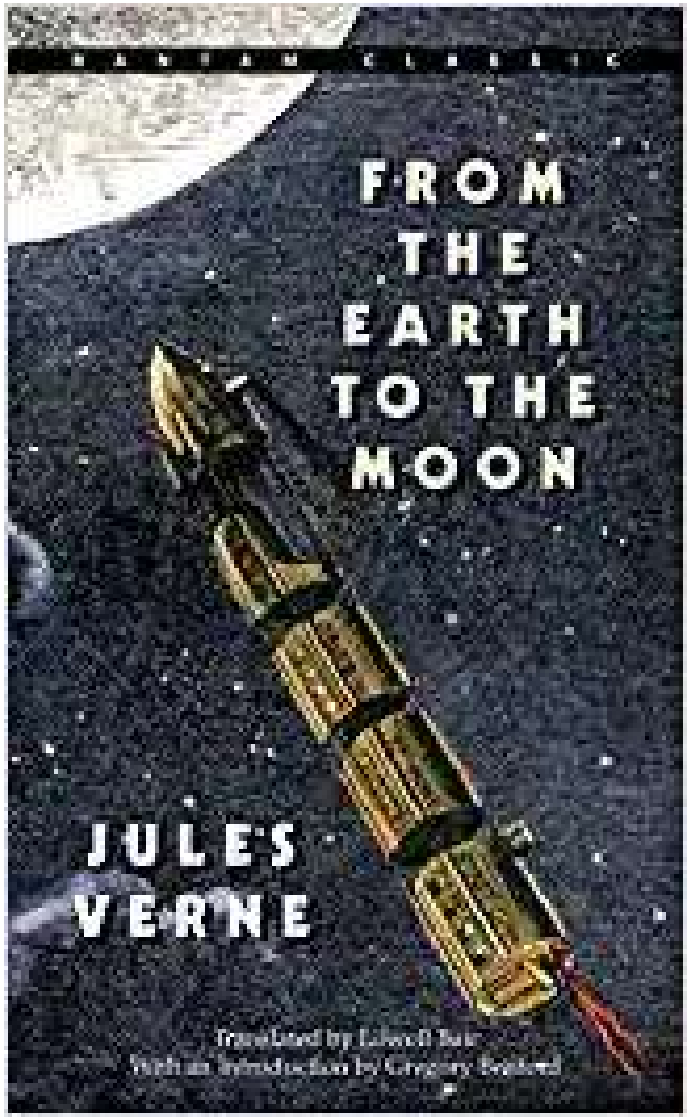
67% of agriculture run on GW



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.’

Data from NASA

Our dreams become reality with materials



Water purification, history

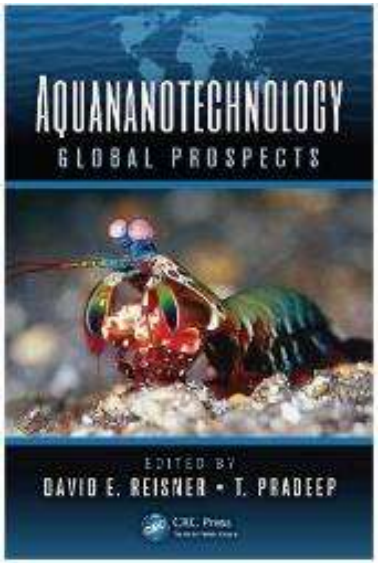
Important milestones in the history of water purification (1800–2007) from the perspective of noble metal nanoparticles in water treatment (compiled from multiple sources on the World Wide Web).

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	*Silent Spring* published, first report on harmful effects of DDT (R. Carson)
1965	World's first commercial RO plant launched
1974	Reports on carcinogenic by-products of disinfection with chlorine Formulation of Safe Drinking Water Act (USEPA)
1975	Development of carbon block for drinking water purification
1994	Report on use of zerovalent iron for degradation of halogenated organics (R. W. Gillham, S. F. O'Hannesin)
1997	Report on use of zerovalent iron nanoparticles for degradation of halogenated organics (C-B. Wang, W.-X. Zhang)
1998	Drinking Water Directive applied in EU
2000	Adoption of Millennium Declaration during the UN Millennium Summit (UN Millennium Development Goals)
2003	Report on use of noble metal nanoparticles for the degradation of pesticides (A.S. Nair, R. T. Tom, T. Pradeep)
2004	Stockholm Convention, banning the use of persistent organic pollutants
2007	Launch of noble metal nanoparticle-based domestic water purifier (T. Pradeep, A. S. Nair, Eureka Forbes Limited)

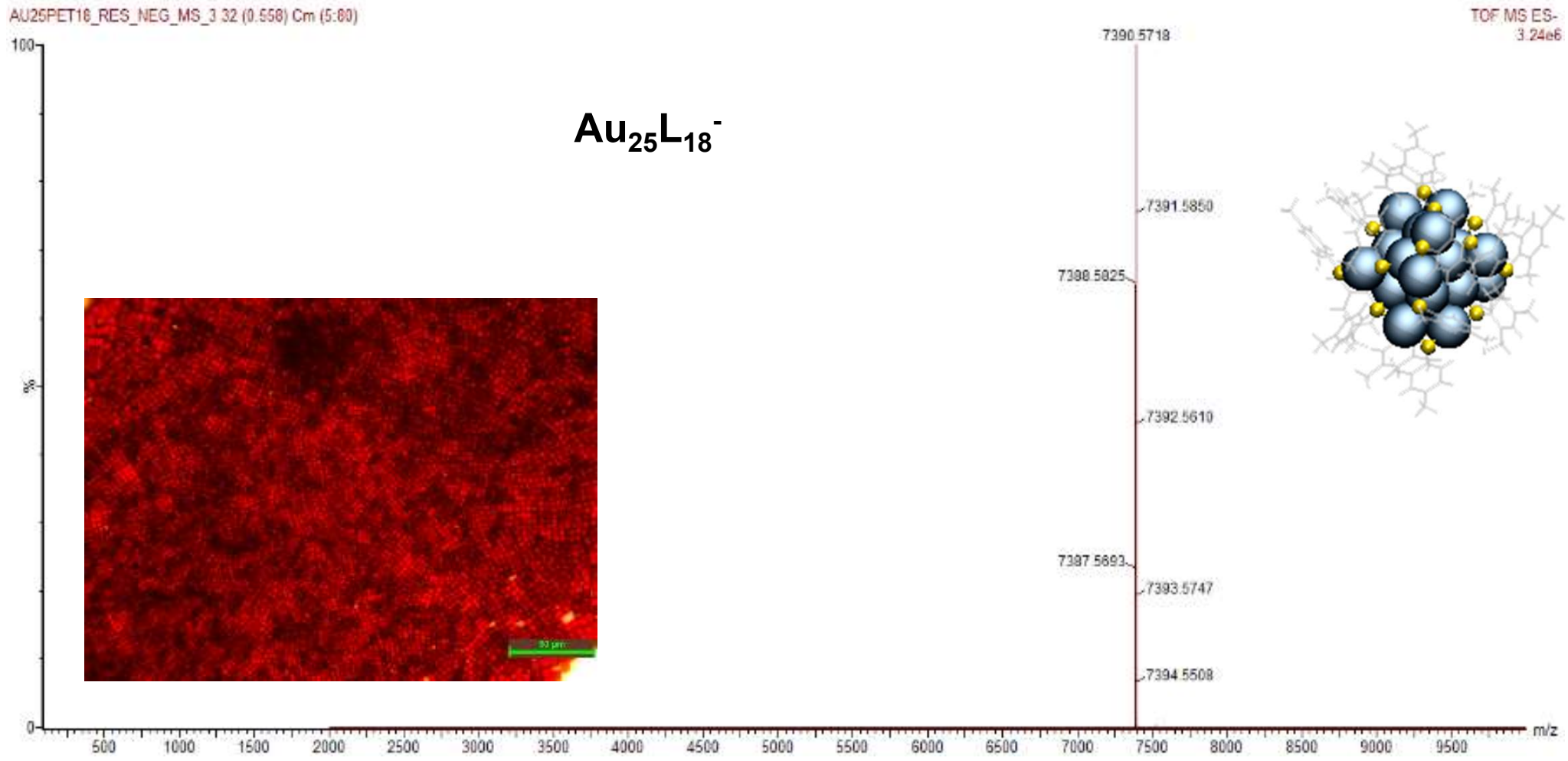
T. Pradeep and Anshup, *Thin Solid Films*, 2009

Affordable clean water is a problem of advanced materials

New adsorbents
New sensors
New catalysts
Novel phenomena
New devices



Nanomaterials are now atomically precise



$Au_{25}L_{18}^-$

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

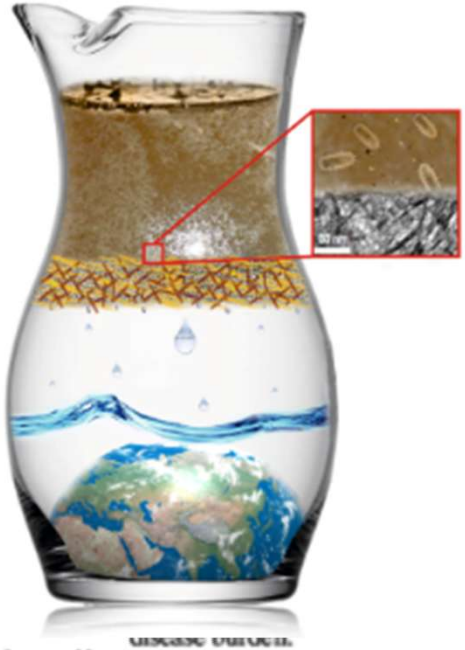
Biopolymer-reinforced synthetic granular nanocomposites for affordable point-of-use water purification

Mohan Udhaya Sankar[1], Sahaja Aigal[1], Shihabudheen M. Maliyekkal[1], Amrita Chaudhary, Anshup, Avula Anil Kumar, Kamalesh Chaudhari, and Thalappil Pradeep[2]

Unit of Nanoscience and Thematic Unit of Excellen

Edited by Eric Hoek, University of California, Los A

Creation of affordable materials for constant
water is one of the most promising ways to p
drinking water for all. Combining the capa
composites to scavenge toxic species such
other contaminants along with the above c
affordable, all-inclusive drinking water purif
without electricity. The critical problem in
synthesis of stable materials that can relea
uously in the presence of complex specie
drinking water that deposit and cause scal
surfaces. Here we show that such constant
be synthesized in a simple and effective fashio
out the use of electrical power. The nanoco
sand-like properties, such as higher shear stre
forms. These materials have been used to d
water purifier to deliver clean drinking water
ily. The ability to prepare nanostructured
ambient temperature has wide relevance f
water purification.



ıs, Chennai 600 036, India

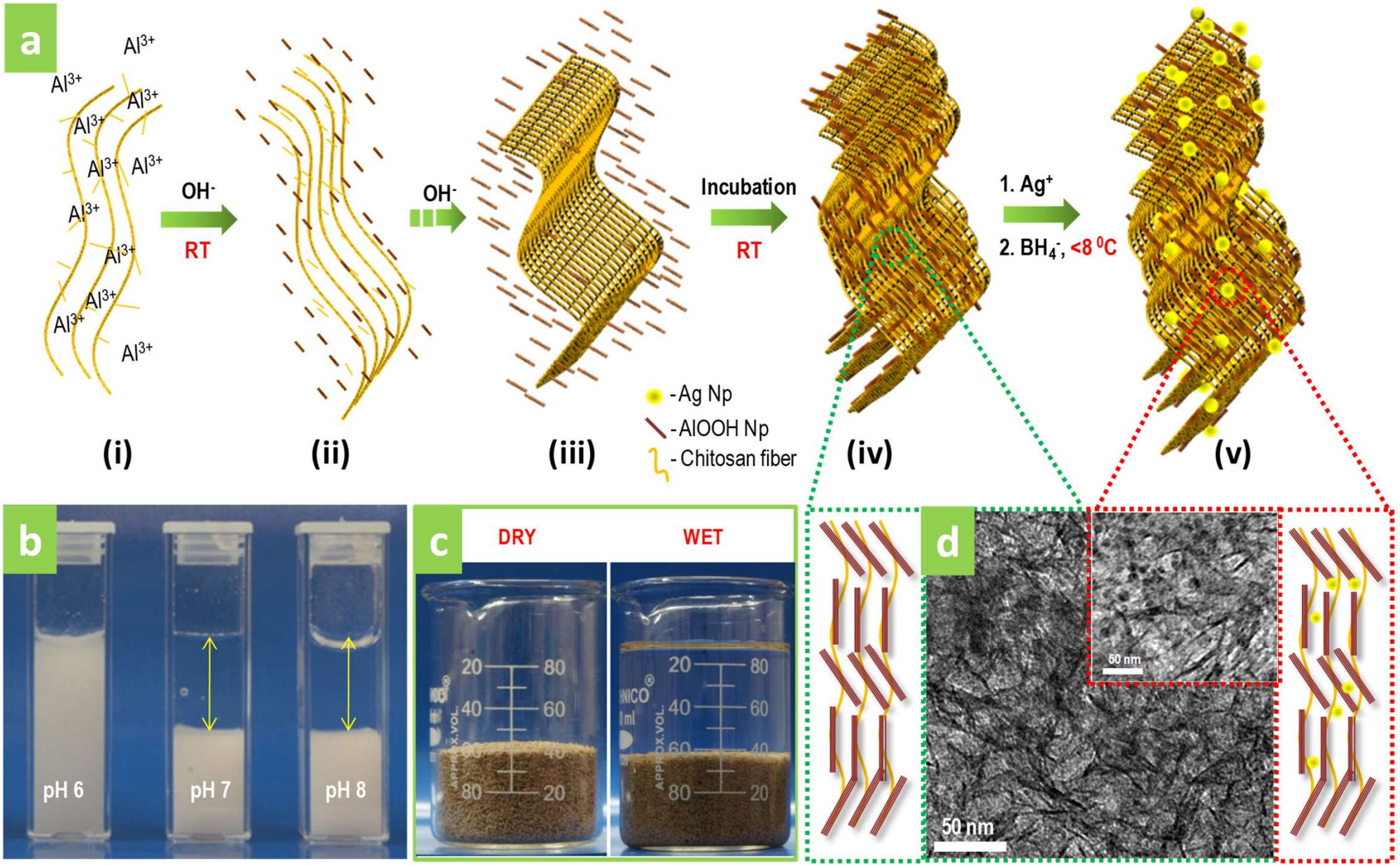
ved for review November 21, 2012)

ble; and (*c*) continued retention
ix is difficult.
unique family of nanocrystalline
nular composite materials pre-
through an aqueous route. The
ition is attributed to abundant -O-
hitosan, which help in the crys-
and also ensure strong covalent
ace to the matrix. X-ray photo-
irms that the composition is rich
sing hyperspectral imaging, the
g in the water was confirmed.
activate the silver nanoparticle
timicrobial activity in drinking
have been developed that can
water. We demonstrate an af-
e based on such composites de-
dergoing field trials in India, as
d eradication of the waterborne

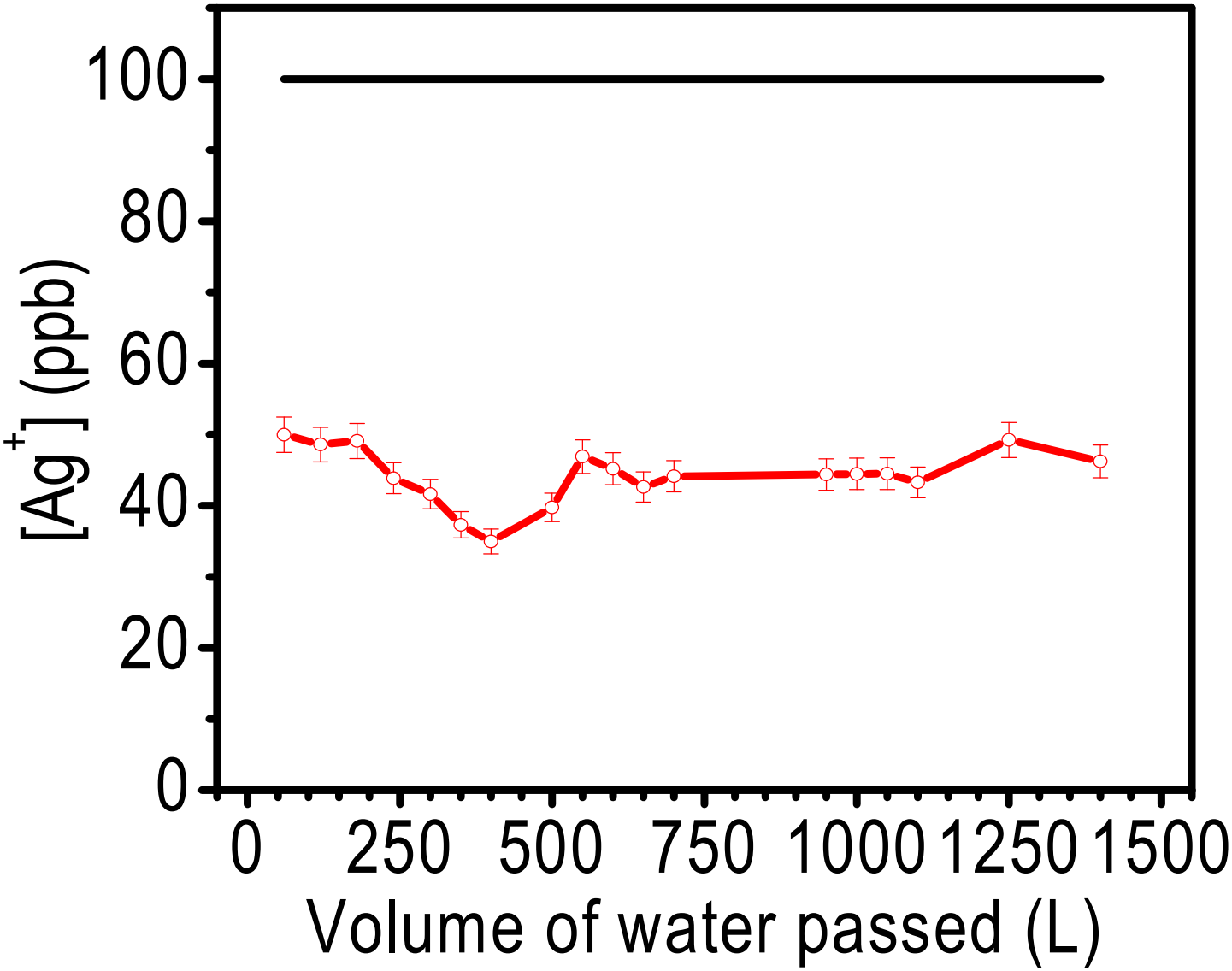
hybrid | green | appropriate technology | frugal science | developing world

