Golden jubilee year

Since 1959

Advanced materials for affordable clean water

T. Pradeep

Institute Professor, IIT Madras

pradeep@iitm.ac.in

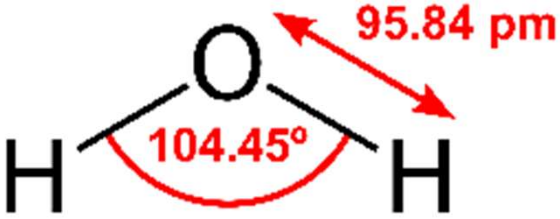
https://pradeepresearch.org

Co-founder

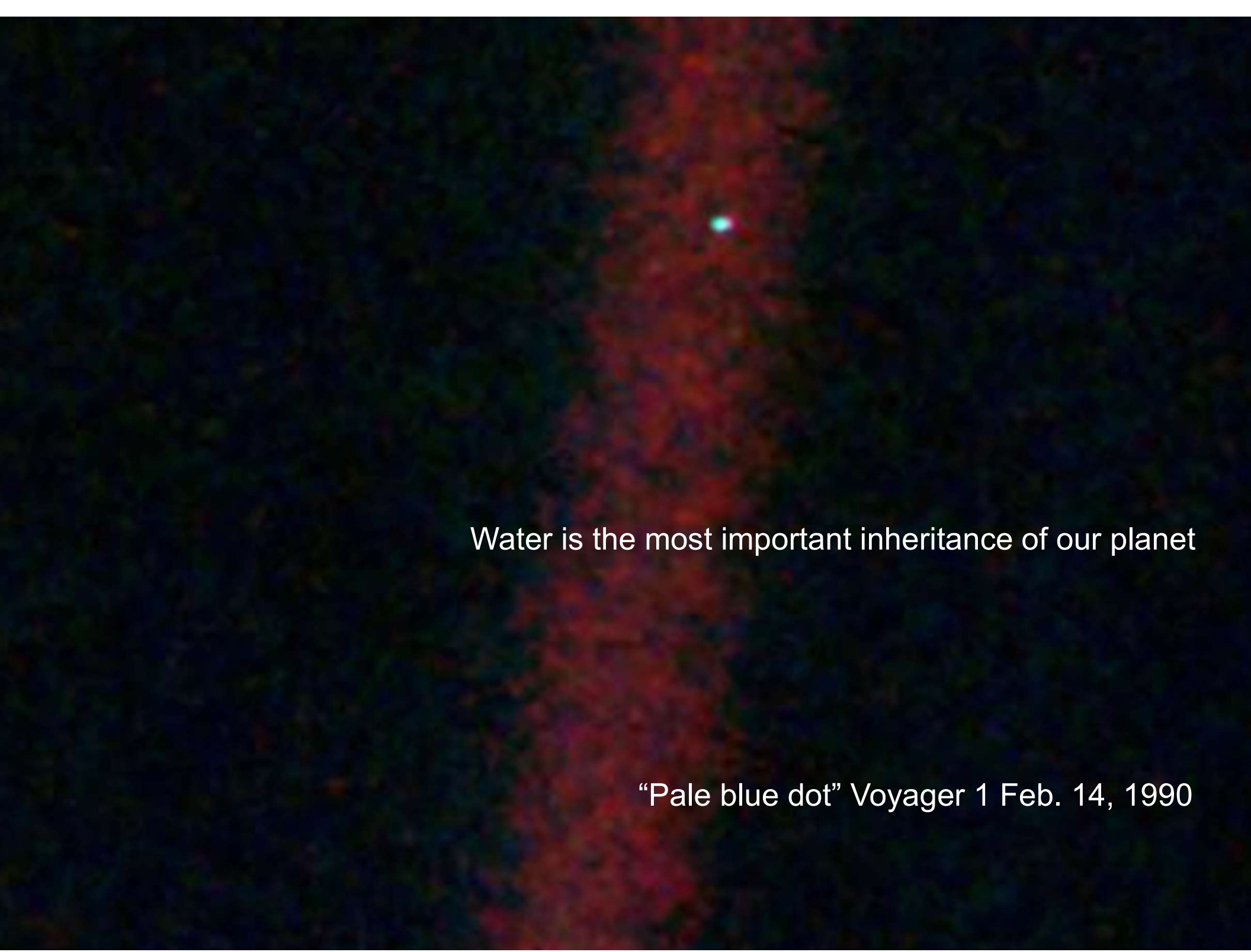
InnoNano Research Pvt. Ltd. 001
InnoDI Water Technologies Pvt. Ltd.
VayuJAL Technologies Pvt. Ltd.
Aqueasy Innovations Pvt. Ltd.
Hydromaterials Pvt. Ltd.
EyeNetAqua Solutions Pvt. Ltd.
DeepSpectrum Innovations Pvt. Ltd.

Professor-in-charge

International Centre for Clean Water



NANOicon 2022, Inter University Centre for Nanomaterials and Devices (IUCND), Cochin University of Science and Technology, Kerala, January 11-15, 2022


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

The truth

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

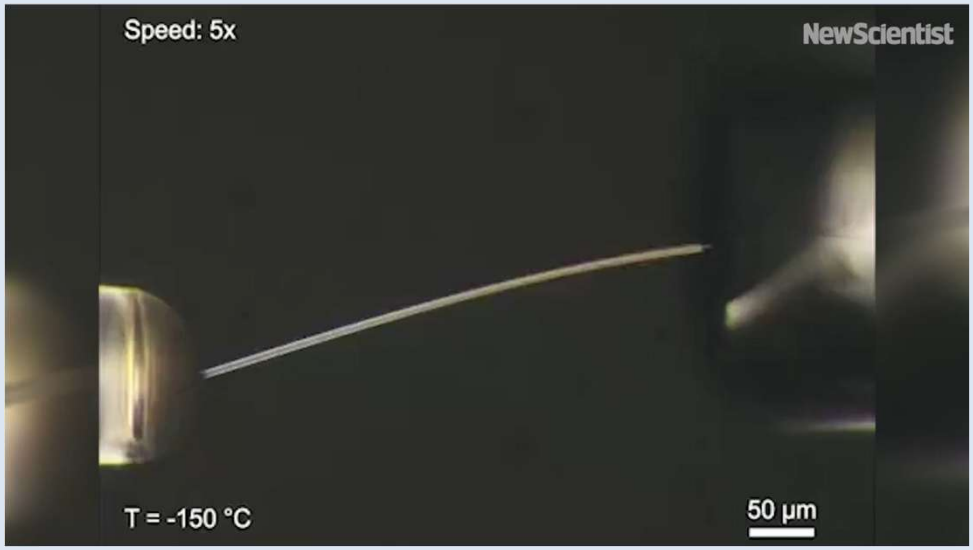
Water is the simplest and simultaneously the most complex problem of humanity.

Everything simplifies to water.

There is water in everything we do.

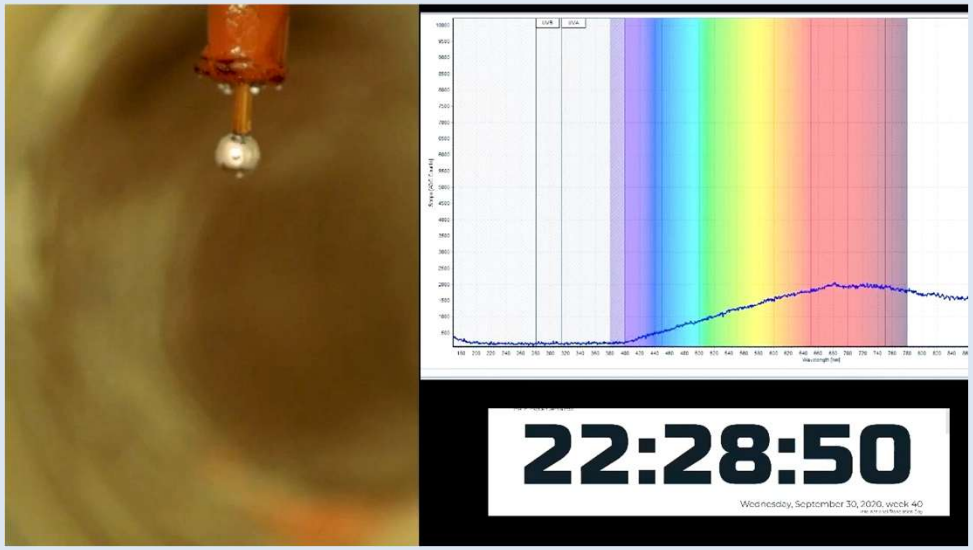
Water continues to fascinate science

Elastic ice



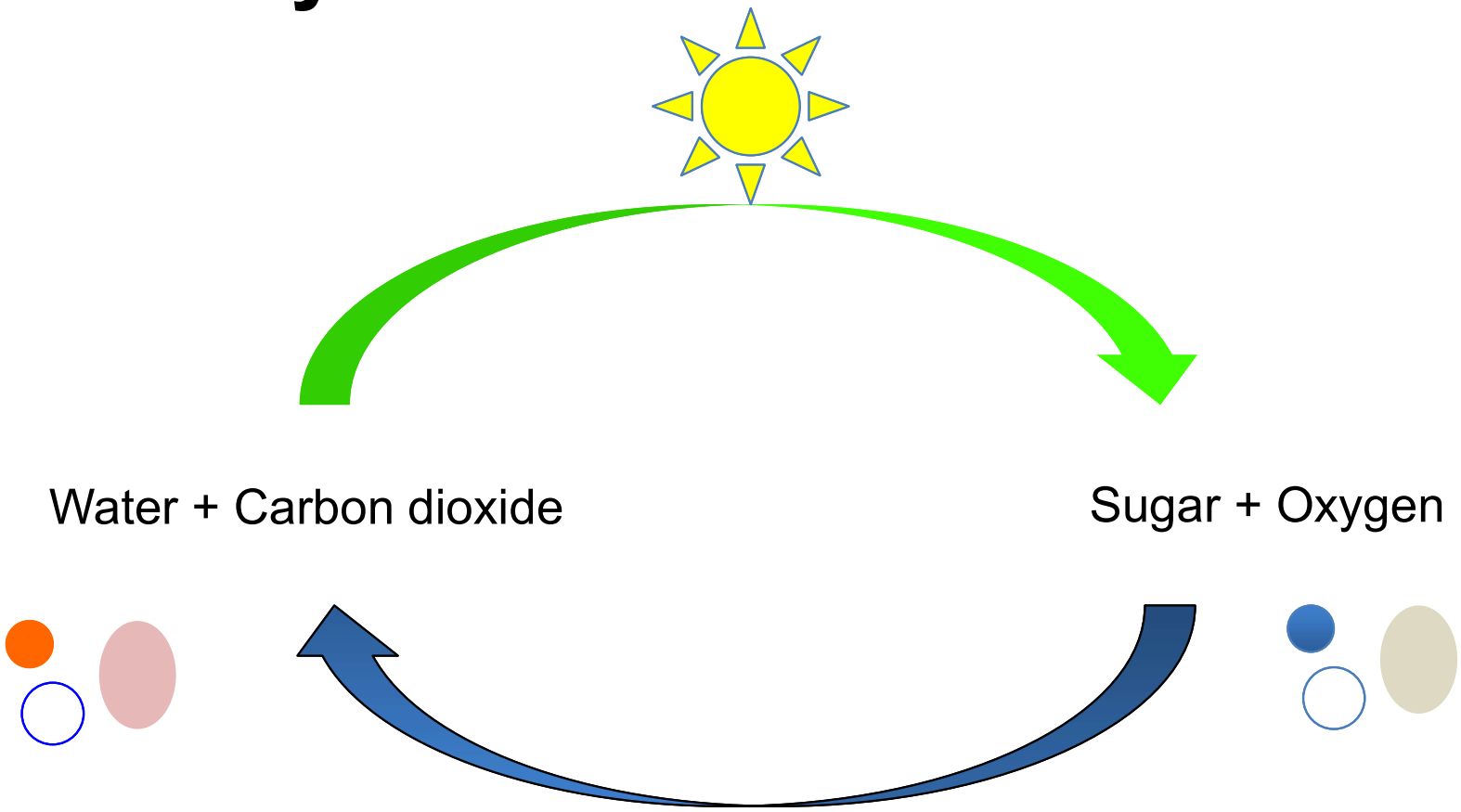
Xu, P. *et al*., *Science*, **2021**, *373*, 187–192

Metallic water



Mason, P. E. *et al., Nature*, **2021**, *595*, 673–676

Circularity and threats



258 billion tons of CO_2

105 billion tons of H_2O

29 billion tons of CO_2

31 billion tons of H_2O needed for our people

http://www.un.org/sustainabledevelopment/blog/2015/12/sustainable-development-goals-kick-off-with-start-of-new-year/#prettyPhoto

Water purification, history

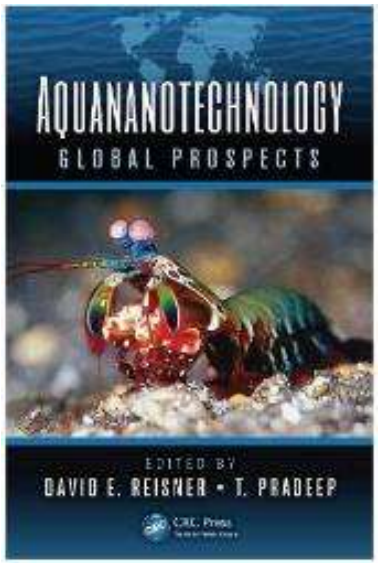
Important milestones in the history of water purification (1800–2007) from the perspective of noble metal nanoparticles in water treatment (compiled from multiple sources on the World Wide Web).

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)

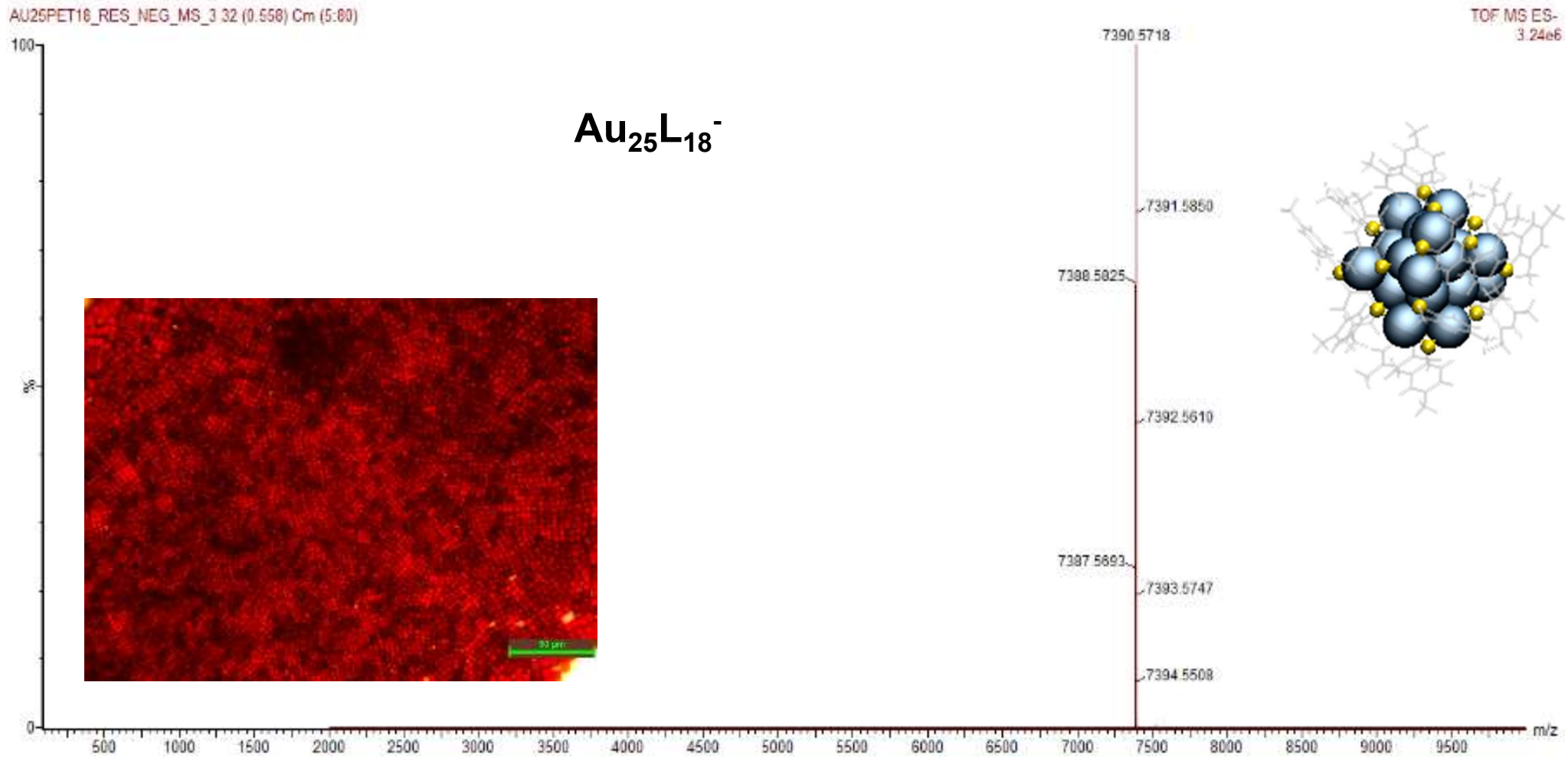
T. Pradeep and Anshup, *Thin Solid Films*, 2009

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 t
ily. The ability
ambient temp
water purifica

