pendence. As reported by Dehmer and Dehmer,[4] a strong pressure dependence was exhibited by peak 5. Below a stagnation pressure of 100 Torr, no dimer features were visible at a nozzle temperature of 300 K. The features due to the dimer increased in intensity up to a stagnation pressure of 800 Torr. Above this pressure, higher clusters were also observed. A gradual increase in the intensity below the appearance energy of the dimer is attributed to the presence of heavier clusters. The evolution of the spectra was studied both by increasing the stagnation pressure and by decreasing the nozzle temperature. As the pressure increased above 800 Torr, the appearance energy kept decreasing. However, the dimer features, particularly peak 5, were still visible. The evolution of the spectra did not suggest the presence of ionization chromophores unlike tha

ational structure of two of the electronic states of Ar_2 has been resolved. For the ate, as many as 14 vibrational excitations are observed. These excitations are assransitions to the higher vibrational levels of $v=32$–45. For the $B\,^2\Pi_{3/2g}$ state, three structures are resolved and are assigned to $v=2$–4 of the ionic state. Accurate he spectroscopic constants of these states are presented. The present values are with the values available in the literature. The D_e values for the $A\,^2\Sigma^+_{1/2u}$ and the ates are estimated to be 1.361 and 0.104 eV, respectively.

I. INTRODUCTION

Dissociation energies of rare gas dimers are much smaller than ambient thermal energy and consequently equilibrium methods are not adequate to study them. Since the development of molecular beam methods, there have been numerous attempts to study a variety of properties of these fascinating species. Part of the interest of late was due to the possible use of these molecules in vacuum ultraviolet lasers. In fact, rare gas dimers are the most studied class of van der Waals molecules. Electronic structure of these species have been studied both by theory[1–3] and by experiment.[4–10] The neutral dimers have a weak van der Waals

observed and found to be weakly bound. This was the photoelectron spectroscopic study in which all the i states were observed.

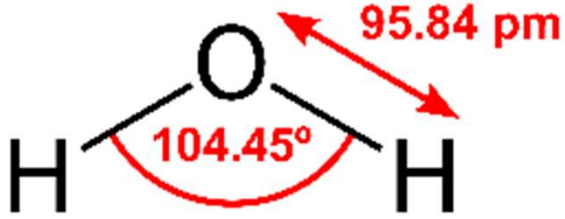
The present study of the photoelectron spectra of gas dimers was undertaken with the objectives of (1) taining the ionization energies of all the electronic st particularly, the $C\,^2\Pi_{3/2u}$ and the $B\,^2\Pi_{1/2g}$ states, w have eluded most of the previous attempts and (2) re ing the vibrational structure of at least a few more stro bound states. We have been successful in both these ol tives.

The vibrational structure of the ionic states has

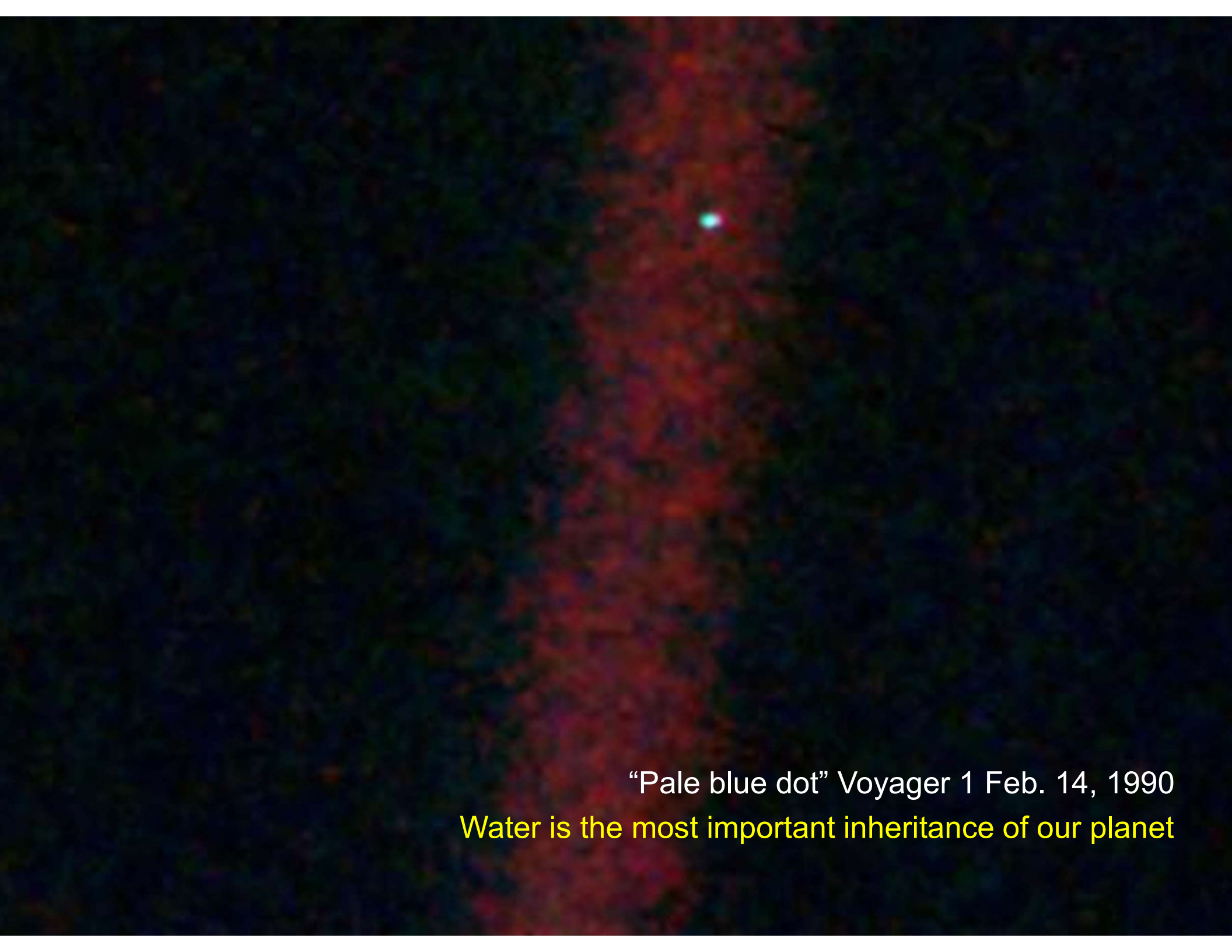
Co-founder

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.

International Centre for Clean Water



Water Desalination and Reuse Center, KAUST, March 17, 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

Variety and diversity are part of water, in problems and opportunities

Water purification, history

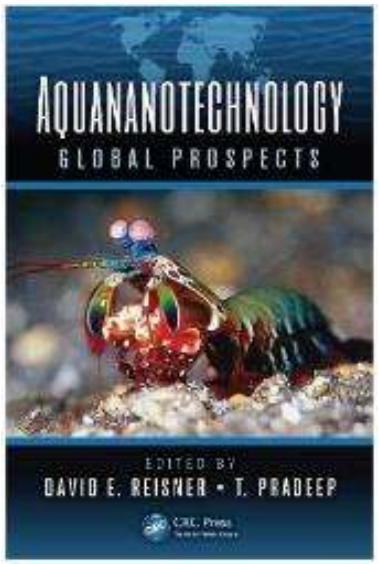
Important milestones in the history of water purification (1800–2007) from the perspective of noble metal nanoparticles in water treatment (compiled from multiple sources on the World Wide Web).

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)

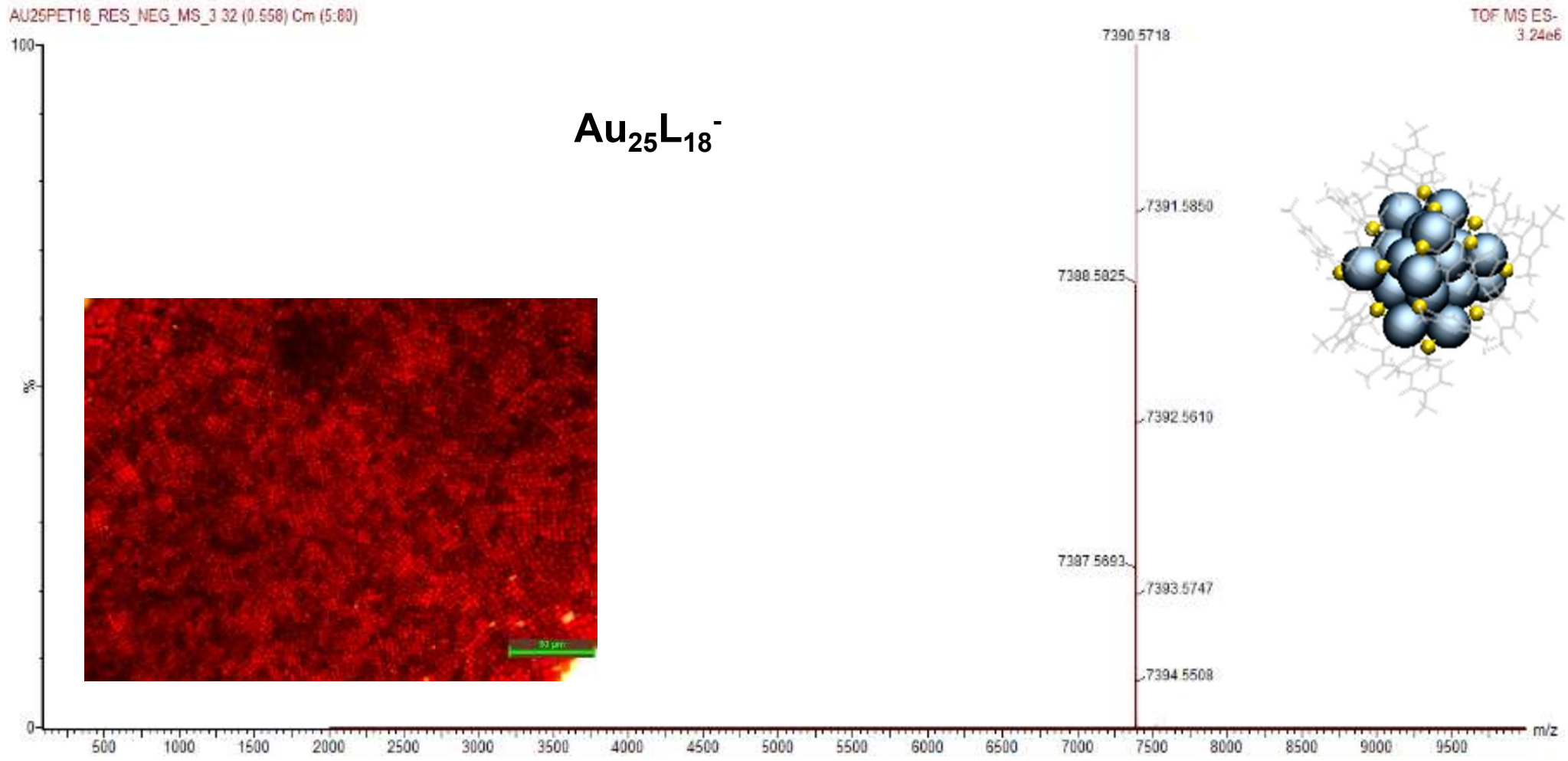
T. Pradeep and Anshup, *Thin Solid Films*, 2009

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.

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 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 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 nano-
composites to
other contami
affordable, all-
without electr
synthesis of st
uously in the
drinking wate
surfaces. Here
be synthesized
out the use of
sand-like prope
forms. These n
water purifier
ily. The ability
ambient temp
water purifica

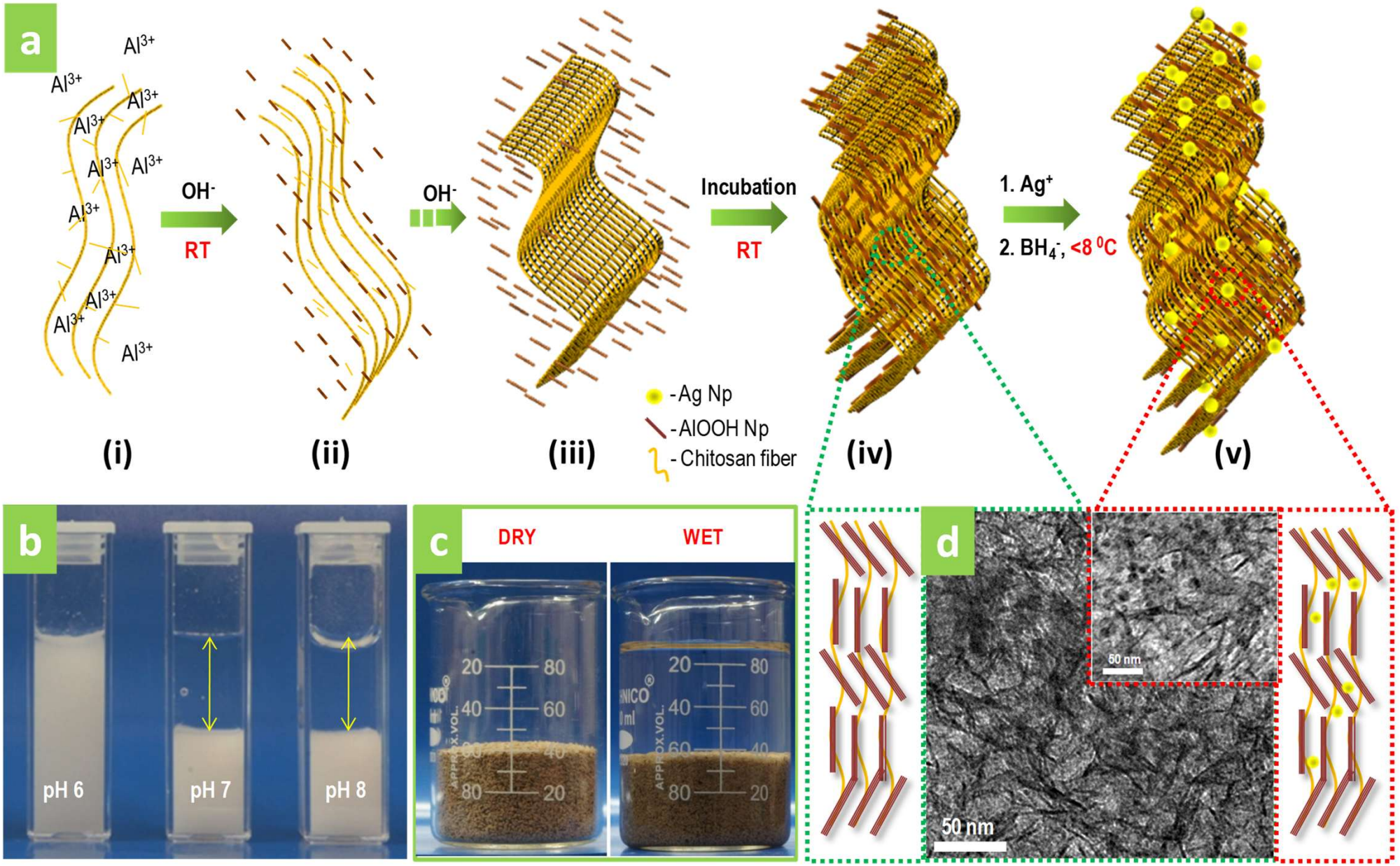
hybrid | green |

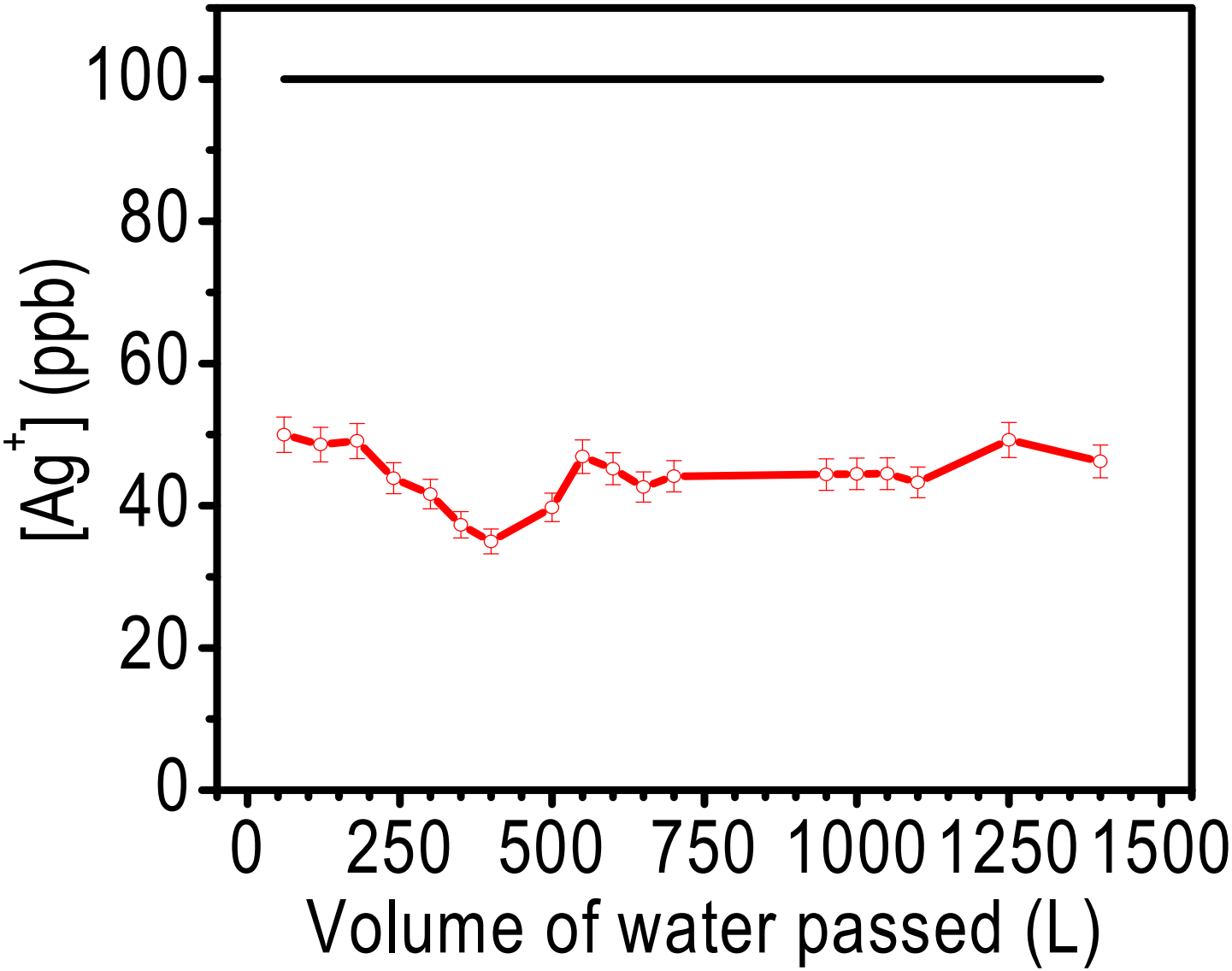
release into water are not available; and (*c*) continued retention of the nanoparticles in the matrix is difficult.