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

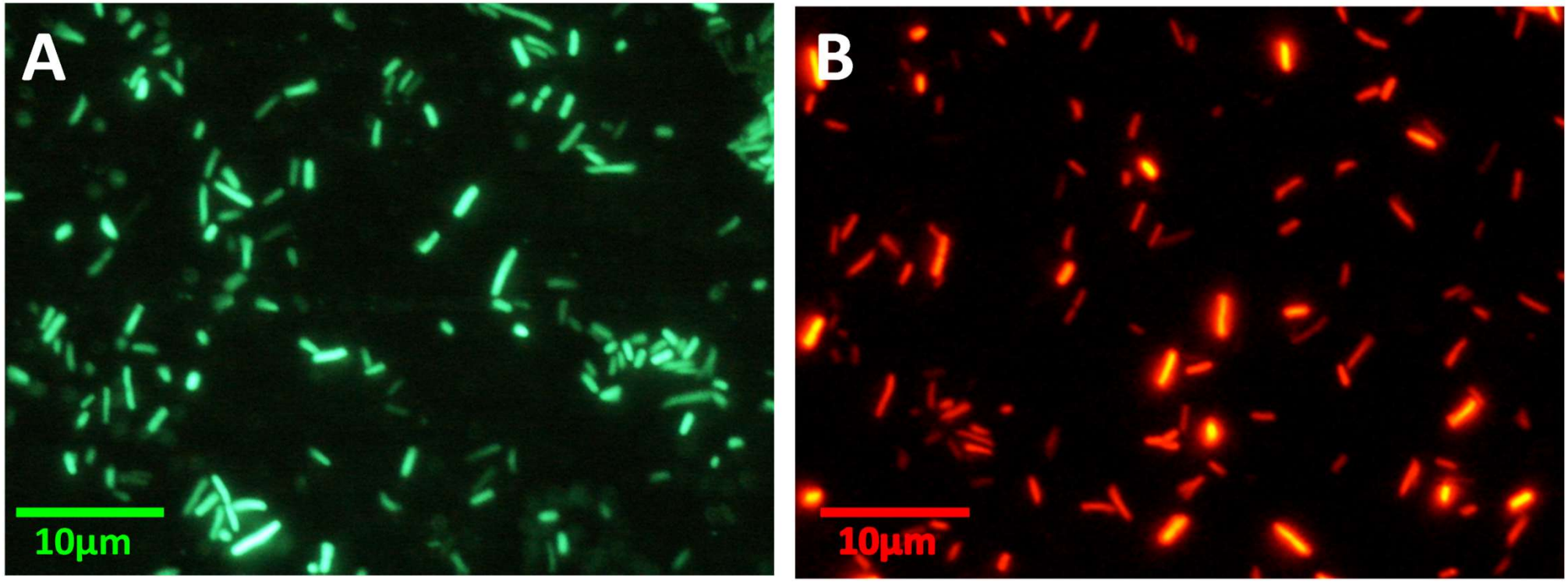
How to make?


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

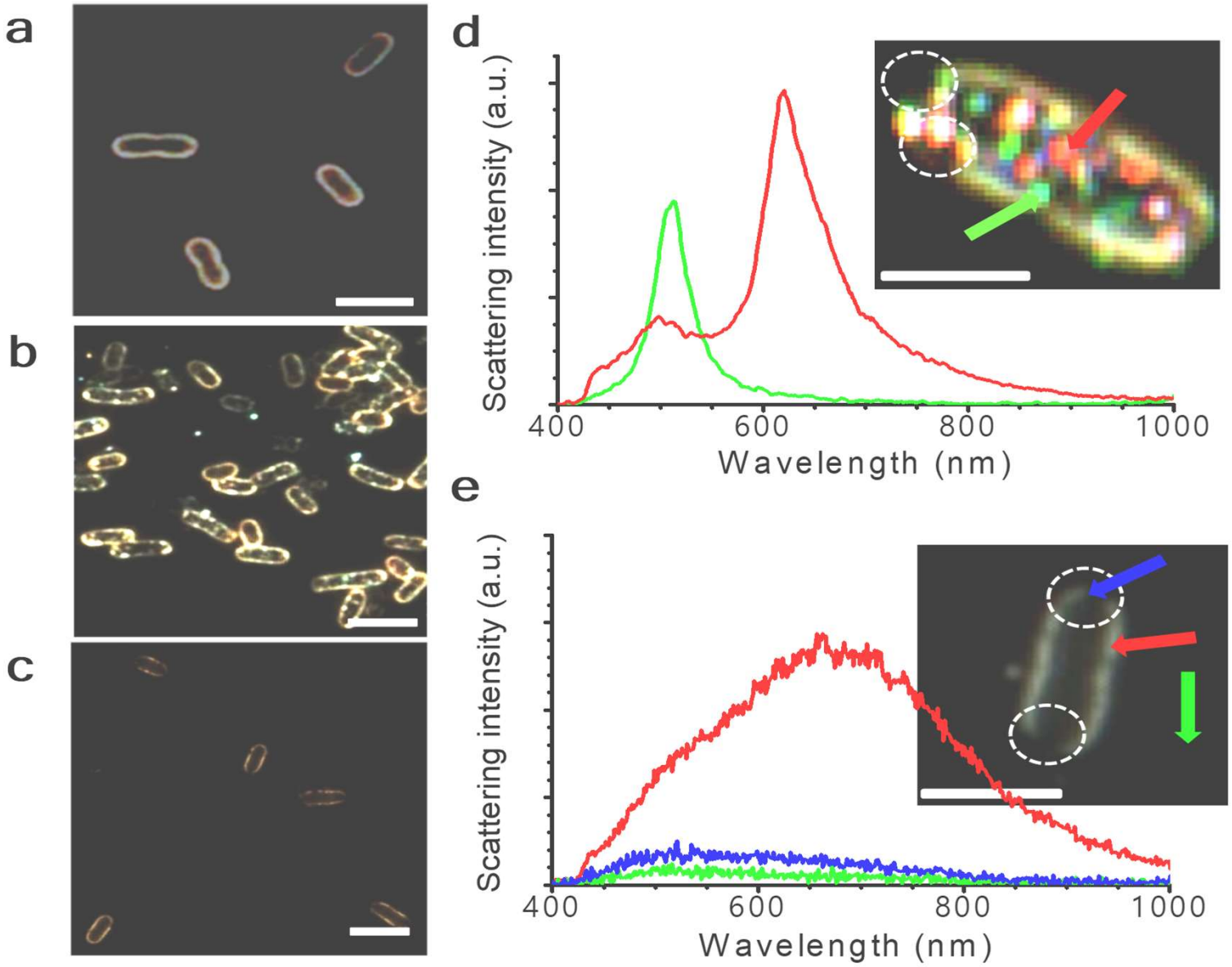
What is special?



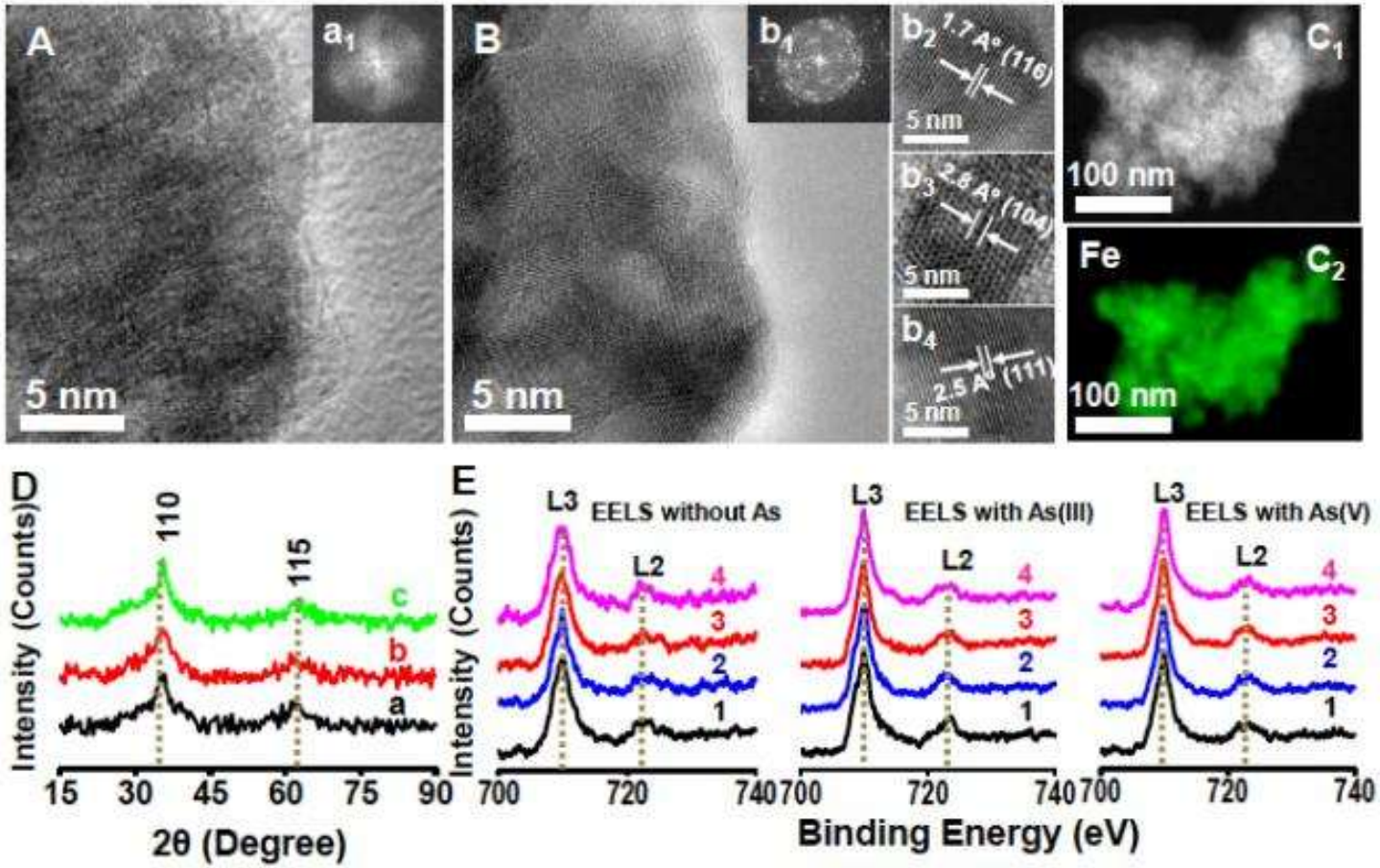
Live/dead staining experiments



No nanotoxicity



Variety of materials



www.advmat.de
ADVANCED MATERIALS

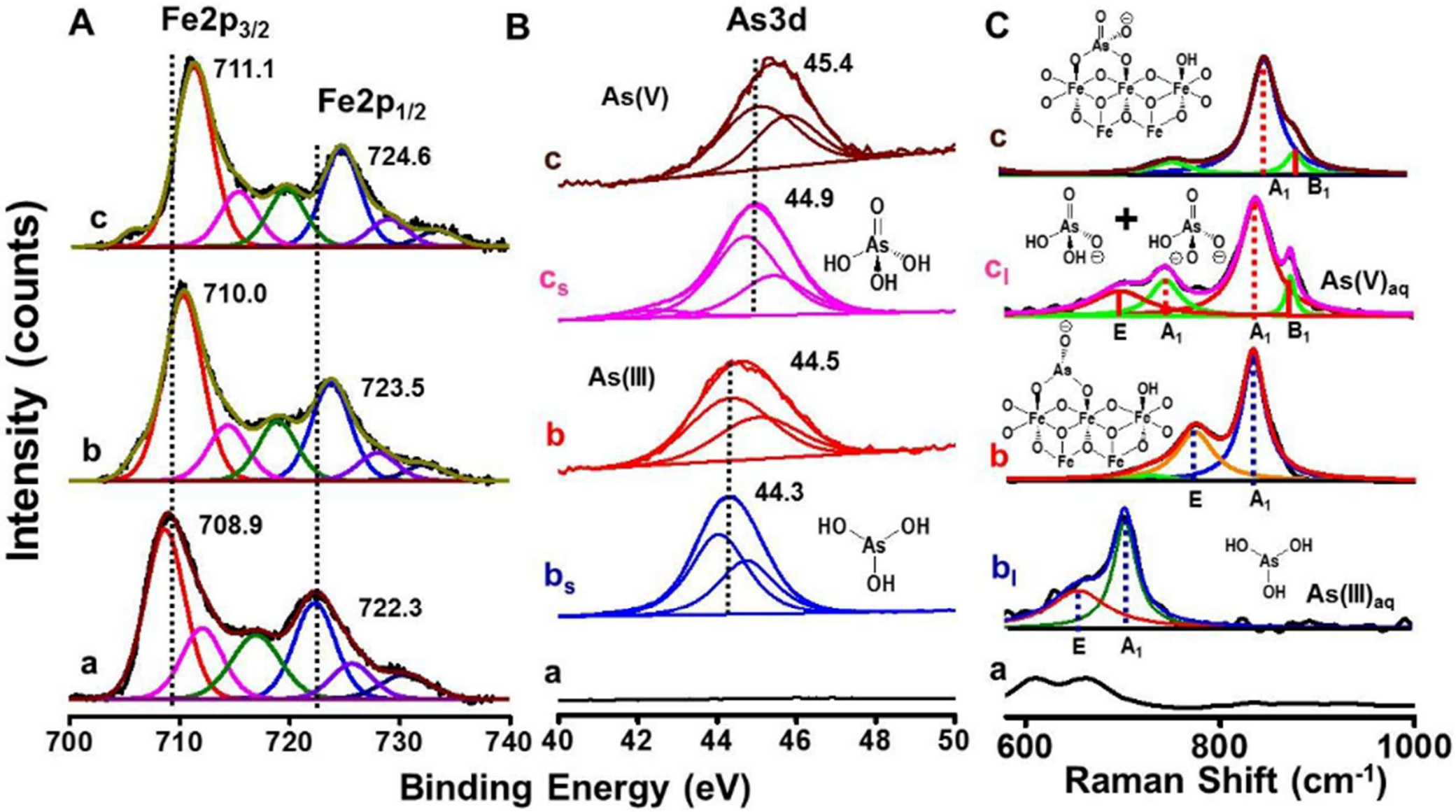
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