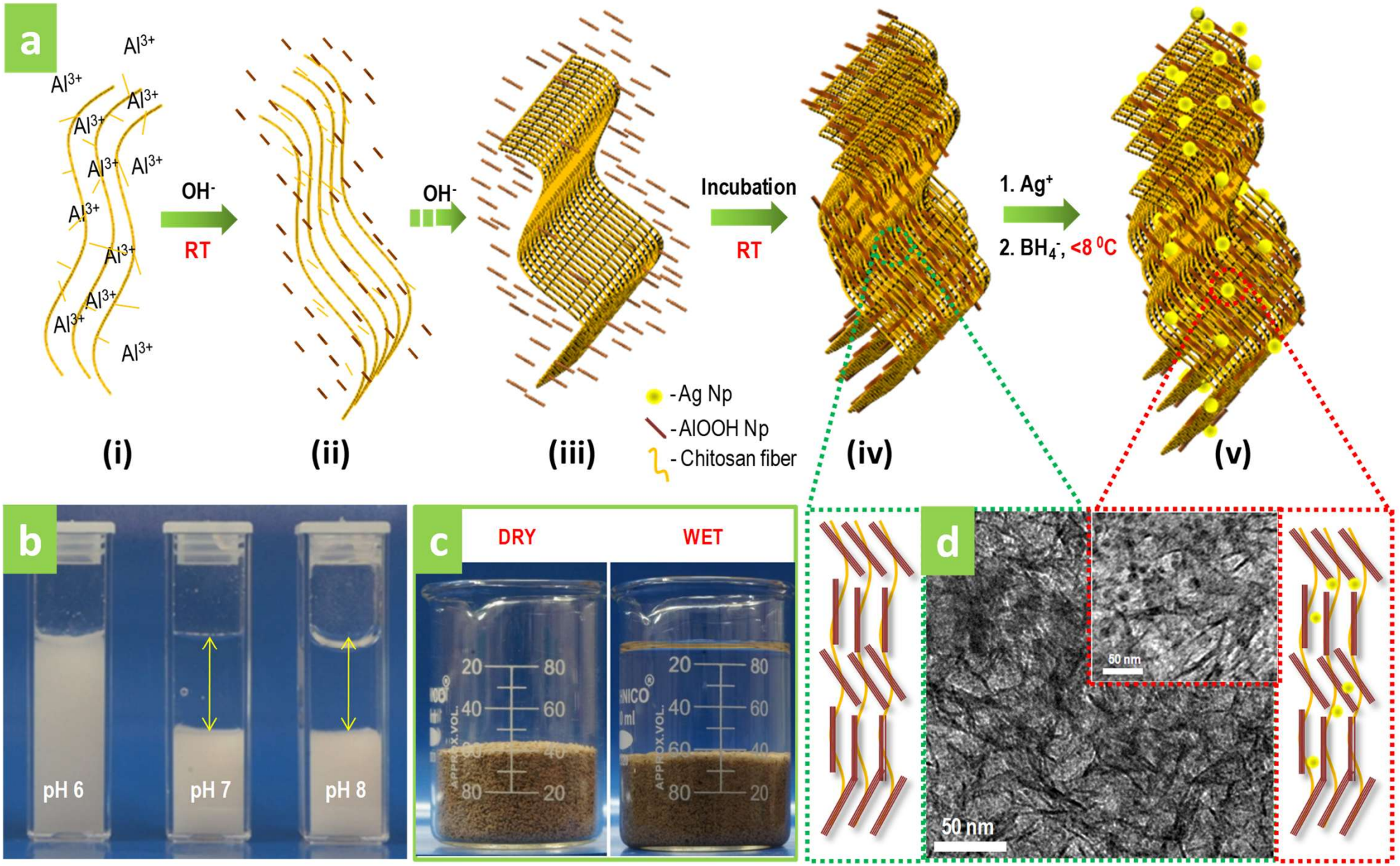
hybrid | green |

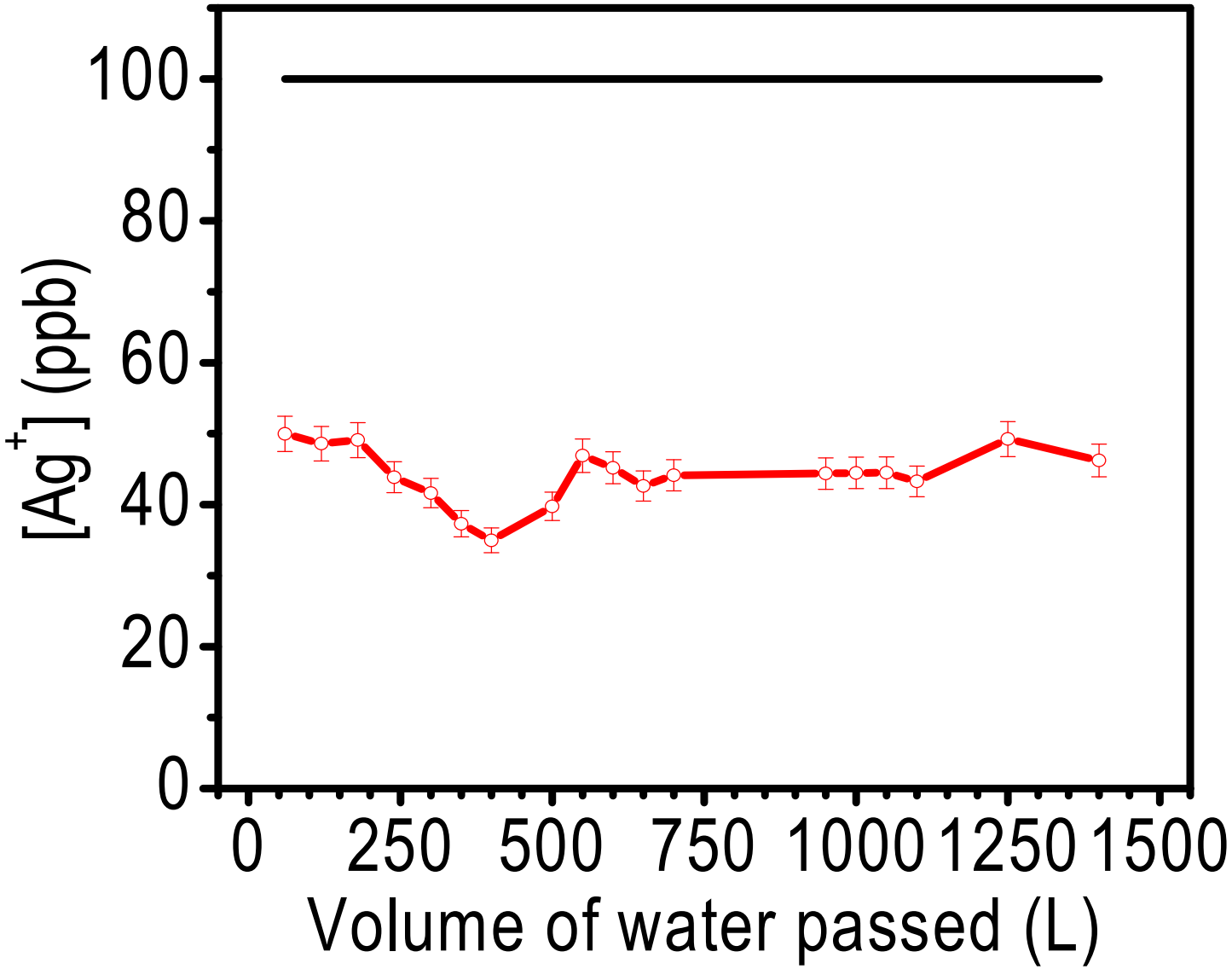
release into water are not available; and (*c*) continued retention of the nanoparticles in the matrix is difficult.

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- l -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-ctron 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.

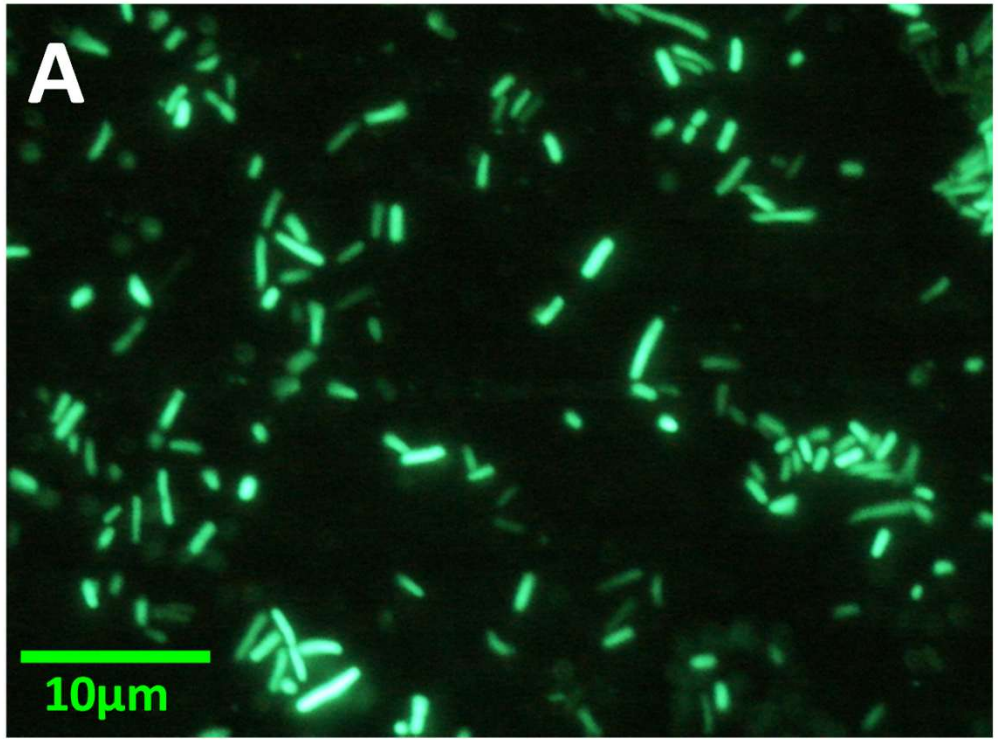
ults and Discussion

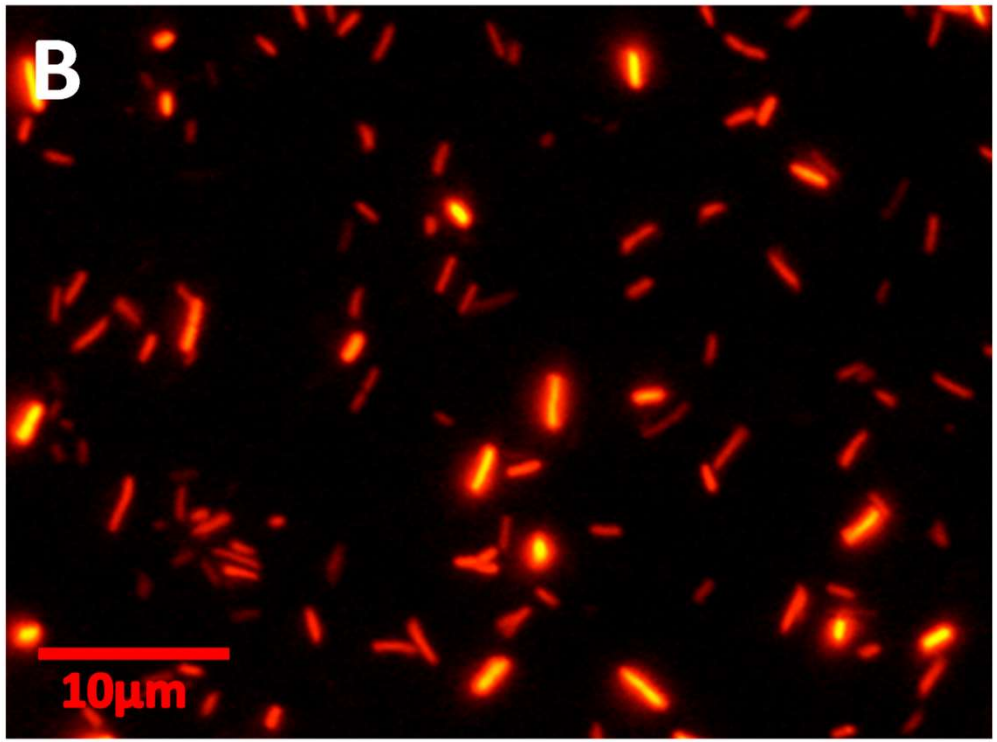
New materials

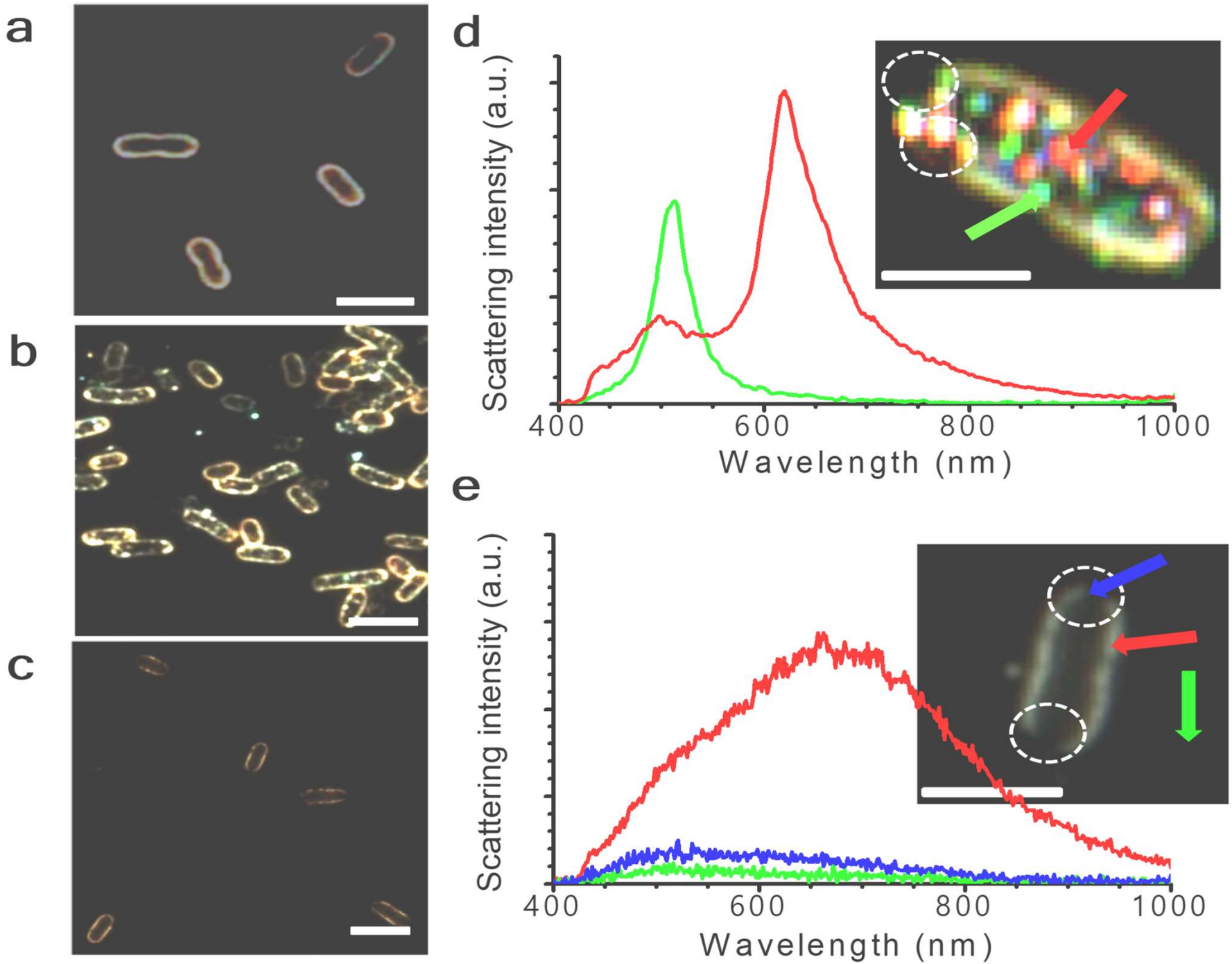


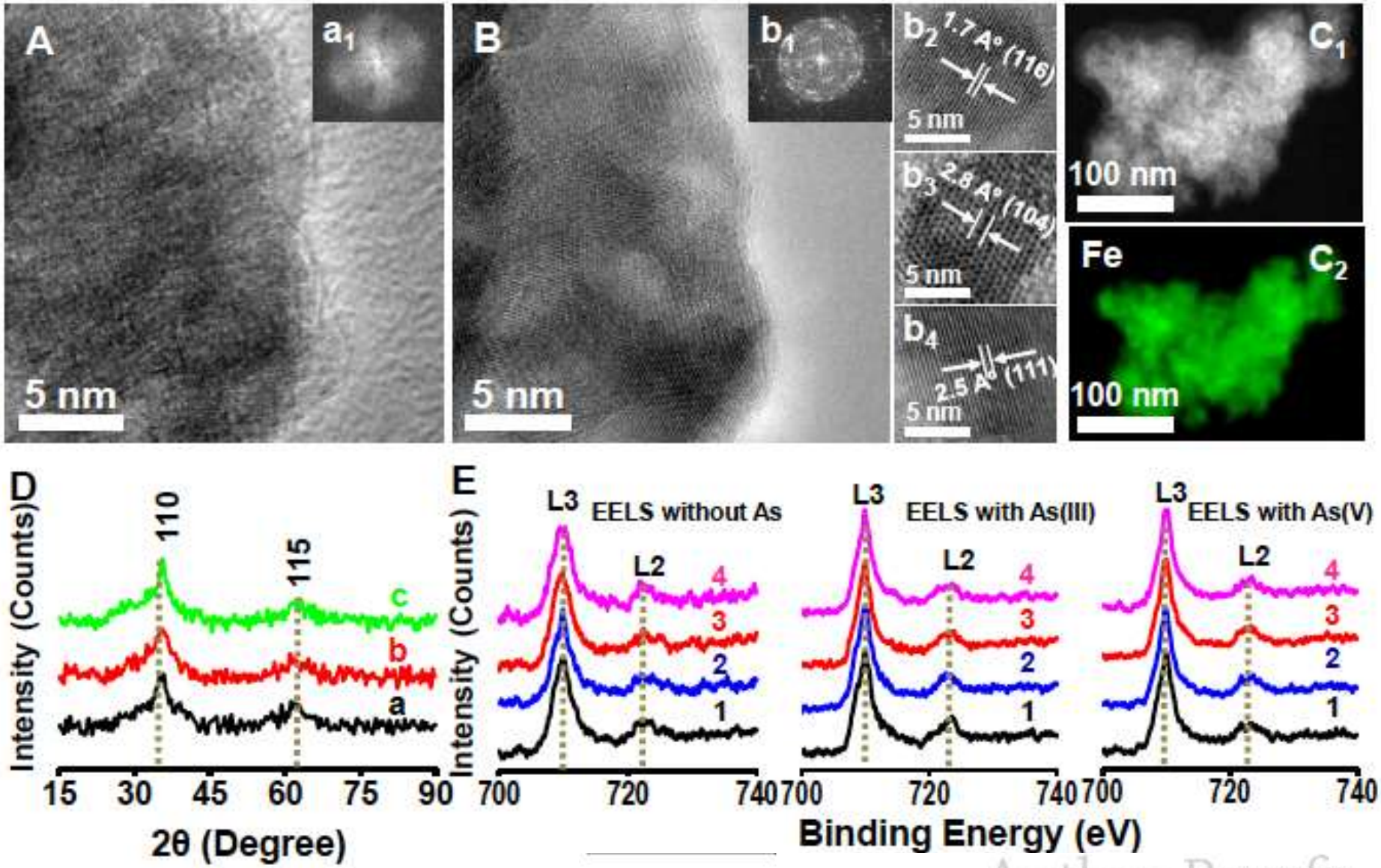

100
80
60
40
20
0
[Ag+] (ppb)
0
250
500
750
1000
1250
1500
Volume of water passed (L)