In this work, we demonstrate a unique family of nanocrystalline tal oxyhydroxide-chitosan granular composite materials pre-ed at near room temperature through an aqueous route. The gin of crystallinity in the composition is attributed to abundant -O- -OH functional groups on chitosan, which help in the crys-ization of metal oxyhydroxide and also ensure strong covalent ding of the nanoparticle surface to the matrix. X-ray photo-tron spectroscopy (XPS) confirms that the composition is rich h surface hydroxyl groups. Using hyperspectral imaging, the ence of nanoparticle leaching in the water was confirmed. ther, a unique scheme to reactivate the silver nanoparticle face is used for continual antimicrobial activity in drinking ers. Several other composites have been developed that can venge other contaminants in water. We demonstrate an af-dable water purification device based on such composites de-oped over several years and undergoing field trials in India, as otential solution for widespread eradication of the waterborne ease burden.

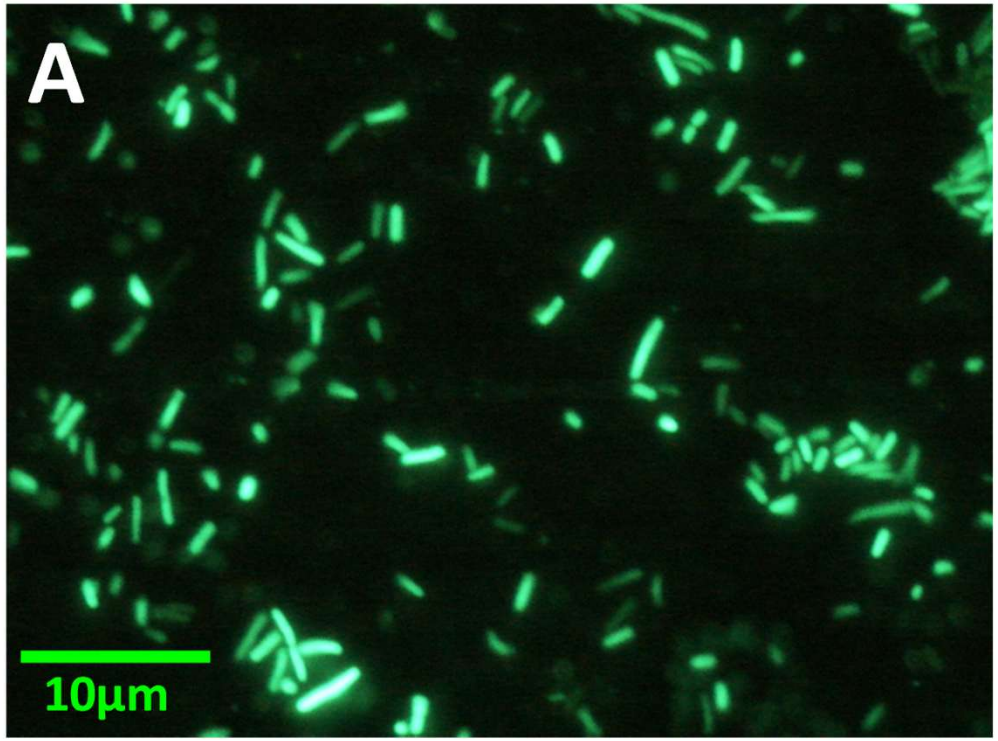
ults and Discussion

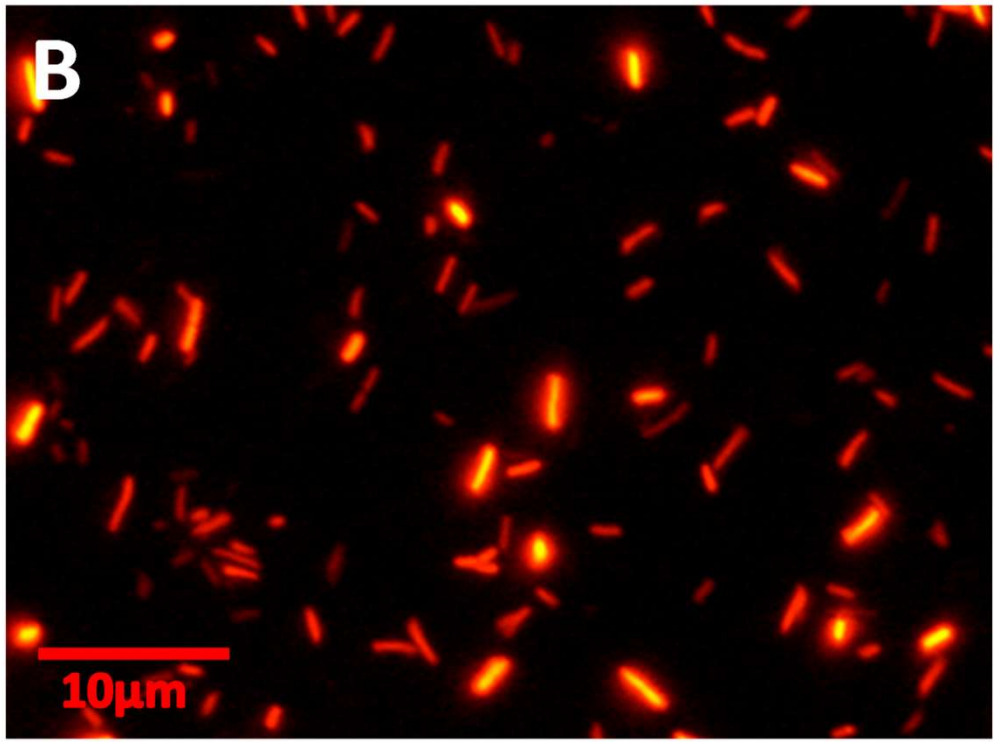
New materials

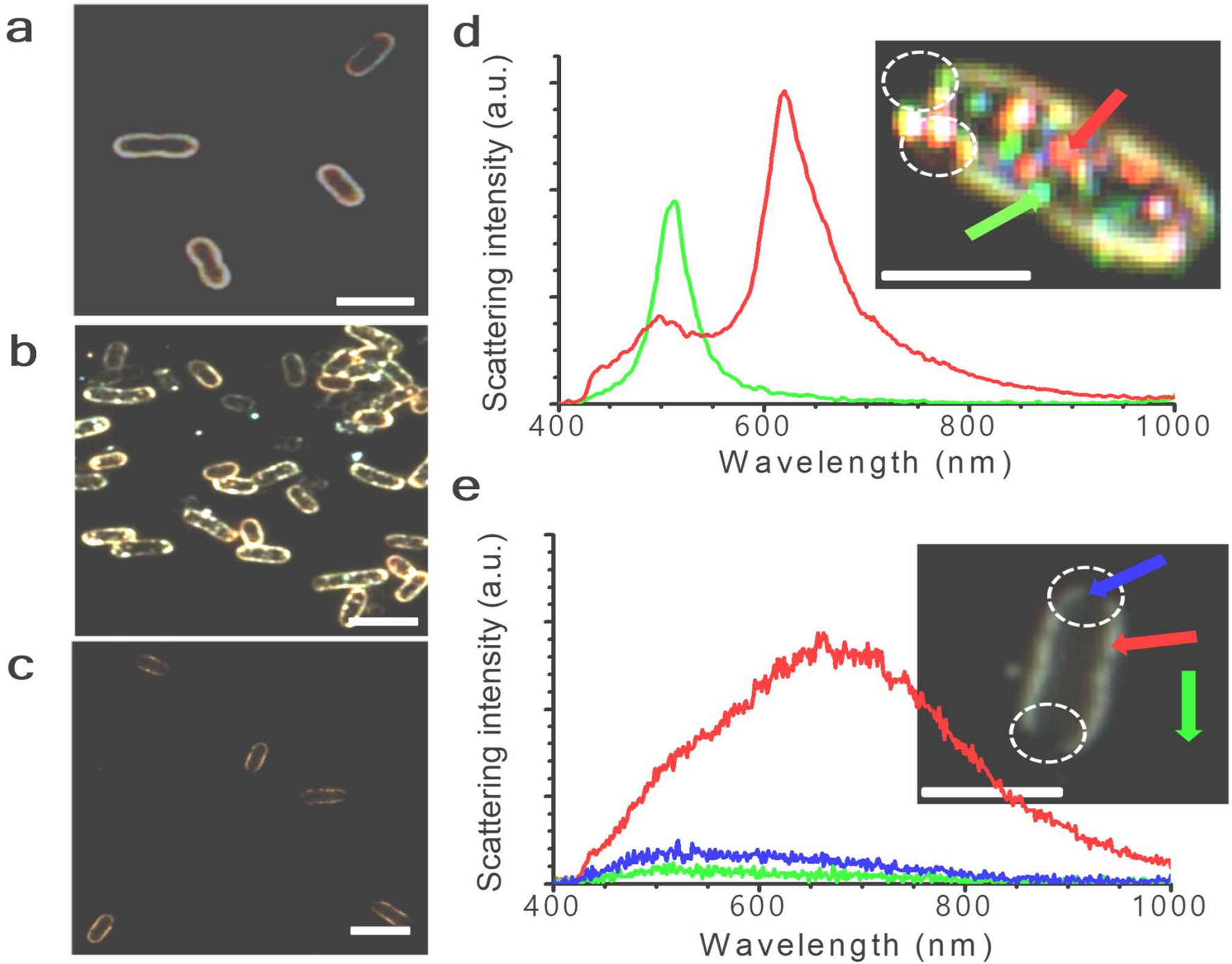


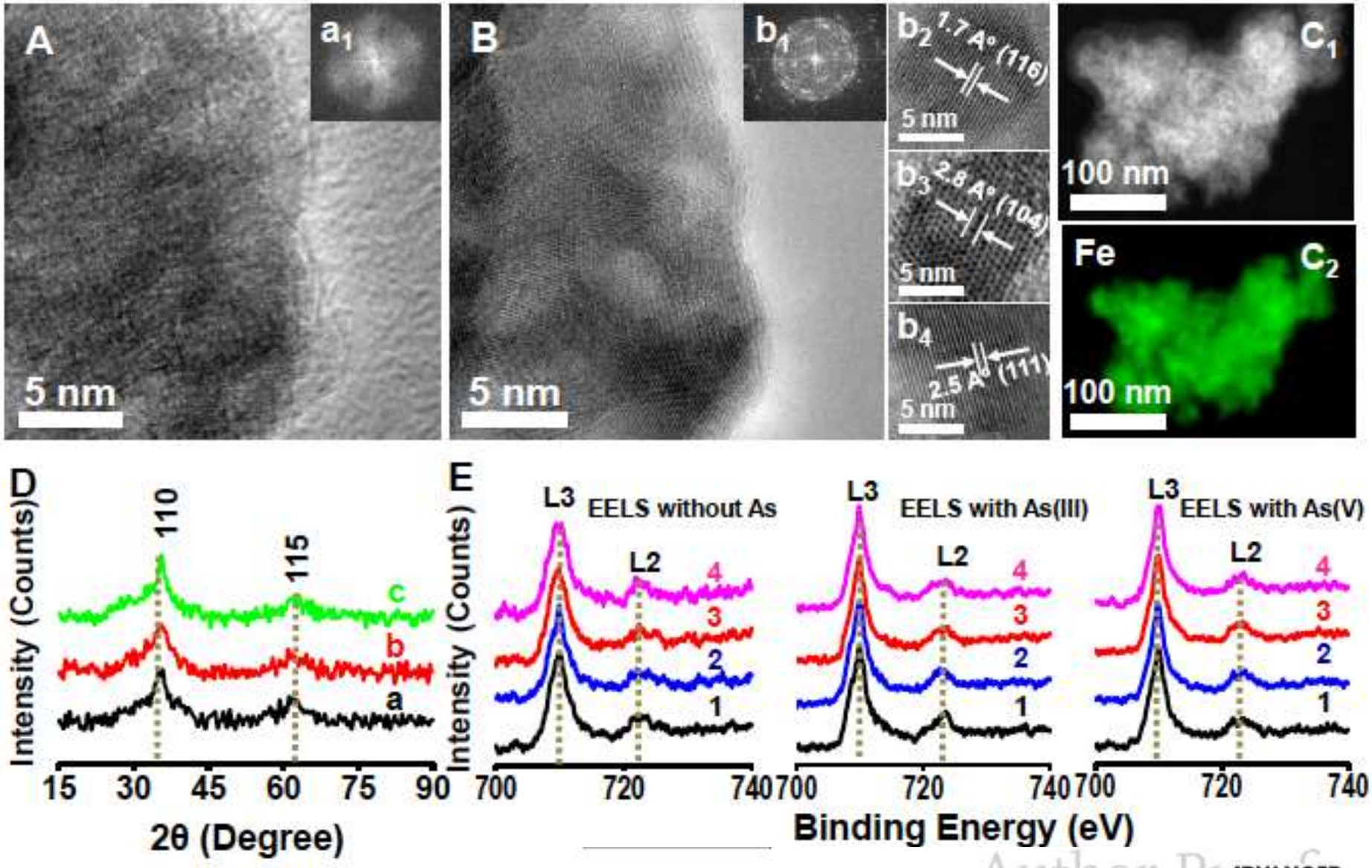

100
80
60
40
20
0
[Ag+] (ppb)
0
250
500
750
1000
1250
1500
Volume of water passed (L)

Live/dead staining experiments






a
b
c
d
Scattering intensity (a.u.)
400
600
800
1000
Wavelength (nm)
e
Scattering intensity (a.u.)
400
600
800
1000
Wavelength (nm)



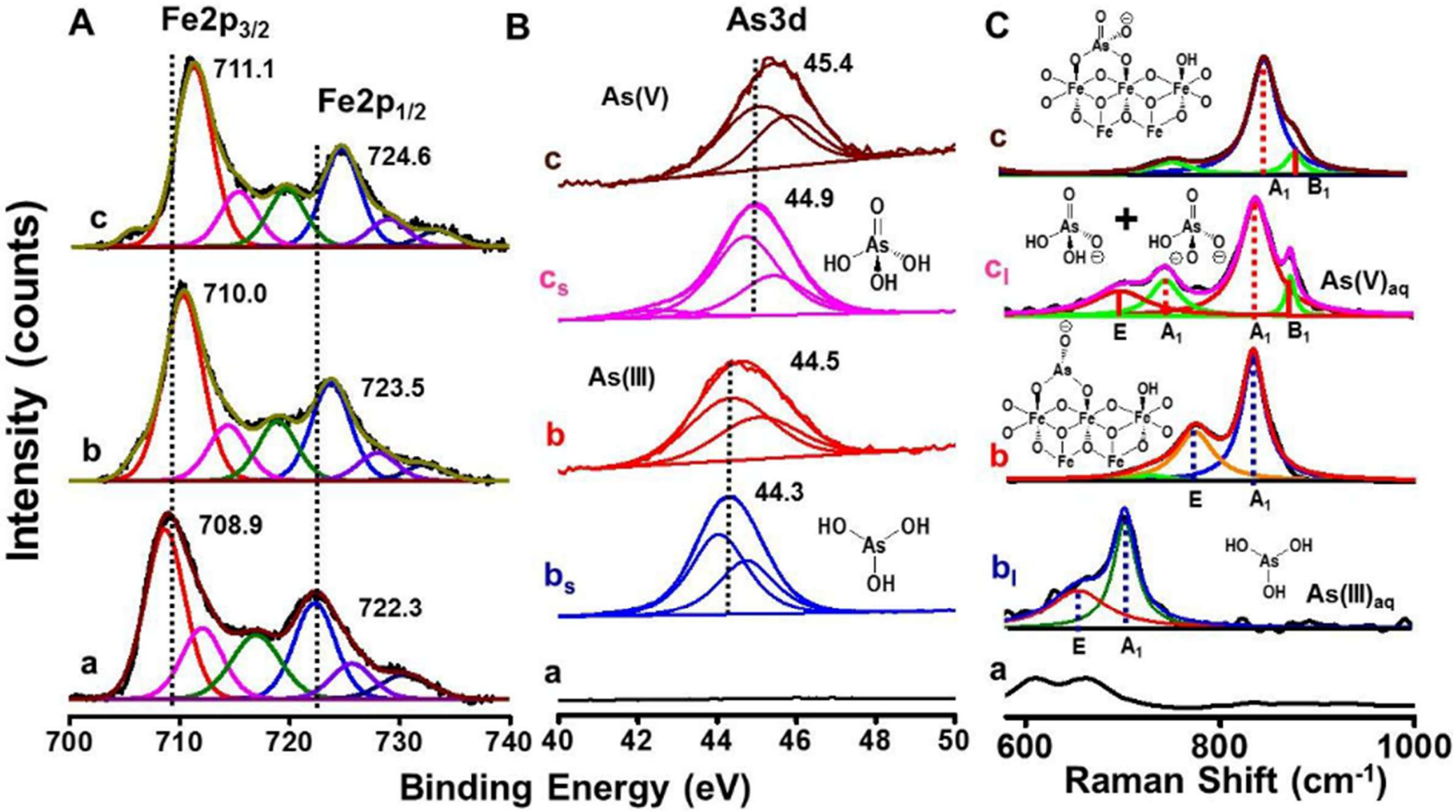
www.advmat.de ADVANCED MATERIALS

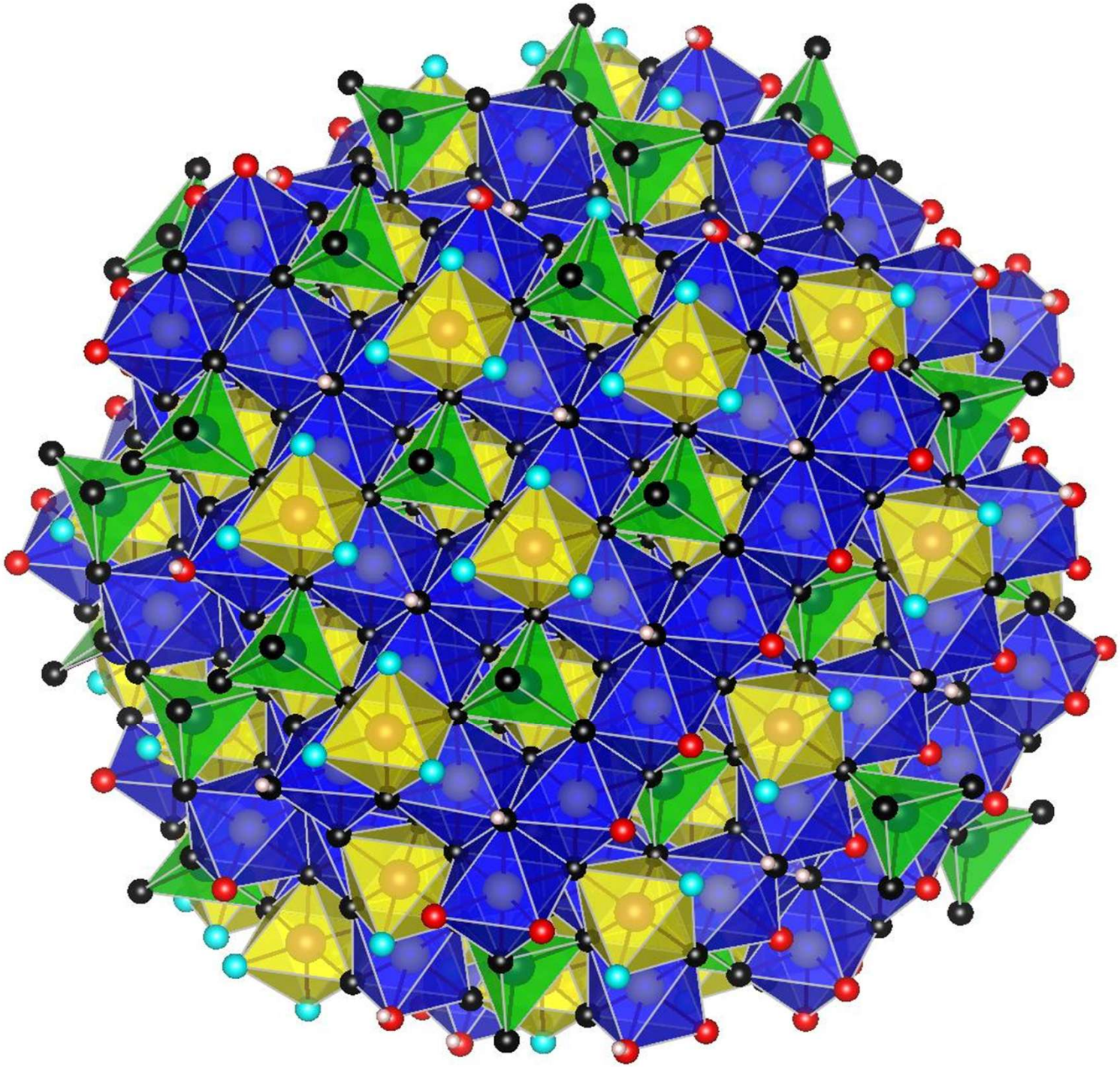
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