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**

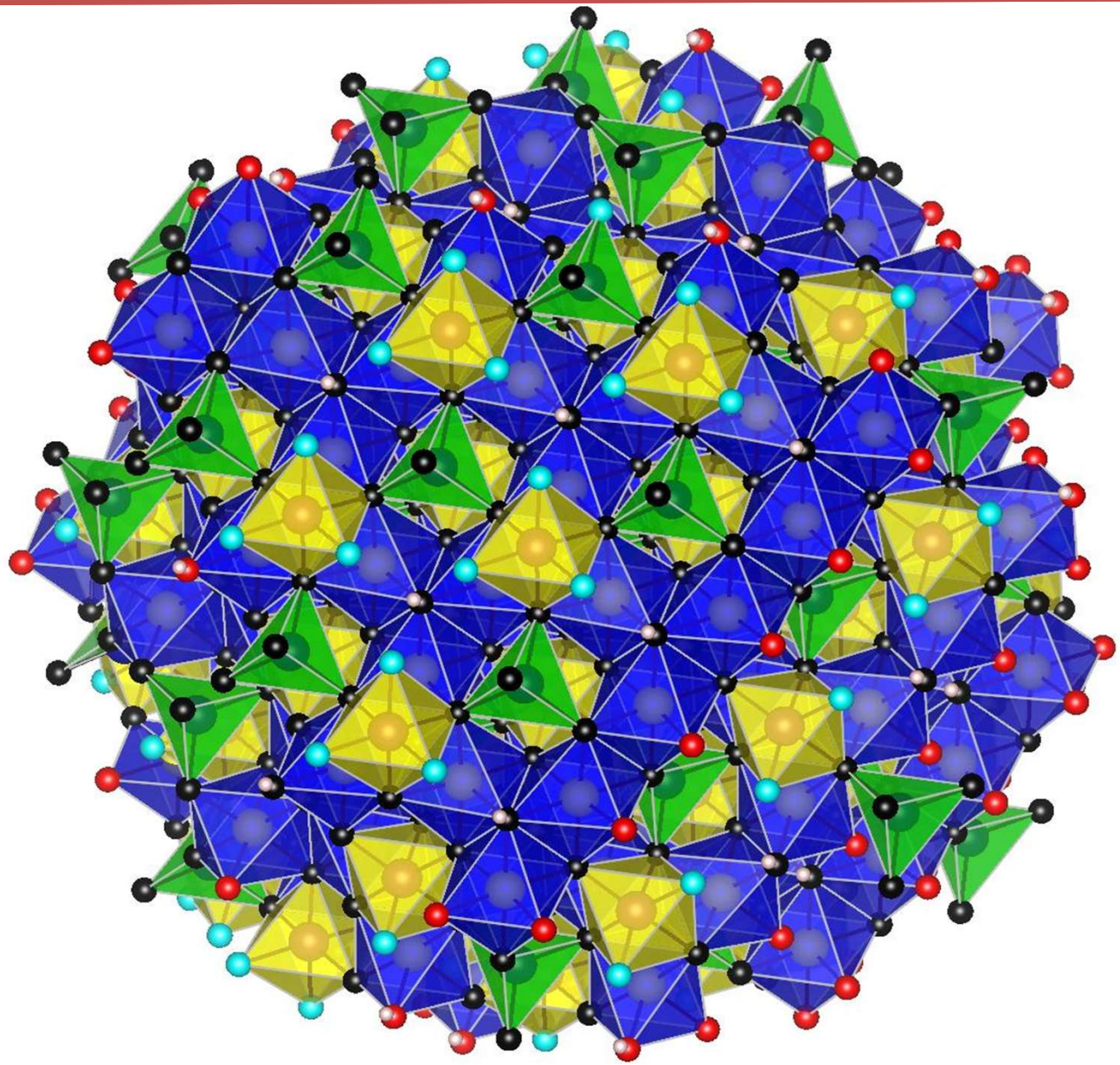
Communication

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

Mechanism

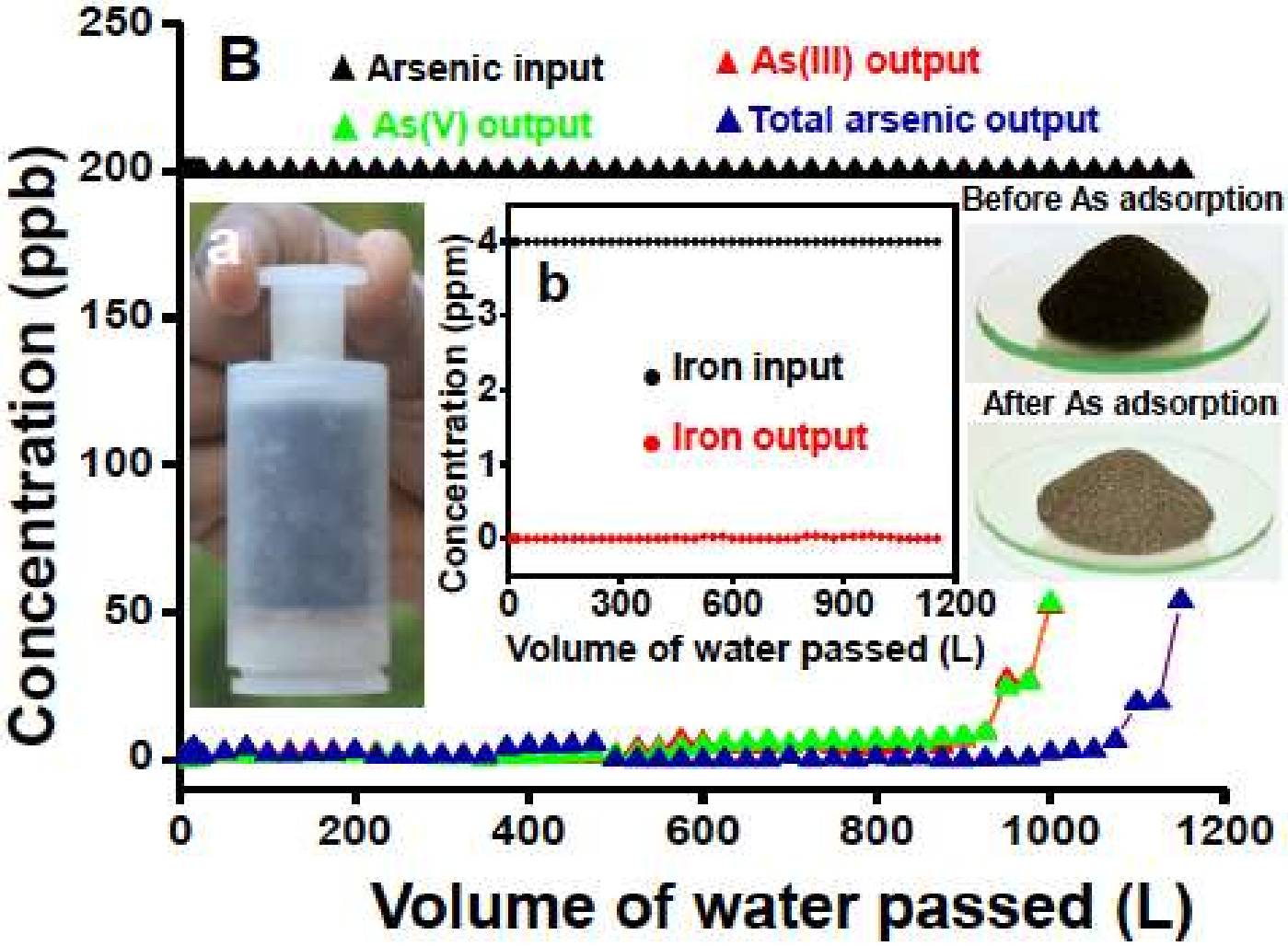

A
Fe2p3/2
711.1
Fe2p1/2
724.6
c
710.0
723.5
b
708.9
722.3
a
Intensity (counts)
700
710
720
730
740
B
As3d
As(V)
45.4
c
44.9
cs
As(III)
44.5
b
44.3
bs
a
40
42
44
46
48
50
Binding Energy (eV)
C
c
A1
B1
cl
As(V)aq
E
A1
A1
B1
b
E
A1
bl
As(III)aq
E
A1
a
600
800
1000
Raman Shift (cm-1)

Modeling surfaces



Chennu Sudhakar, et al. *ACS Sustainable Chemistry & Engineering*, 6 (2018) 9990-10000

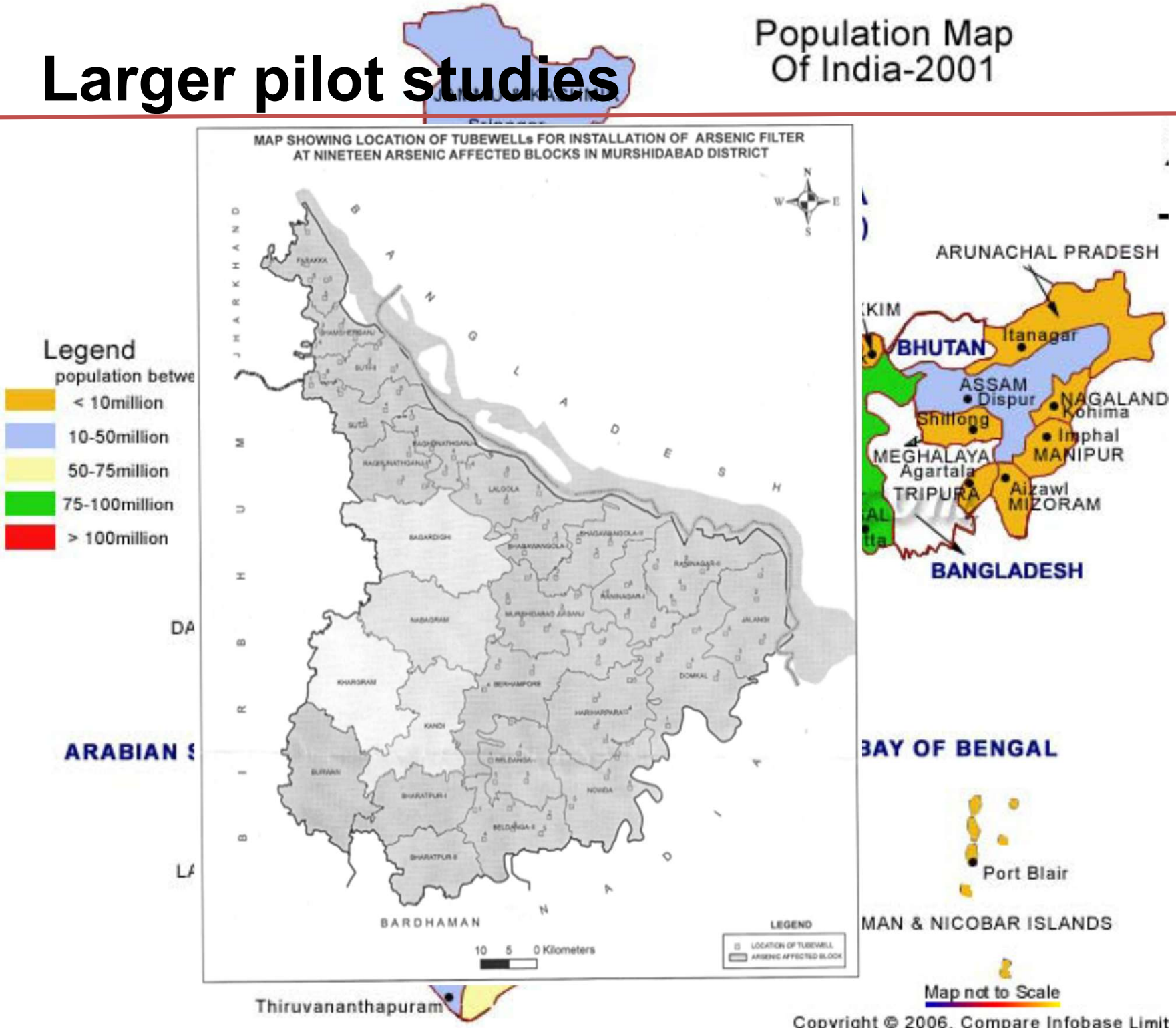
Lab studies



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

Initial pilot studies

Larger pilot studies



Changing the dynamics in the field

- Existing unit for iron and arsenic removal – 20 m^3/h
- Uses activated alumina and iron oxide (old generation of adsorbents)

- Existing unit for iron and arsenic removal – 18 m^3/h
- Uses iron oxyhydroxide (new generation of adsorbents)
- Input arsenic concentration: 168 ppb
- Output arsenic concentration: 2 ppb


Completed 3 years maintenance (stipulated: 2 years)
for 330 bamboo unit project in Nadia, WB
03471-250221
Minimum uptime: 91%, Maximum: 98%
Only 4/330 have reported arsenic above 10 ppb
Benefiting over 100,000 children and villagers
Glimpse of Installed units (330 nos)

Implementation - From 25 KLD to 1 MLD

Large water supply schemes

Capacity: above 1 MLD

5 schemes in use across India

Retrofitted Water Purification Plant

Capacity: 0.1-1 MLD

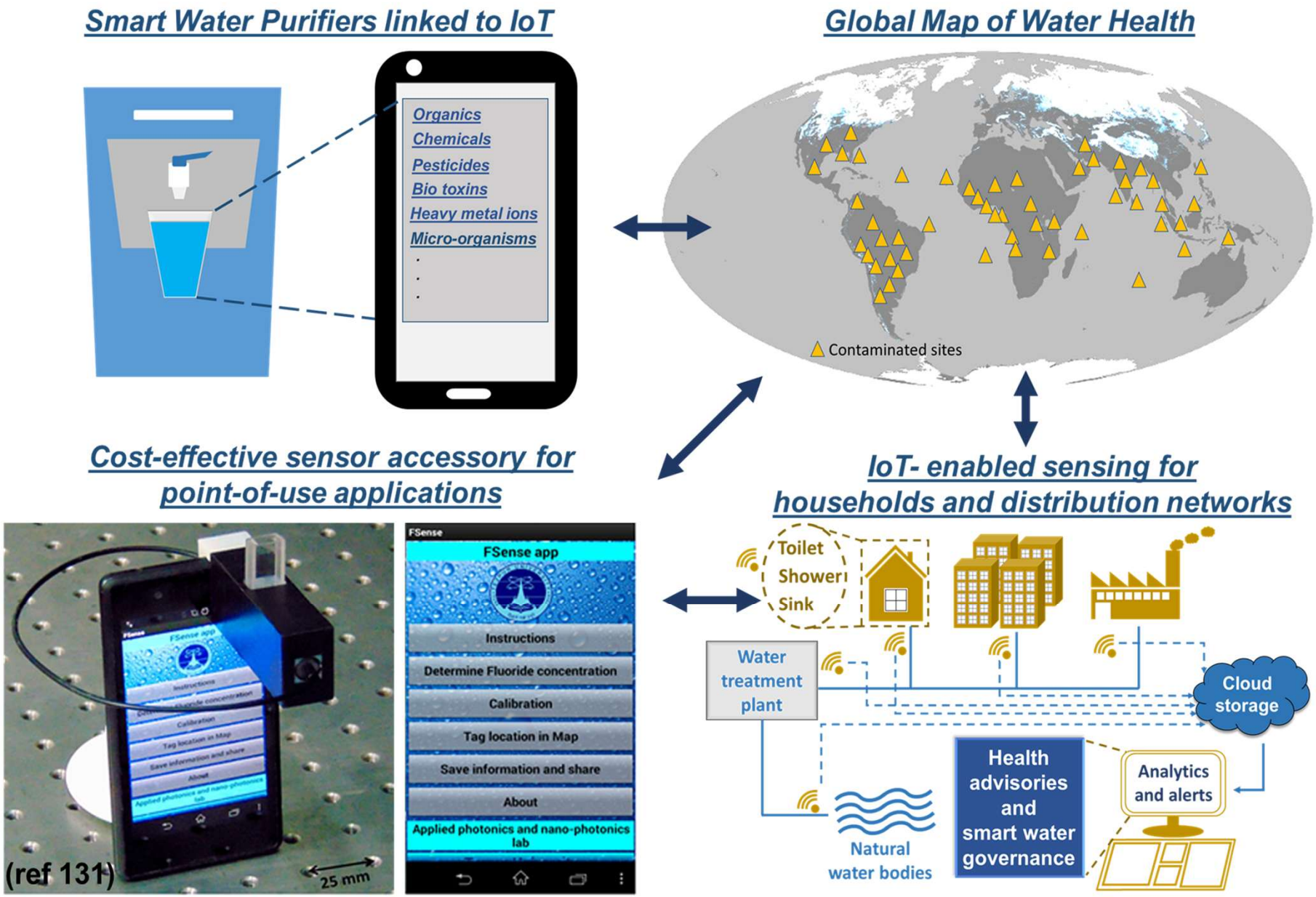
Over 180 units in use across India

Cleanwater at 2.1 paise per litre!