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)



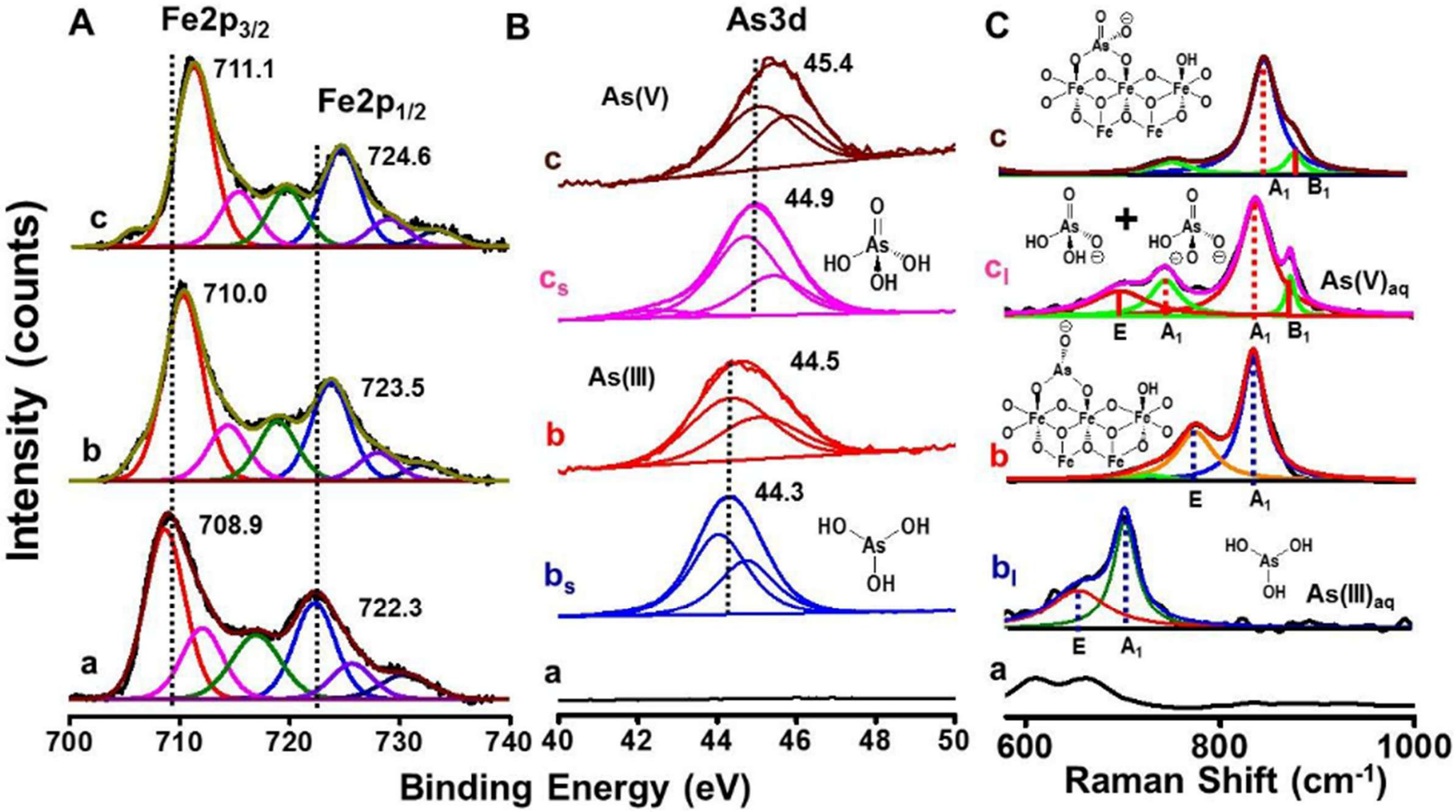
www.advmat.de ADVANCED MATERIALS

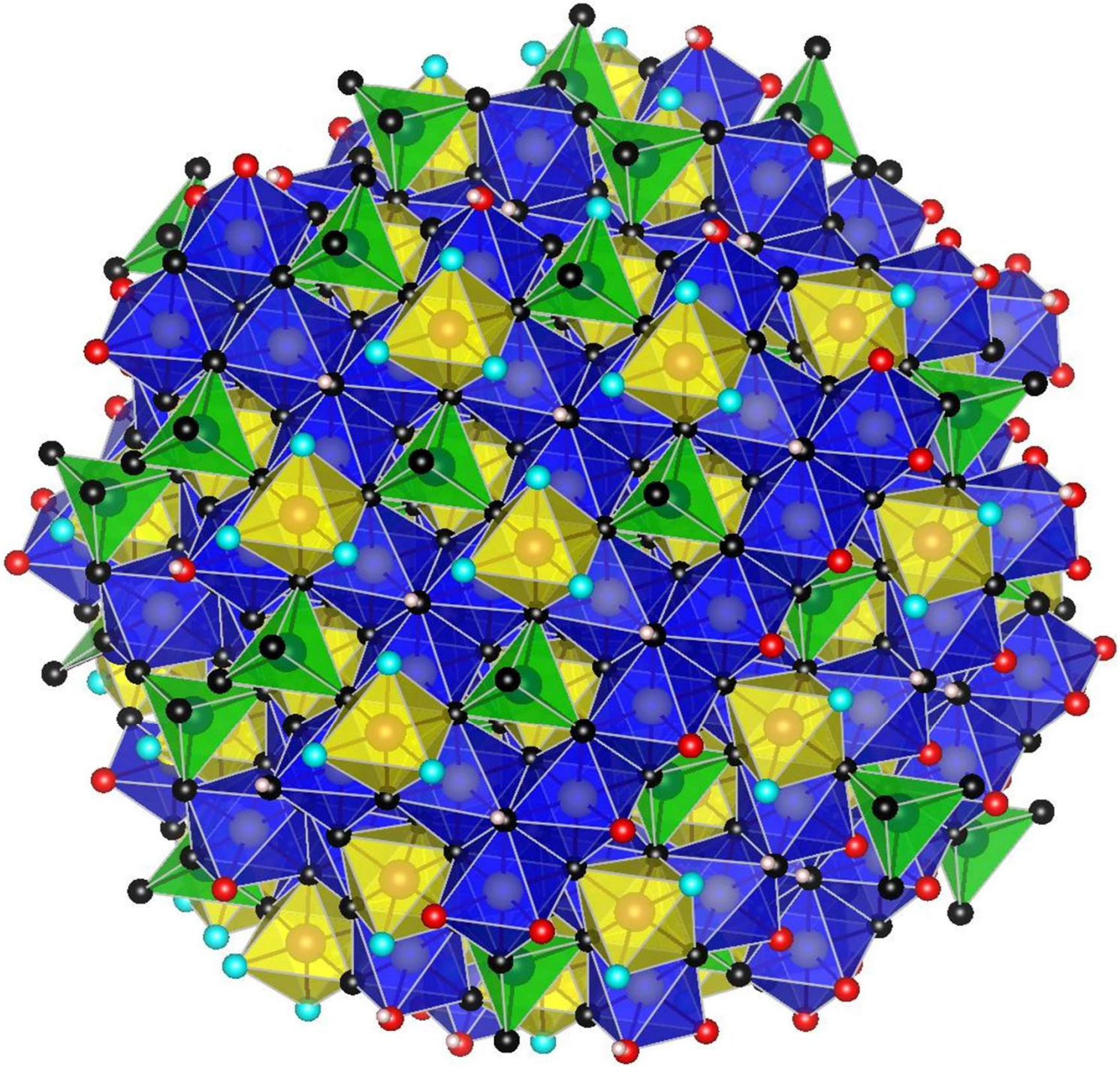
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

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**

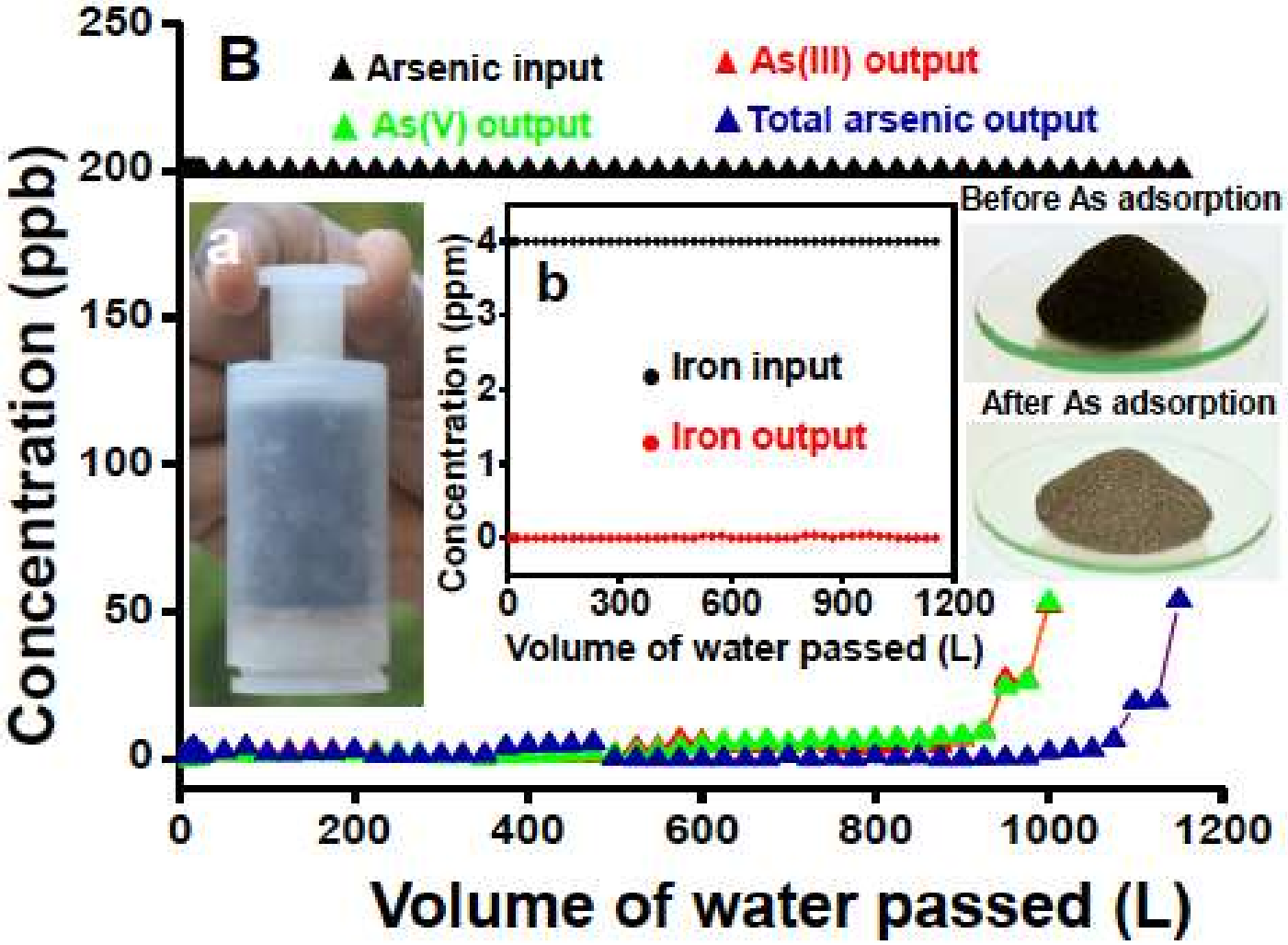
A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

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



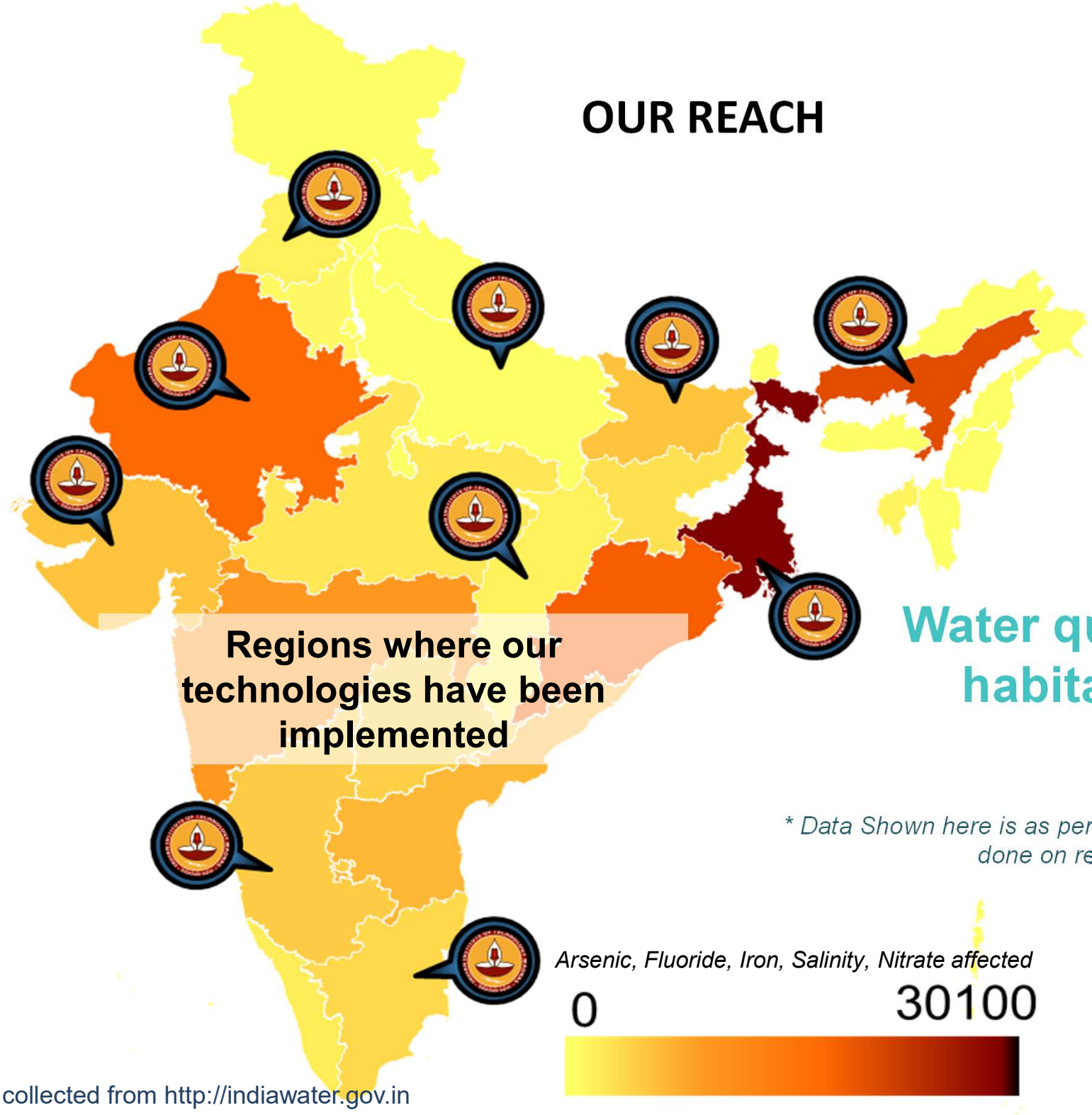
A. Anil Kumar, et. al. *Adv. Mater.*, 29 (2016) 1604260.