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**

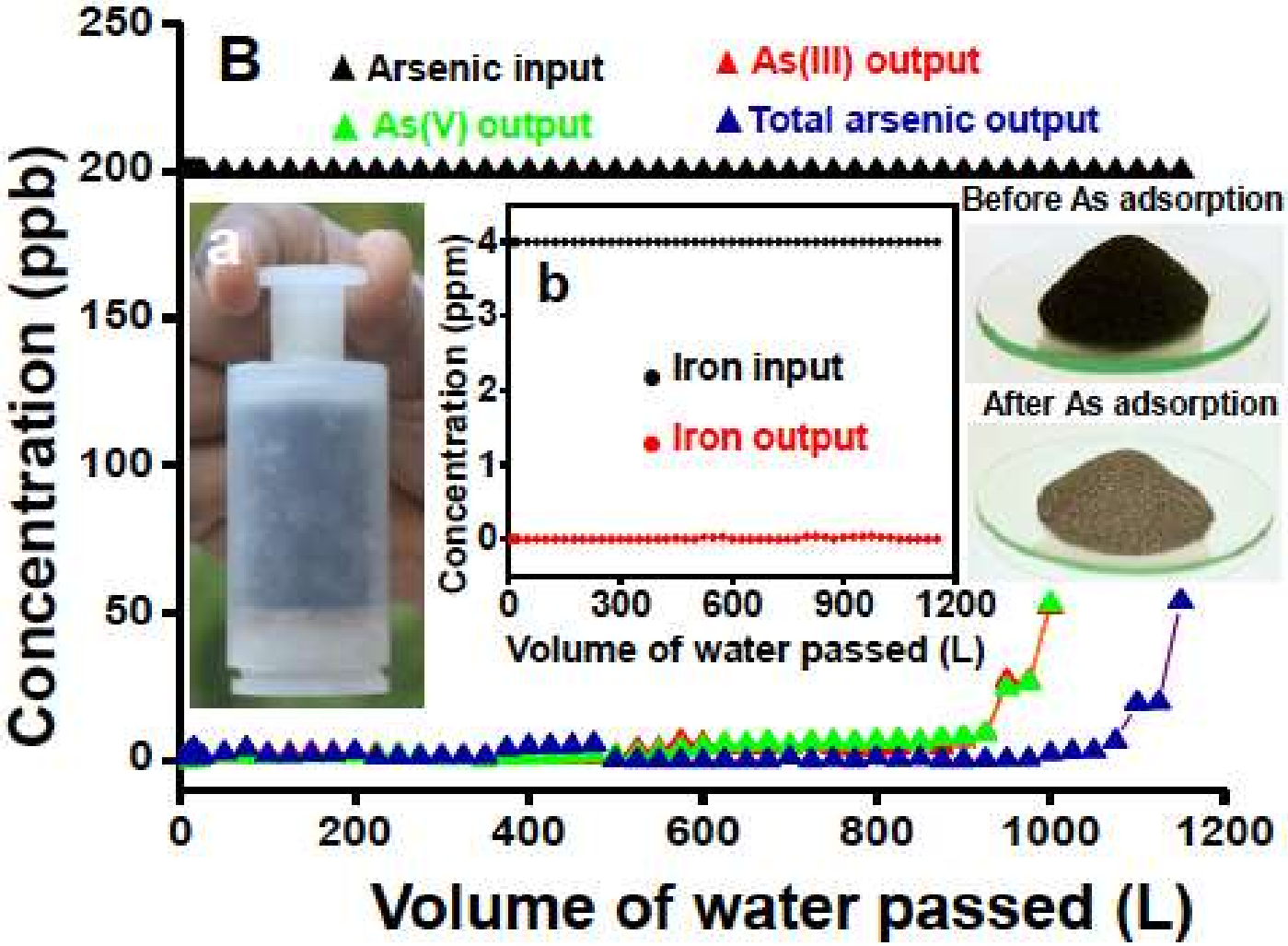
A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

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
b
bl
As(III)aq
a
600
800
1000
Raman Shift (cm-1)



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



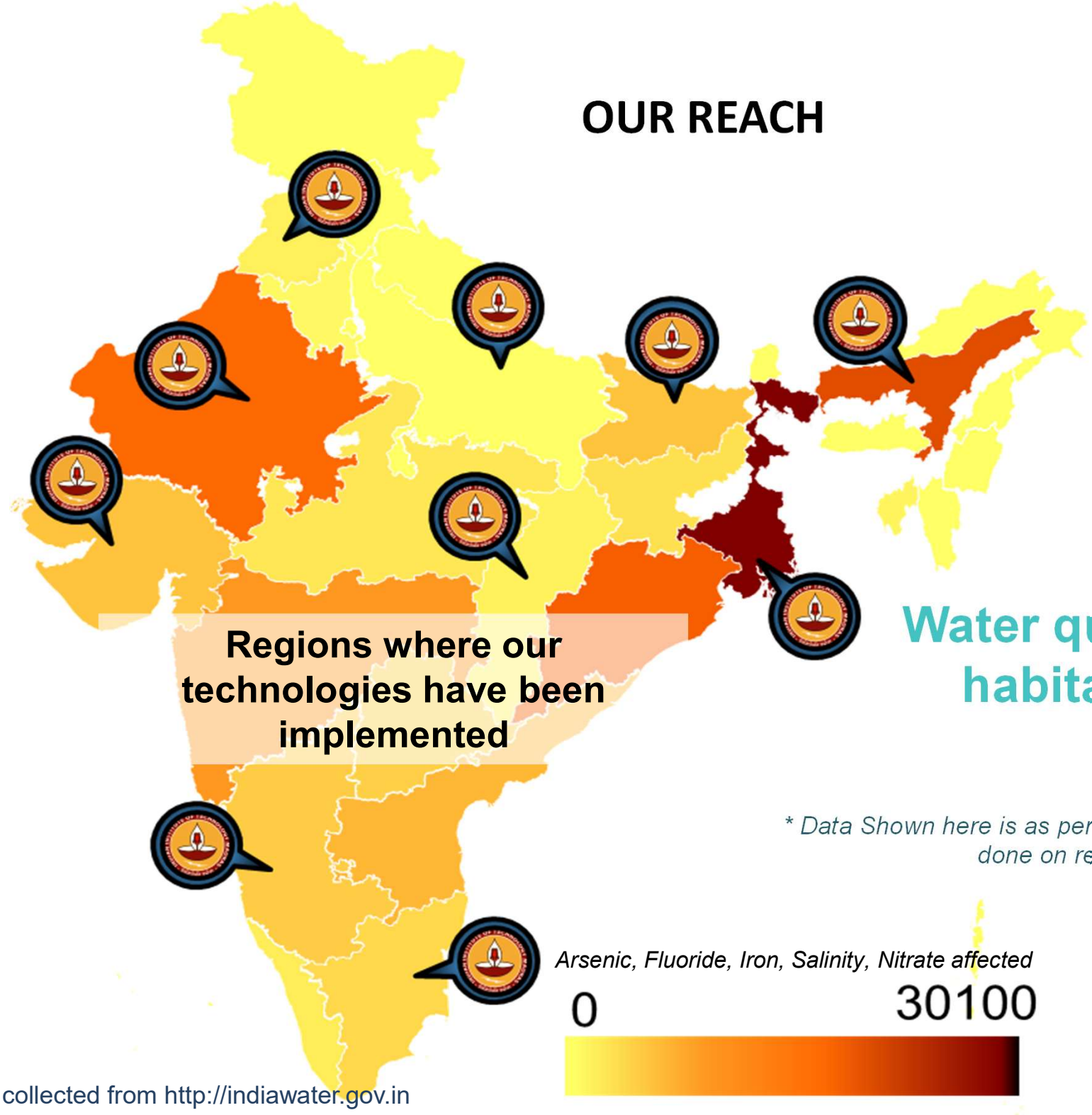
A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

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

OUR REACH



Data collected from http://indiawater.gov.in


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)

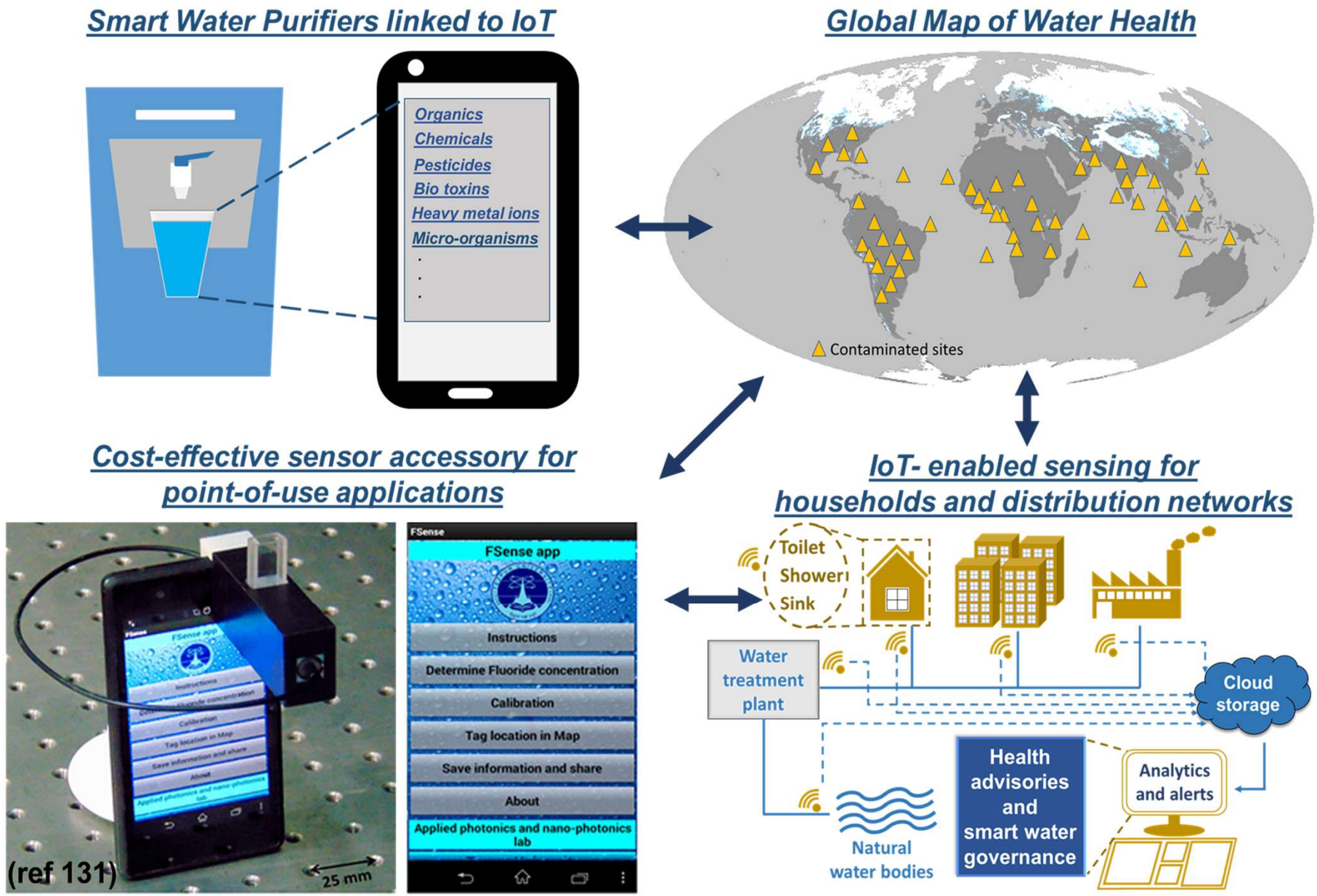
Installed in 2018, in February 2022

Cleanwater at 2.1 paise per litre!

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

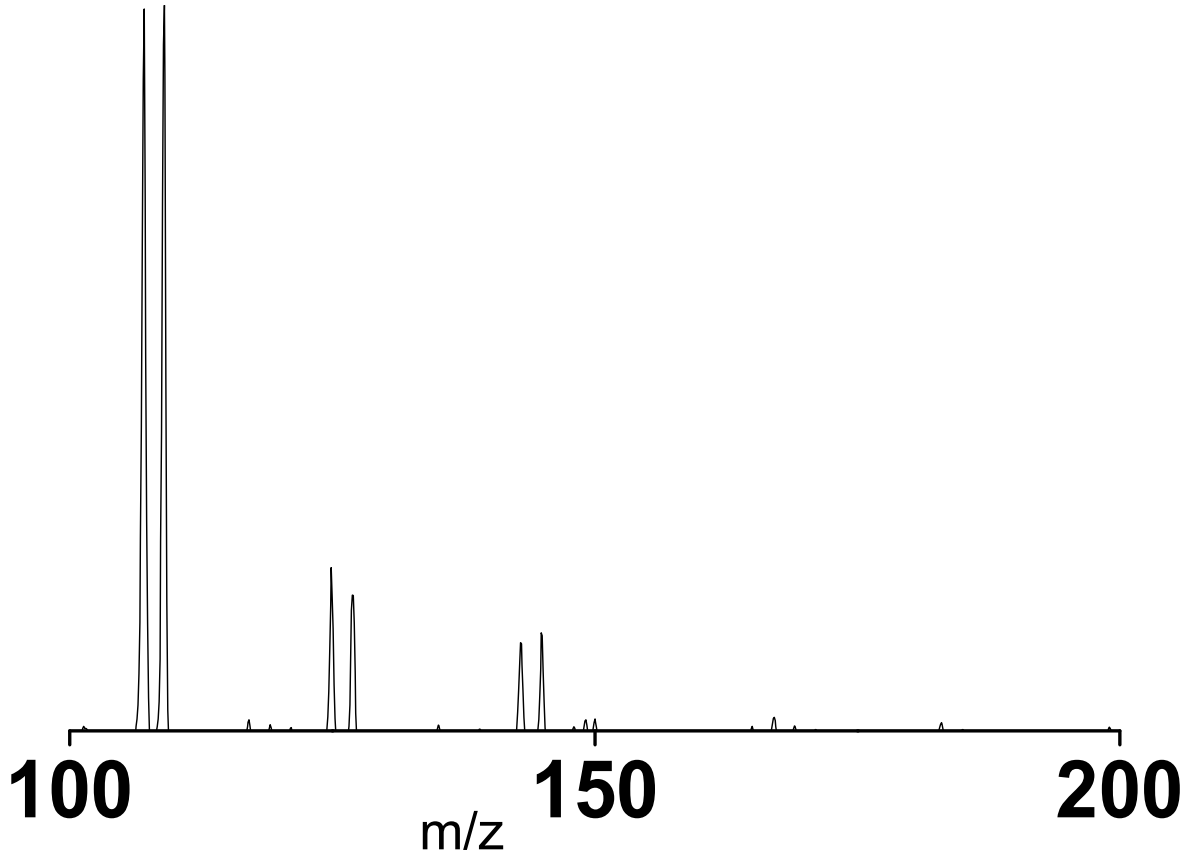
	Design population	1,071	Plant capacity/70 LPCD
Sr.No.	**Item/Description**	**Cost / Quantity**	**Remarks**
1	Cost of Replacement of Iron removal media	56400	After minimum two years if Iron concentration is more than 5 ppm. But iron concentration is more than 5 ppm at only two to three places. Therefore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