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

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

Smart water purifiers and big data



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

Waste management

Adsorbents conform to toxicity characteristic leaching procedure

Elemental waste goes back to local environment

Safe disposal of arsenic (or any other) laden waste

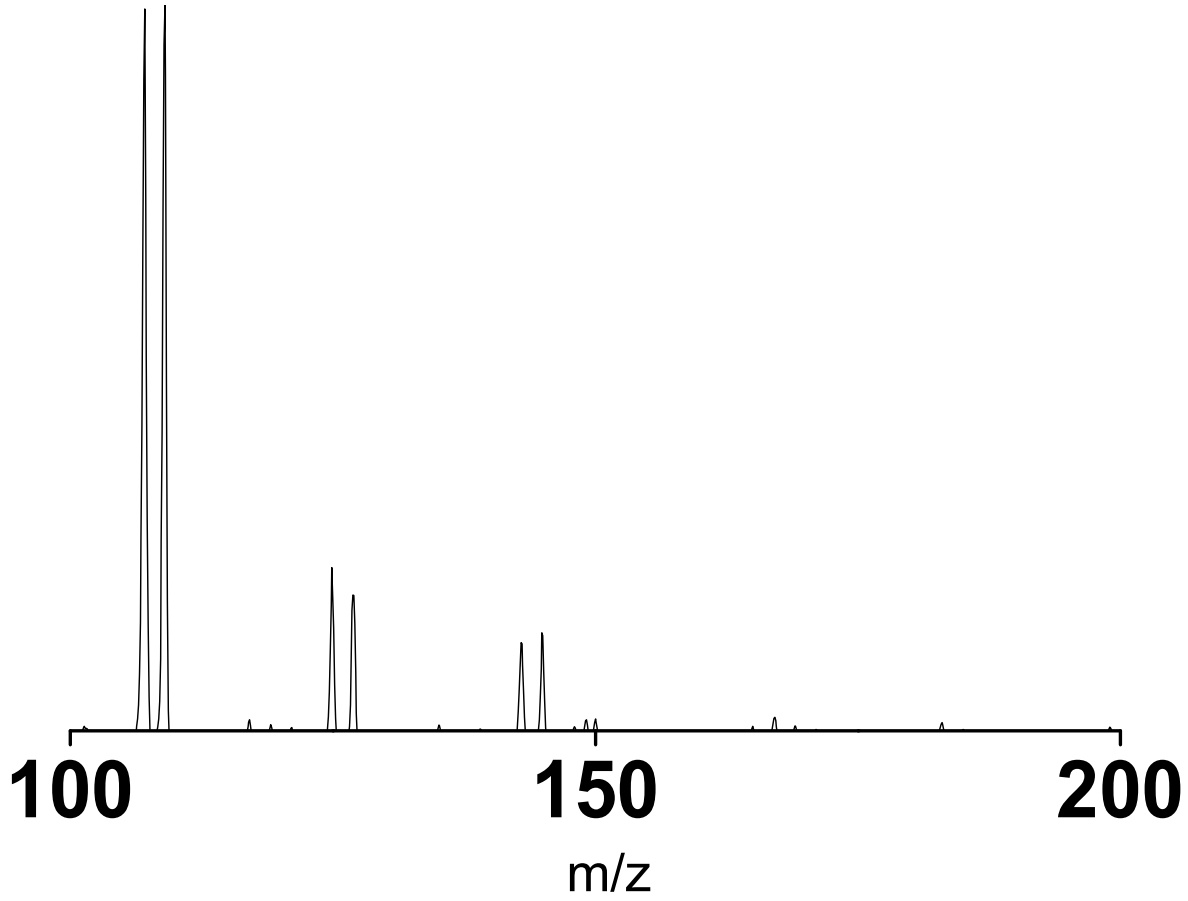
Additional protection could be considered, if necessary

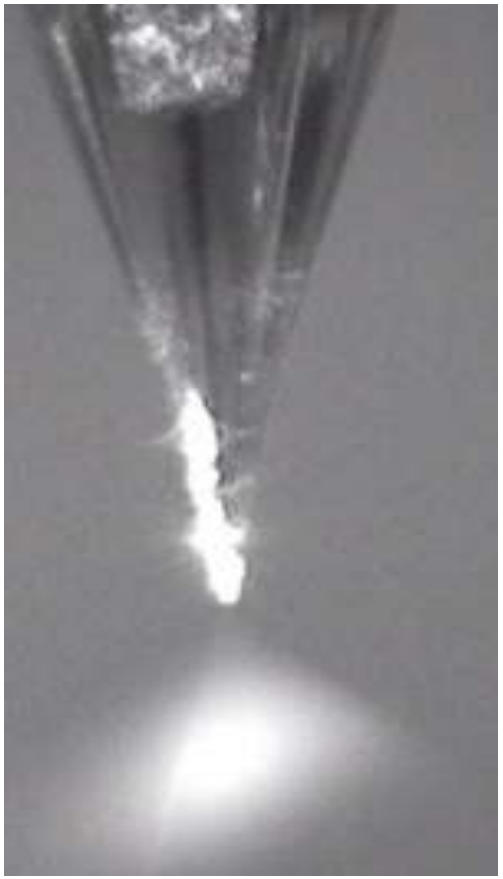
Exploring viable uses

A sample of new installations

Across the country

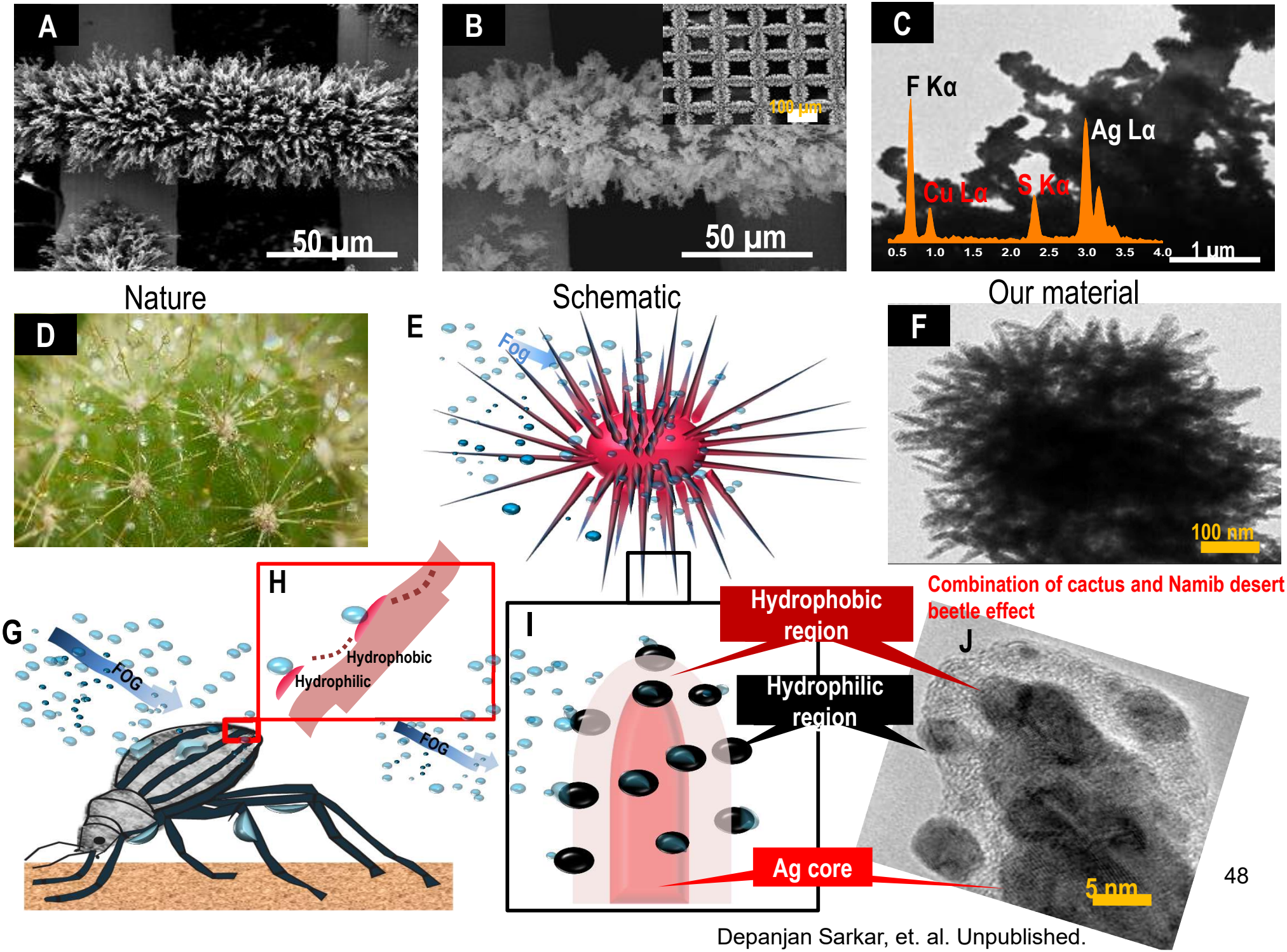
Atmospheric water harvesting



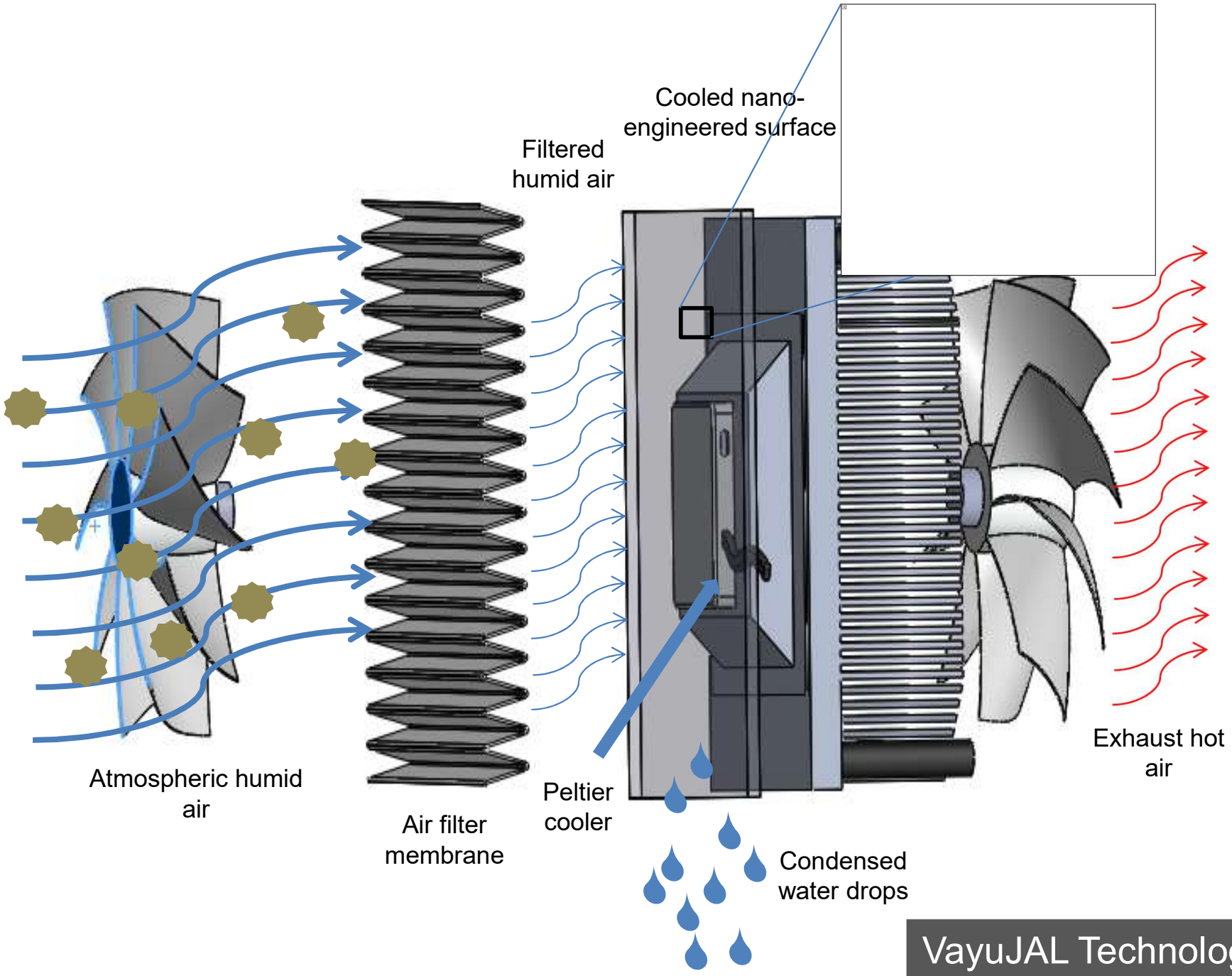


New harvesters

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



Depanjan Sarkar, et. al. Unpublished.

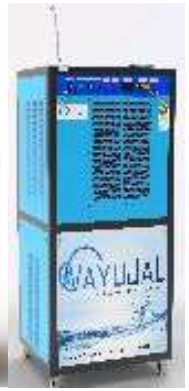


VayuJAL Technologies Pvt. Ltd.

Ramesh Kumar Soni and Ankit Nagar

Products in the field

35 LPD



120 LPD

400 LPD

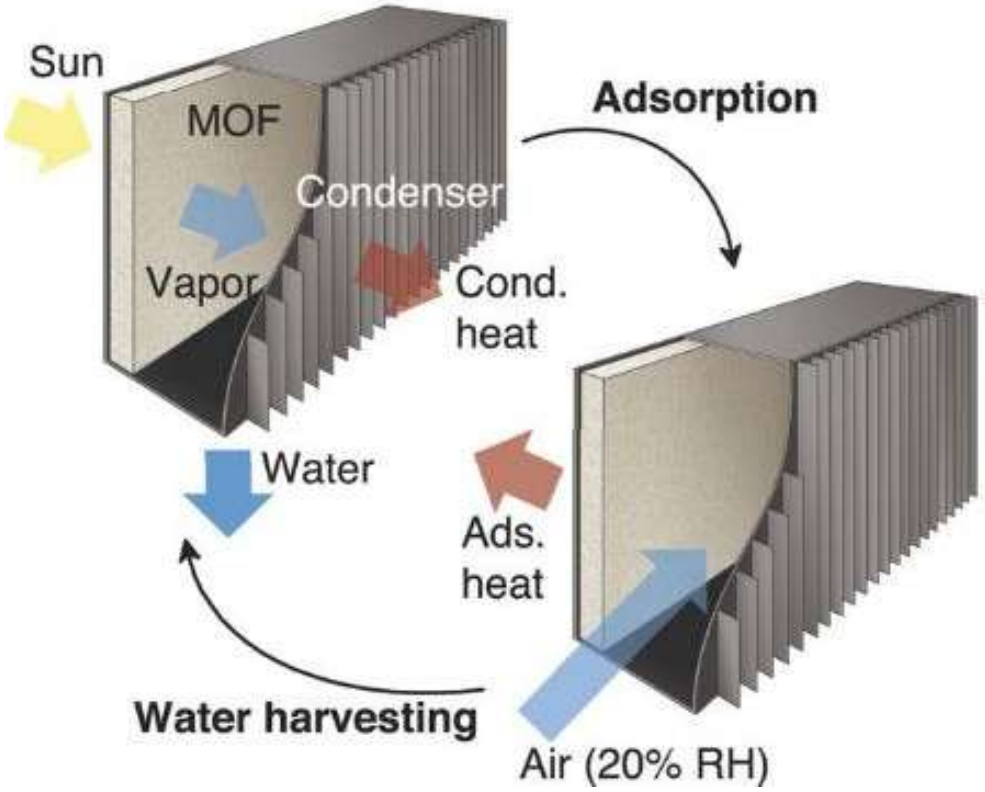
1000 LPD

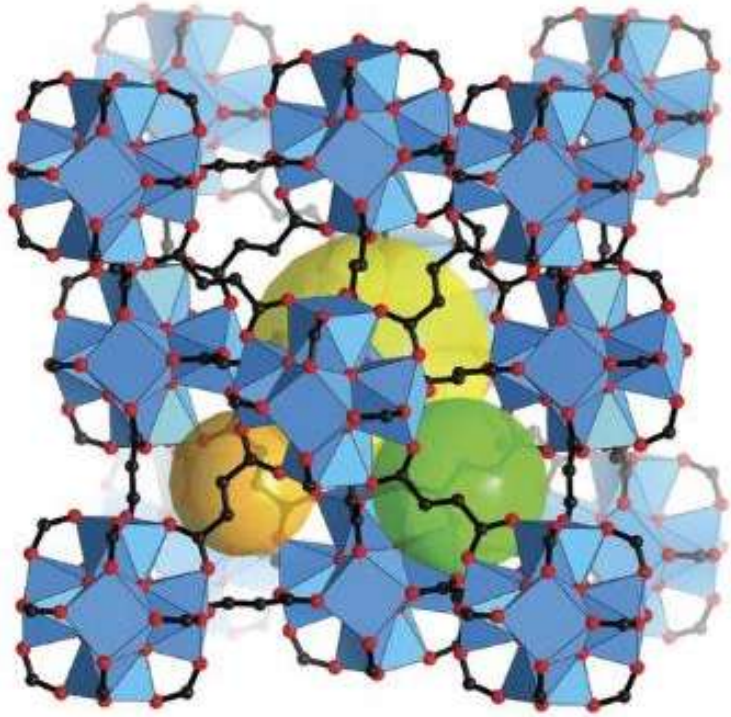
2000 LPD

(LPD: Litres per day)