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

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)

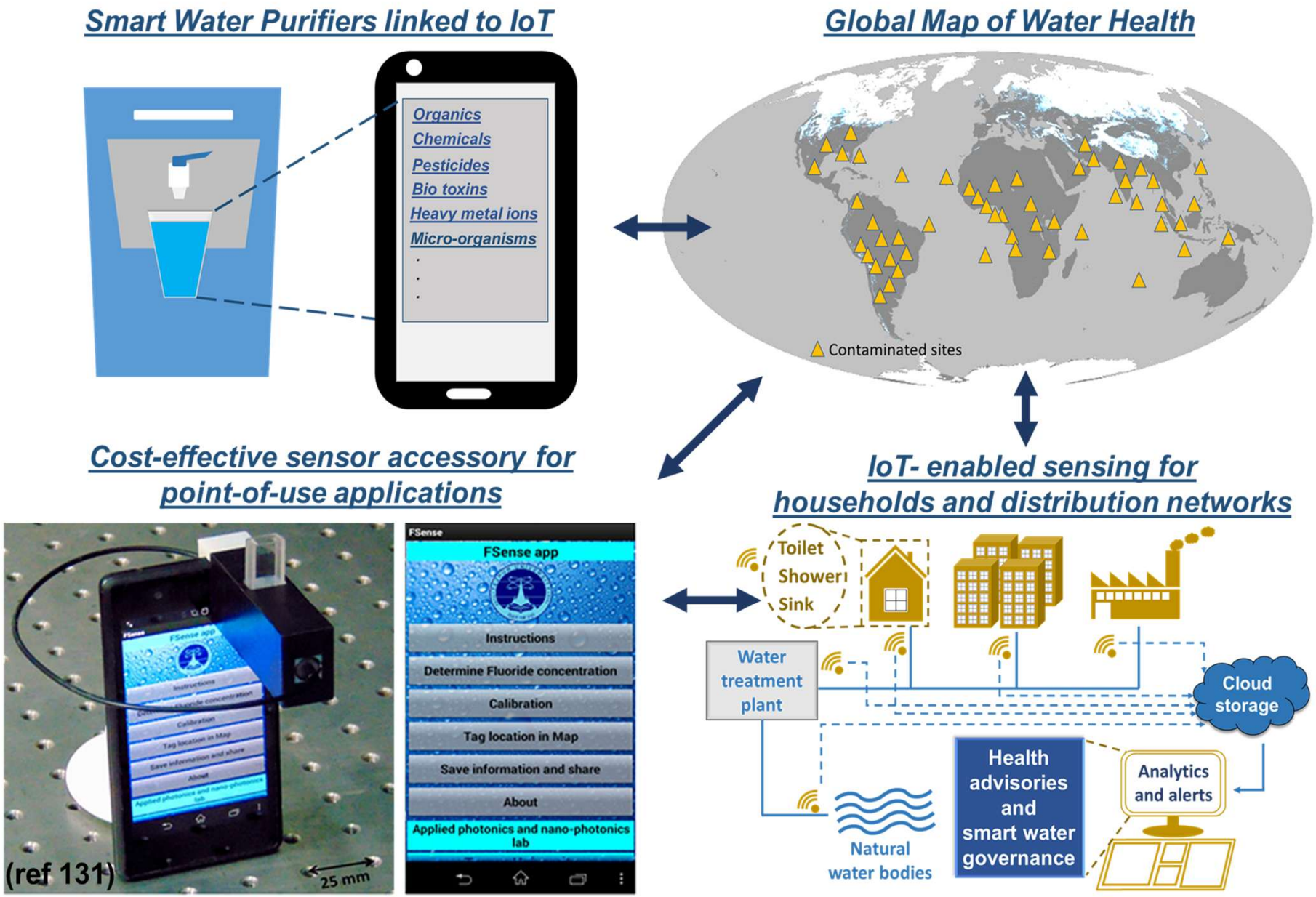
Name of the scheme: Mahilan Wala (TW9144), District: Amritsar
Population: 2610, Daily demand@70 LPCD: 188 kLD, OHSR Capacity: 100 kL

Cleanwater at 2.1 paise per litre!

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

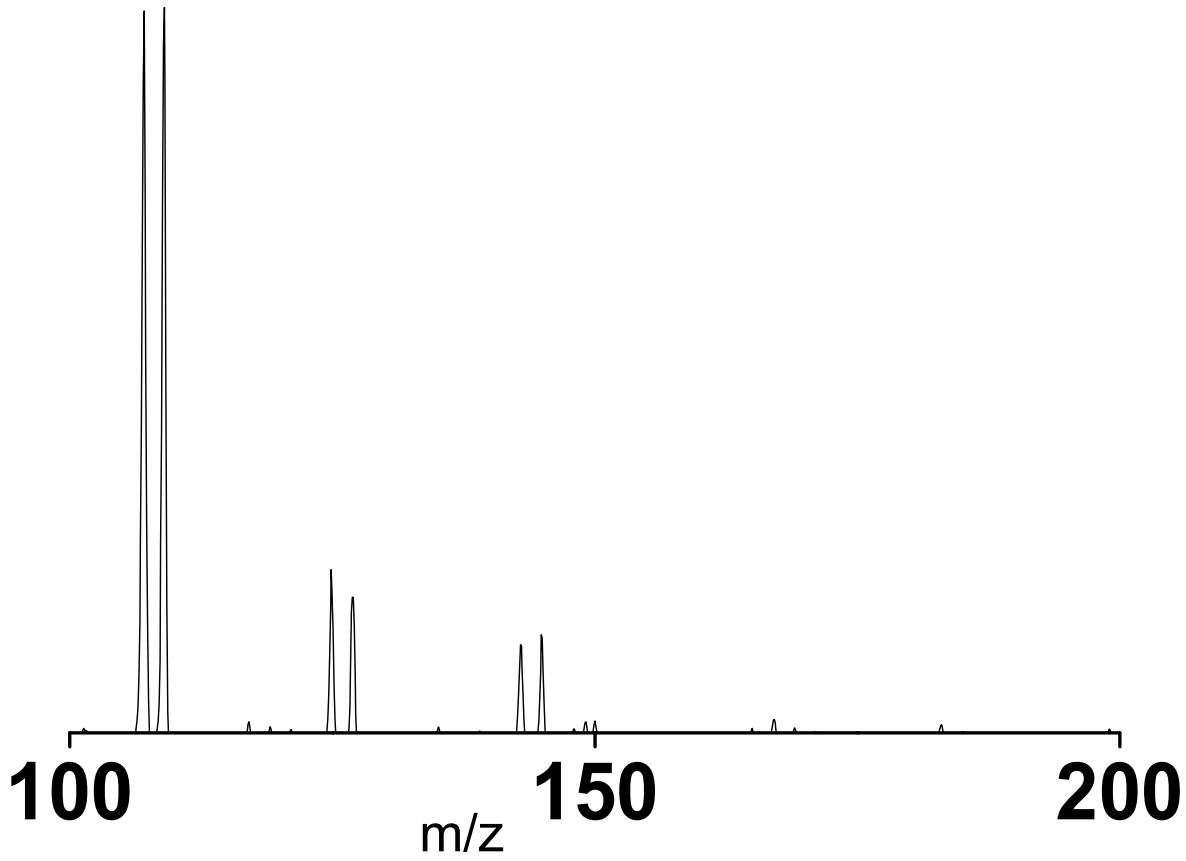
	Design population	1,071	Plant capacity/70 LPCD
Sr.No.	**Item/Description**	**Cost / Quantity**	**Remarks**
1	Cost of Replacement of Iron removal media	56400	After minimum two years if Iron concentration is more than 5 ppm. But iron concentration is more than 5 ppm at only two to three places. Therefore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