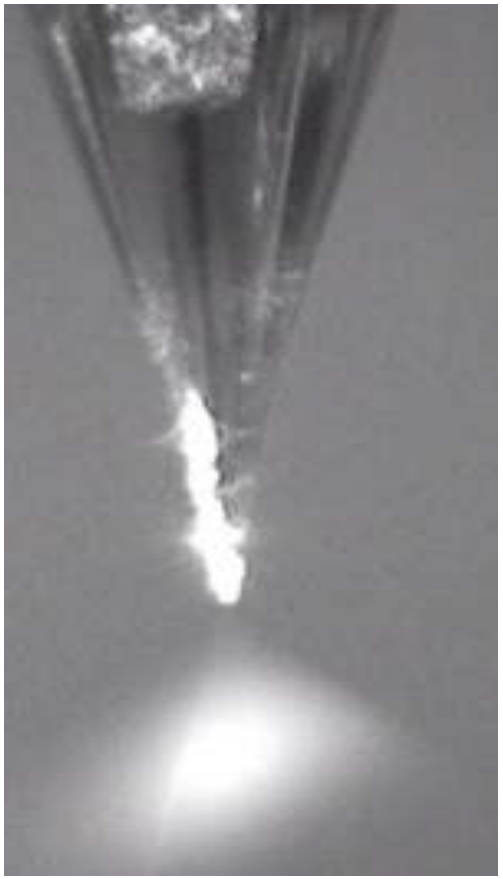
Smart water purifiers and big data



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

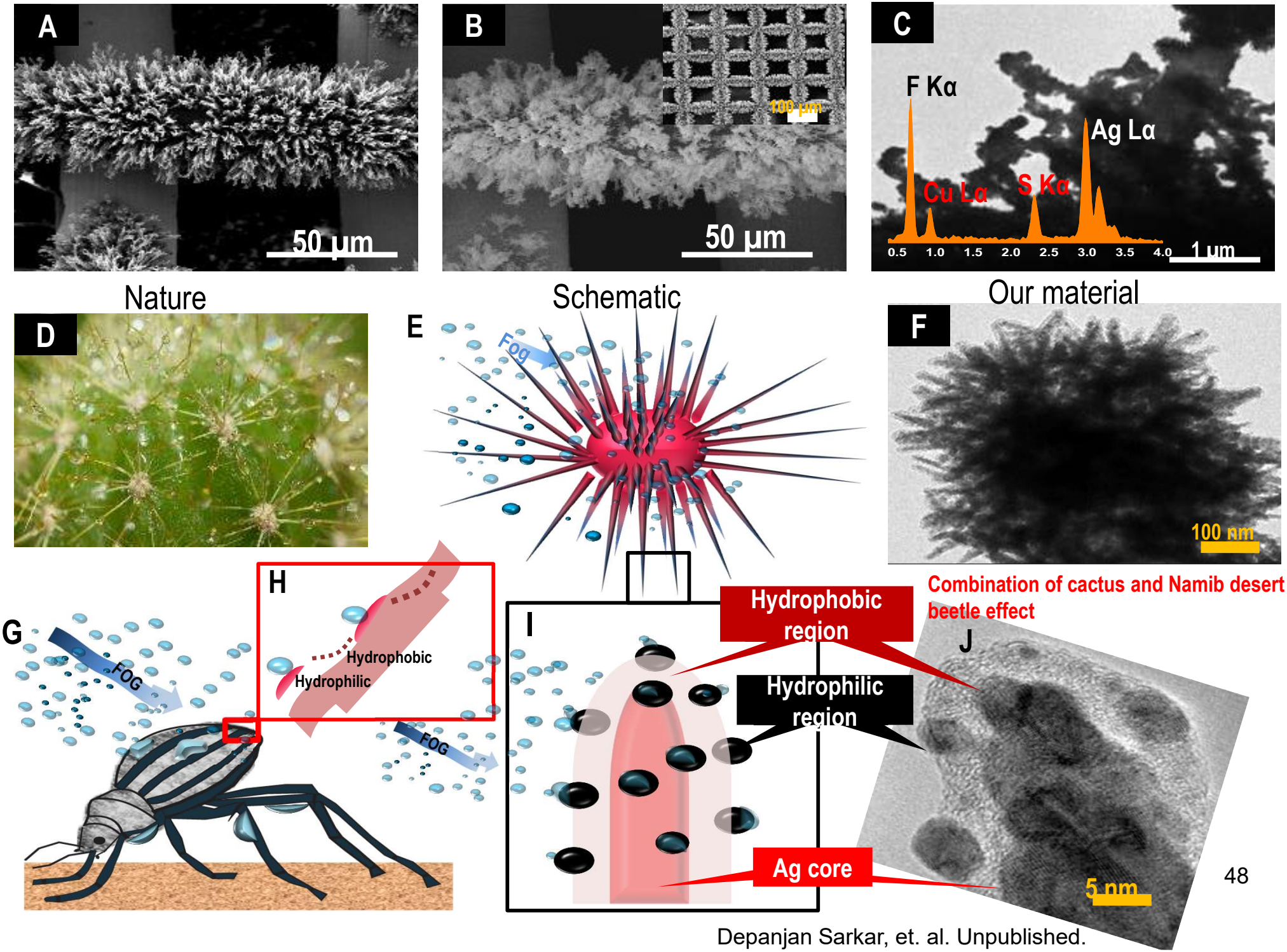
Atmospheric water harvesting



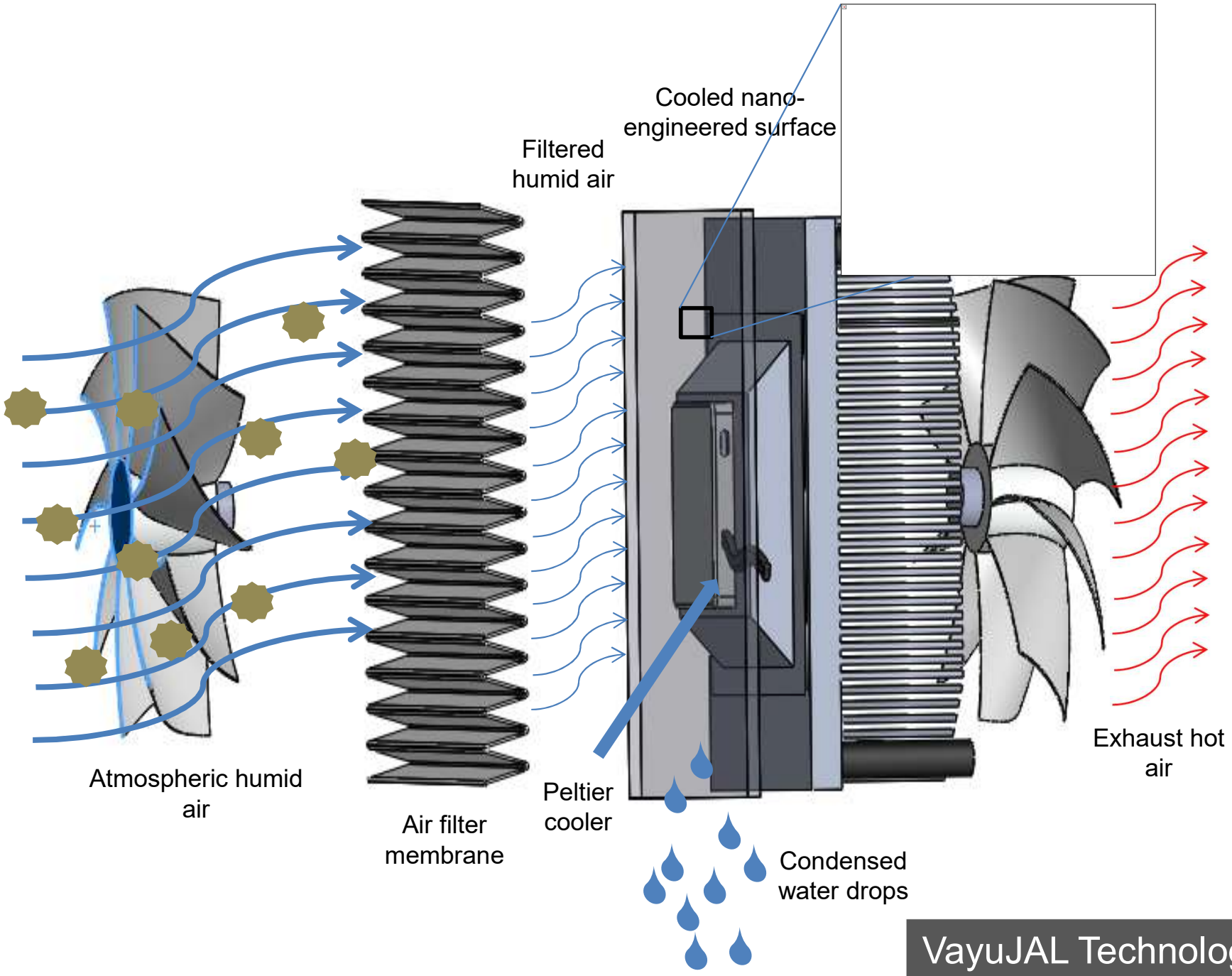


New harvesters

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



Depanjan Sarkar, et. al. Unpublished.

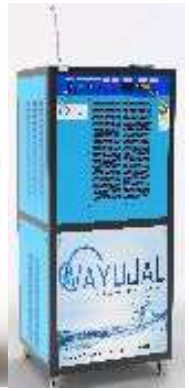


VayuJAL Technologies Pvt. Ltd.

Ramesh Kumar Soni and Ankit Nagar

Products in the field

35 LPD



120 LPD

400 LPD

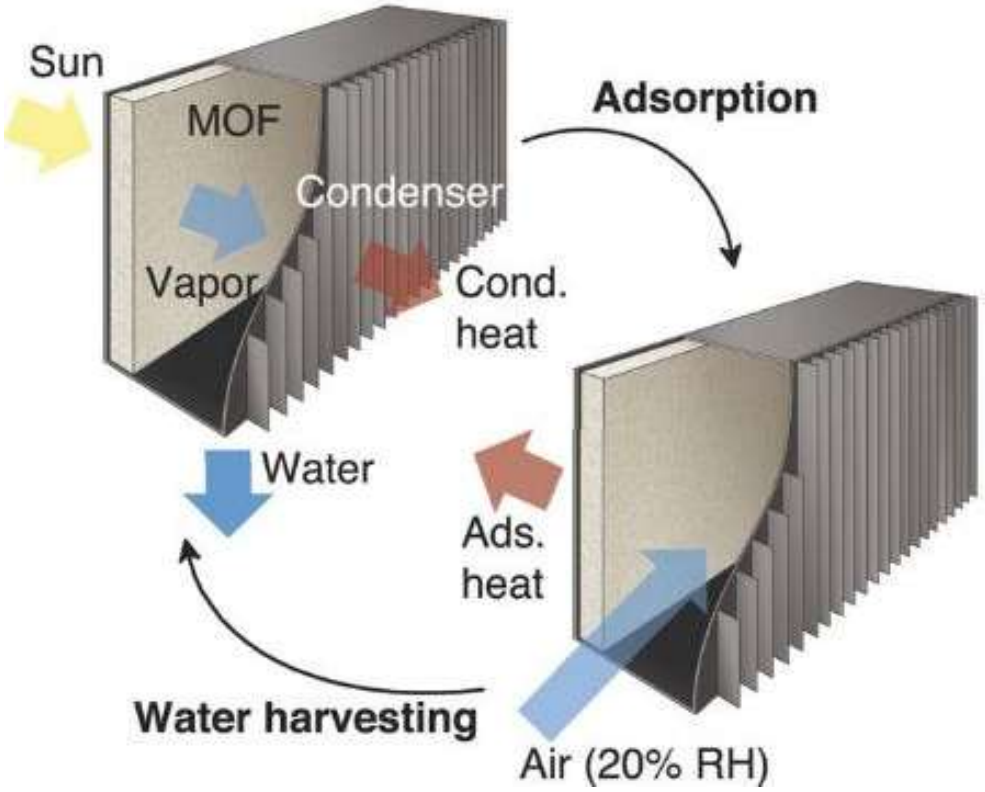
1000 LPD

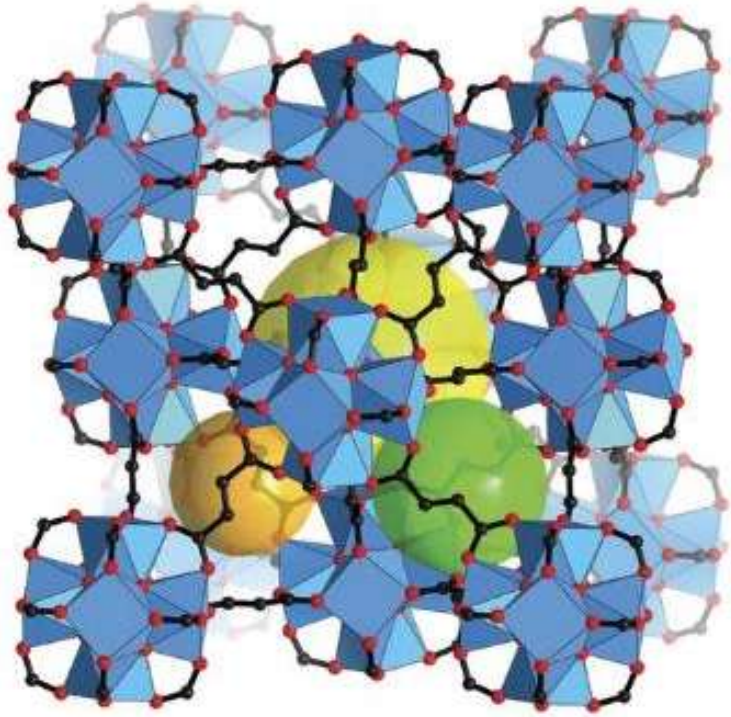
2000 LPD

(LPD: Litres per day)

Sustainable atmospheric water harvesting

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

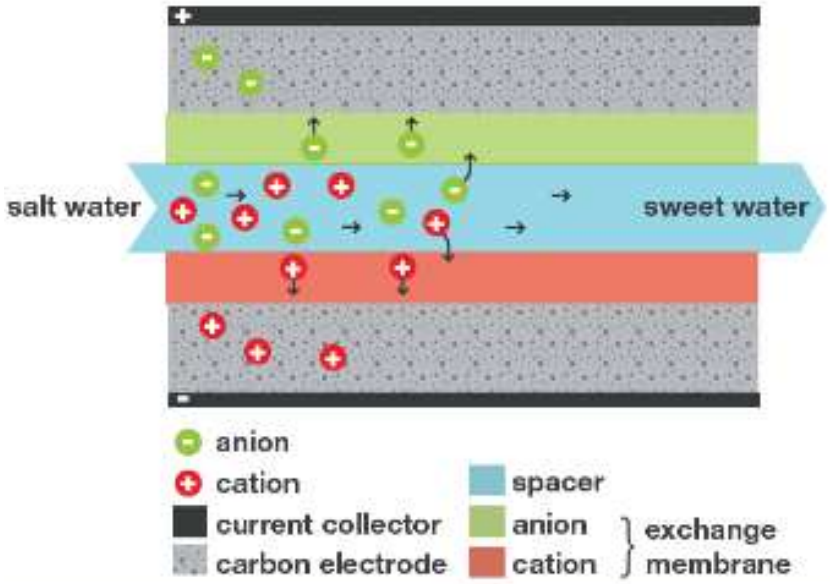


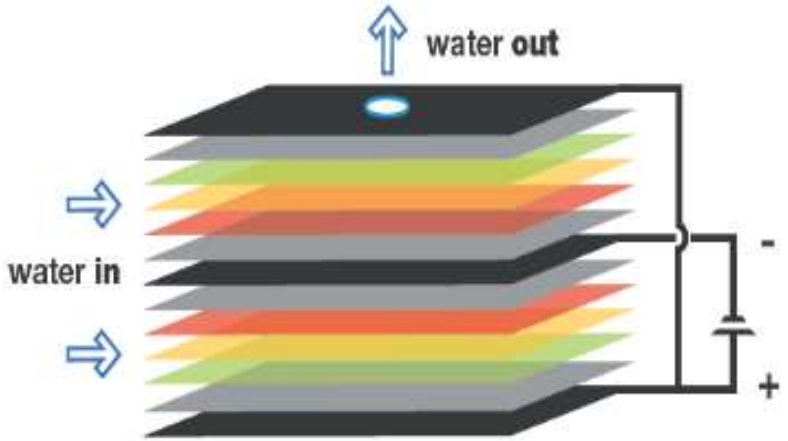


Porous metal-organic framework (MOF-801, $Zr_6O_4(OH)_4(fumarate)_6$)

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

Capacitive Desalination (CDI)