Sustainable atmospheric water harvesting

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

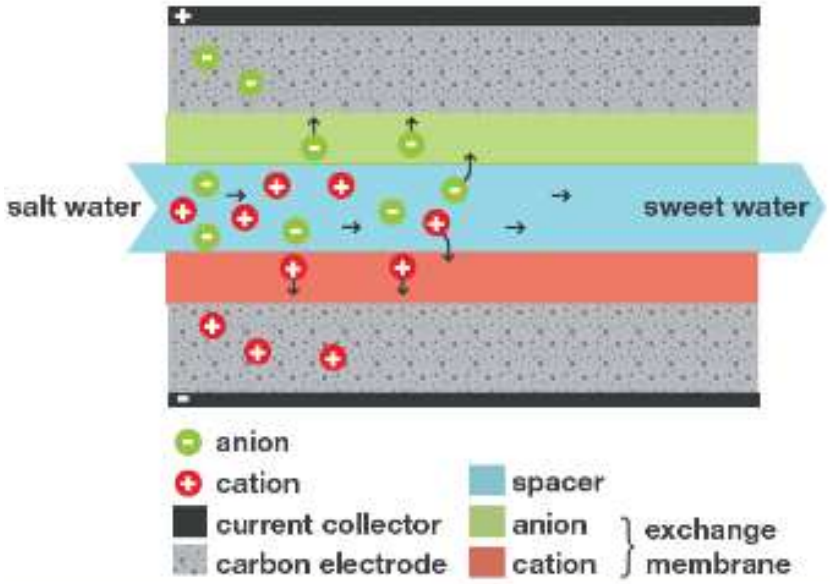


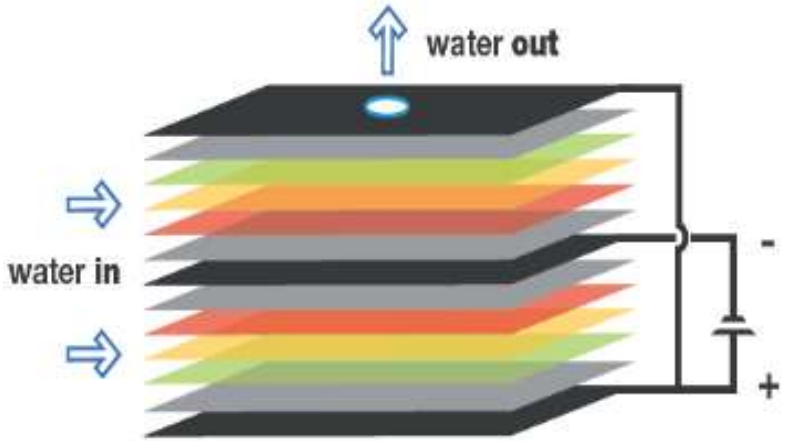


Porous metal-organic framework (MOF-801, $Zr_6O_4(OH)_4(fumarate)_6$)

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

Capacitive Desalination (CDI)

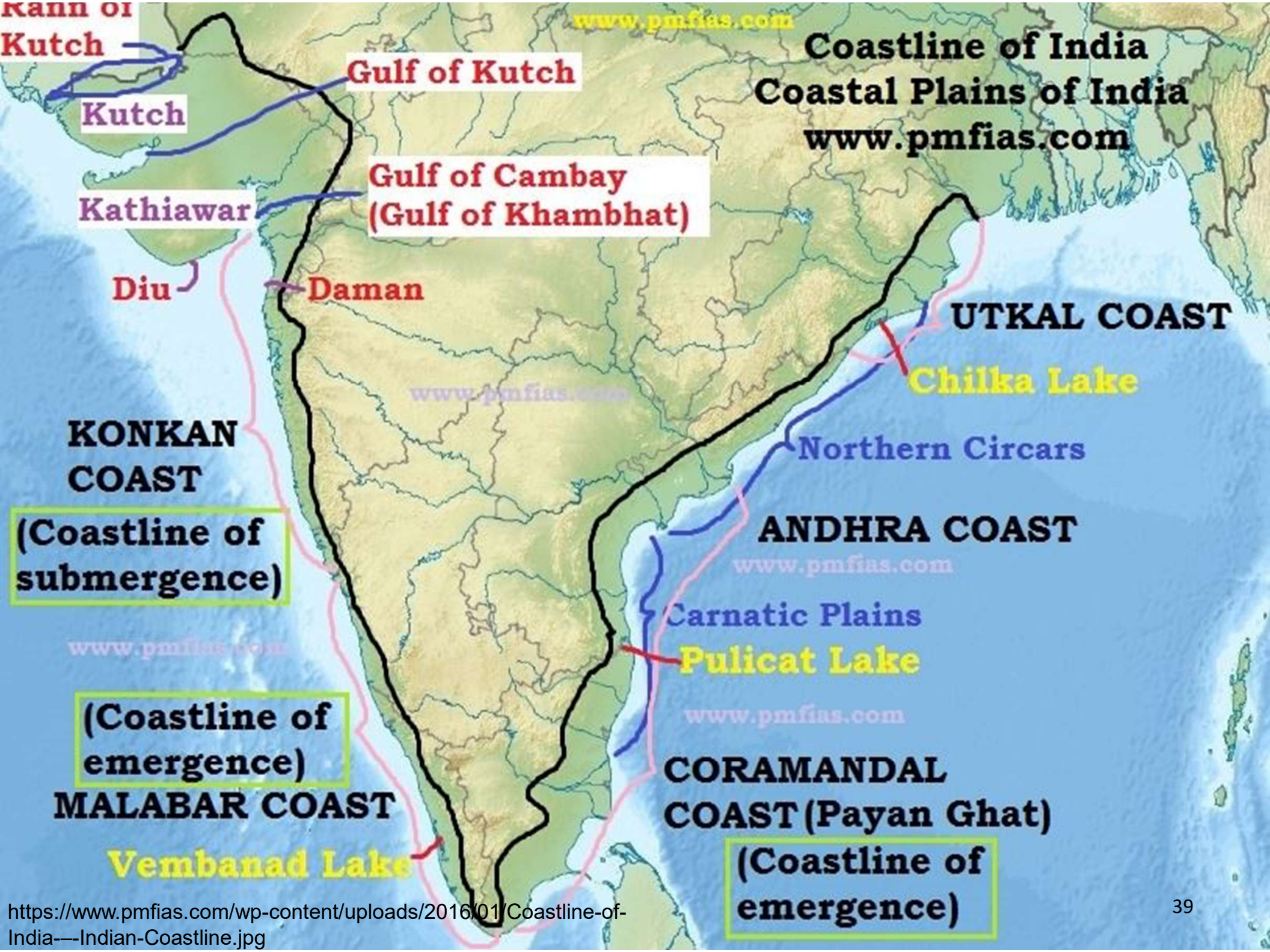




innODI

Our new company

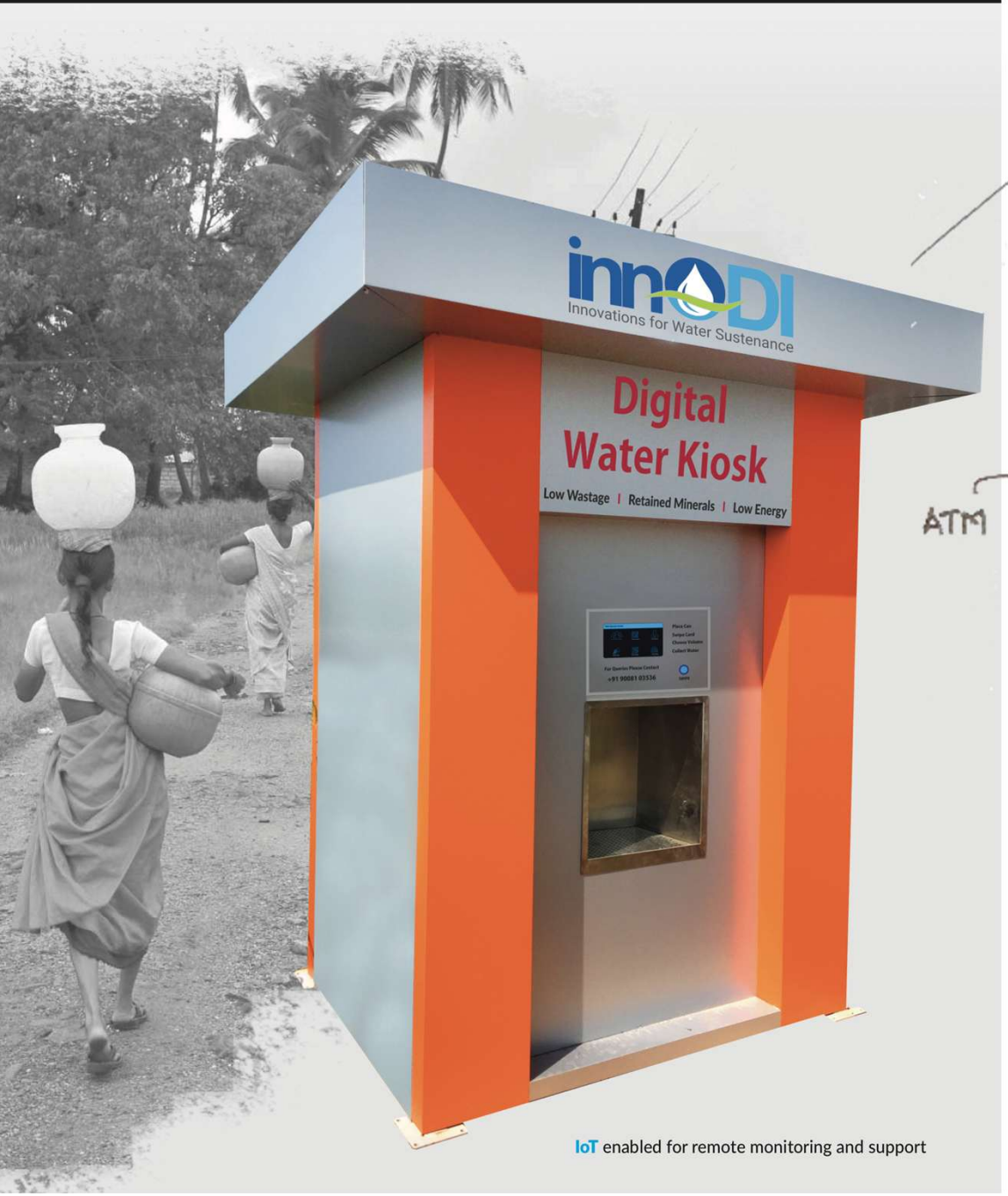
Soujit Sengupta, Rabiul Islam and others

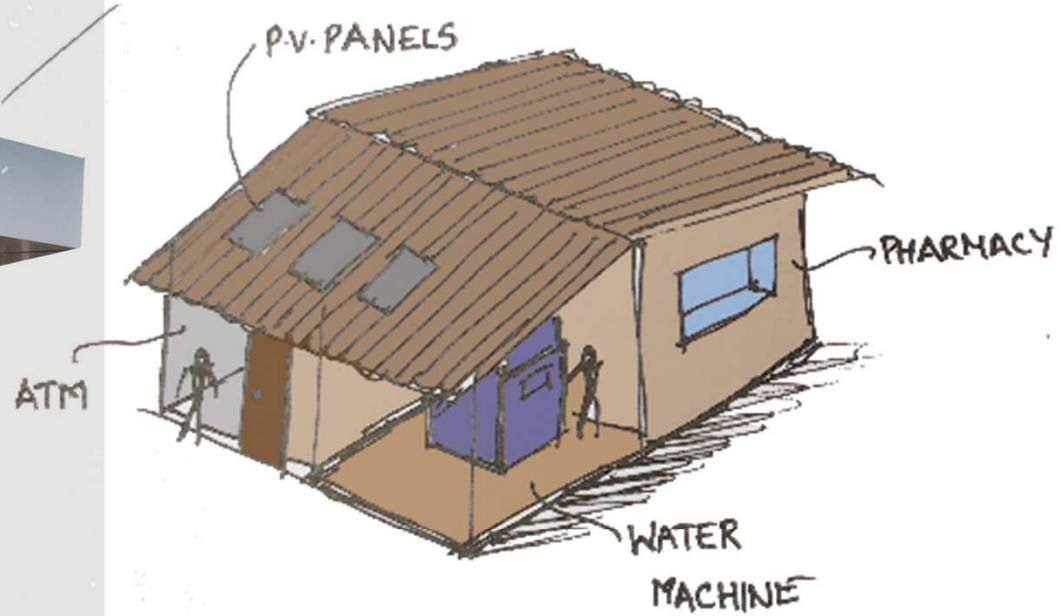


https://www.pmfias.com/wp-content/uploads/2016/01/Coastline-of-India-–-Indian-Coastline.jpg

DIGITAL WATER KIOSK

for community drinking using CDI Technology

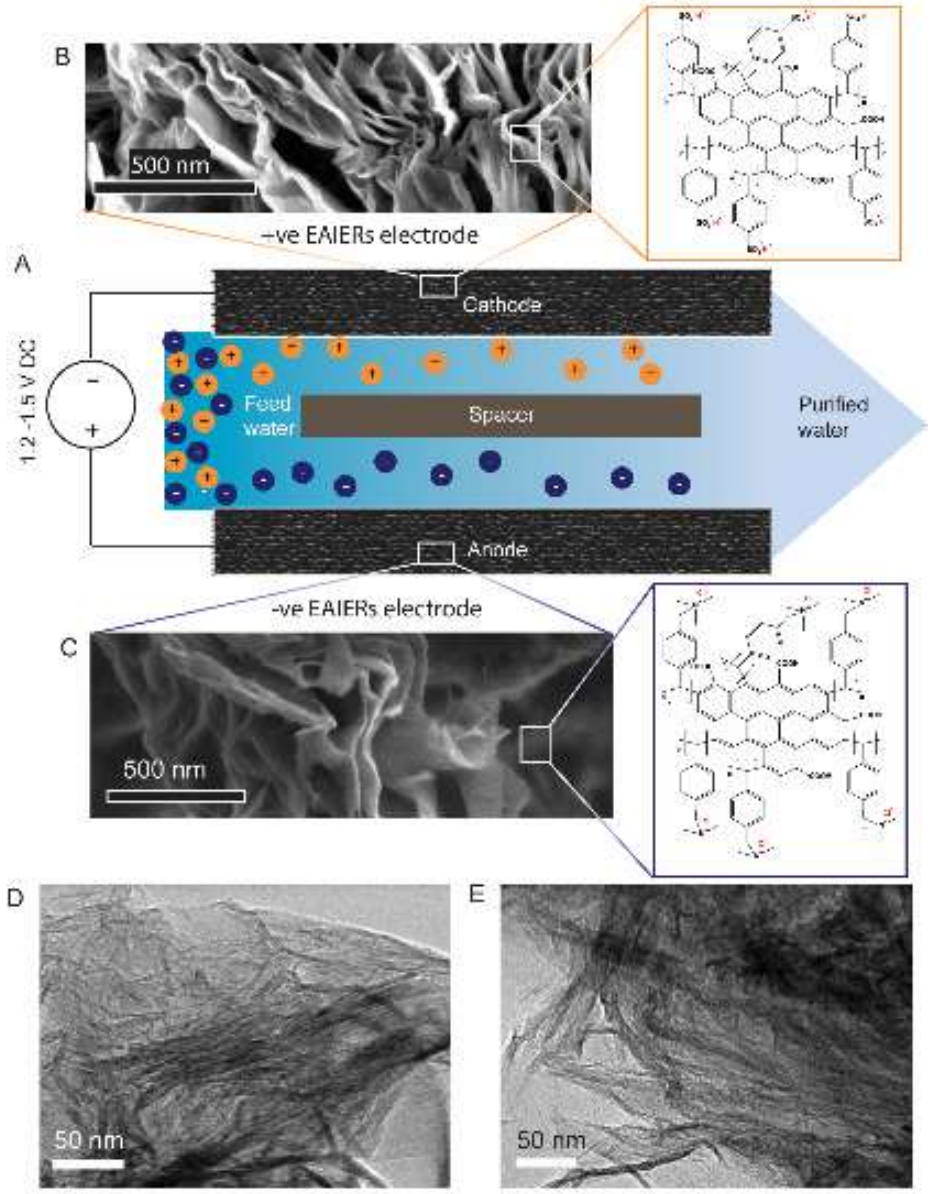




Products under implementation

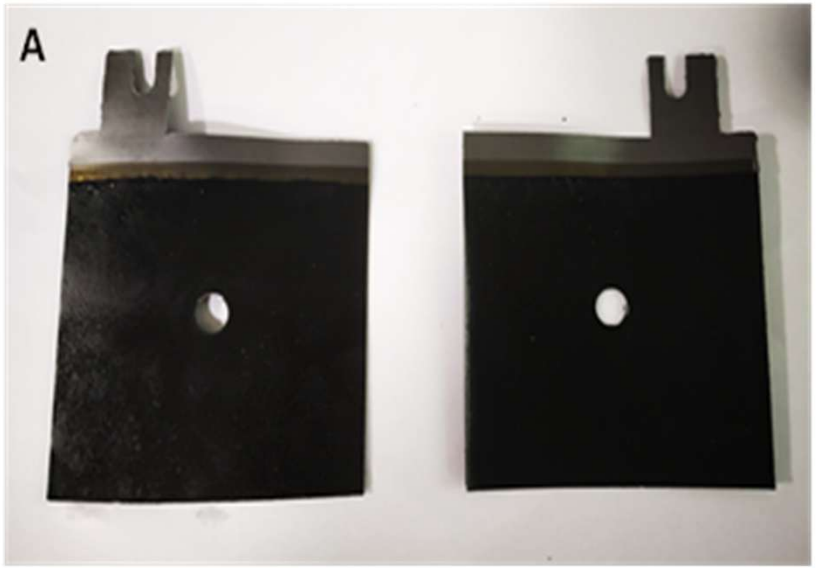
Vijay Sampath and Tullio Servida

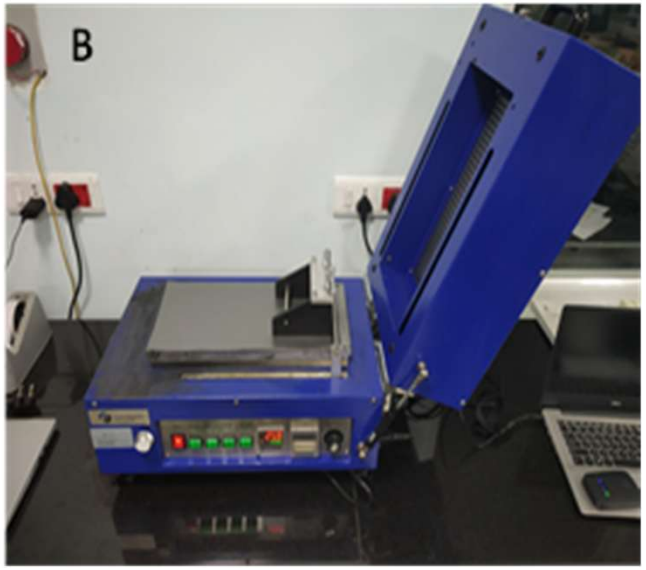
A Covalently Integrated Reduced Graphene Oxide -Ion Exchange Resin Electrode for Efficient CDI