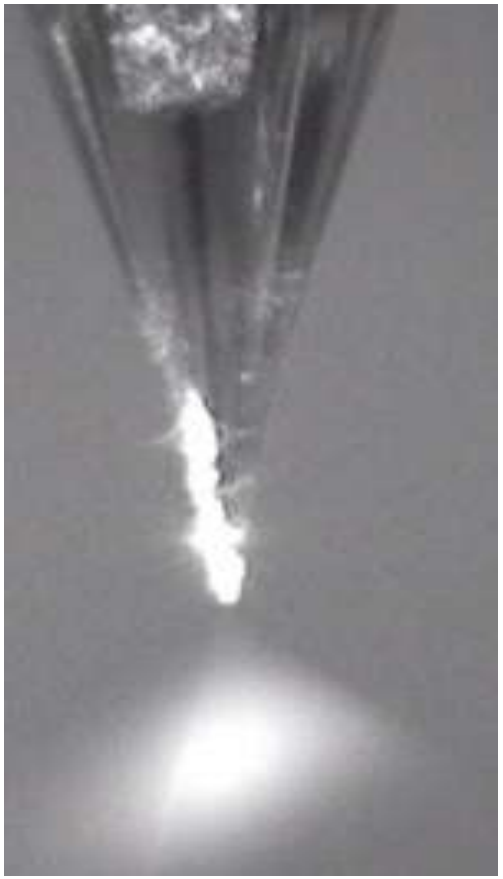
Smart water purifiers and big data



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

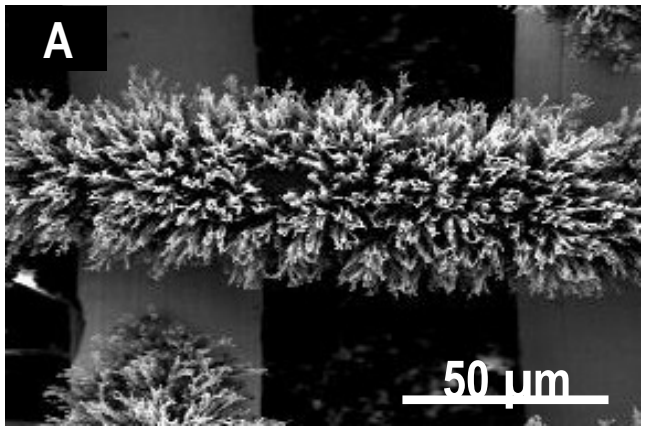
Atmospheric water harvesting

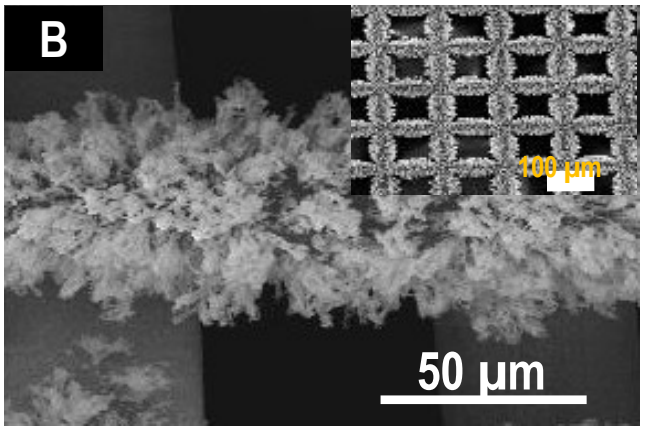


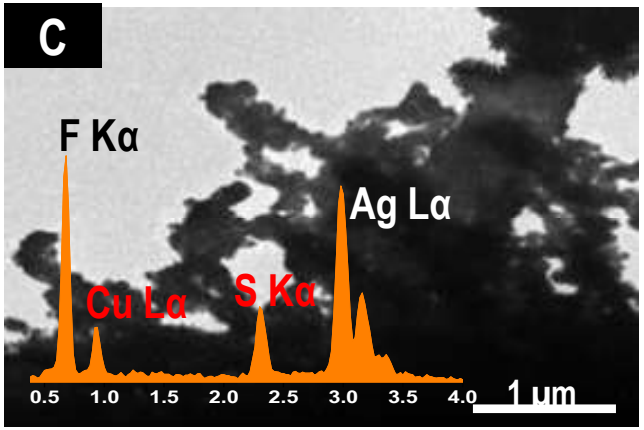


New harvesters

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

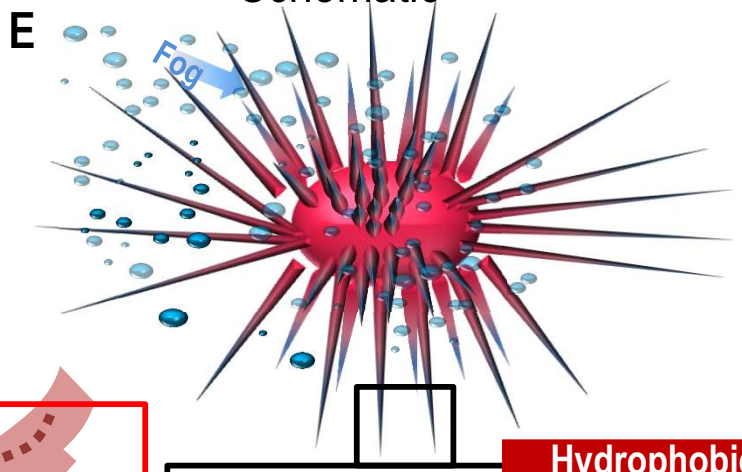




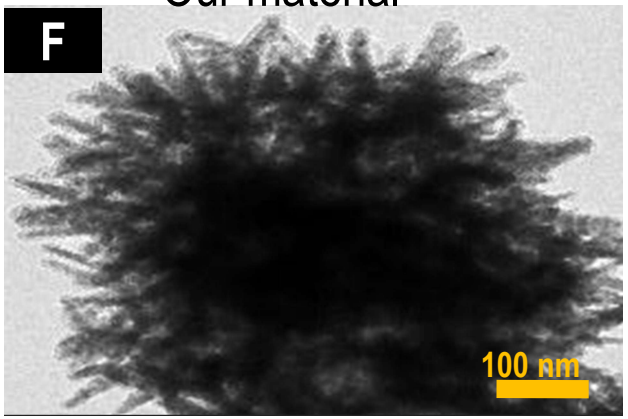


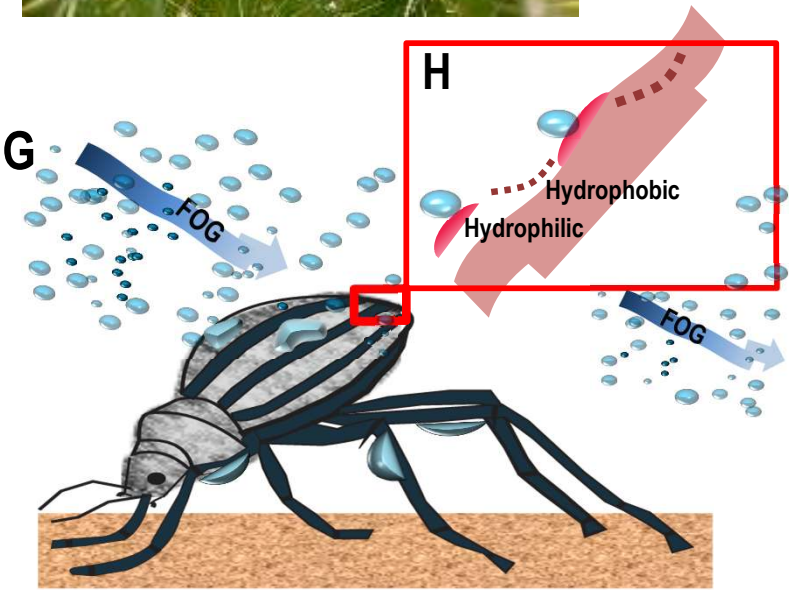
Nature

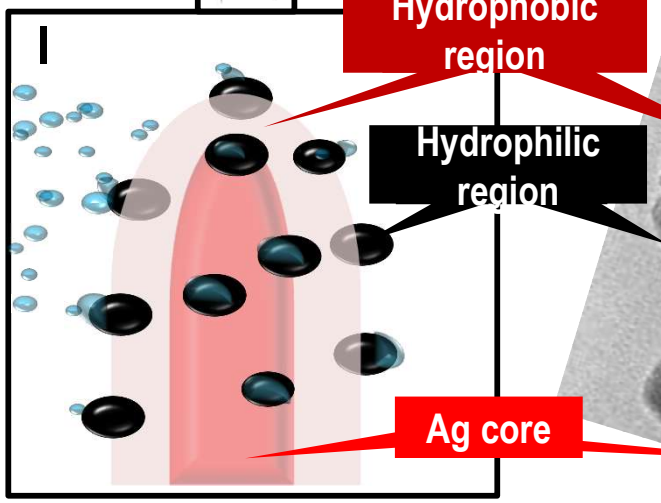
Schematic



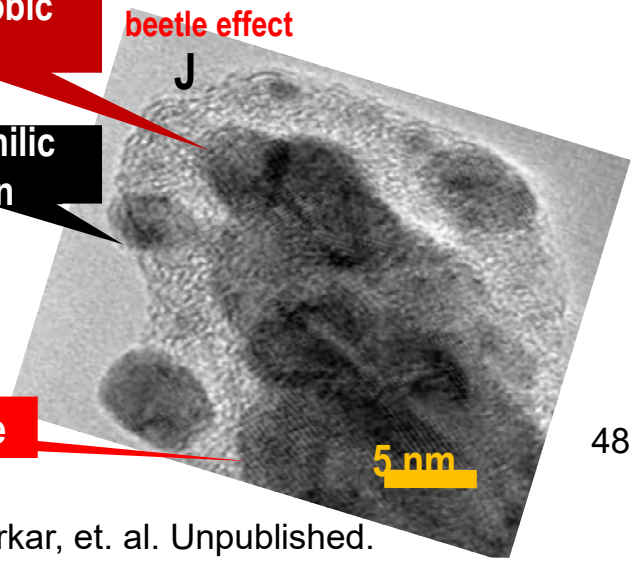
Our material



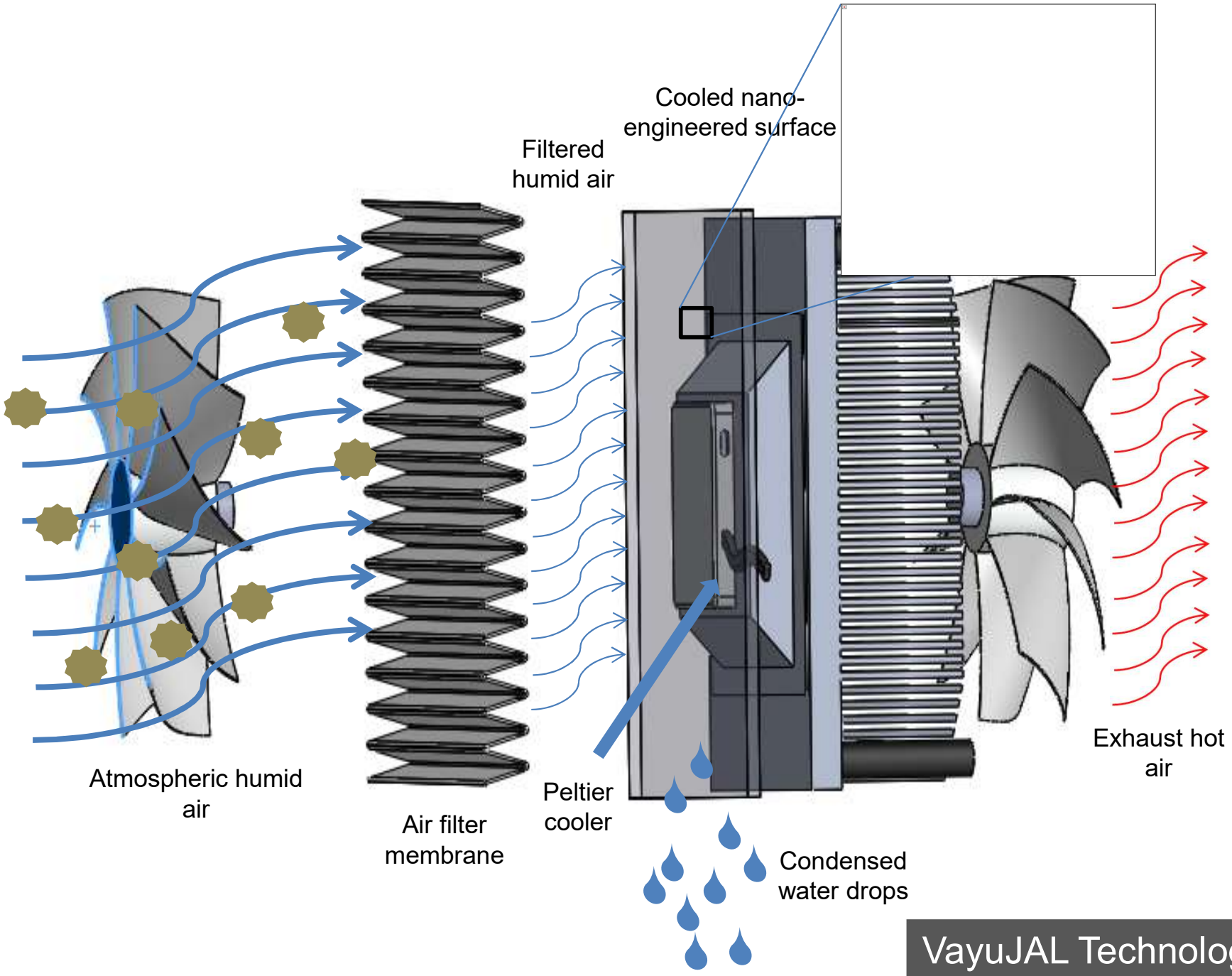




Combination of cactus and Namib desert beetle effect



Depanjan Sarkar, et. al. Unpublished.

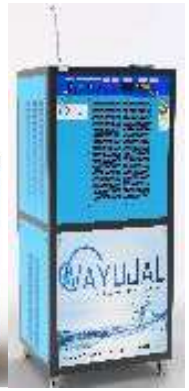


VayuJAL Technologies Pvt. Ltd.

Ramesh Kumar Soni and Ankit Nagar

Products in the field

35 LPD



120 LPD

400 LPD

1000 LPD

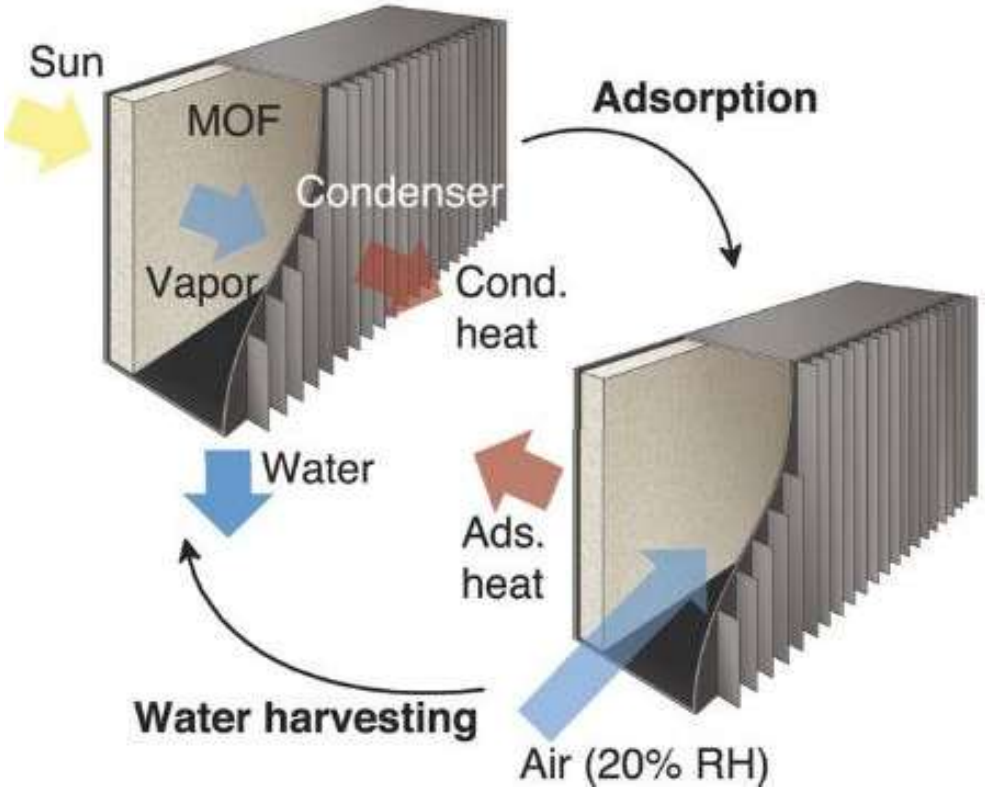
2000 LPD

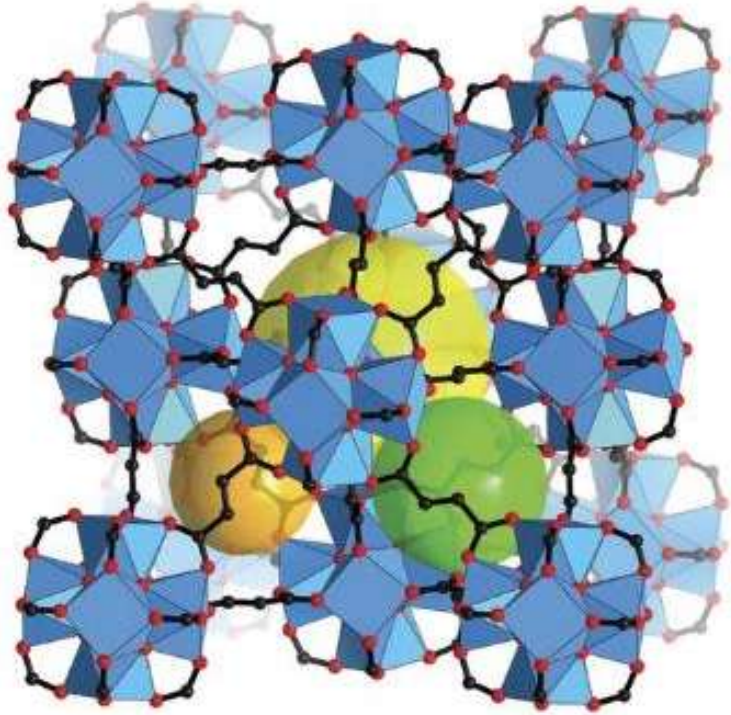
(LPD: Litres per day)


'VAYUJAL MISSION OF
IIT-MADRAS IS SIGNIFICANT'
VAYUJAL
AN IIT MADRAS INCUBATED COMPANY
WATER FROM AIR - ANYTIME, ANYWHERE
PROF. K. VIJAYRAGHAVAN
Principal Scientific Advisor
Govt of India
NEWS 18
THE HINDU
CHENNAI
Mandir celebrated their golden jubilee reunion
an atmospheric water generator (AWG) to their
potable water with the moisture in the air.

Sustainable atmospheric water harvesting

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

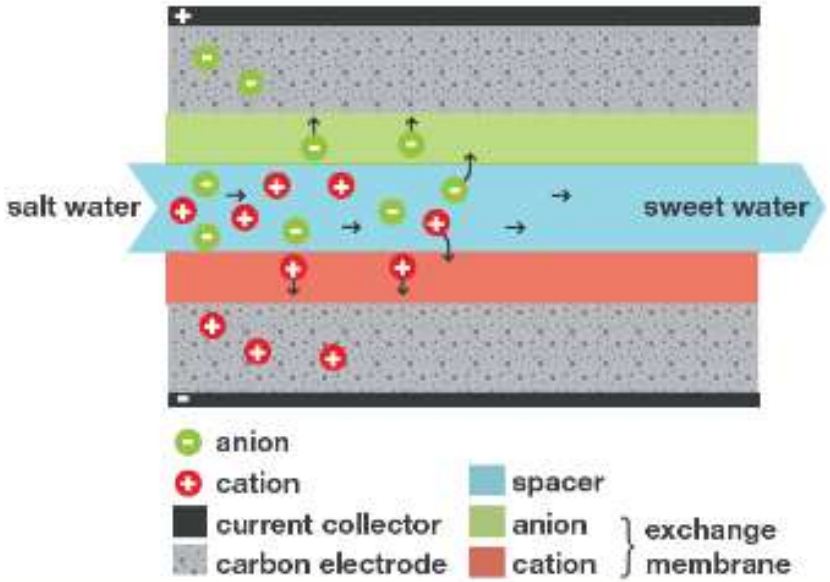


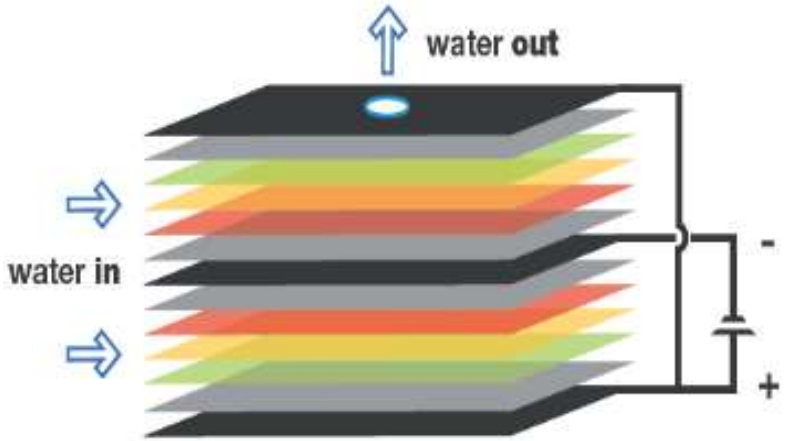


Porous metal-organic framework (MOF-801, $Zr_6O_4(OH)_4(fumarate)_6$)

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

Capacitive Desalination (CDI)

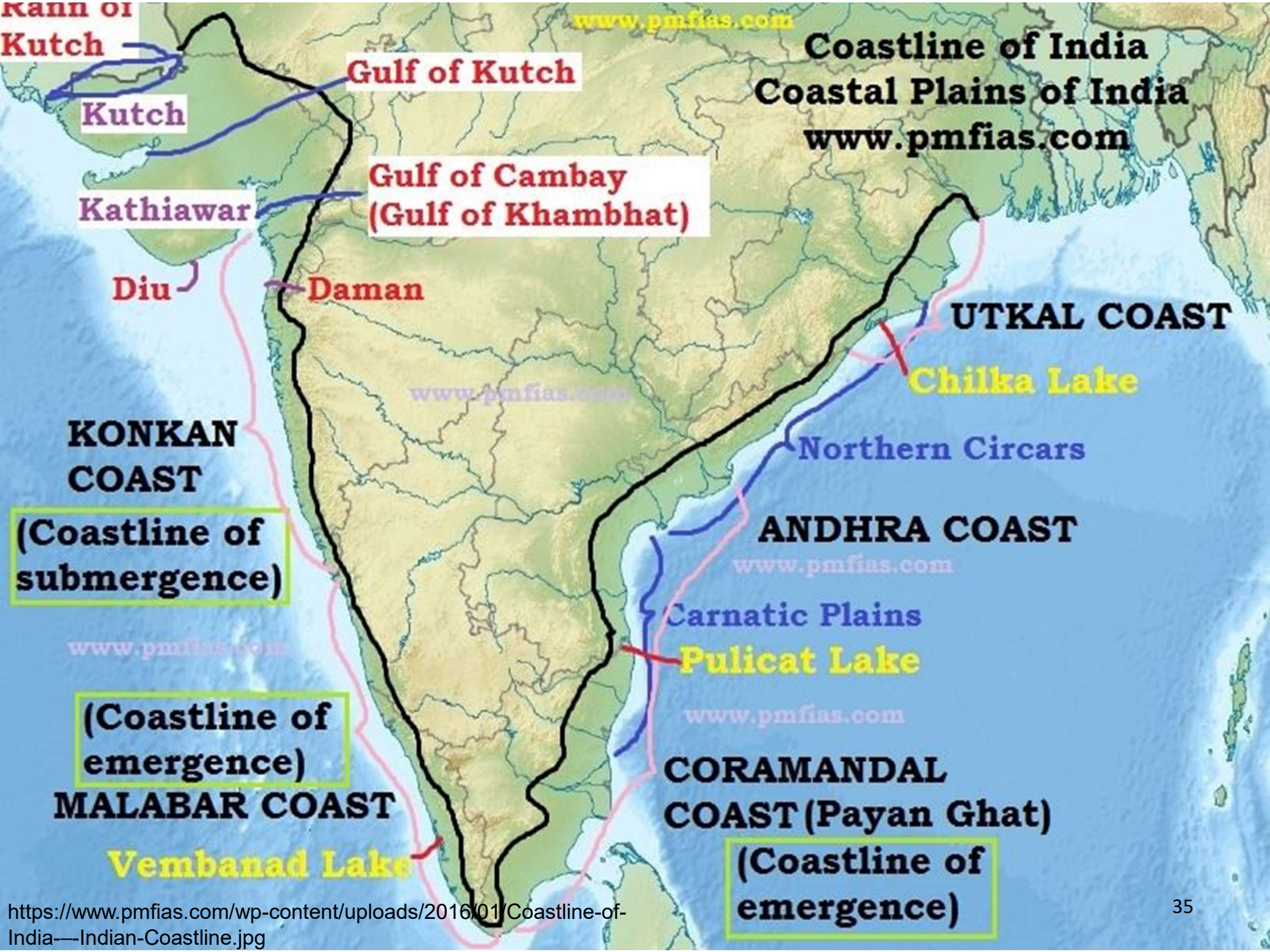




innODI

Our new company

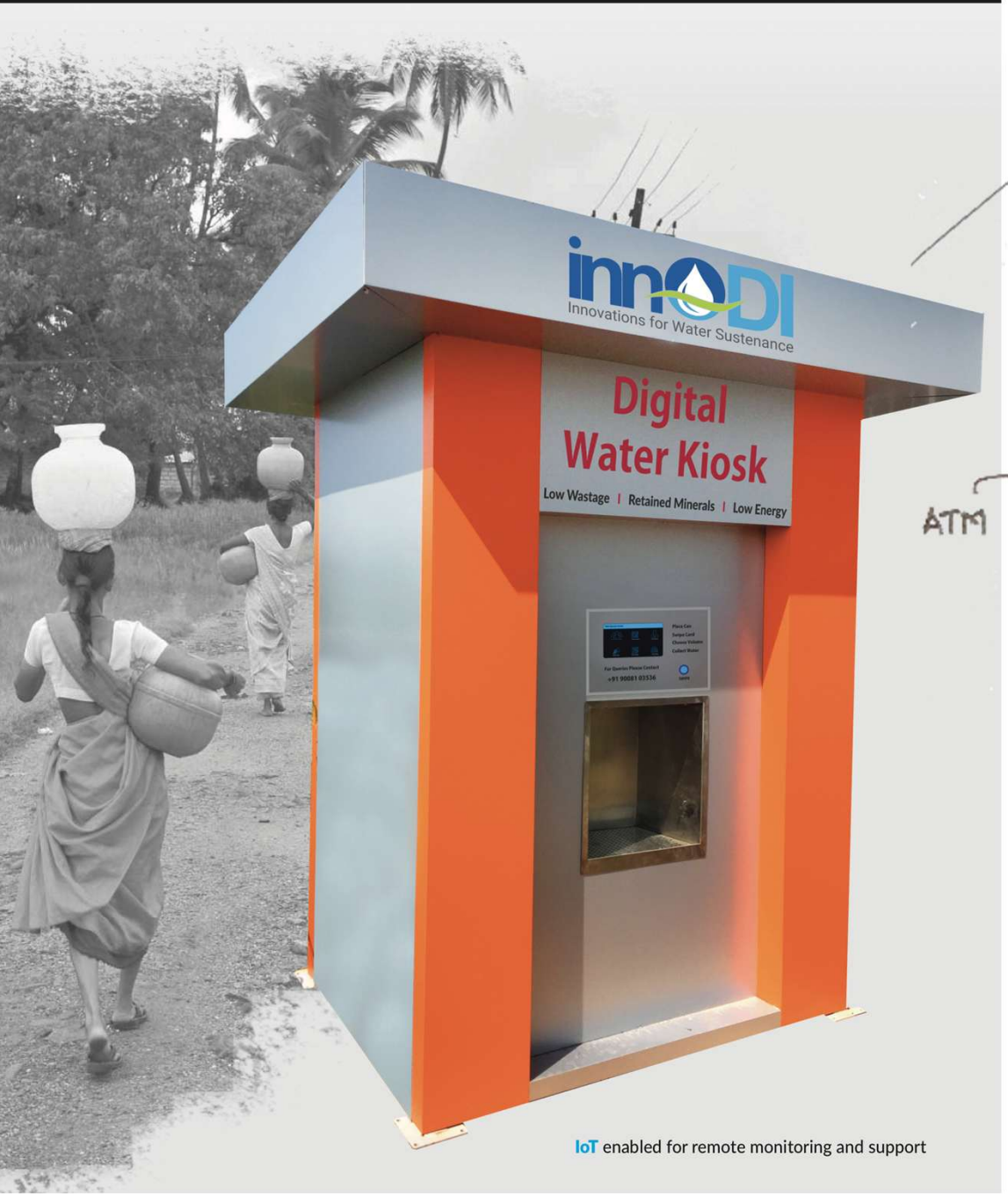
Soujit Sengupta, Rabiul Islam and others