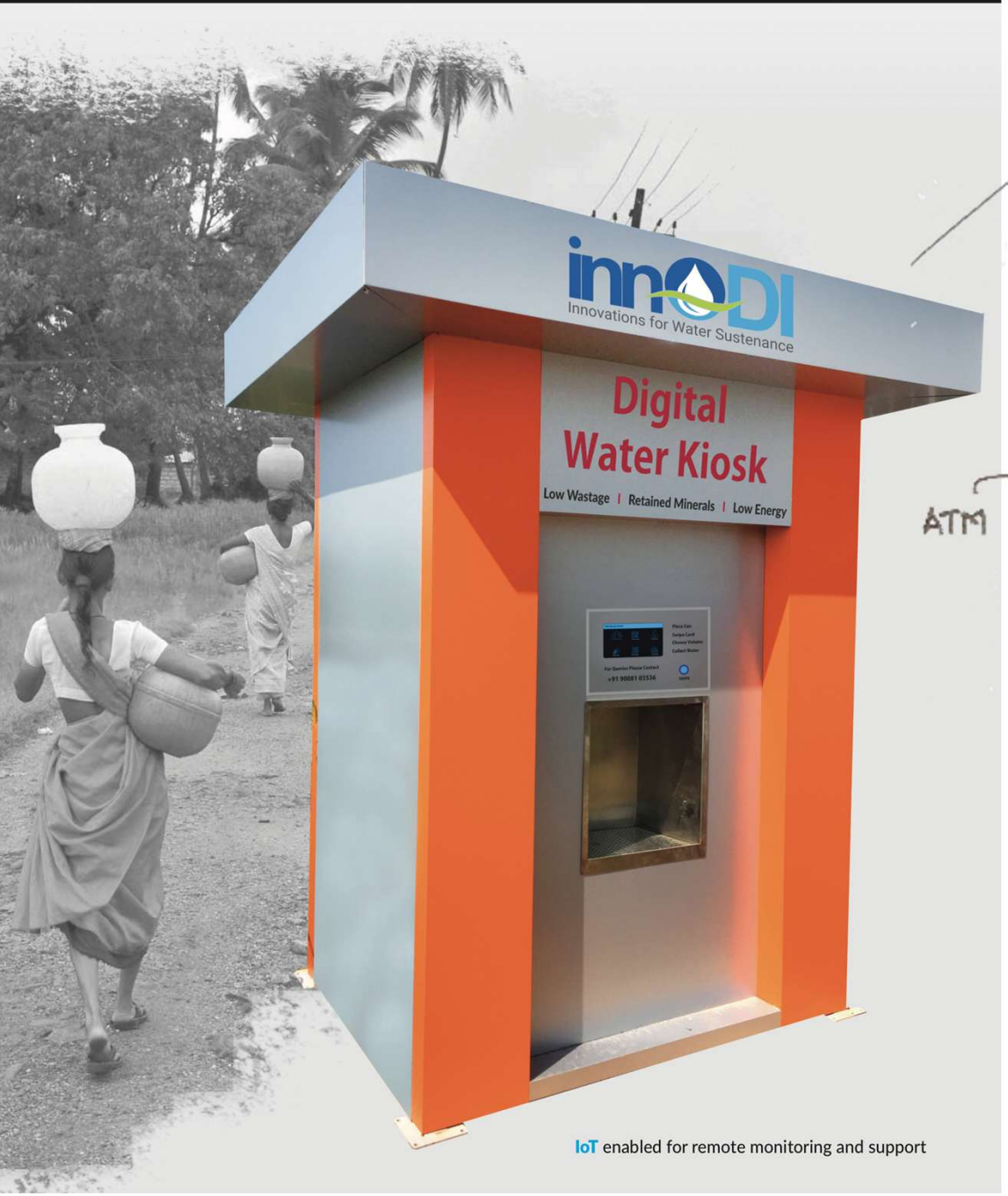
innODI

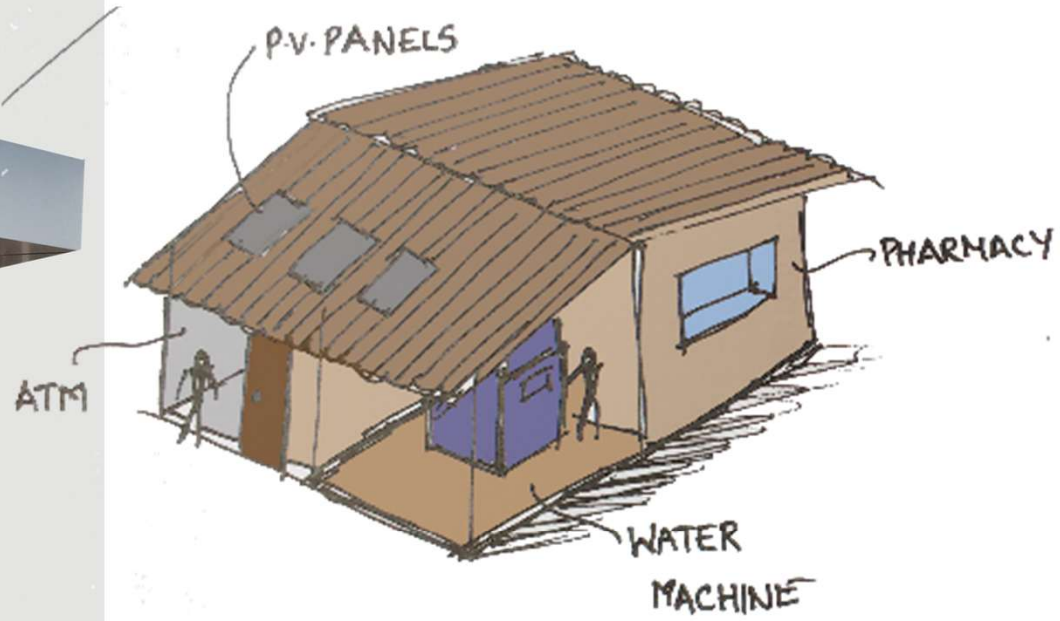
Our new company

Soujit Sengupta, Rabiul Islam and others

DIGITAL WATER KIOSK

for community drinking using CDI Technology

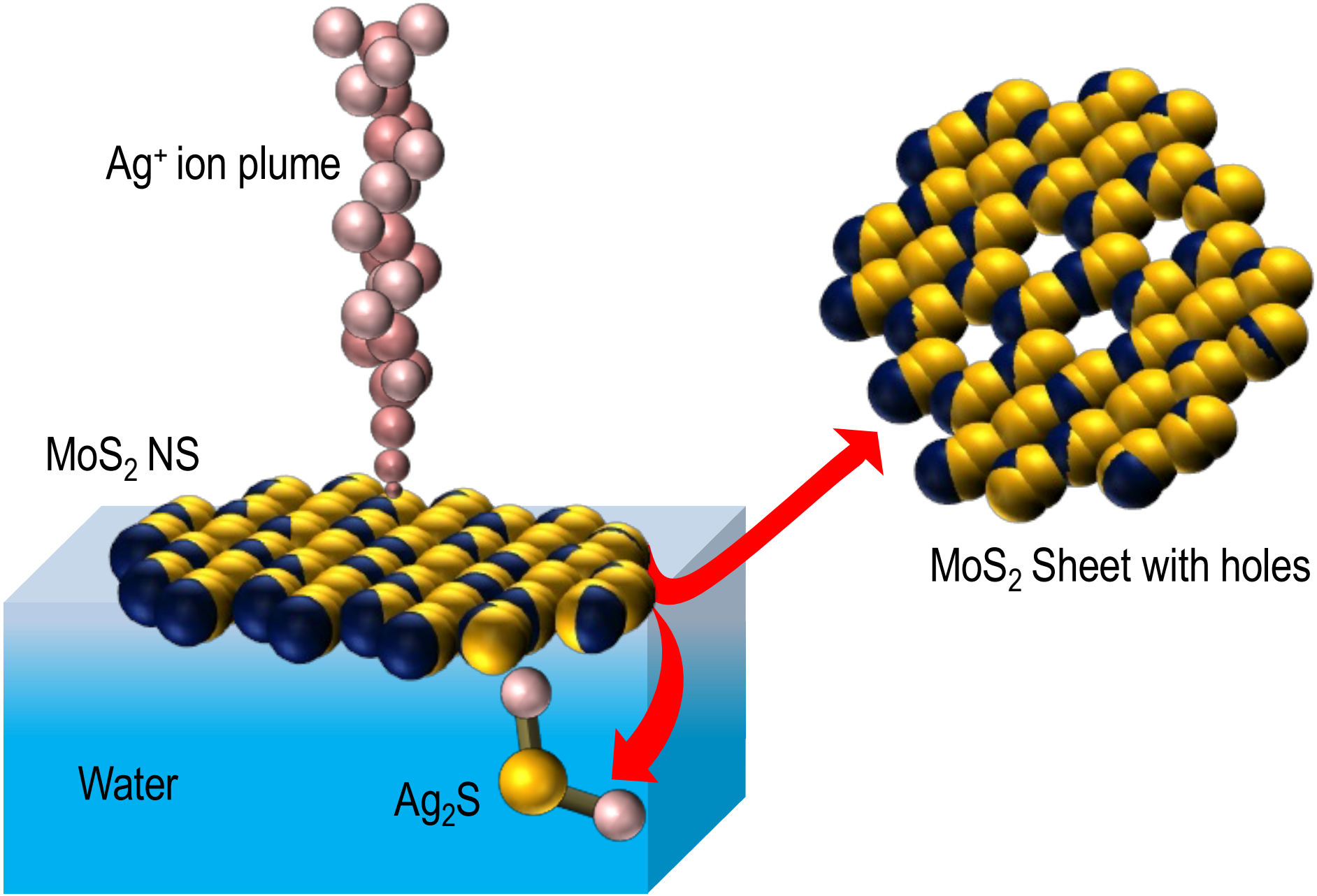




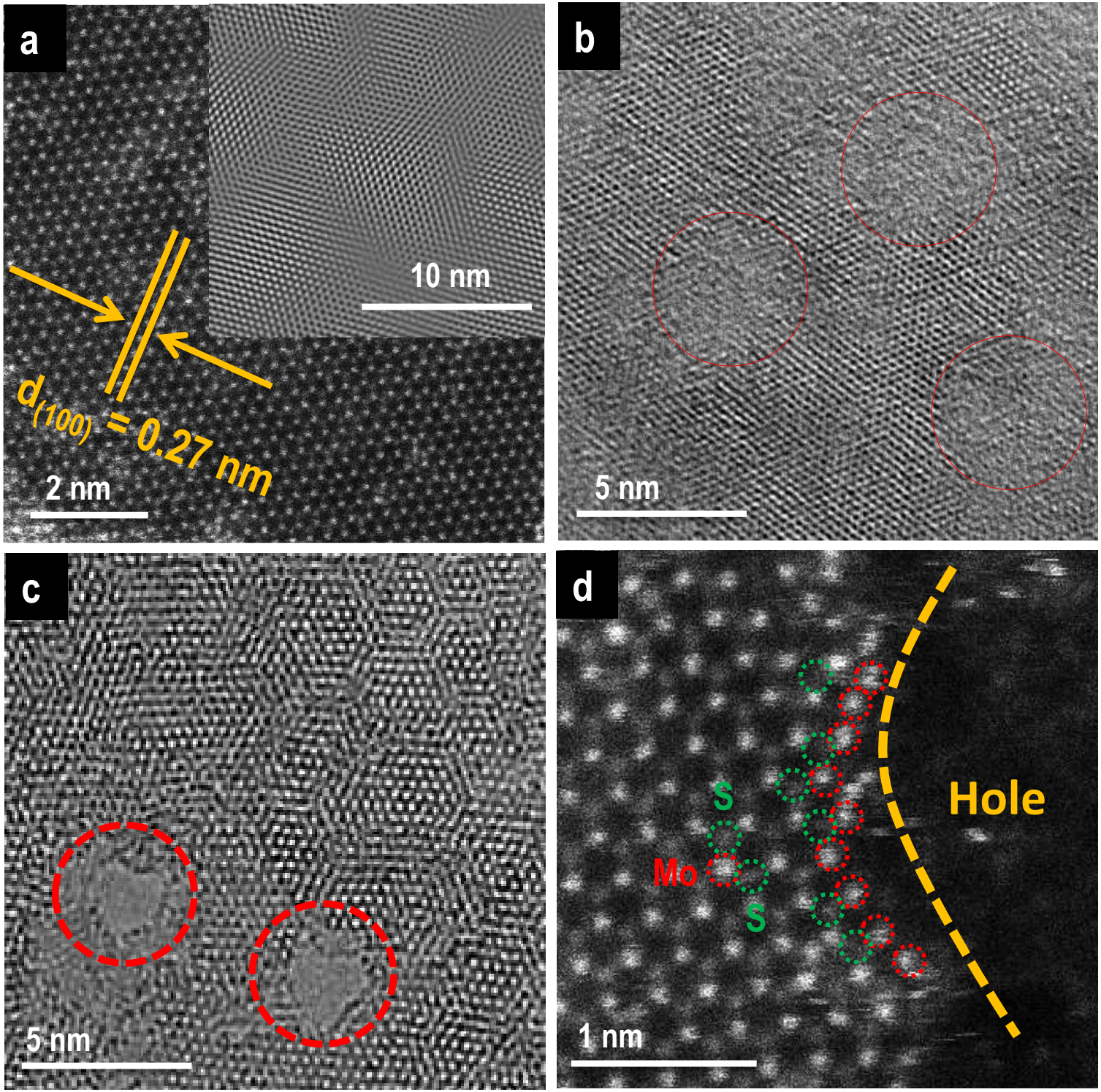
Products under implementation

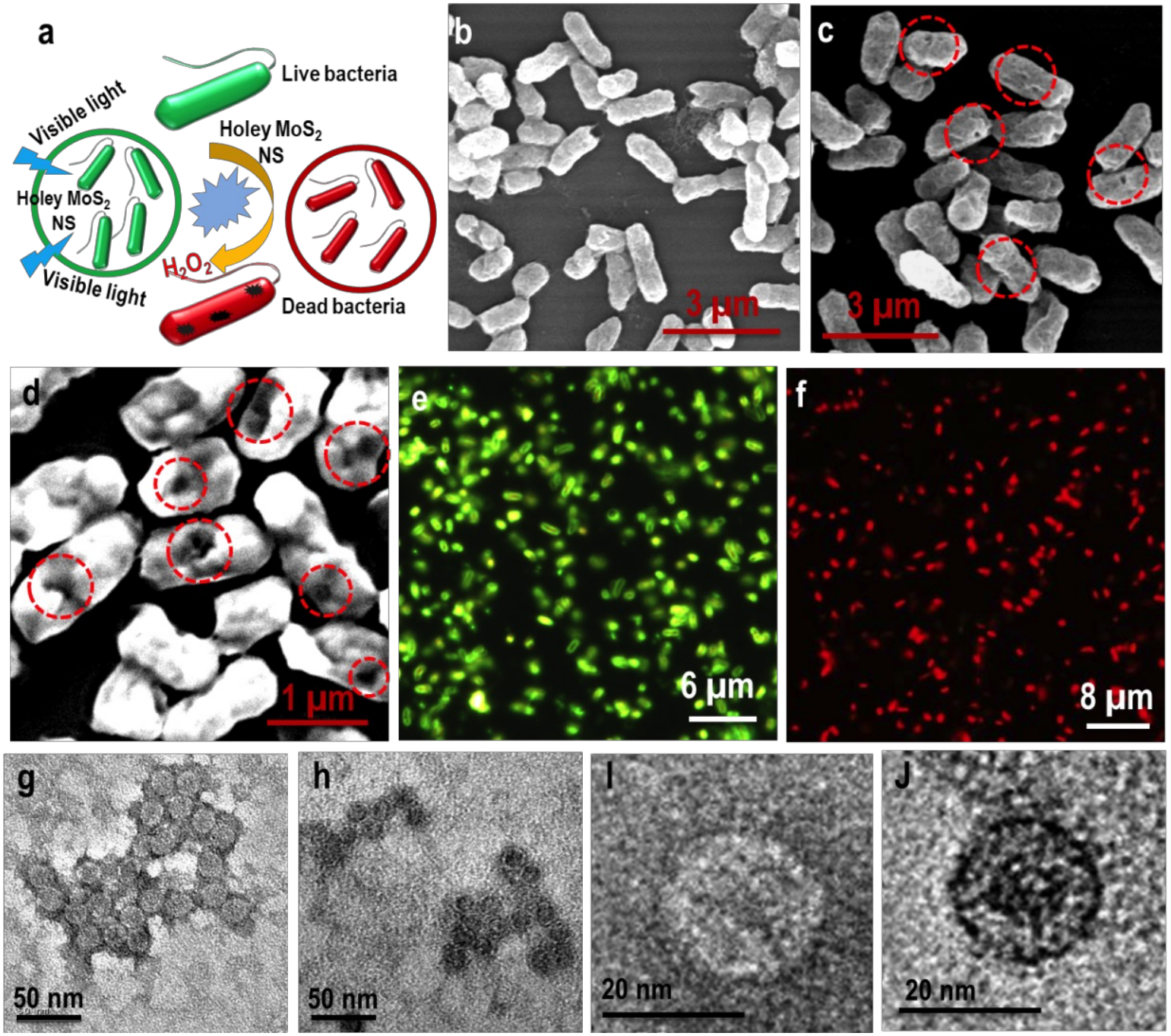
Vijay Sampath and Tullio Servida

2D materials, nanopores

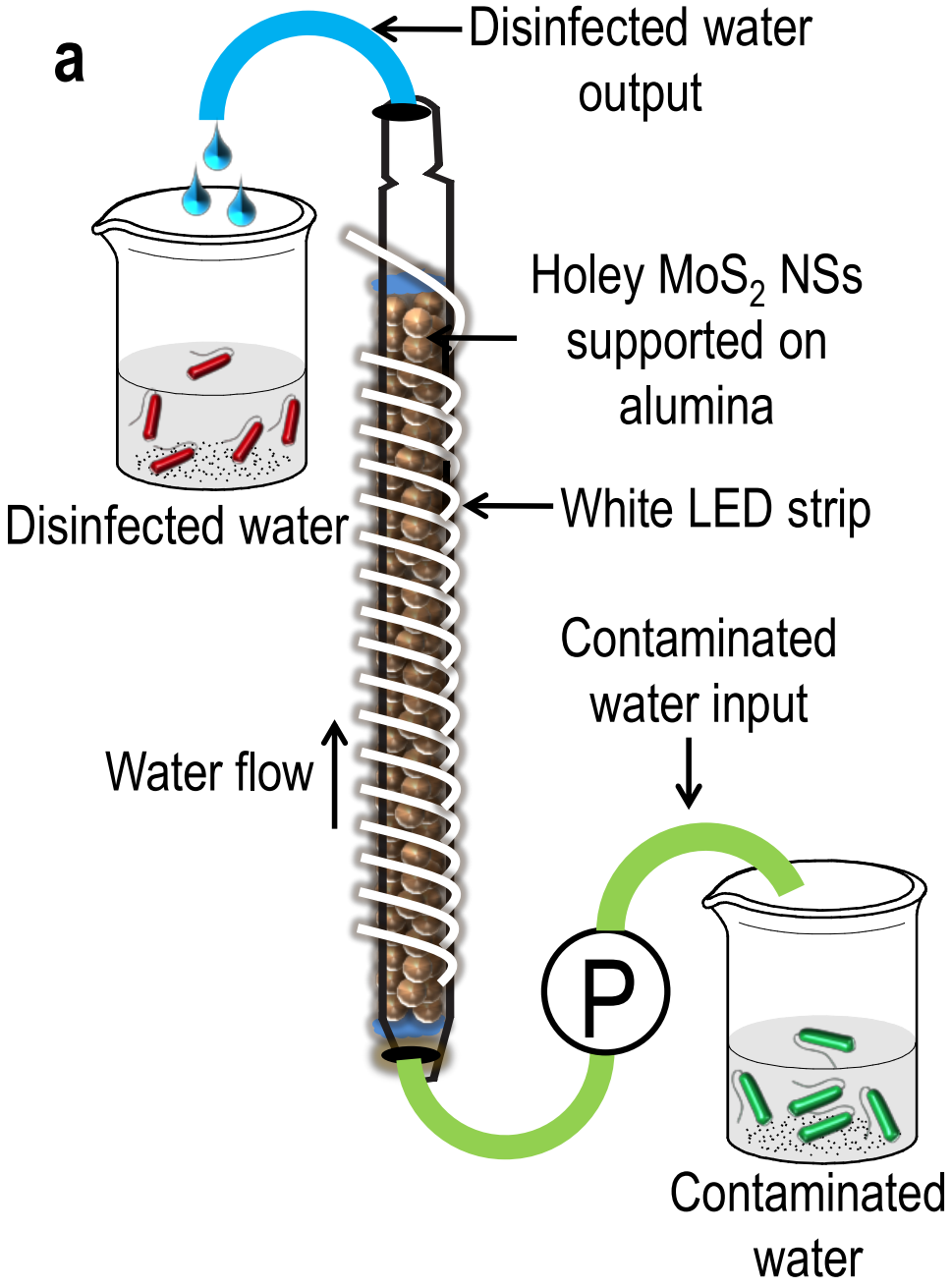


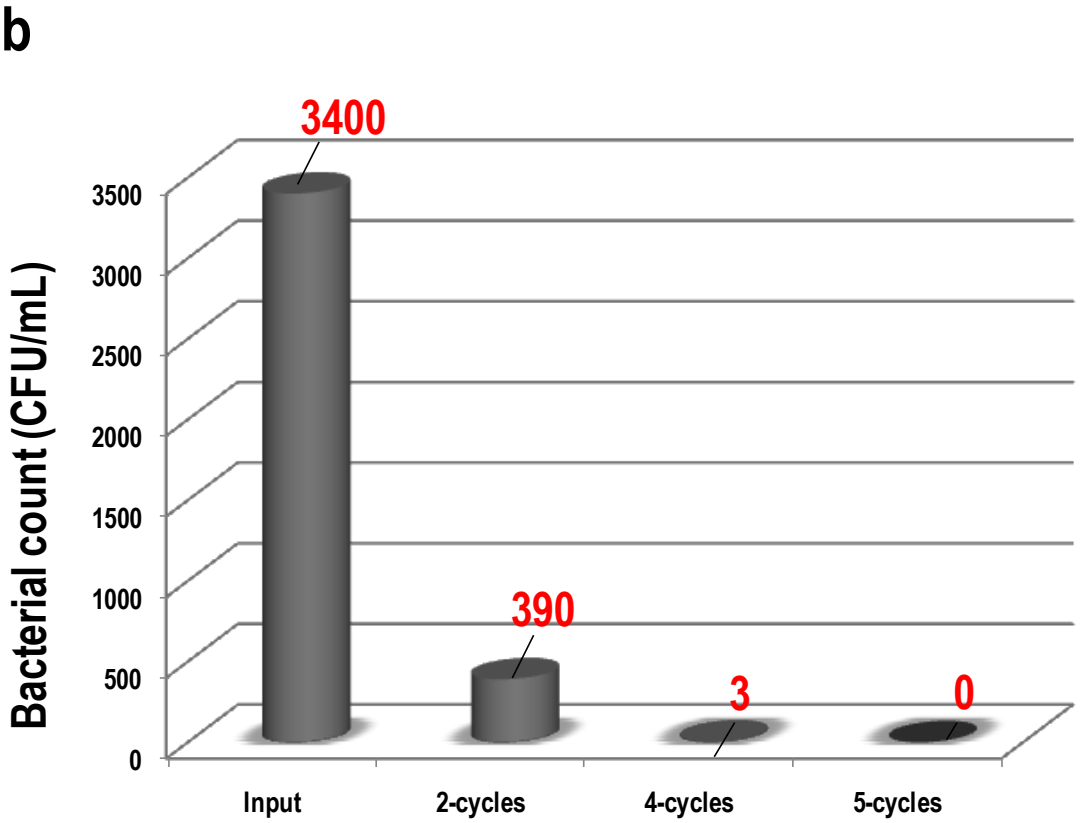
Depanjan Sarkar, Biswajit Mondal, et. al., *Global Challenges, 2* (12), 2018