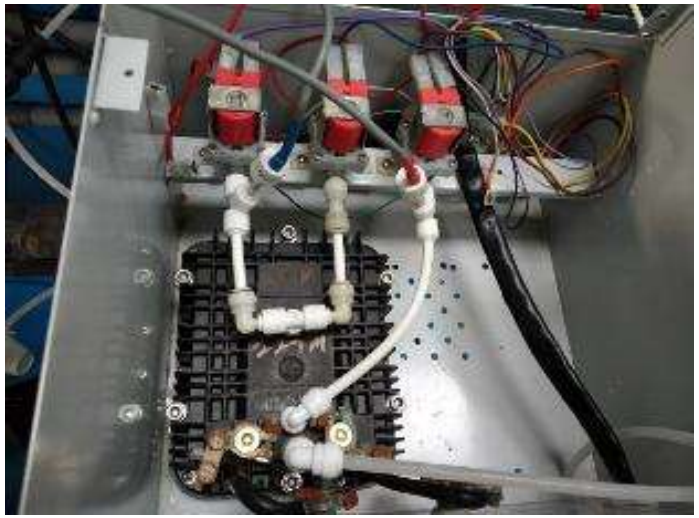


Rabiul *et al., Adv. Mater. Interfaces* **2021**, *8,* 2001998

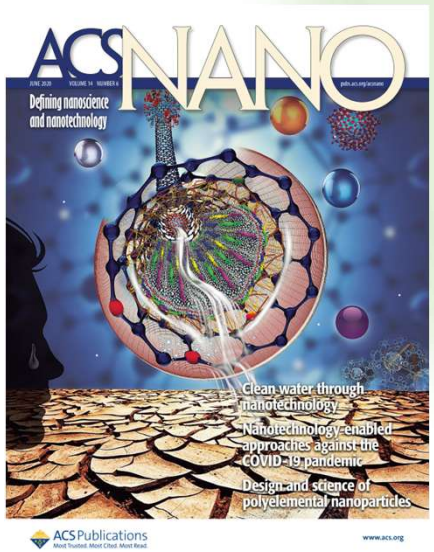
Various stages of electrode preparation

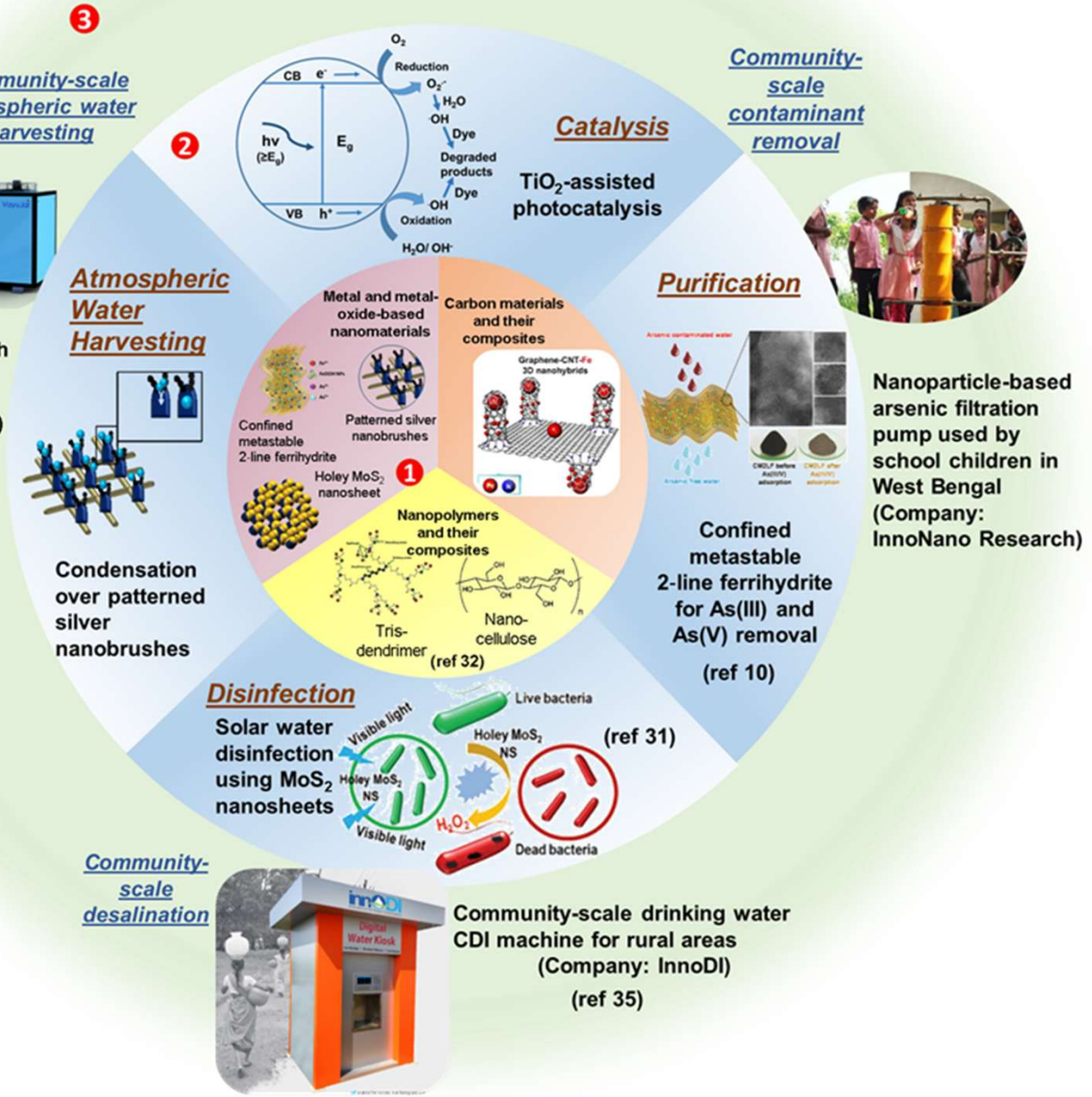






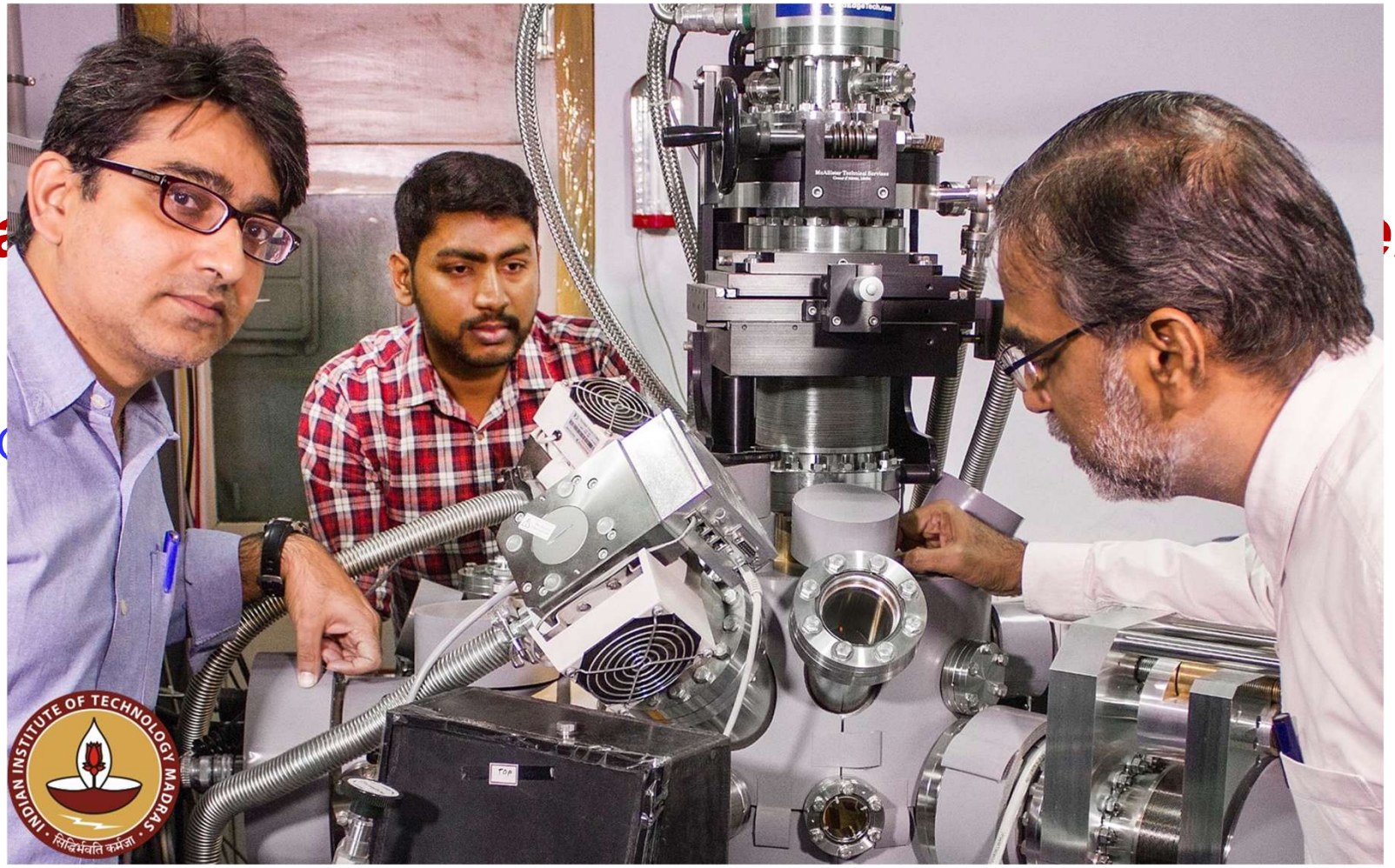
Evolution of materials to products





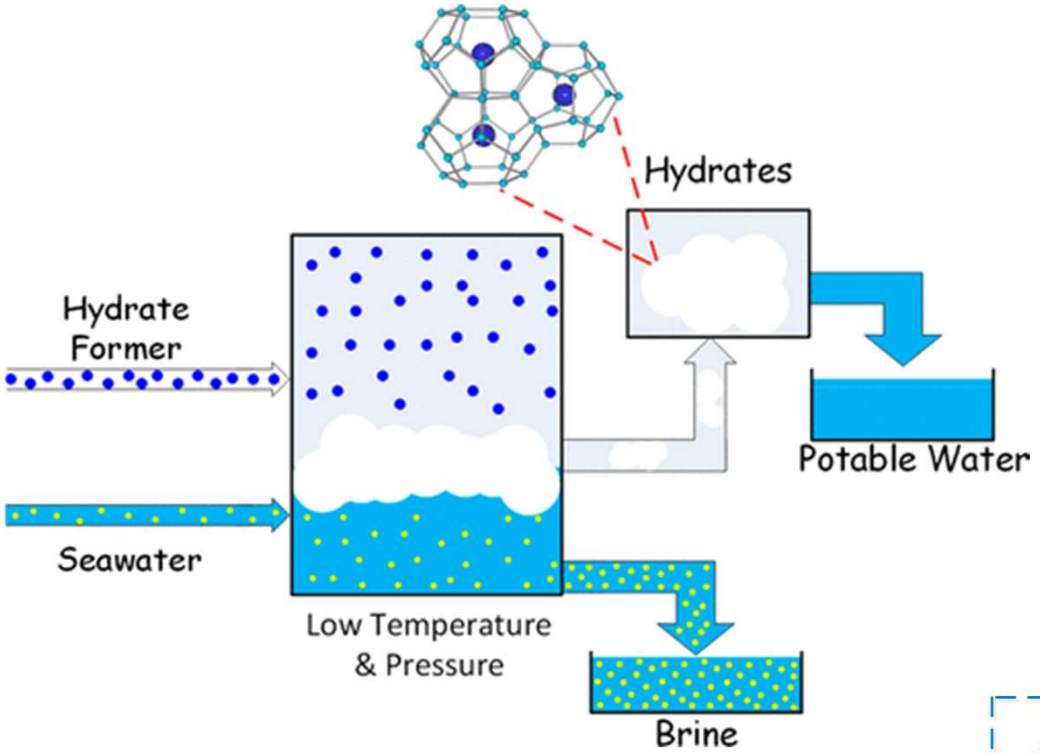
Ankit Nagar and T. Pradeep 14(2020). *ACS Nano*, 6420-6435

New phenomena



With Rajnish Kumar

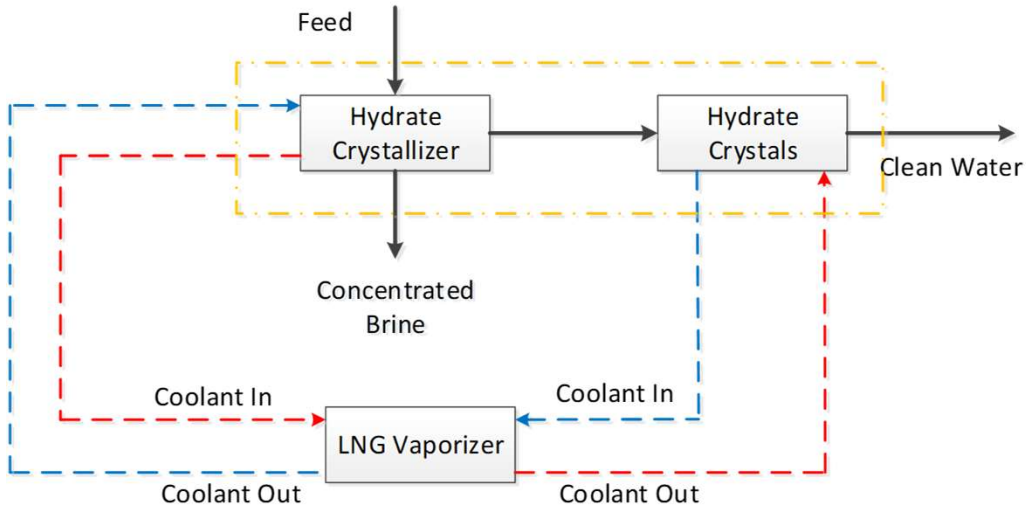
Hydrate-based desalination (HyDesal)