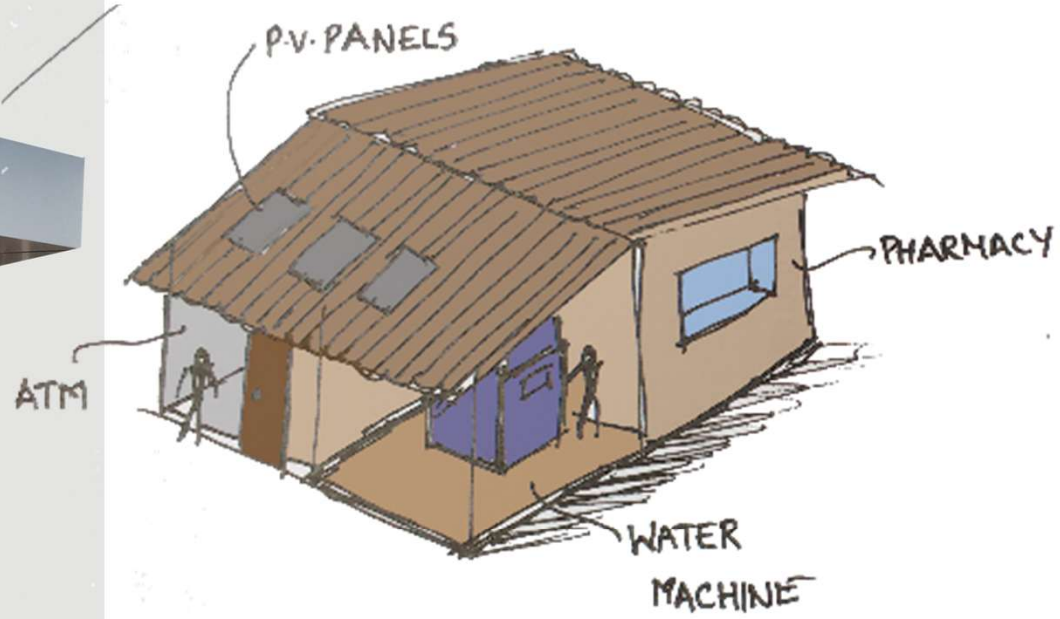


https://www.pmfias.com/wp-content/uploads/2016/01/Coastline-of-India-–-Indian-Coastline.jpg