a
10 nm
$d_{(100)}$ = 0.27 nm
2 nm
b
5 nm
c
5 nm
d
S
Mo
S
Hole
1 nm

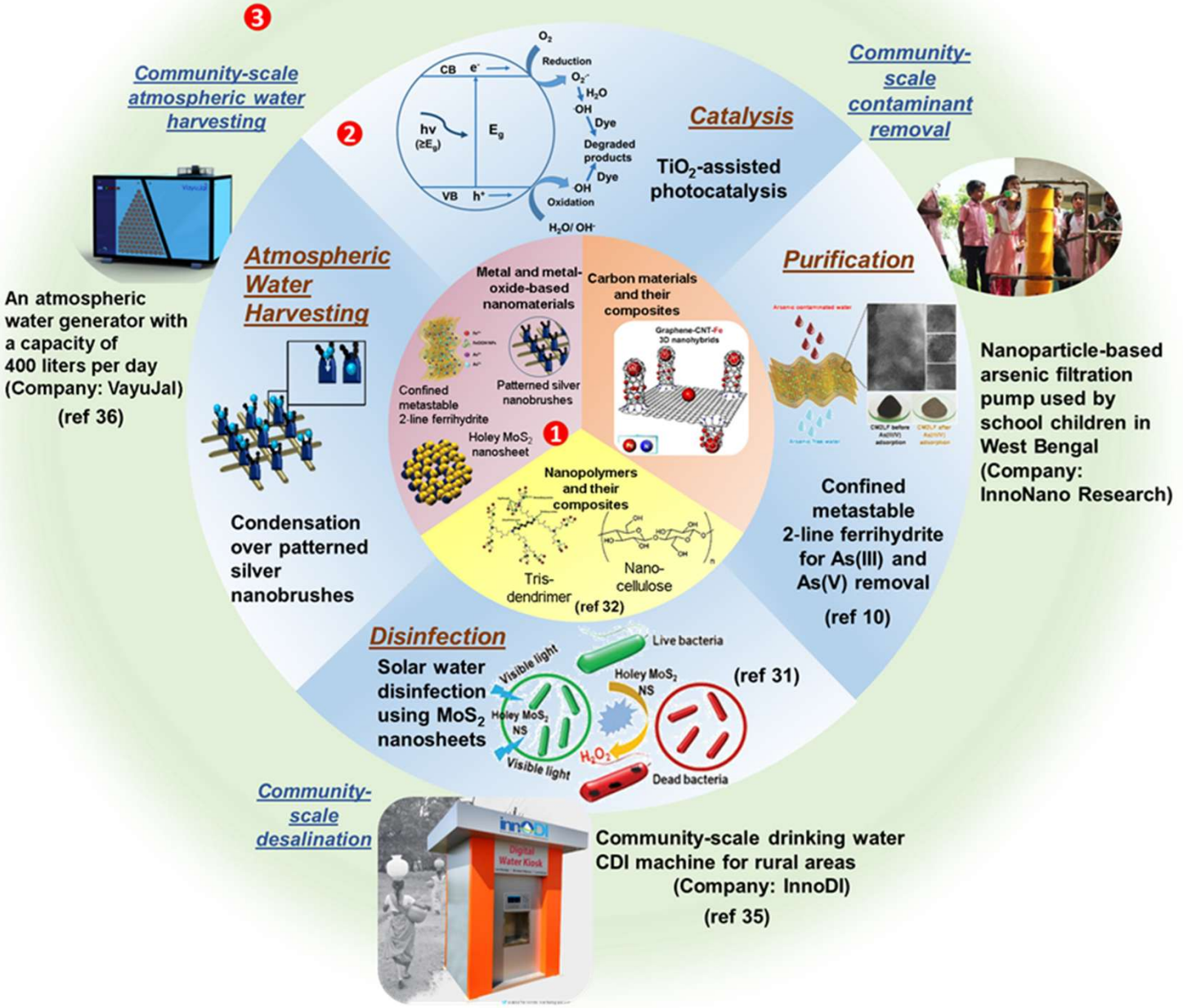

a
Live bacteria
Visible light
Holey MoS_2 NS
Holey MoS_2 NS
H_2O_2
Visible light
Dead bacteria
b
3 μm
c
3 μm
d
1 μm
e
6 μm
f
8 μm
g
50 nm
h
50 nm
I
20 nm
J
20 nm

Prototype


a
Disinfected water output
Holey MoS_2 NSs supported on alumina
White LED strip
Disinfected water
Contaminated water input
Water flow
P
Contaminated water

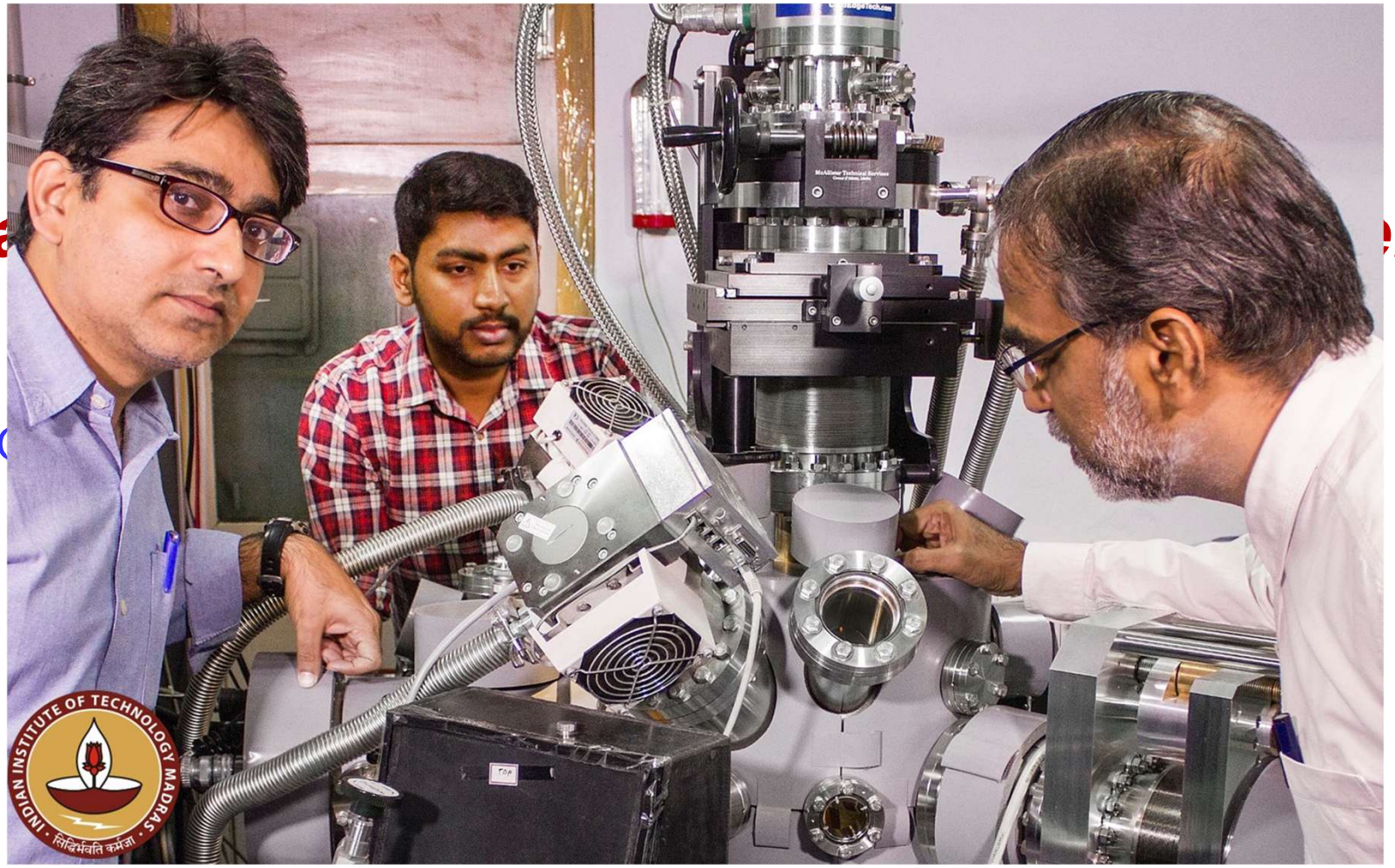

b
Bacterial count (CFU/mL)
3400
390
3
0
3500
3000
2500
2000
1500
1000
500
0
Input
2-cycles
4-cycles
5-cycles

Evolution of materials to products



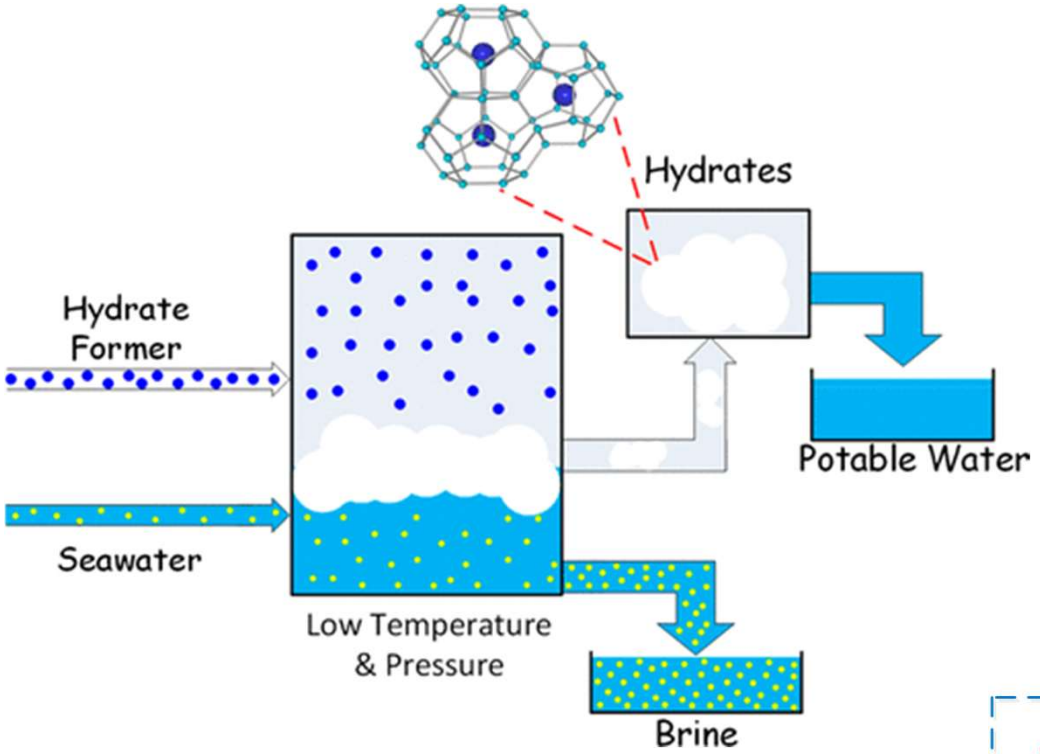
Ankit Nagar and T. Pradeep 14(2020). *ACS Nano*, 6420-6435

New phenomena



With Rajnish Kumar

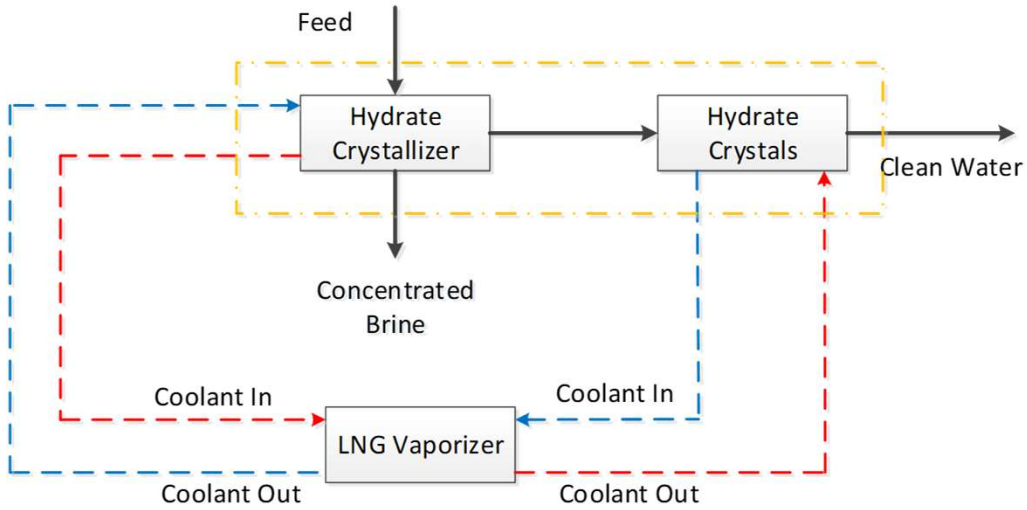
Hydrate-based desalination (HyDesal)



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

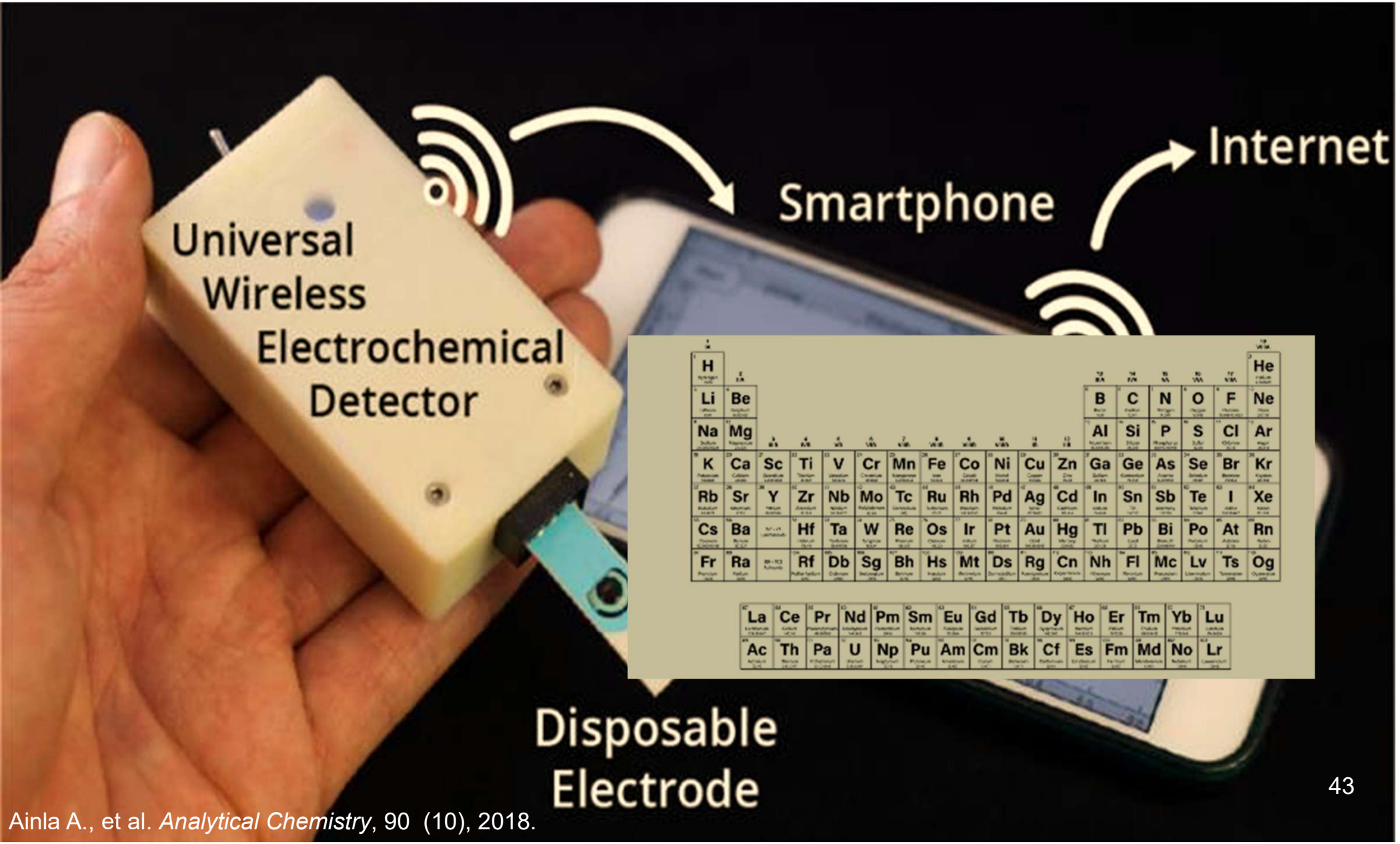


Cold Energy in LNG terminals can be harvested to produce water

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

Slide from Prof. Praveen Linga, NUS

Analytical devices

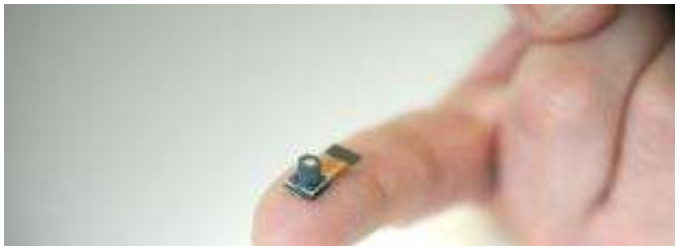


Ainla A., et al. *Analytical Chemistry*, 90 (10), 2018.