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

Water dissociated from hydrate is pure

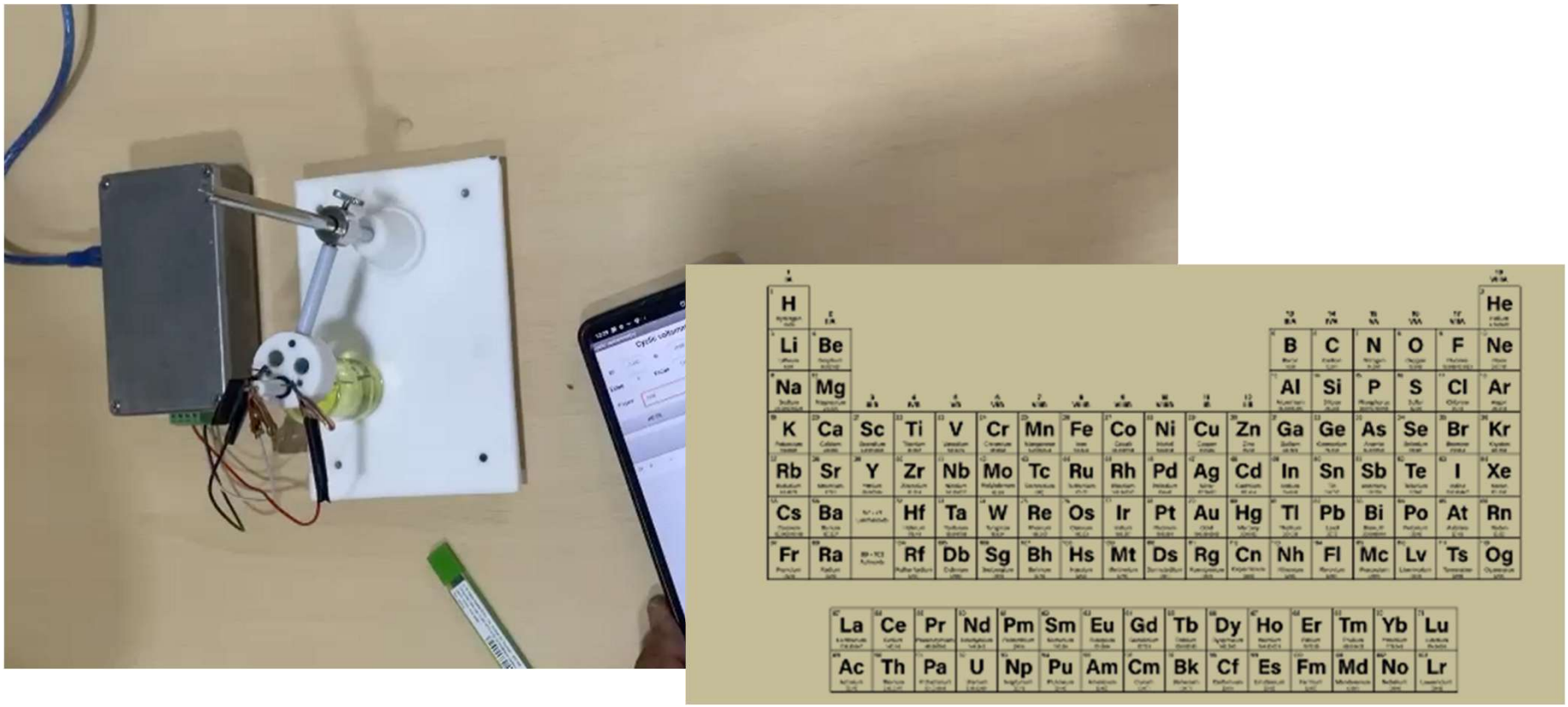


Cold Energy in LNG terminals can be harvested to produce water

Babu et al. ACS Sustainable Chemistry and Engineering (2018), 6 (7), 8093-8107

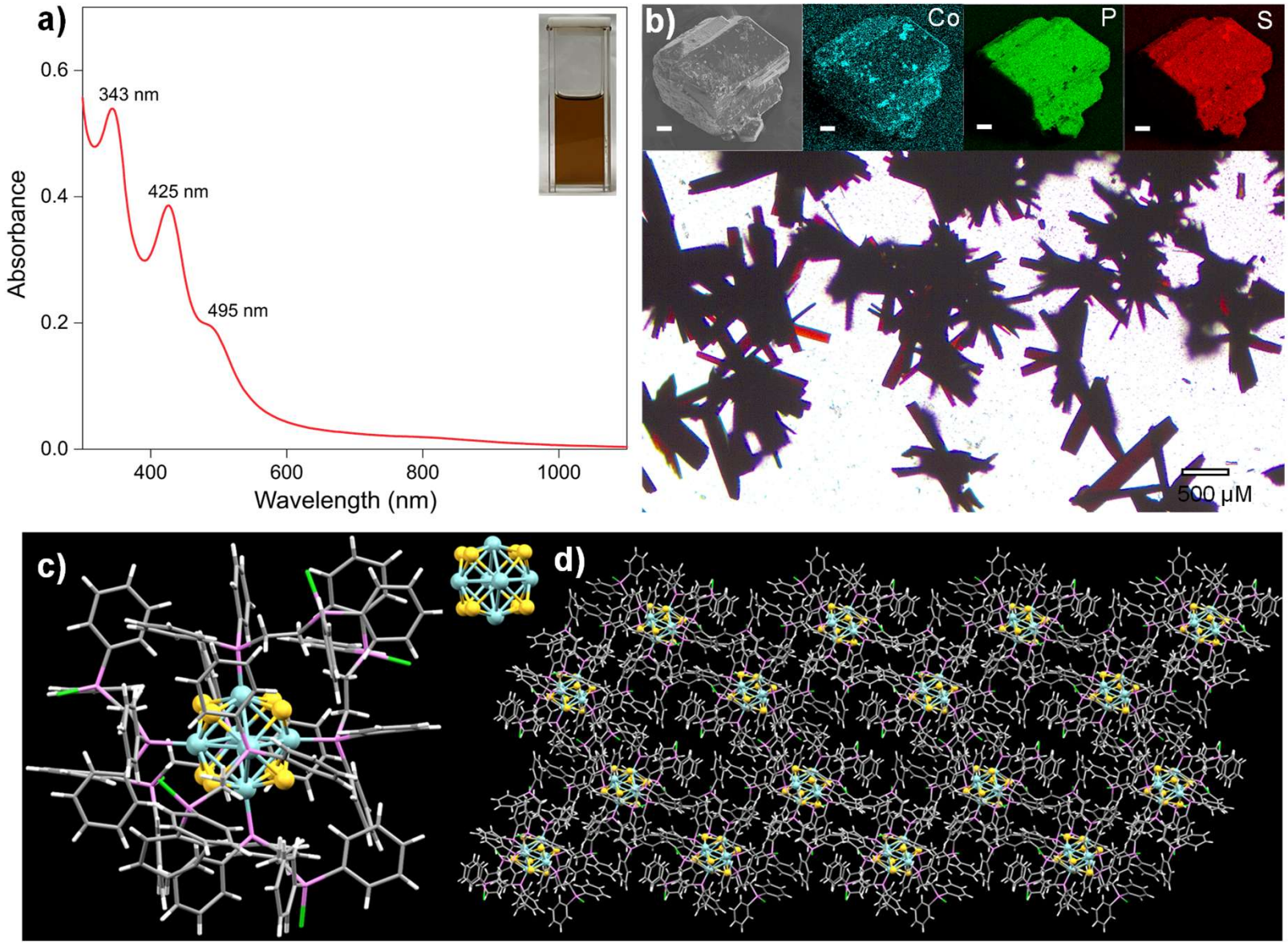
Slide from Prof. Praveen Linga, NUS

Sensors and analytical devices



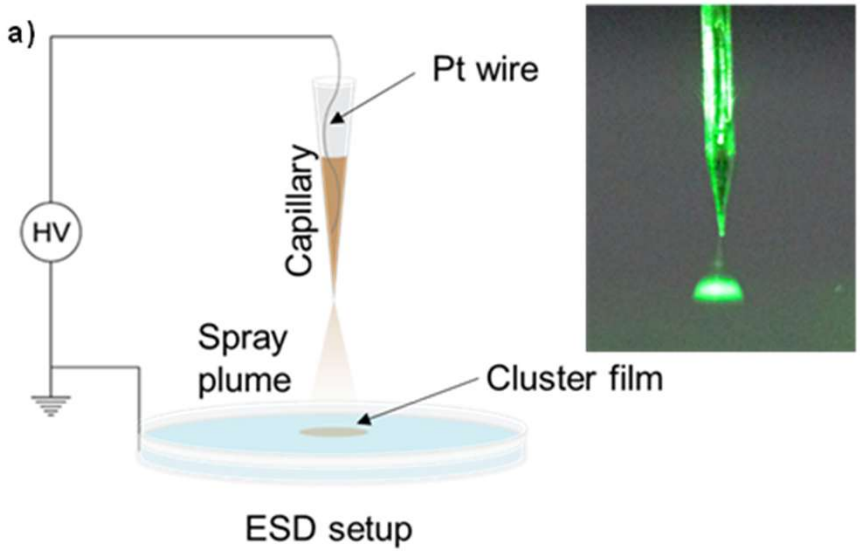
Sourav Kanti Jana

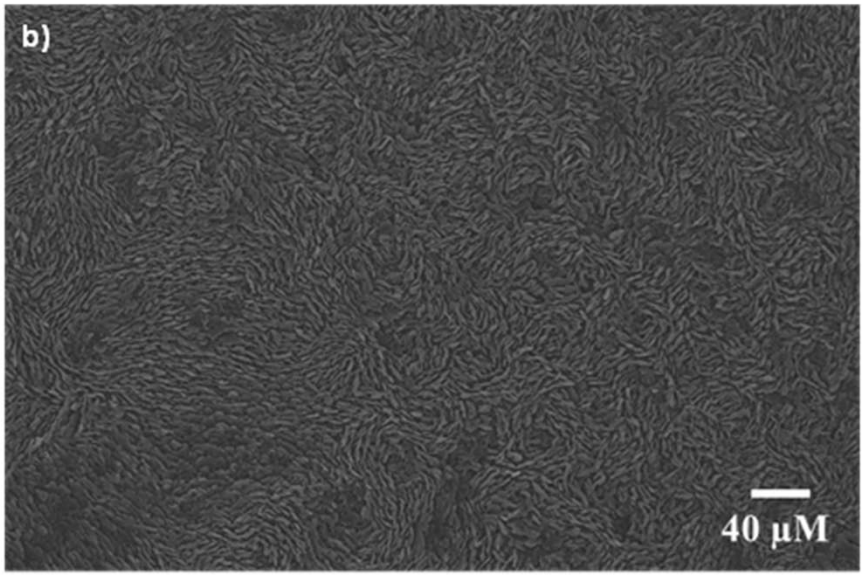
New electrodes - Aligned nanoplates

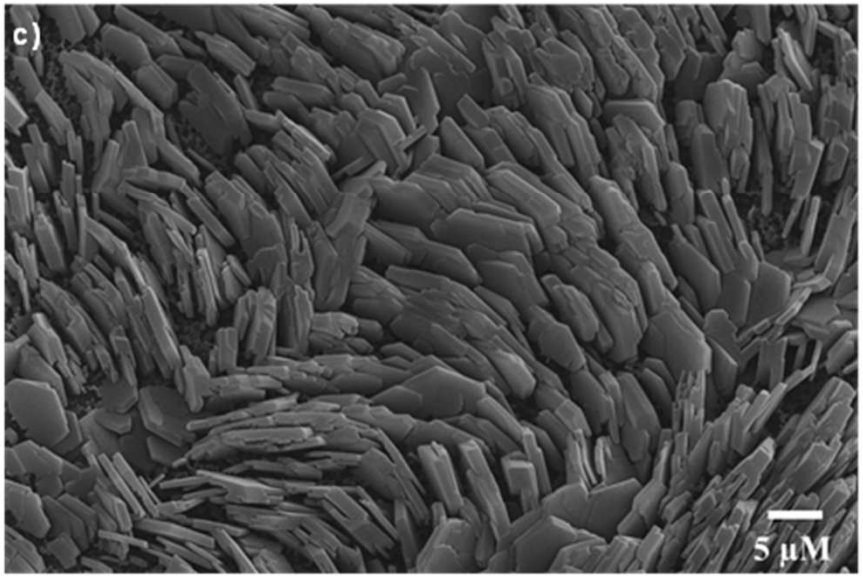


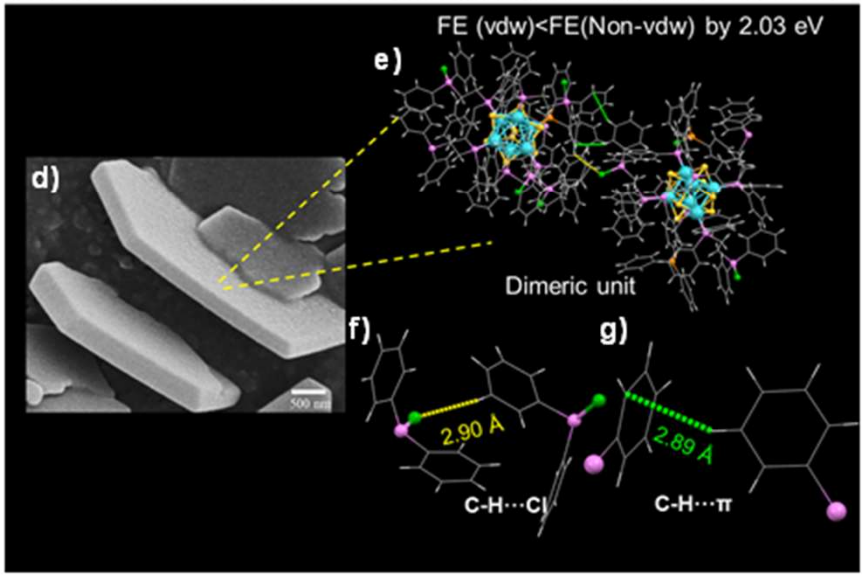
Anagha Jose et al, 2022 (unpublished)