DIGITAL WATER KIOSK

for community drinking using CDI Technology

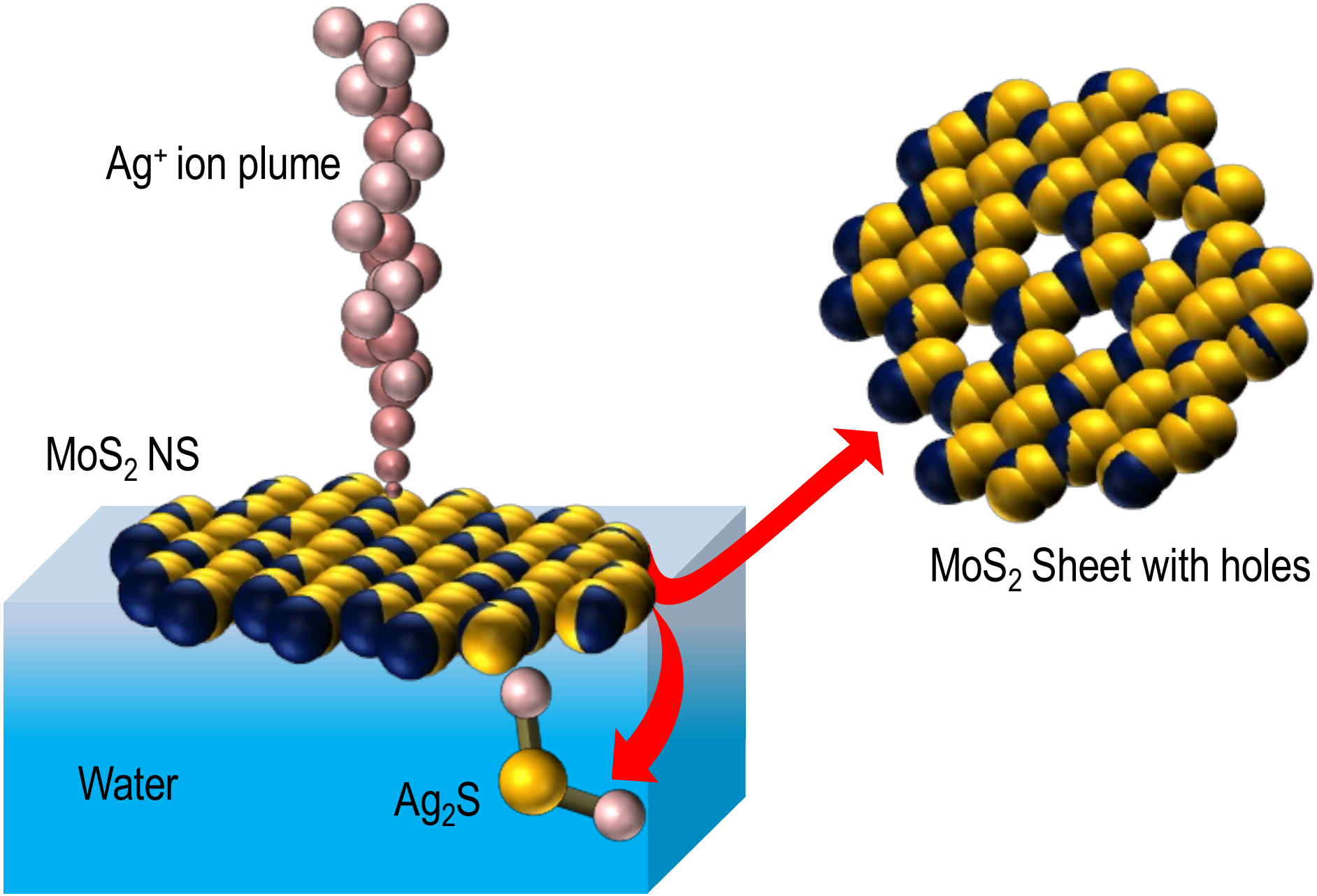




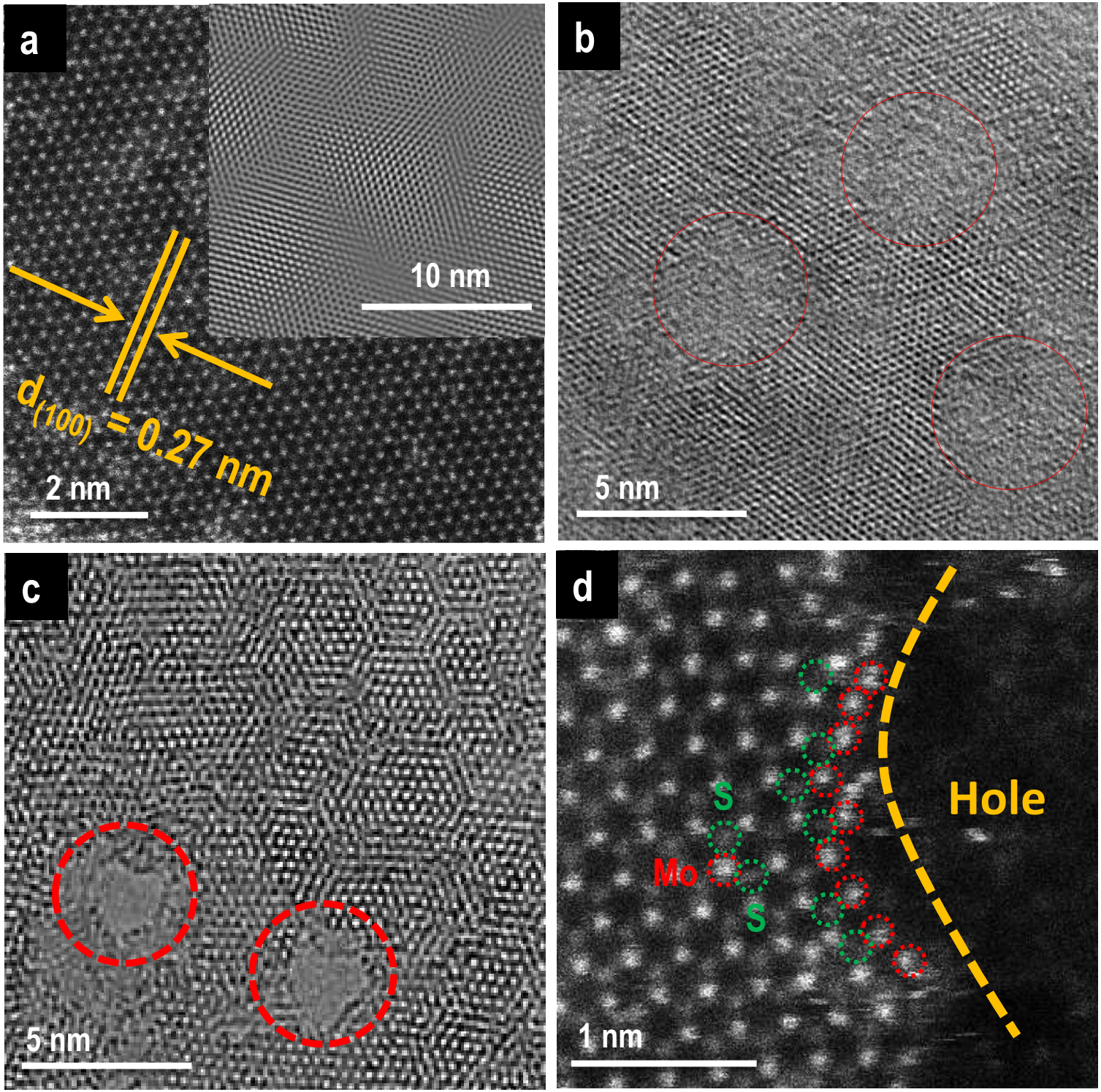
Products under implementation

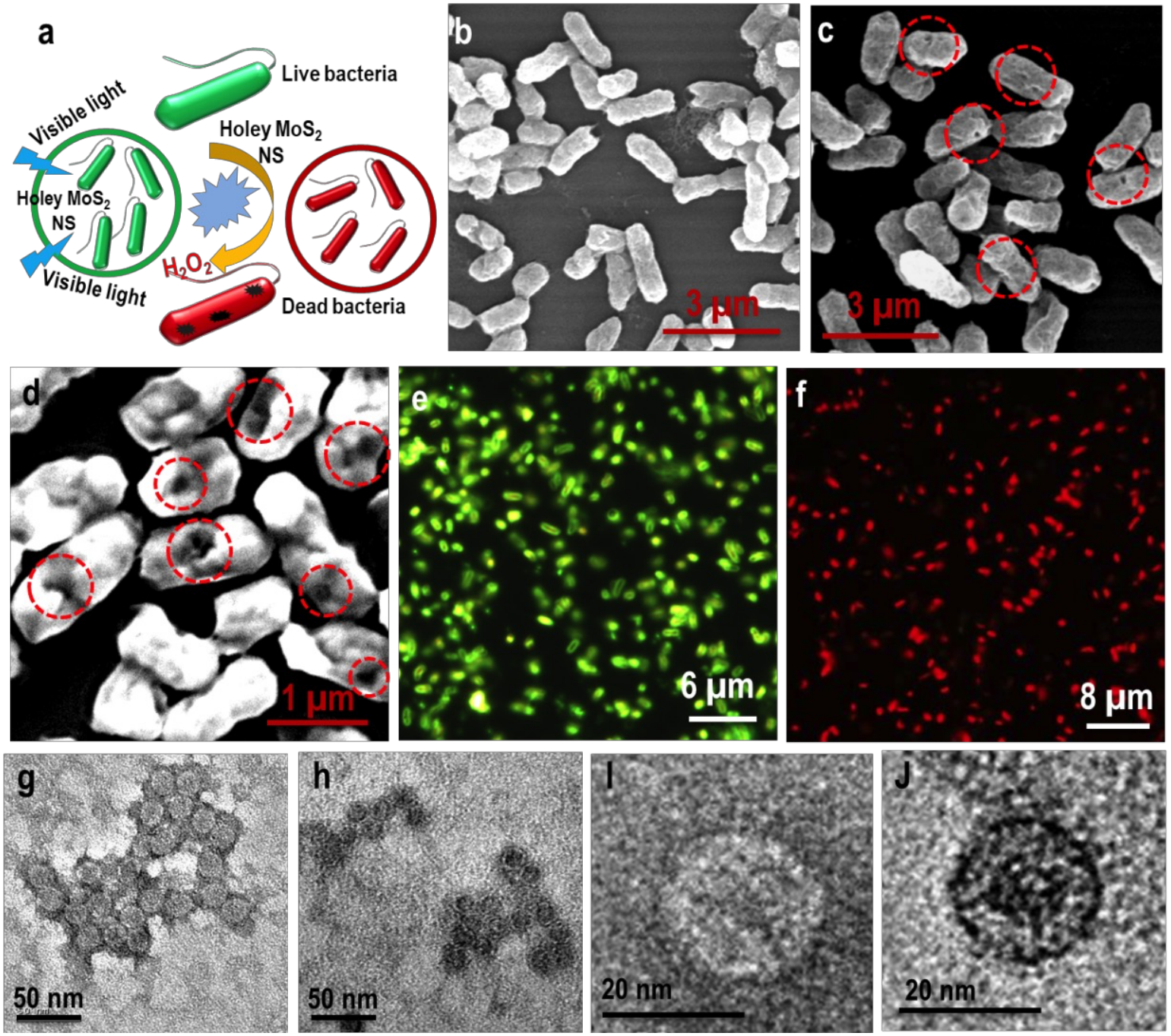
Vijay Sampath and Tullio Servida

2D materials, nanopores

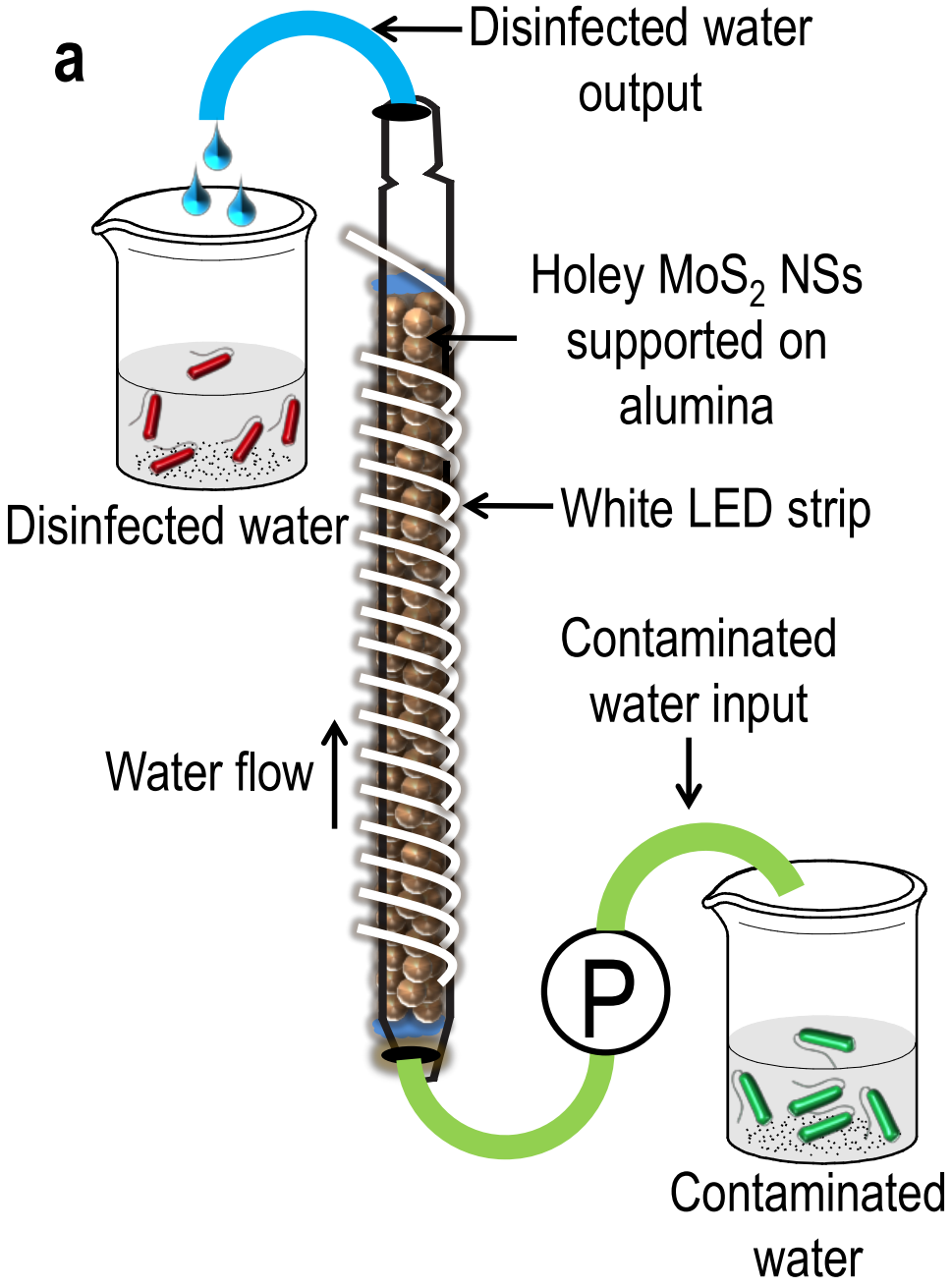


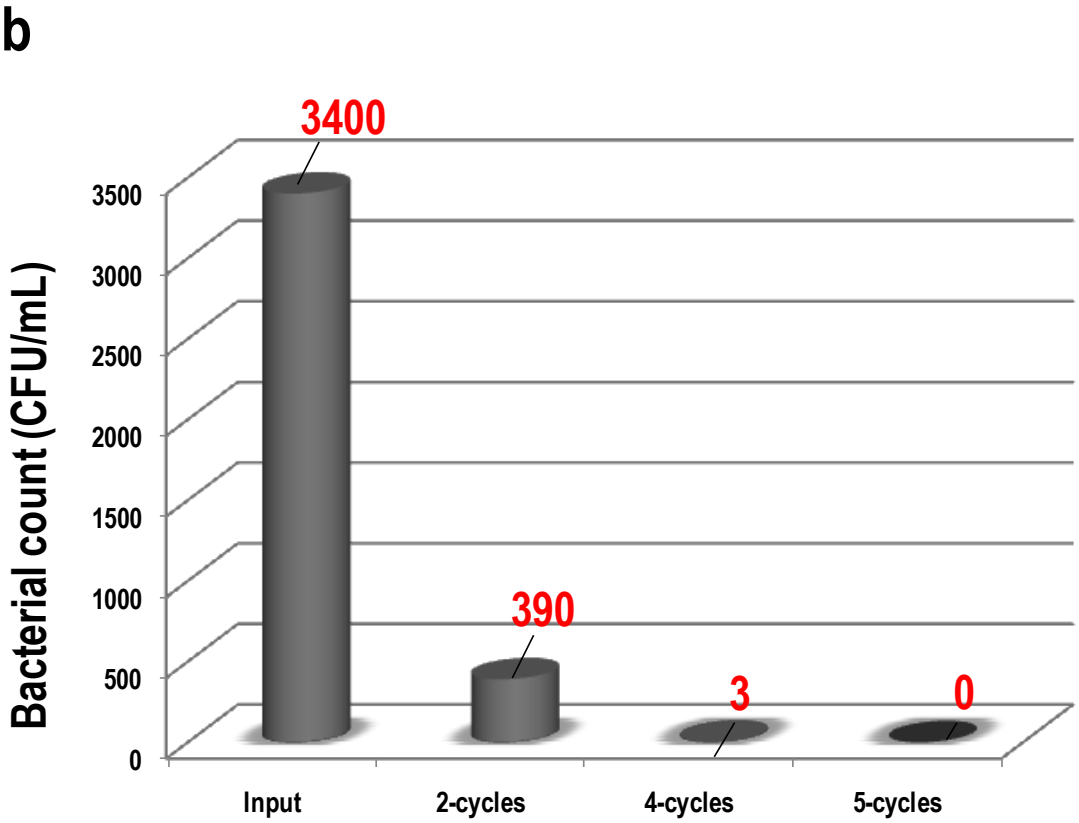
Depanjan Sarkar, Biswajit Mondal, et. al., *Global Challenges, 2* (12), 2018


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

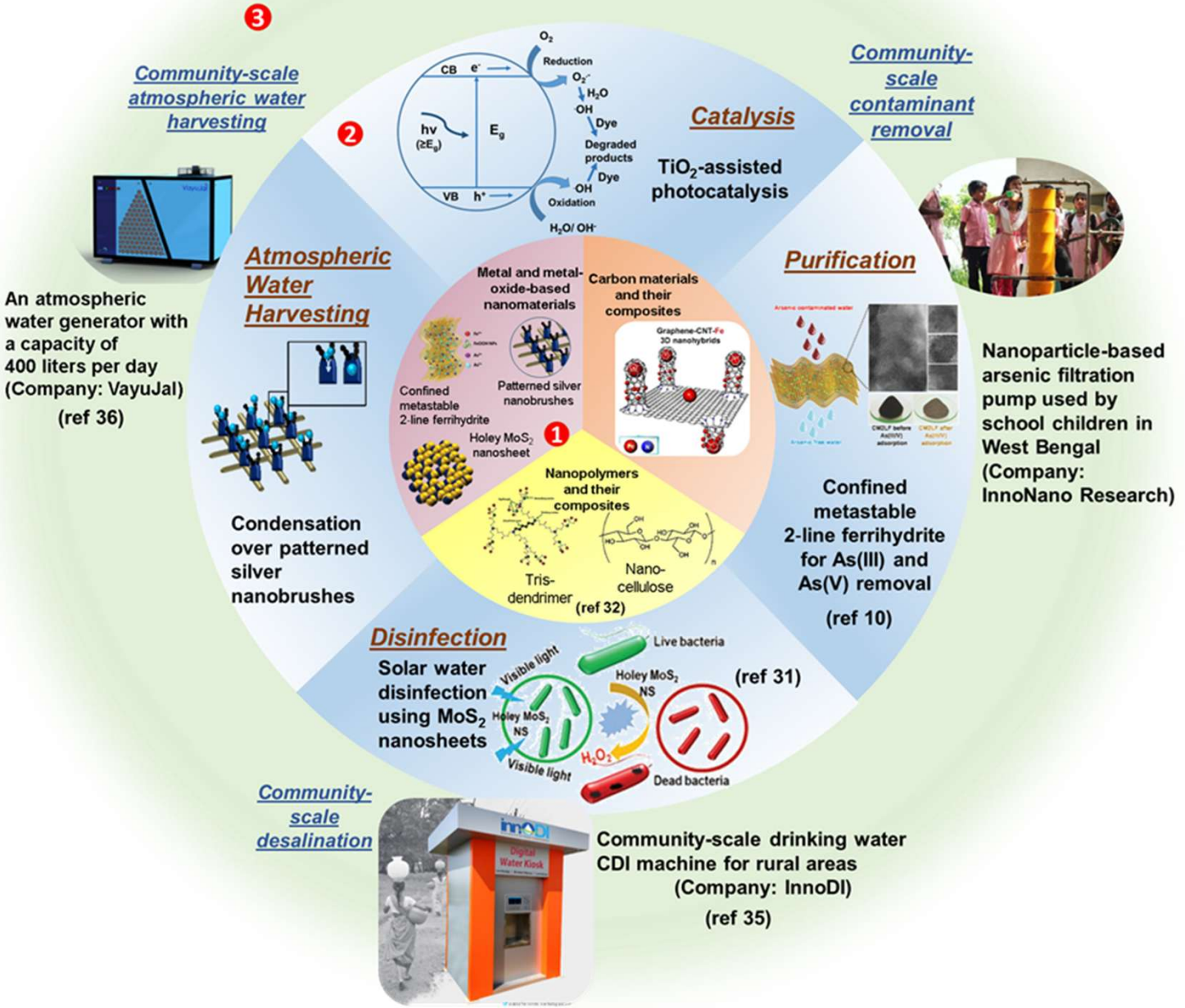

a
Live bacteria
Visible light
Holey MoS_2 NS
Holey MoS_2 NS
H_2O_2
Visible light
Dead bacteria
b
3 μm
c
3 μm
d
1 μm
e
6 μm
f
8 μm
g
50 nm
h
50 nm
I
20 nm
J
20 nm

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

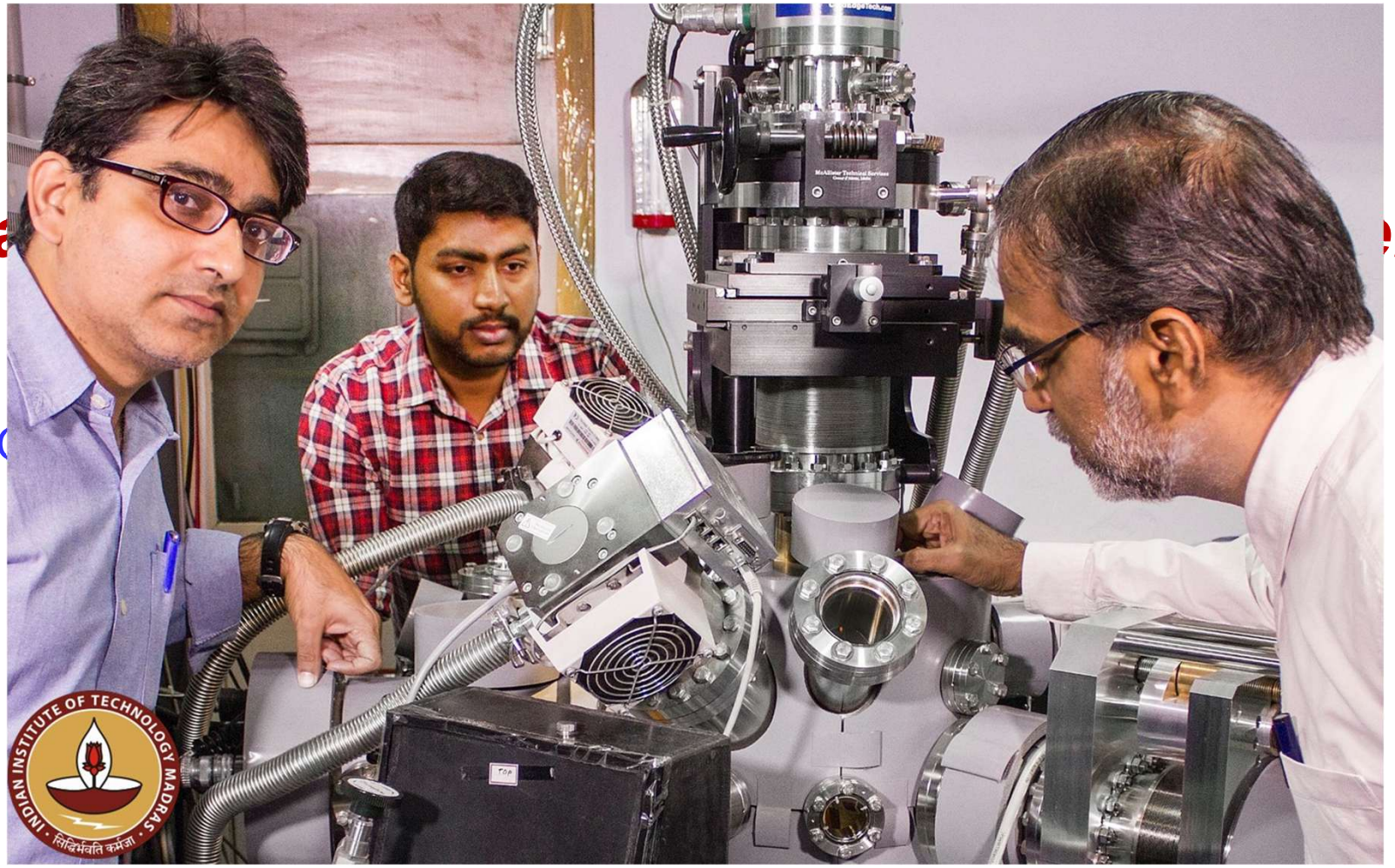

b
Bacterial count (CFU/mL)
3400
390
3
0
3500
3000
2500
2000
1500
1000
500
0
Input
2-cycles
4-cycles
5-cycles

Evolution of materials to products



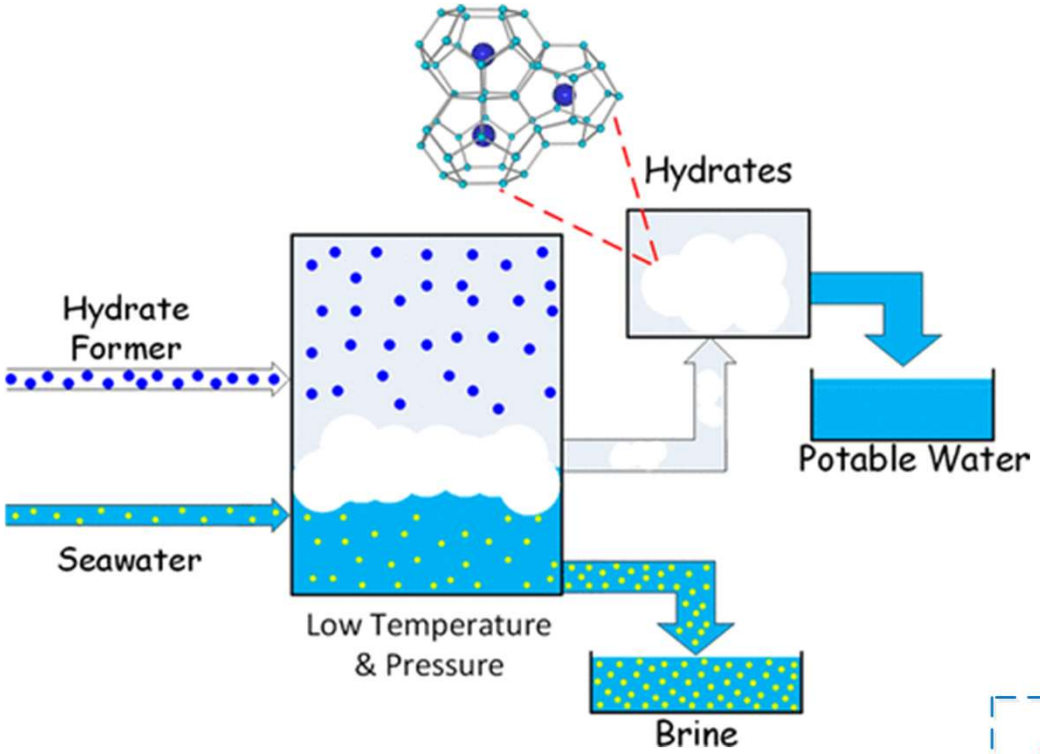
Ankit Nagar and T. Pradeep 14(2020). *ACS Nano*, 6420-6435

New phenomena



With Rajnish Kumar

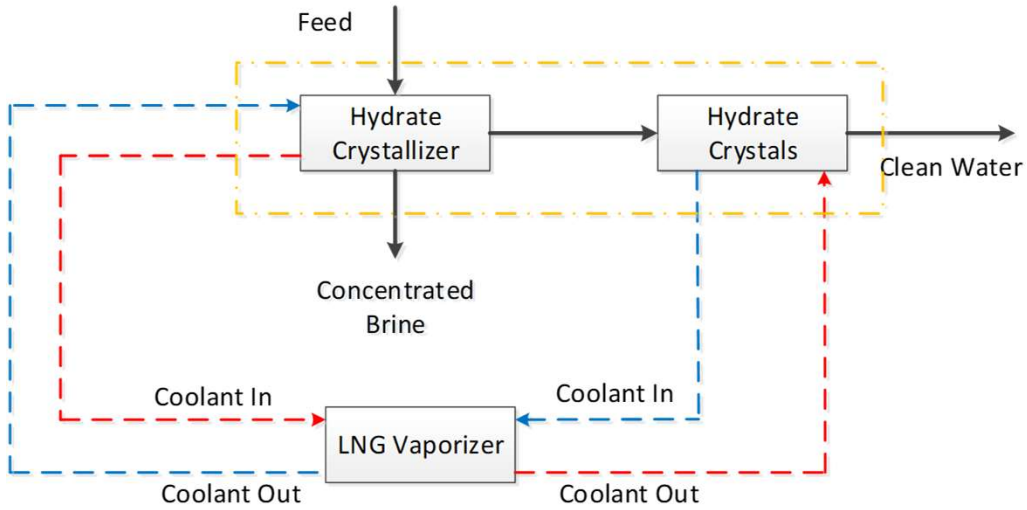
Hydrate-based desalination (HyDesal)