Sensors and new opportunities

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

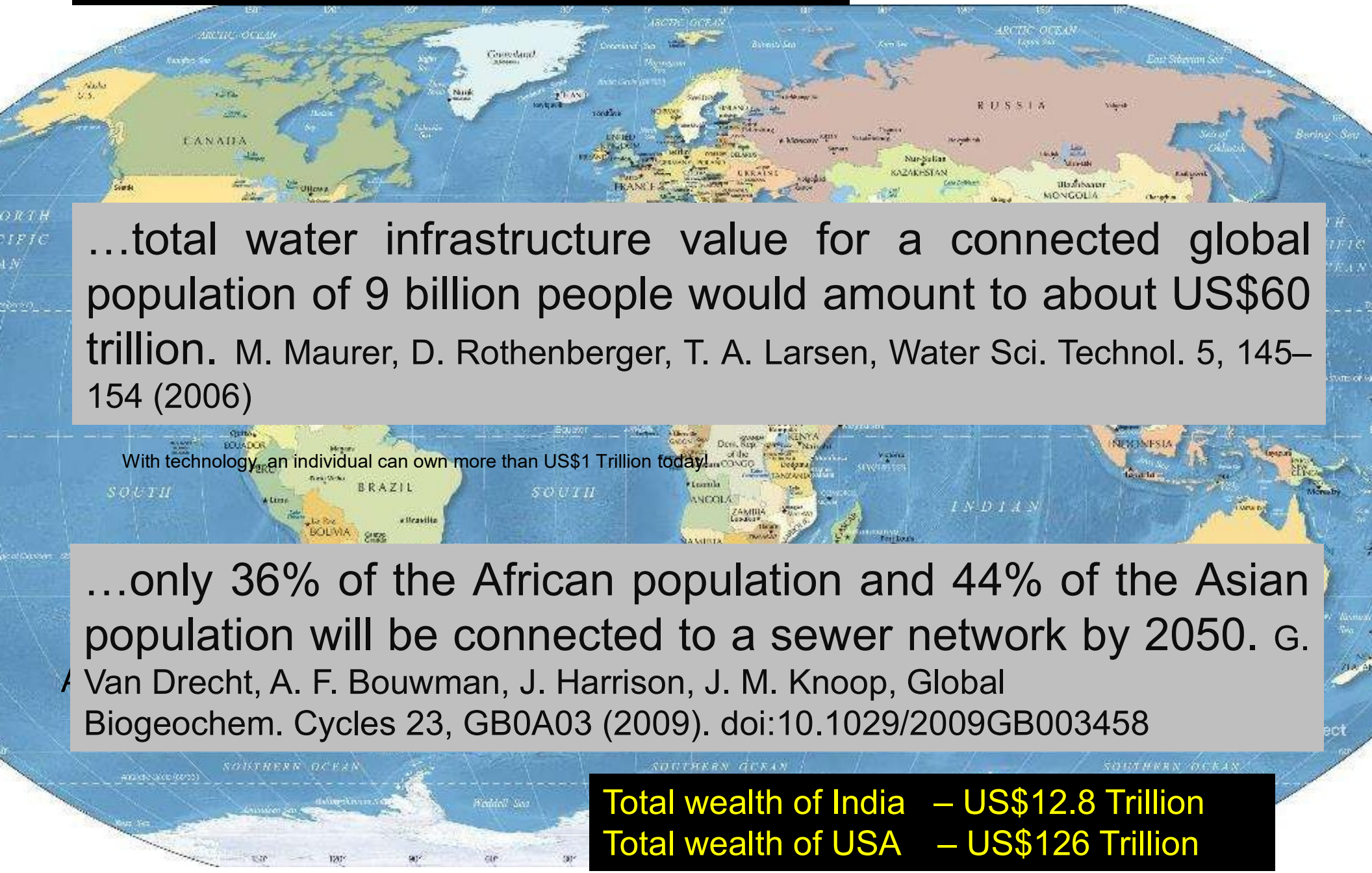
Ultra compact Low Cost
Spectral Sensor Module
~ Billions units (? 2027)



Water quality measurement – In the pipeline

nanoλ

Water, sanitation and inequality



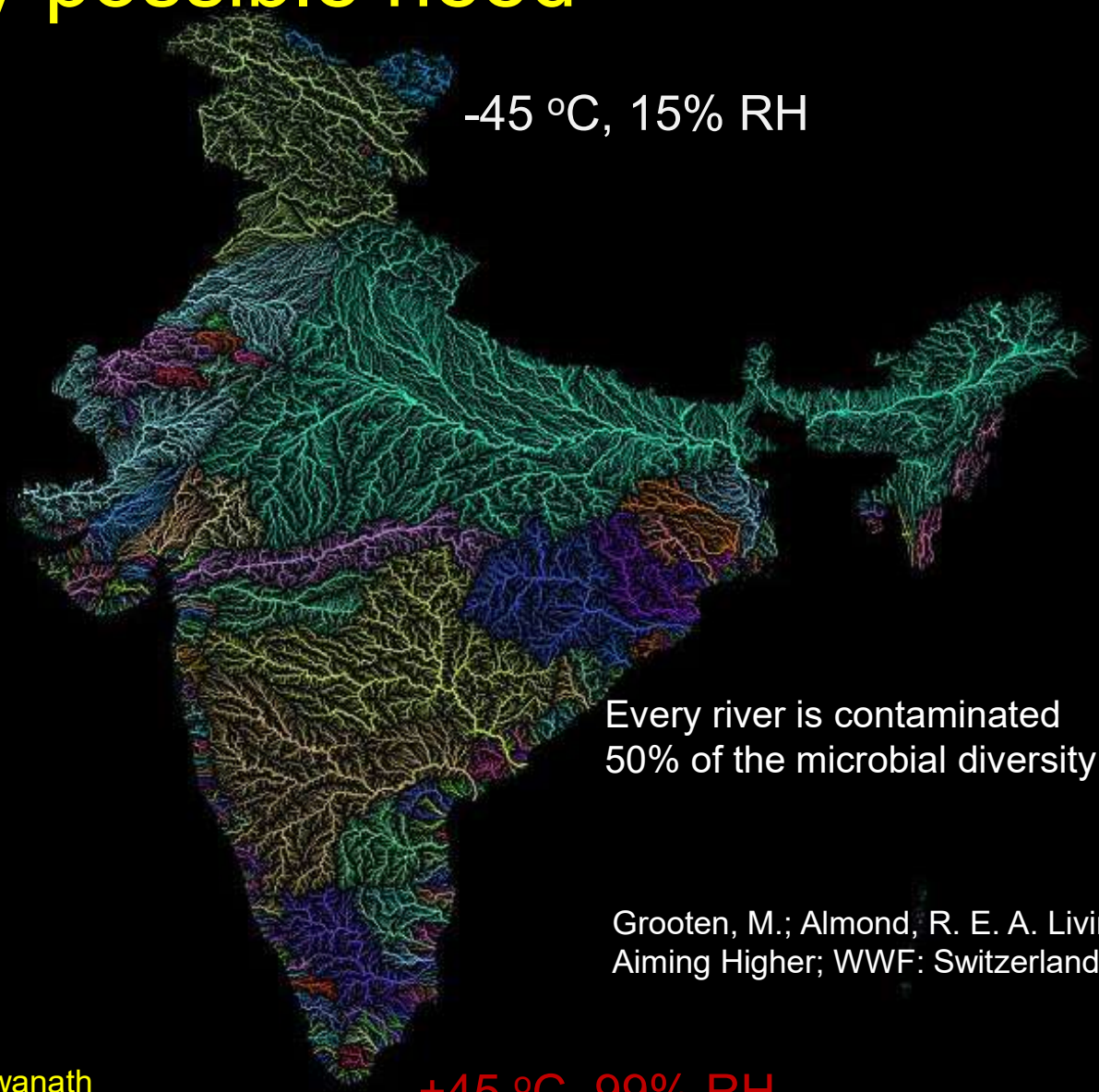
…total water infrastructure value for a connected global population of 9 billion people would amount to about US$60 trillion. M. Maurer, D. Rothenberger, T. A. Larsen, Water Sci. Technol. 5, 145–154 (2006)

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



-45 °C, 15% RH

+45 °C, 99% RH

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

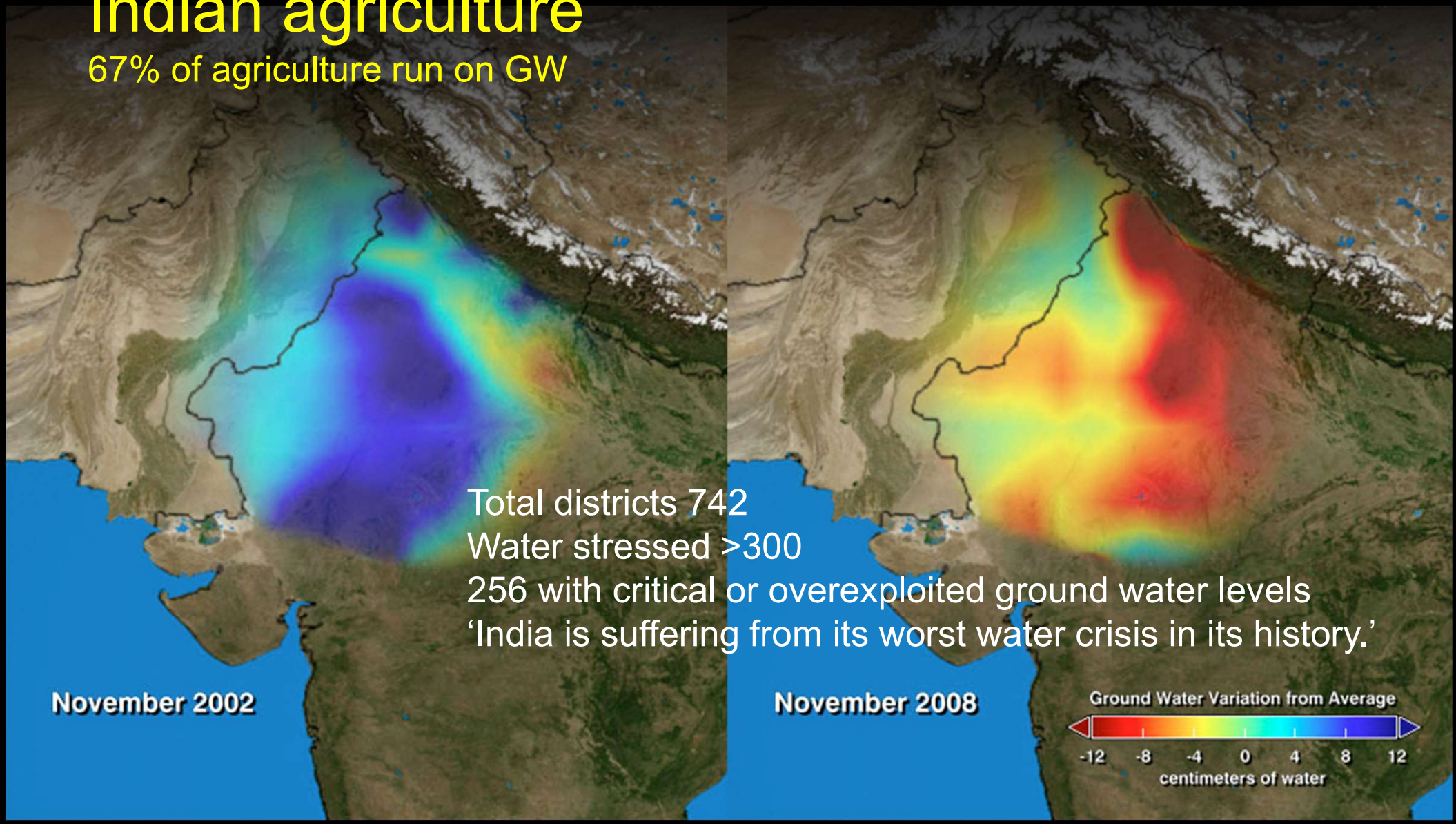
Every river is contaminated
50% of the microbial diversity is lost for ever

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

From S. Vishwanath

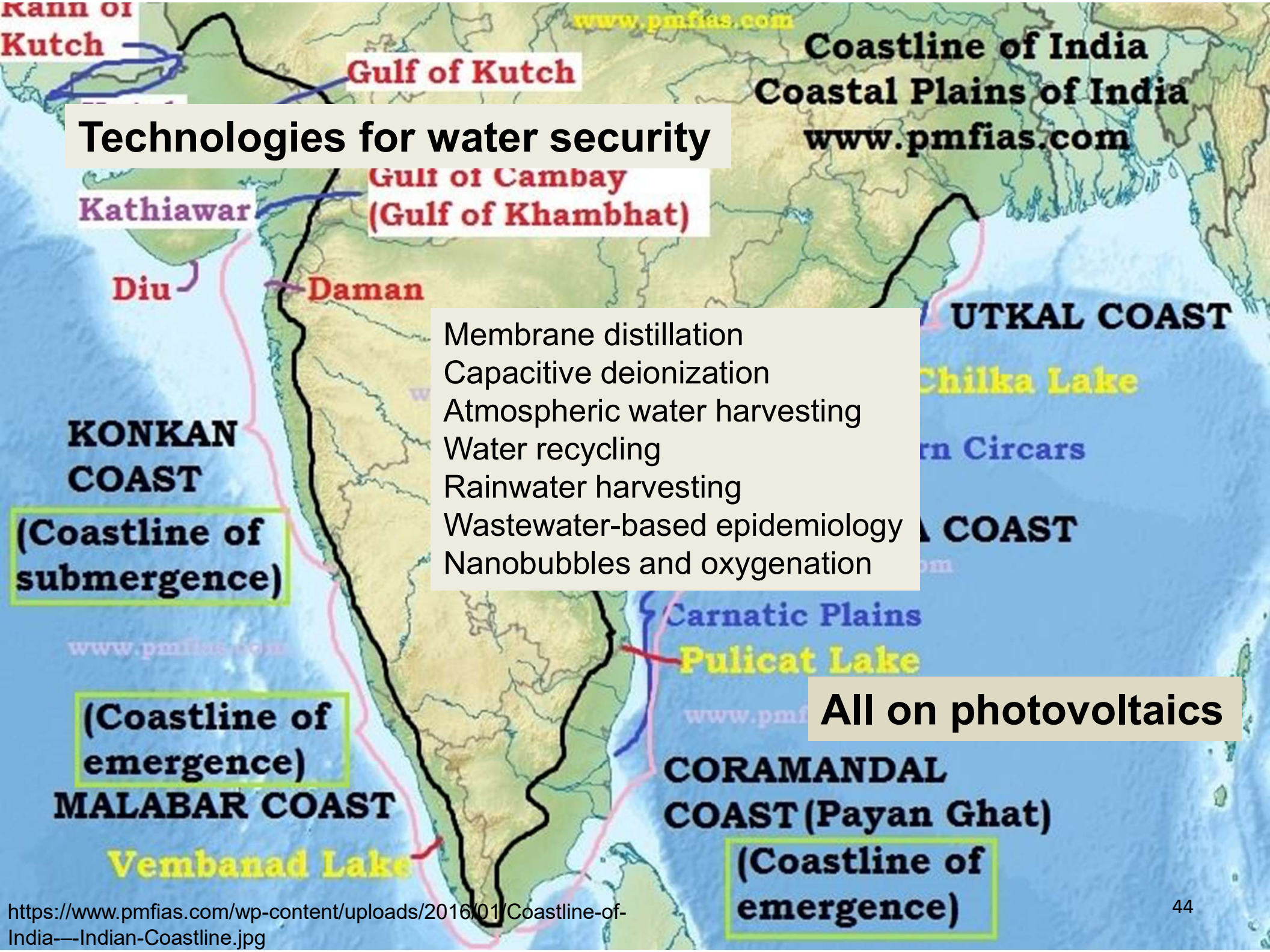
Indian agriculture

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

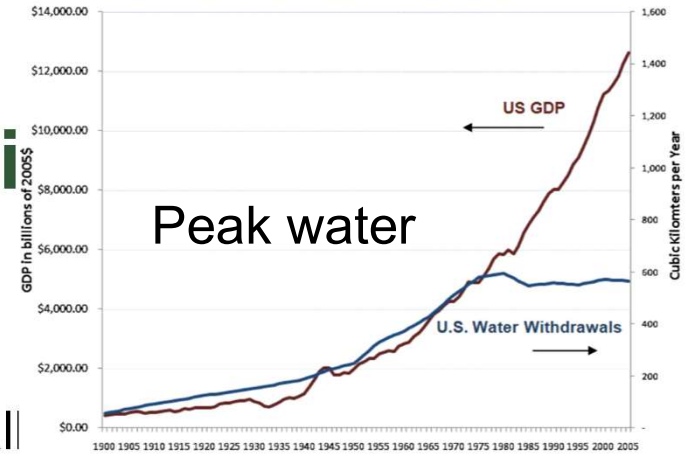


https://www.pmfias.com/wp-content/uploads/2016/01/Coastline-of-India-–-Indian-Coastline.jpg

Water is big and …. India i

Per capita water availability – 1500 CM

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 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!