Electrospray deposition

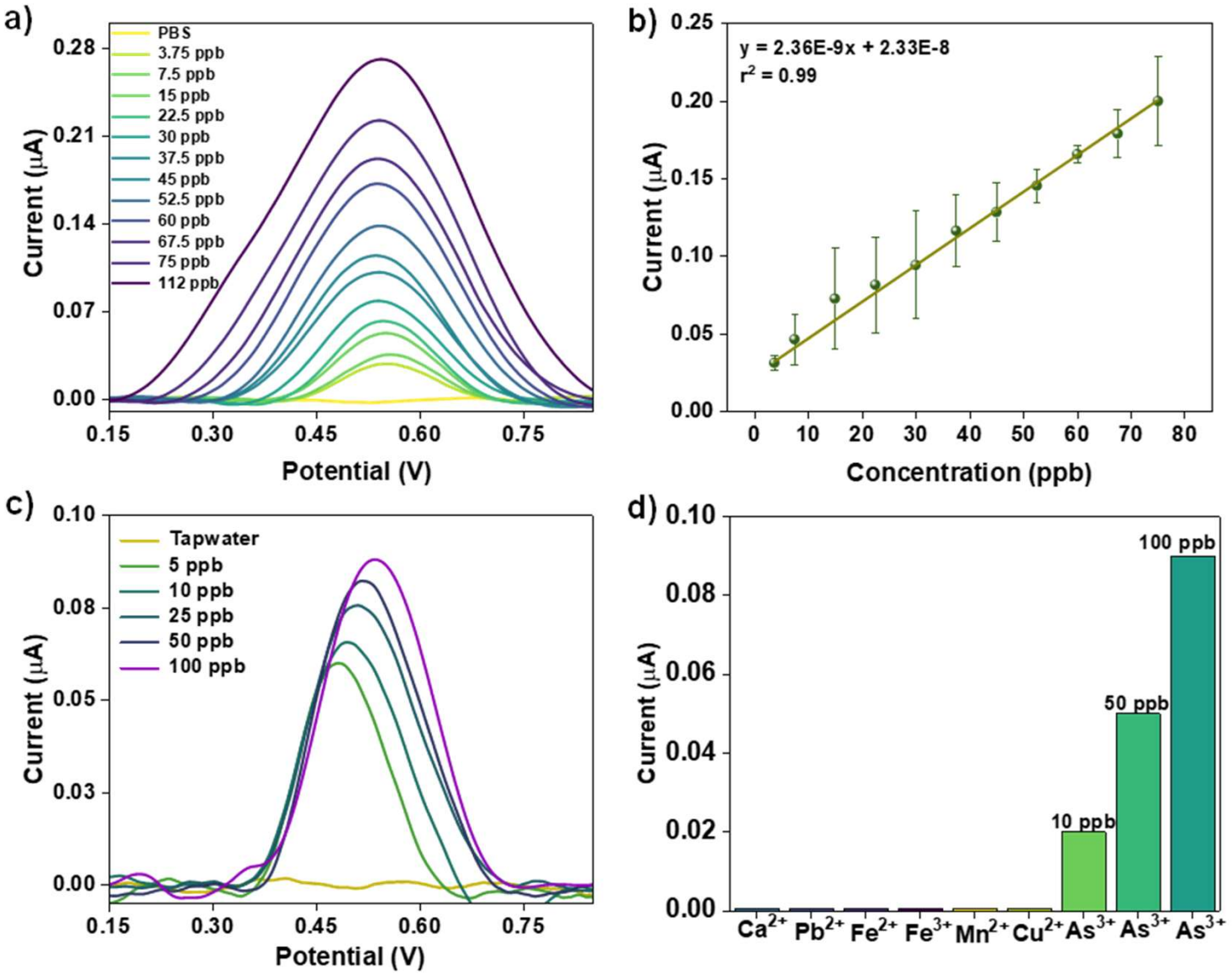








Sensing

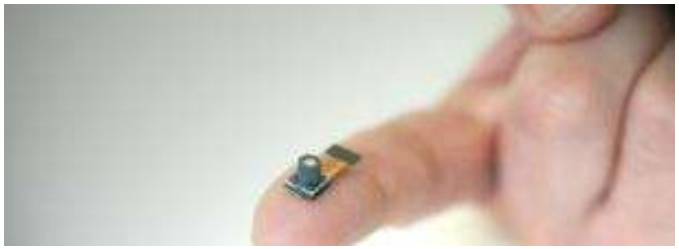


Anagha Jose et al, 2022 Patent filed

Sensors and new opportunities

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

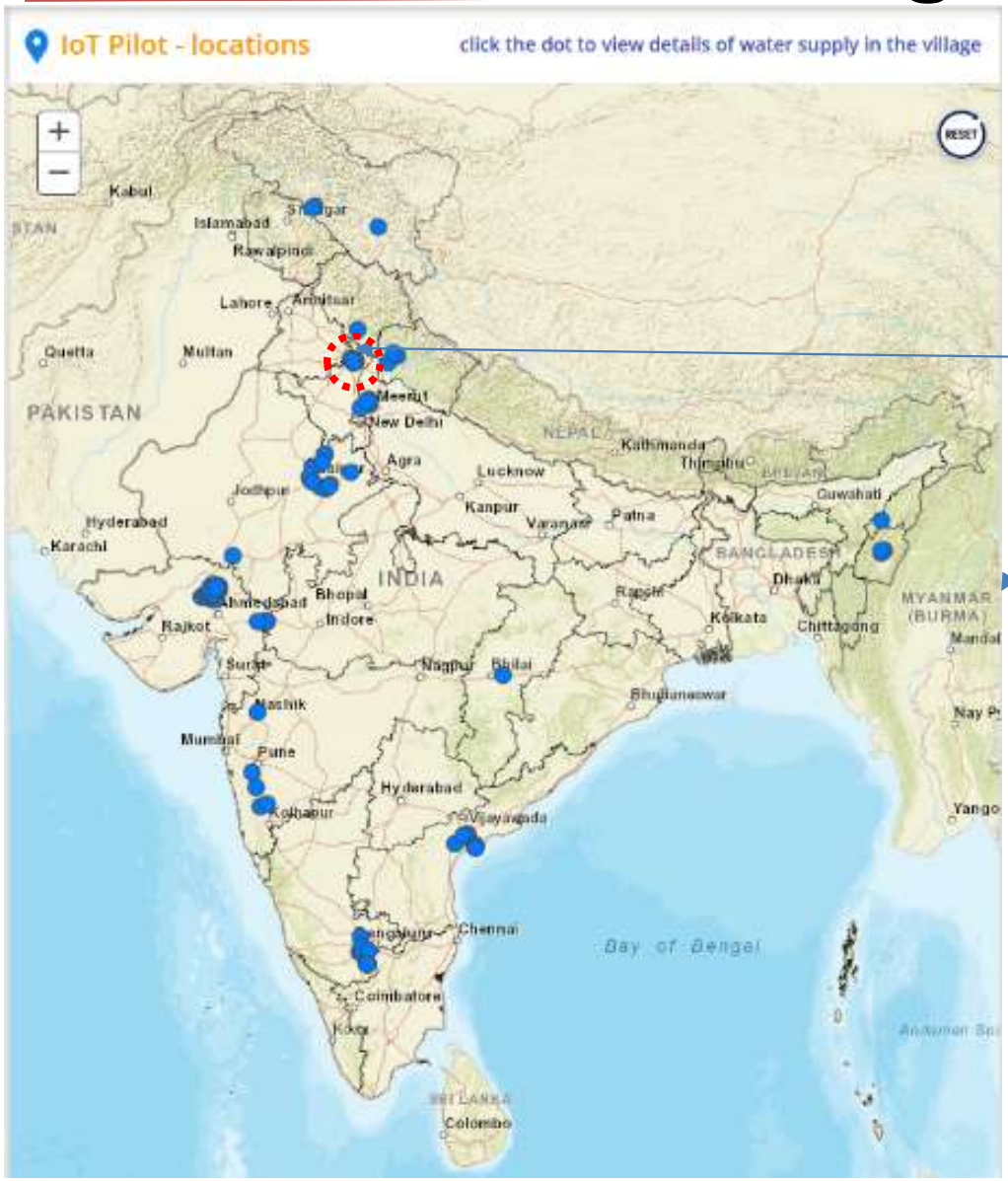
Ultra compact Low Cost
Spectral Sensor Module
~ Billions units (? 2027)



Water quality measurement – In the pipeline

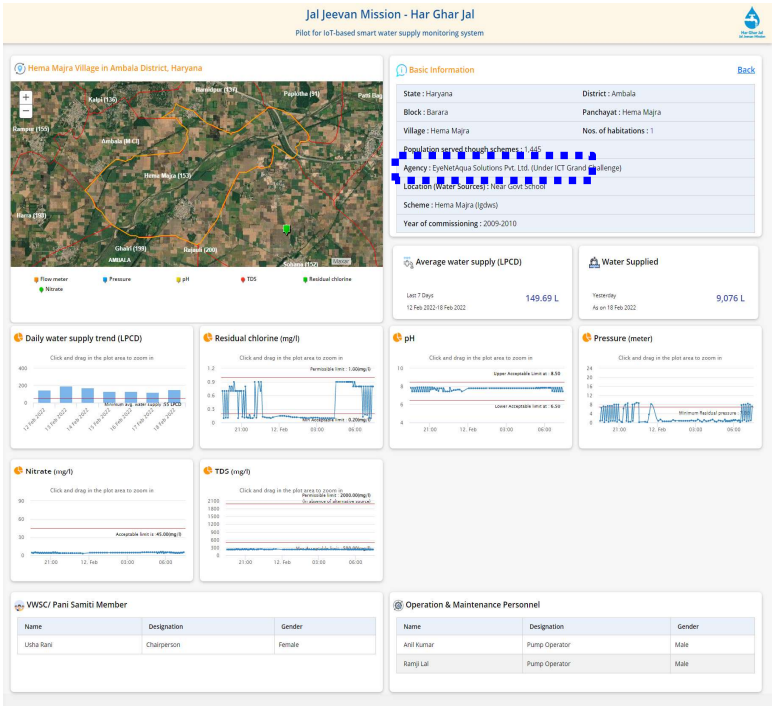
nanoλ

India’s water is being monitored



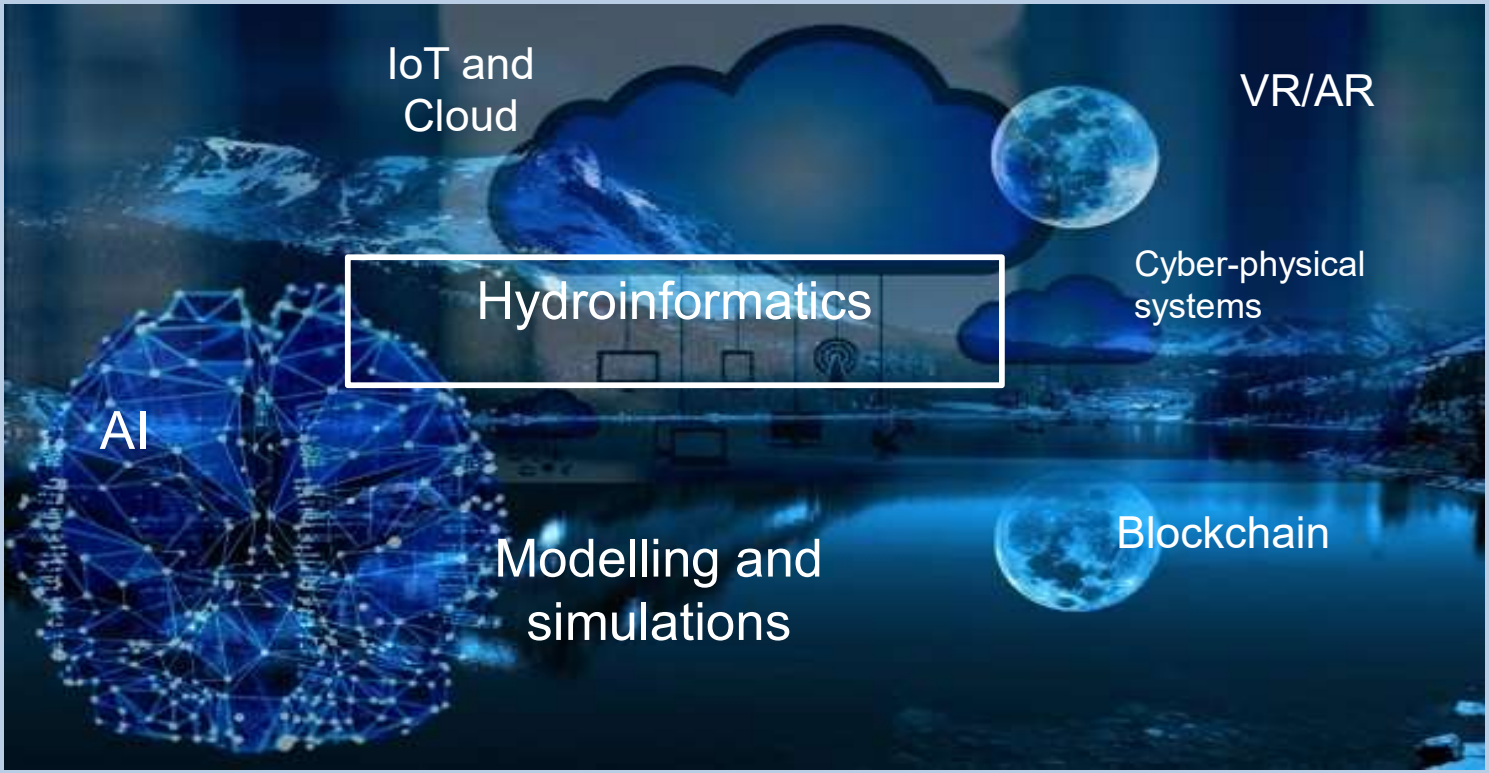
IITM/IISc

Installations made by four companies



Hydroinformatics

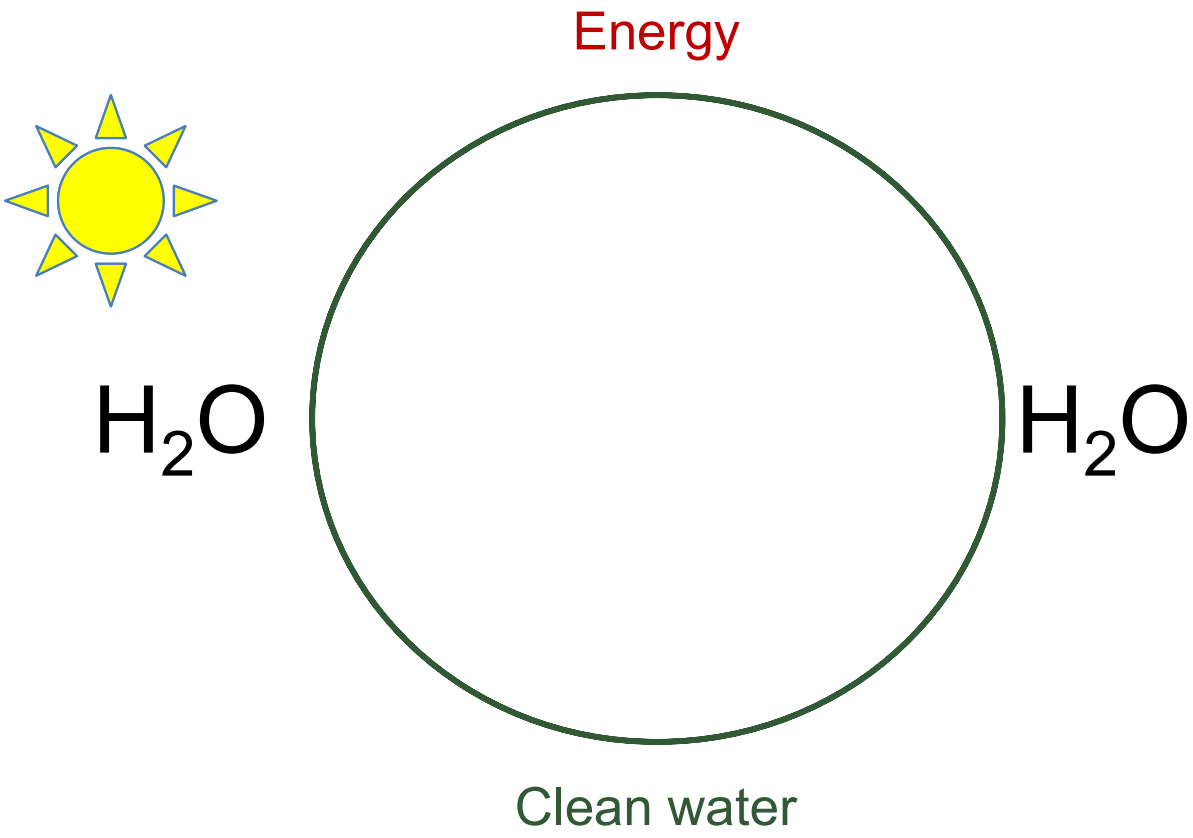
Application of computing technologies for efficient, sustainable and equitable water management.

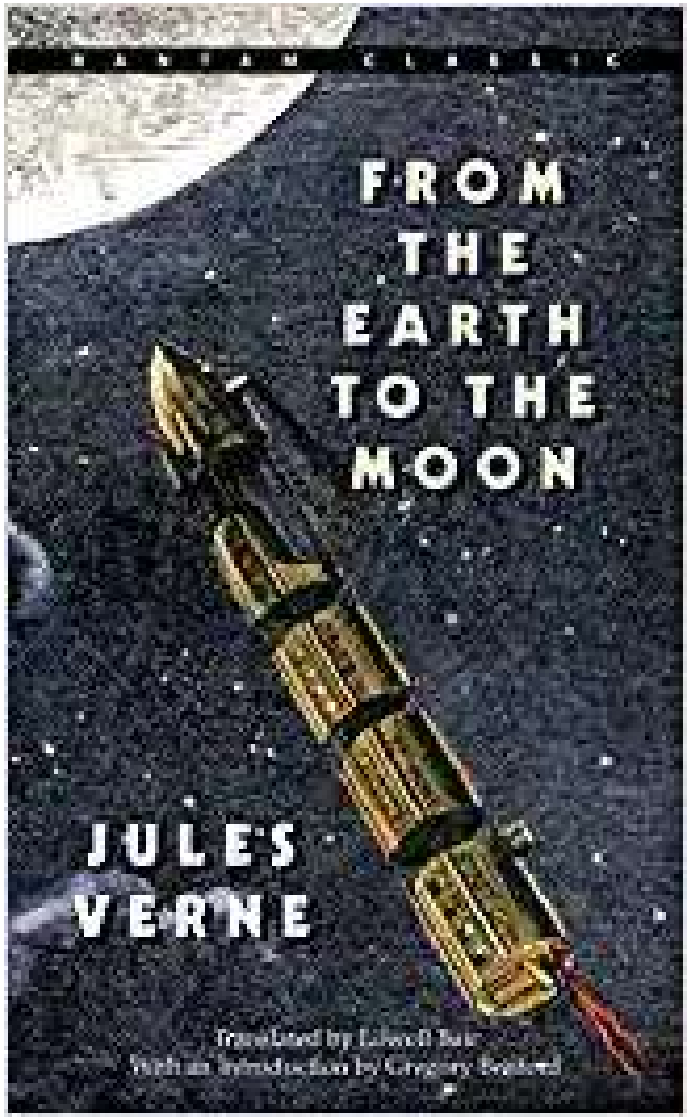


Digital water or water 4.0 will revolutionize water management.


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

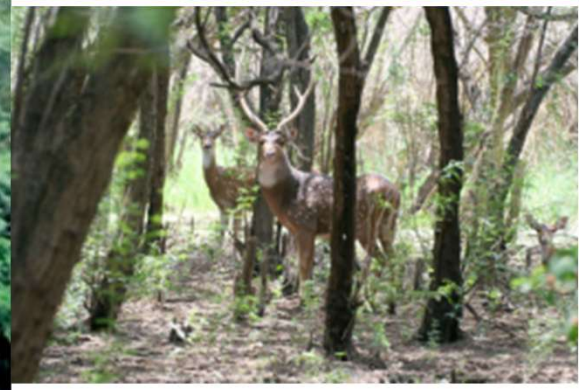
Funding: Department of Science and Technology, Government of India

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 Bhuin, 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, Esma 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



Bhaskar Ramamurthi/V. Kamakoti

Associate Editor

ACS Sustainable Chemistry & Engineering

RESEARCH GROUP

THEMATIC UNIT OF EXCELLENCE

Thank you all