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

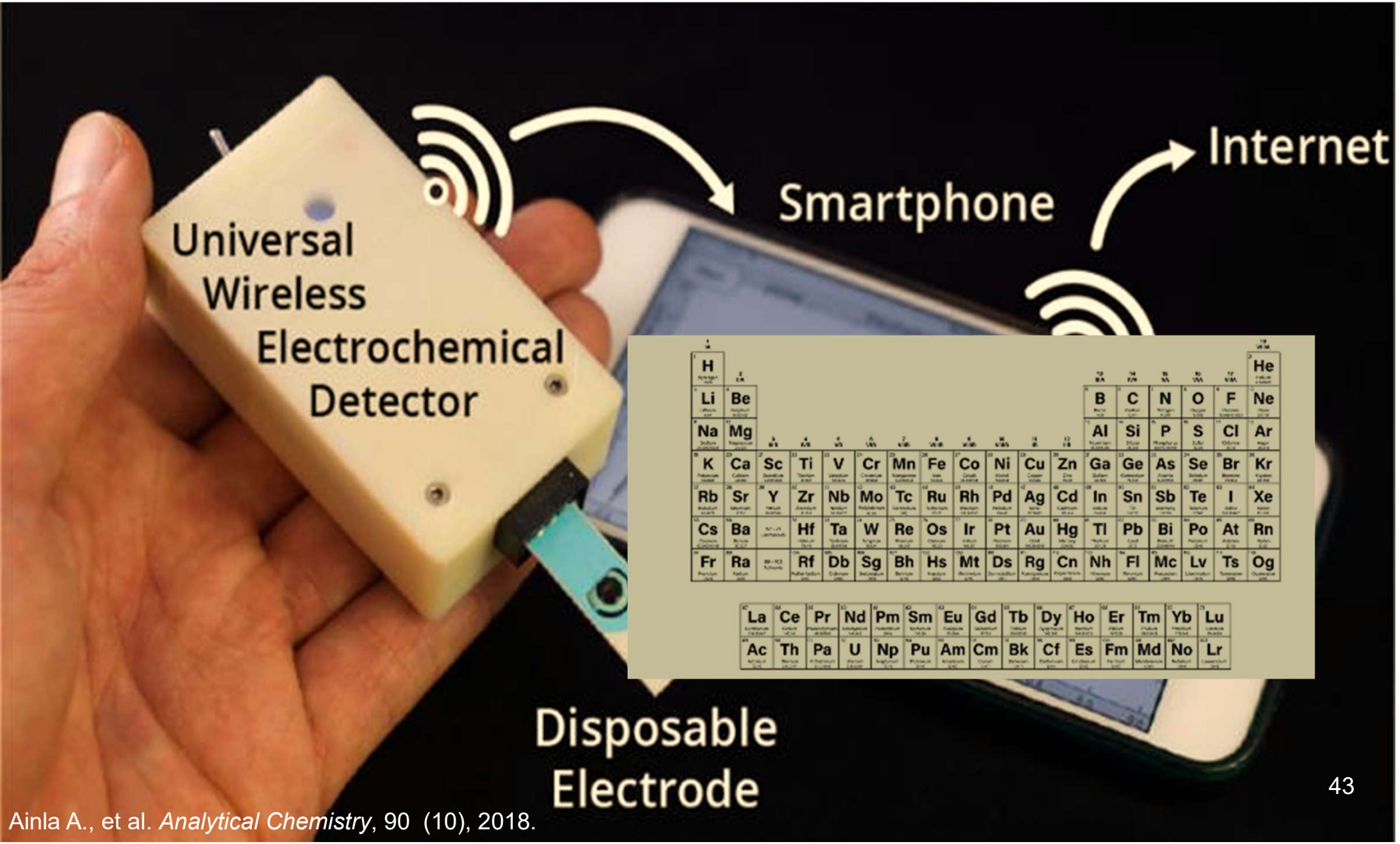


Cold Energy in LNG terminals can be harvested to produce water

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

Slide from Prof. Praveen Linga, NUS

Analytical devices

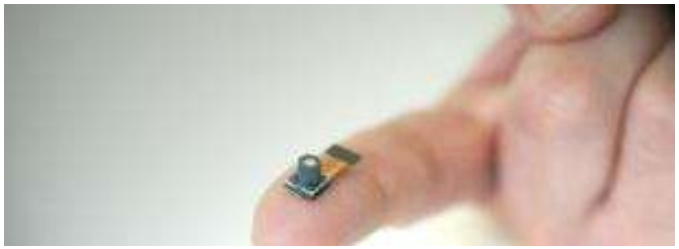


Ainla A., et al. *Analytical Chemistry*, 90 (10), 2018.

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)

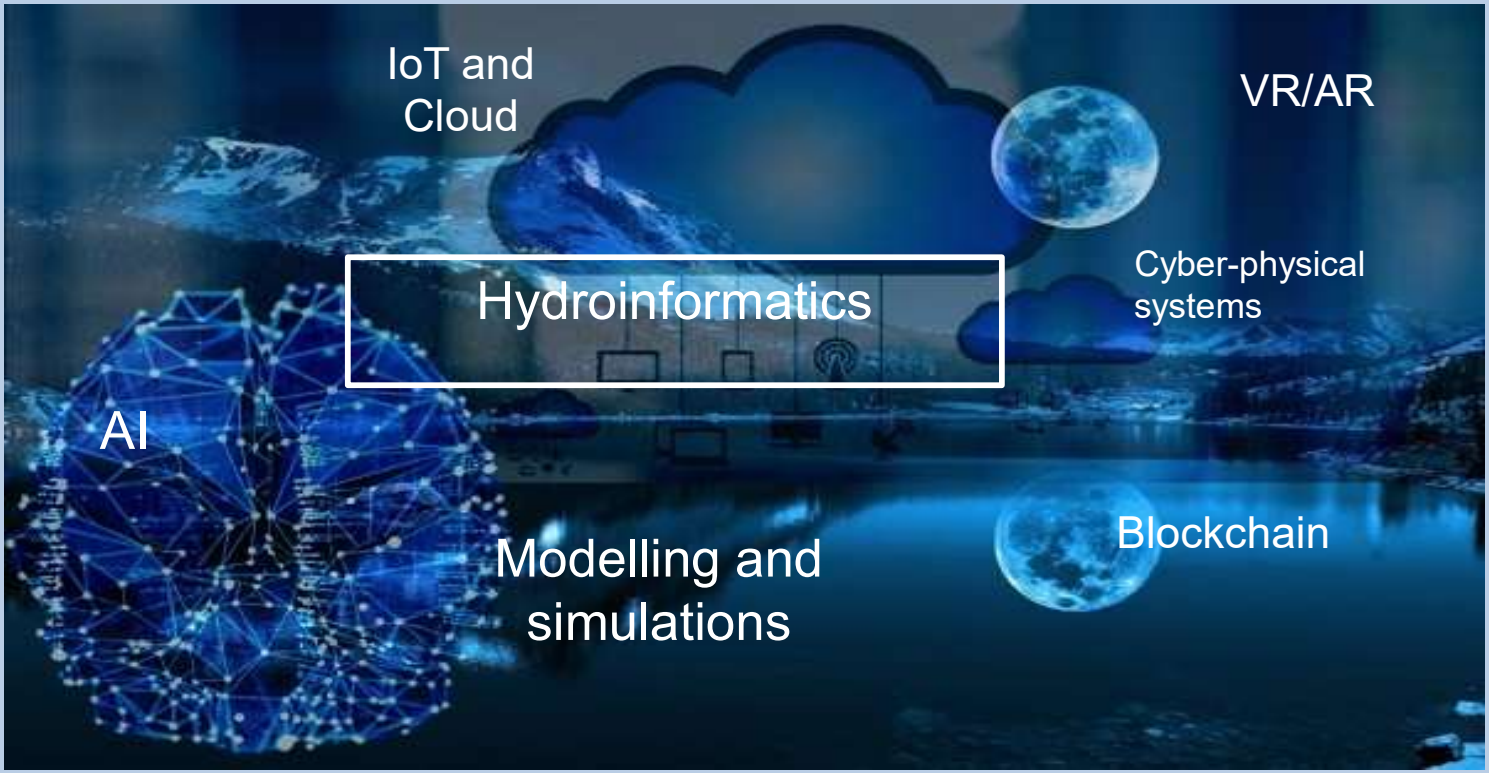


Water quality measurement – In the pipeline

nanoλ

Hydroinformatics

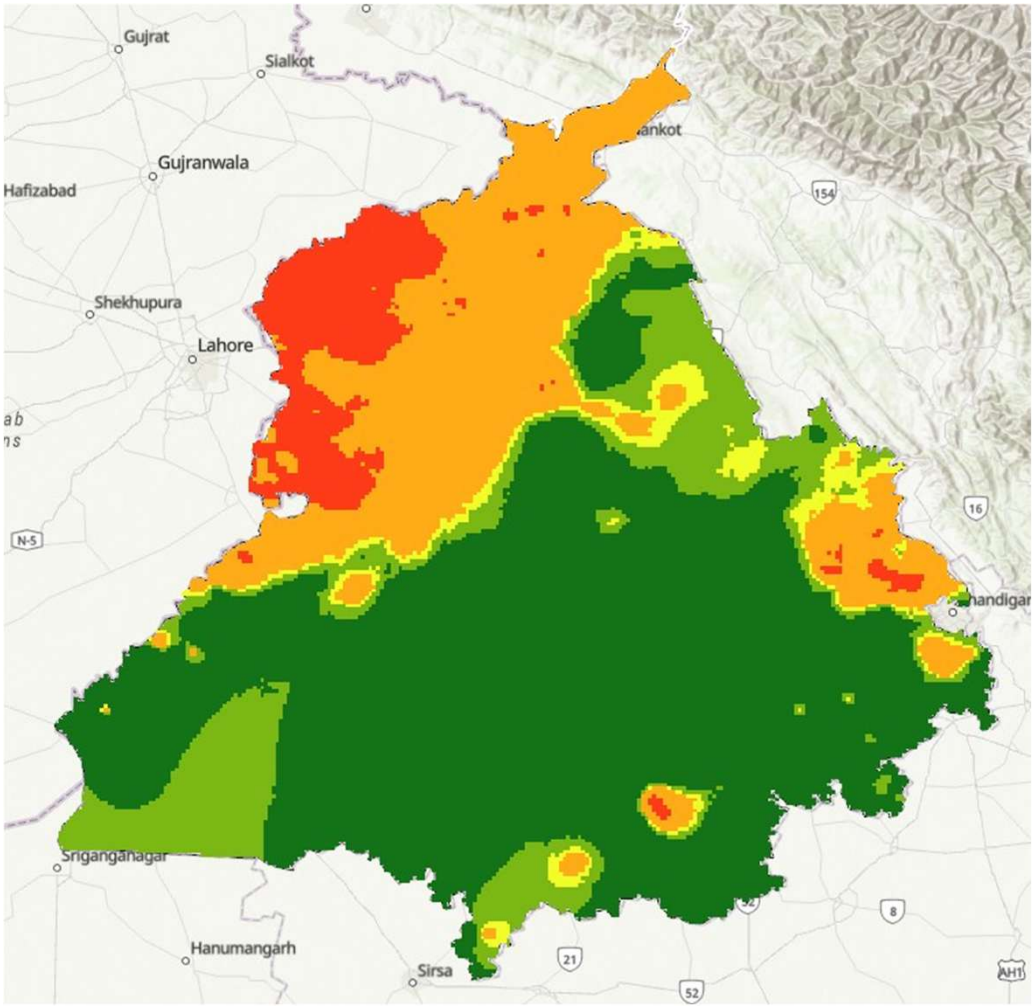
Application of computing technologies for efficient, sustainable and equitable water management.



Digital water or water 4.0 will revolutionize water management.

Average of arsenic at 7000 locations

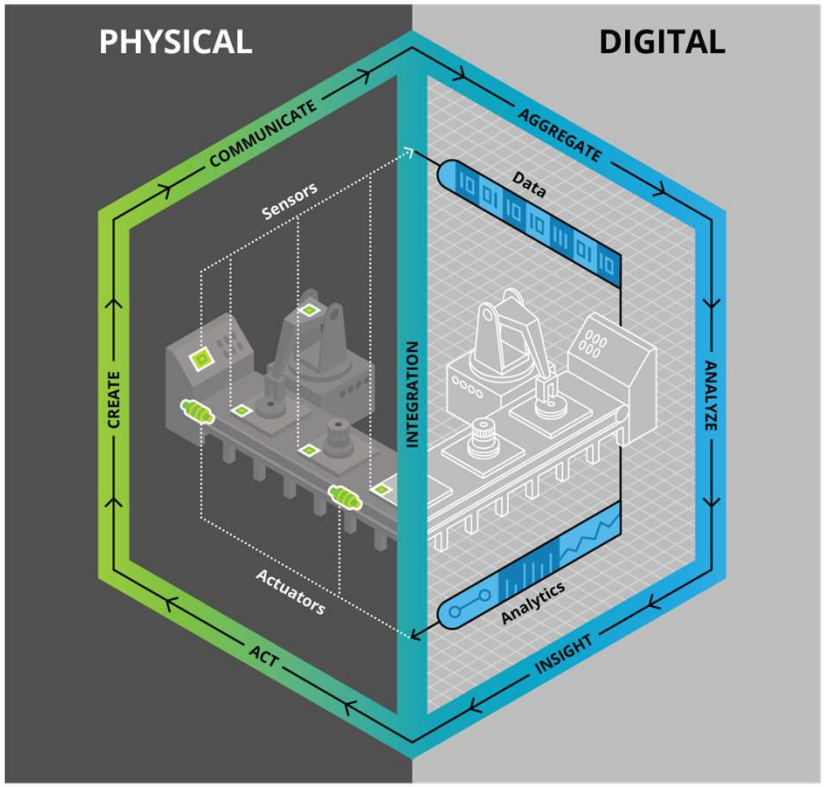
2017-2020



Arsenic in mg/L

- 0 - 0.001
- 0.001 - 0.002
- 0.002 - 0.004
- 0.004 - 0.006
- 0.006 - 0.008
- 0.008 - 0.01
- 0.01 - 0.02
- 0.02 - 0.04
- 0.04 - 0.06
- 0.06 -0.2

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.

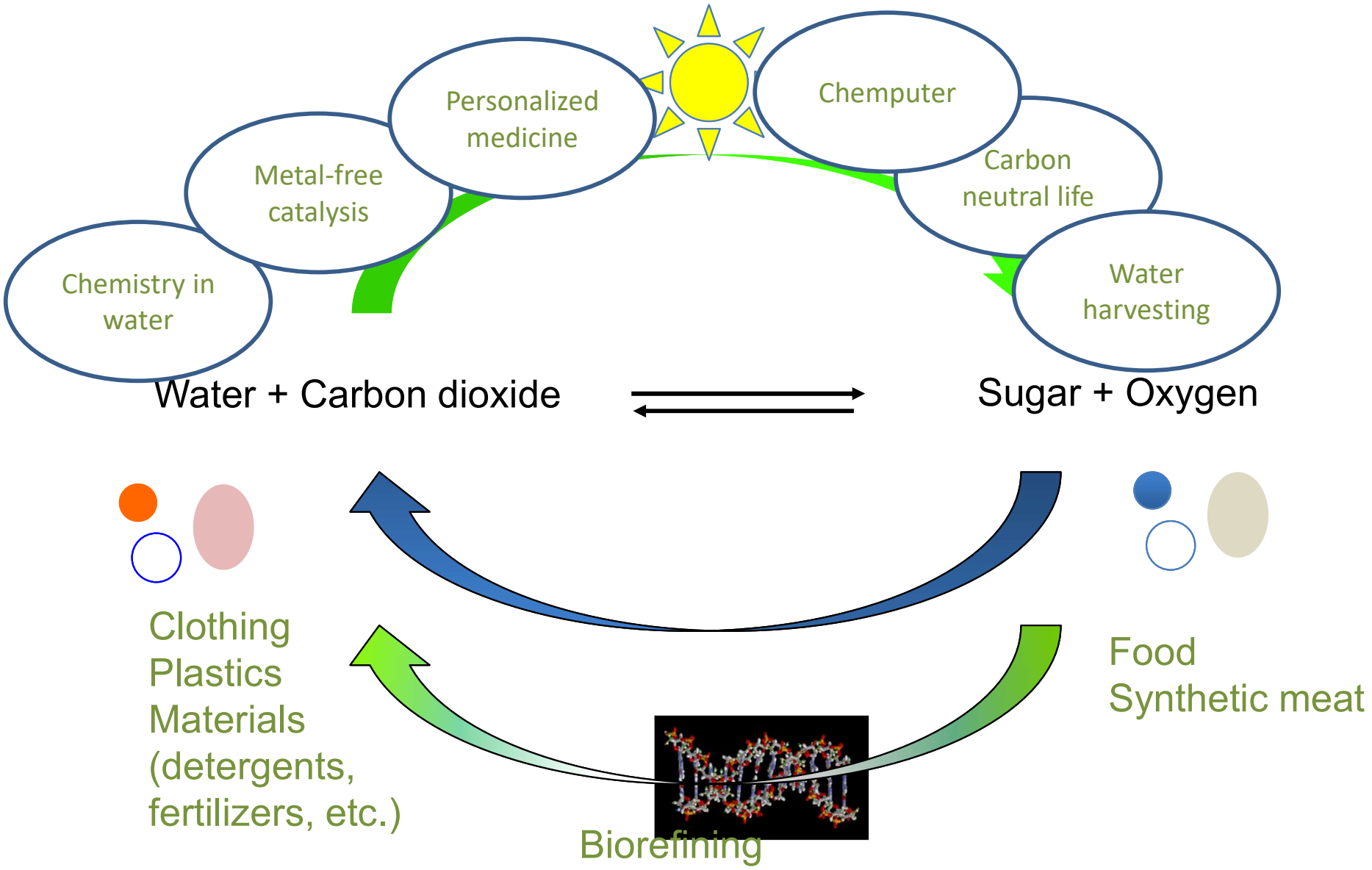
Create a digital twin of different elements of hydrologic environment – surface water bodies, ground water, rivers, and urban water utilities.

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.


Policy

Sustainability and opportunities




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

सत्यमेव जयते

Start-ups and partners:

Mahindra WORLD CITY

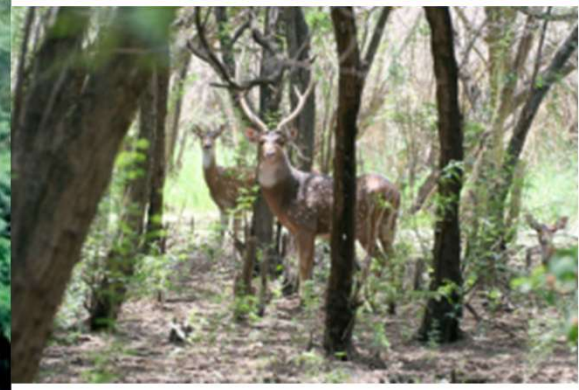
Our collaborators

Ministry of Drinking Water and Sanitation, Govt. of Indi

Indian Institute of Technology Madras







Bhaskar Ramamurthi, Director

Associate Editor

ACS Sustainable Chemistry & Engineering

Pradeep Research Group

Thematic Unit of Excellence

Thank you all