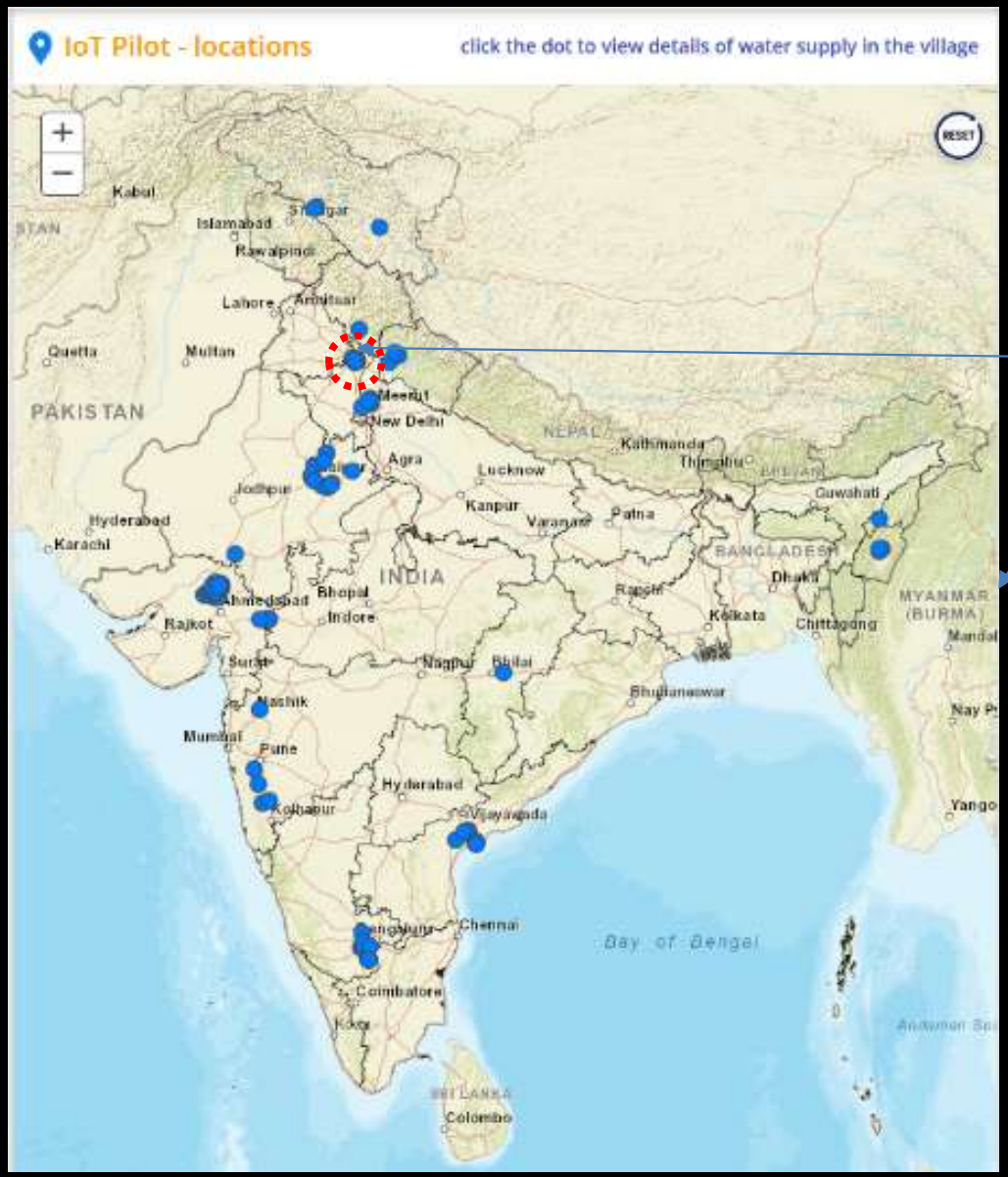
GDP can grow even by capping freshwater withdrawals

We must find technologies of relevance

Energy - food – clothing – construction – manufacturing - …..

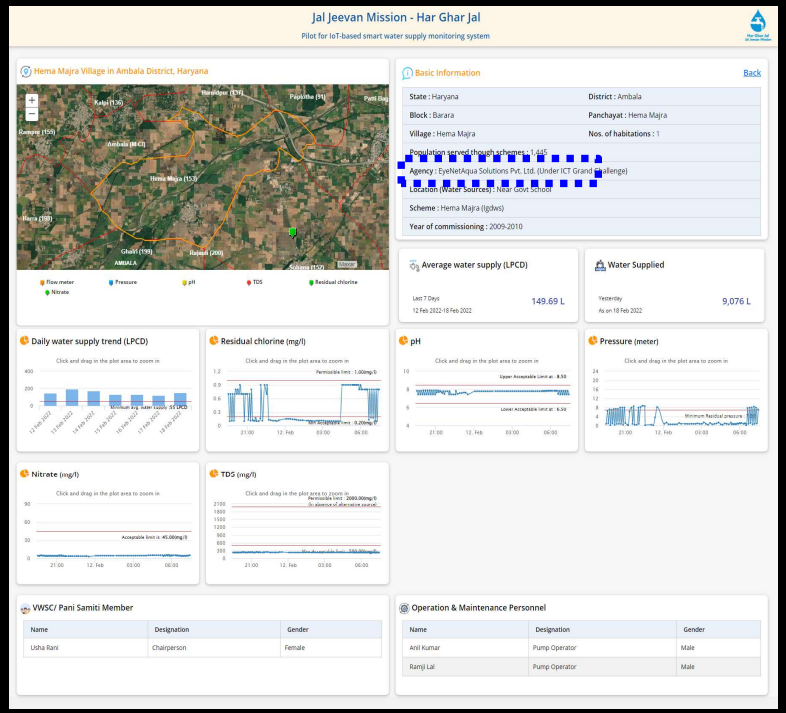
Water is big in every scale – Gaps, opportunities, wealth, satisfaction

India’s water is being monitored



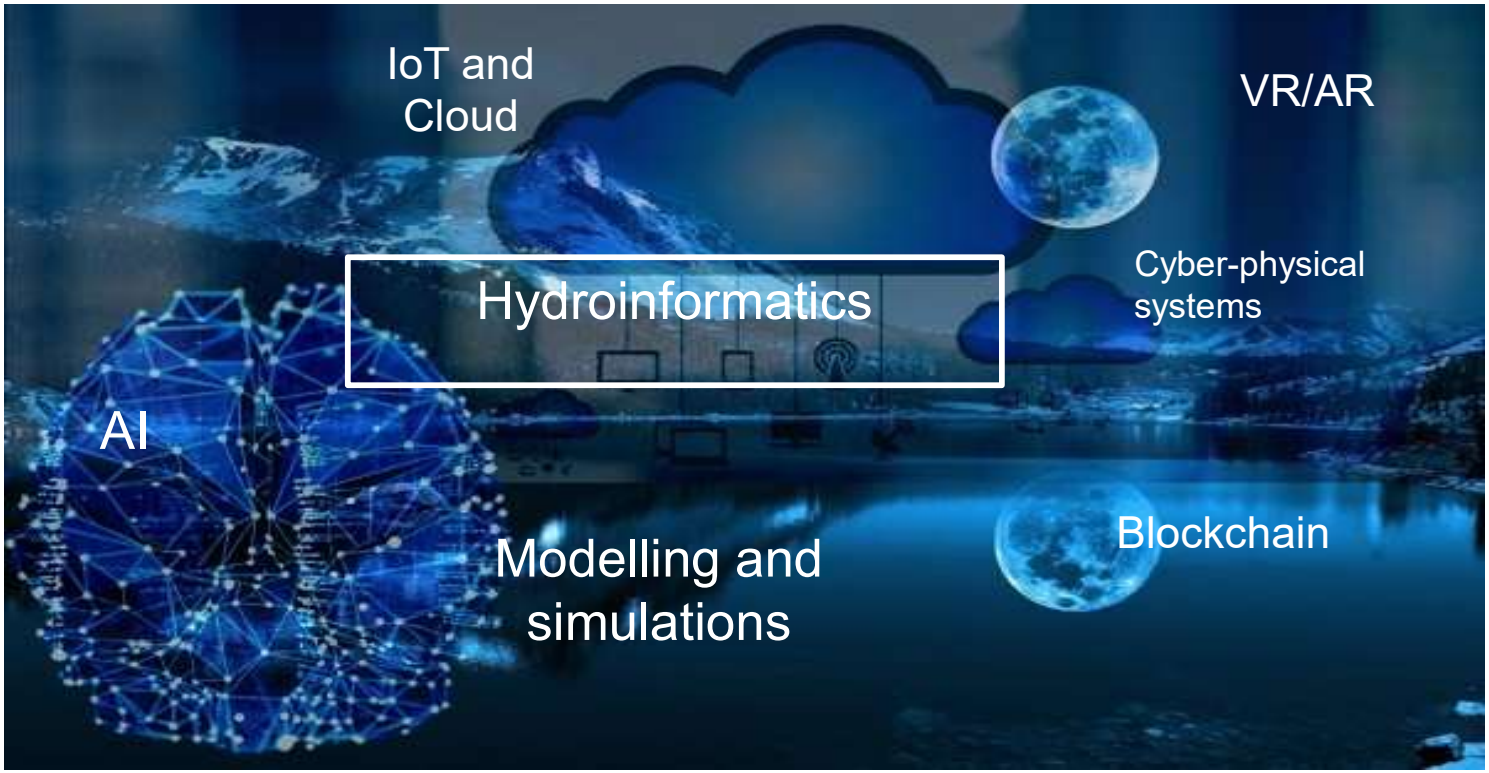
IITM/IISc

Installations made by four companies



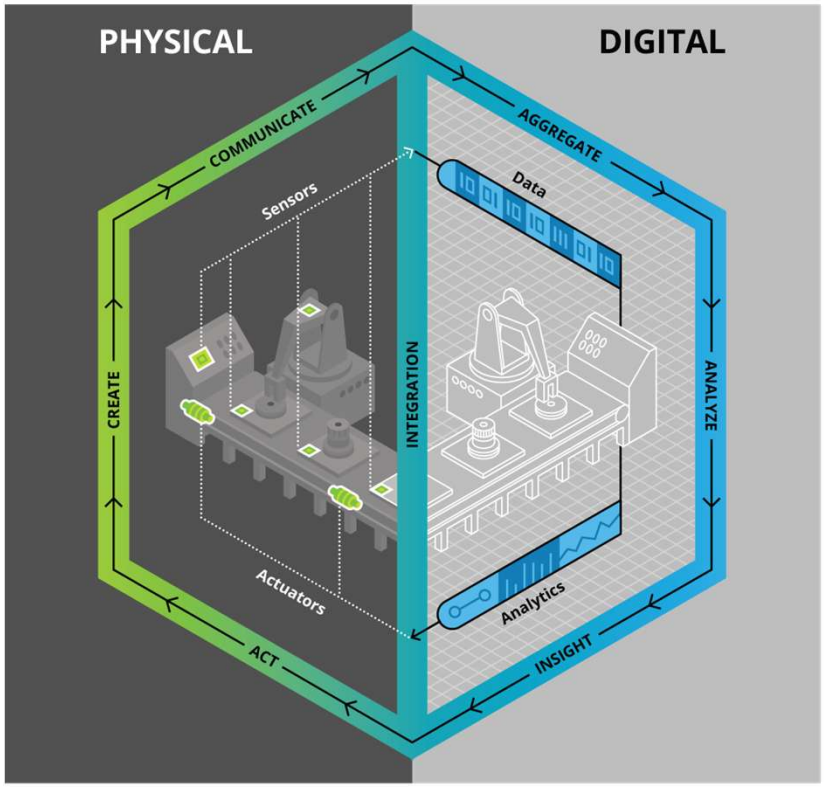
Hydroinformatics

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



Water 4.0

Digital twin of water resources



Source: Deloitte University Press.

Deloitte University Press | dupress.deloitte.com

Digital twin is the digital visualization and representation of a physical or natural system, which may gather data continuously from its physical counterpart and interact with it via a control system.

Create a digital twin of different elements of hydrologic environment – surface water bodies, ground water, rivers, and urban water utilities.

Data-driven modelling of events such as flood inundation of rural and urban areas with 3D visualization using the digital twin representation of the landscape.

Integration of real-time modelling of groundwater and surface water, water supply networks and utilities combined with analytics platform more accurate decision making.

Traditional knowledge

https://www.unnatisilks.com/blog/naturally-colored-cottons-a-regain-in-popularity/

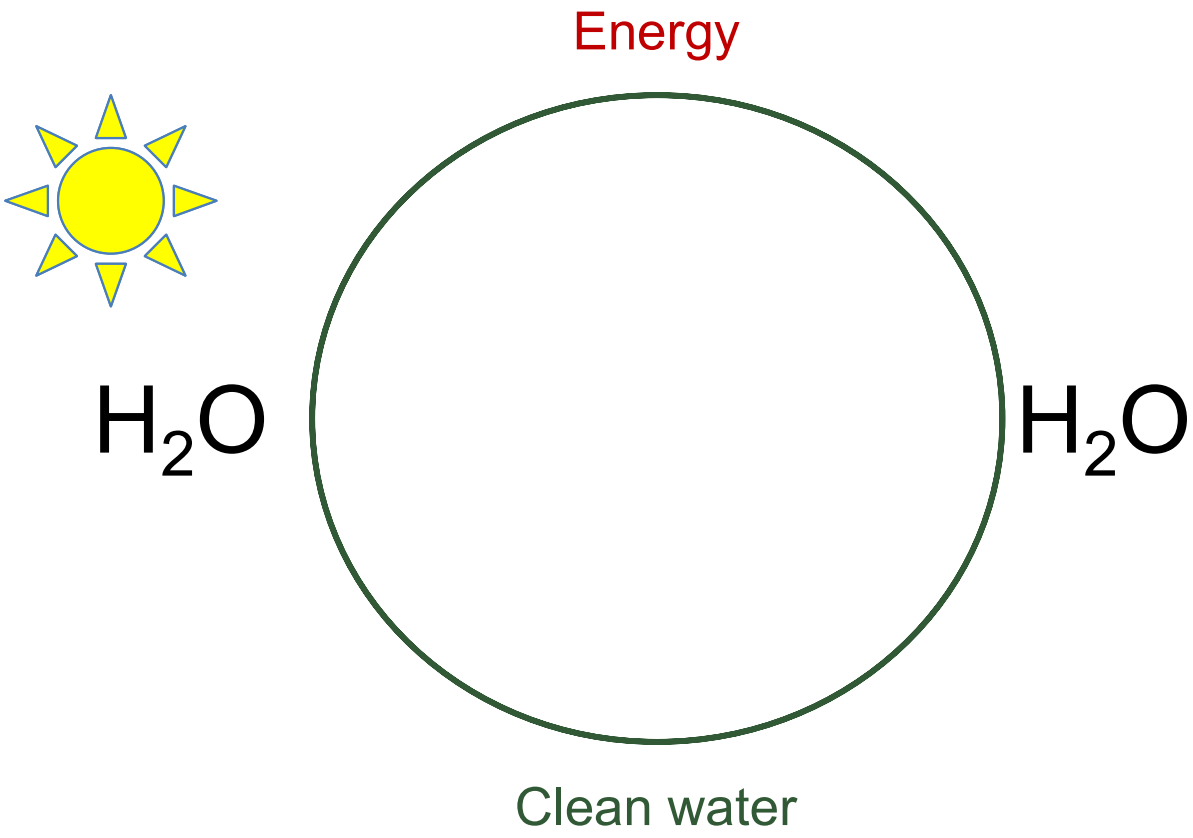
Arsenic free rice

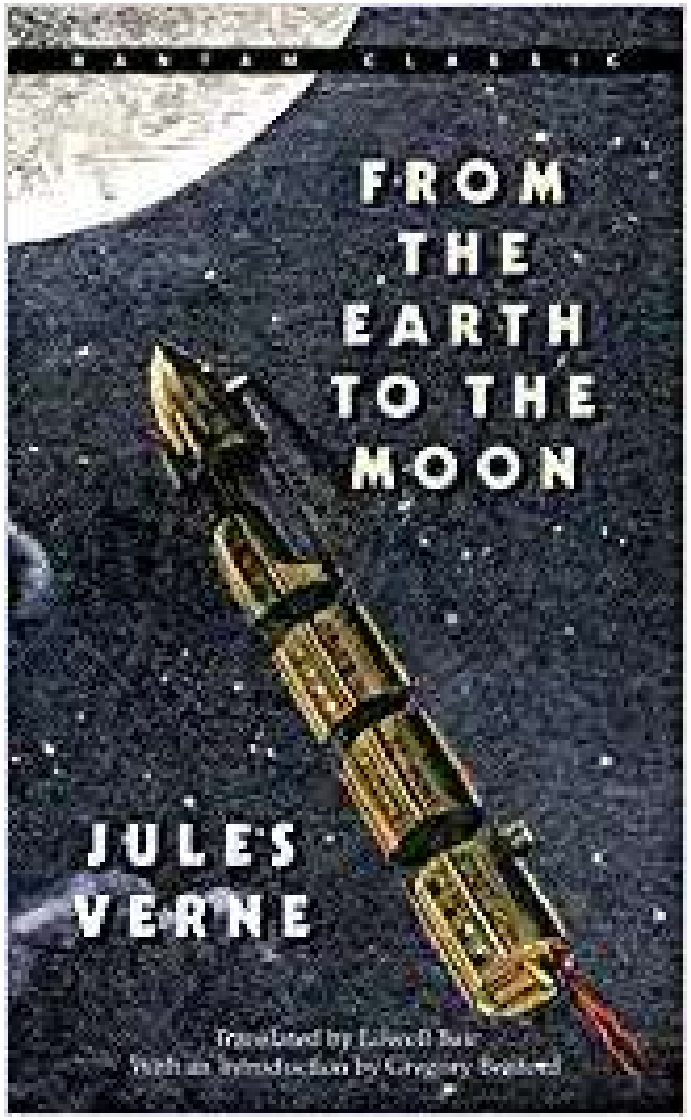
Iron rich, silver rich, etc. rice

So much is happening on the ground


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

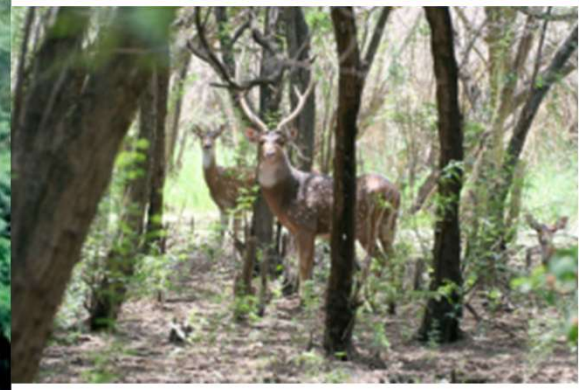
Group during 2018, along with Prof. Graham Cooks

Mahindra WORLD CITY

Our collaborators

Ministry of Drinking Water and Sanitation, Govt. of Indi

Indian Institute of Technology Madras



Directors - past and present

Associate Editor

ACS Sustainable Chemistry & Engineering

Pradeep Research Group

Thematic Unit of Excellence

Thank you all