Now in the 58th year

Nanomaterials and Clean Water

T. Pradeep

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Co-founder

InnoNano Research Pvt. Ltd.

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VayuJAL Technologies Pvt. Ltd.

Aqueasy Innovations Pvt. Ltd.

IIT Madras Incubated Companies

Associate Editor

ACS Sustainable Chemistry & Engineering

THEMATIC UNIT OF EXCELLENCE

International Conference on Biological Applications of Nanoparticles, ICON-BIO 2017, December 4-5, 2017

Challenges and opportunities

- About 780 million people live without clean drinking water.
- More than two billion people worldwide rely on wells for their water.
- By 2025, an estimated 1.8 billion people will live in areas plagued by water scarcity.
- Half of the global population lives in countries where water tables are rapidly falling - Ogallala Aquifer in the United States is an example.
- Over the past 40 years the world's population has doubled and use of water has quadrupled.
- Agriculture accounts for ~70% of global freshwater withdrawals and up to 90% in some fast-growing economies.

- By 2035, energy consumption will increase by 35 percent, increasing water use by 15 percent.
- In the US, thermoelectric power plants account for nearly 50% of all freshwater withdrawals.
- 46% of the globe's (terrestrial) surface is covered by transboundary river basins which can lead to future conflicts over water.
- 67% of Indian agriculture is based on ground water.
- The global middle class will surge from 1.8 to 4.9 billion by 2030, which will result in a significant increase in freshwater consumption.

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

Indian realities

- Over xx million suffer due to arsenic
- Over xx million suffer due to fluoride
- Cr, Mn, Pb, U, and many more are found in water
- uCKD and others are around
- Endocrine disrupting chemicals are plenty

……

GHI was released a month ago

Should we continue to be where we are?

…..Long-term exposure to arsenic from drinking-water and food can cause cancer and skin lesions. It has also been associated with developmental effects, cardiovascular disease, neurotoxicity and diabetes.
http://www.who.int/mediacentre/factsheets/fs372/en/

Where is Liberty, Equality, Fraternity?

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Founder
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An IIT Madras Incubated Compan

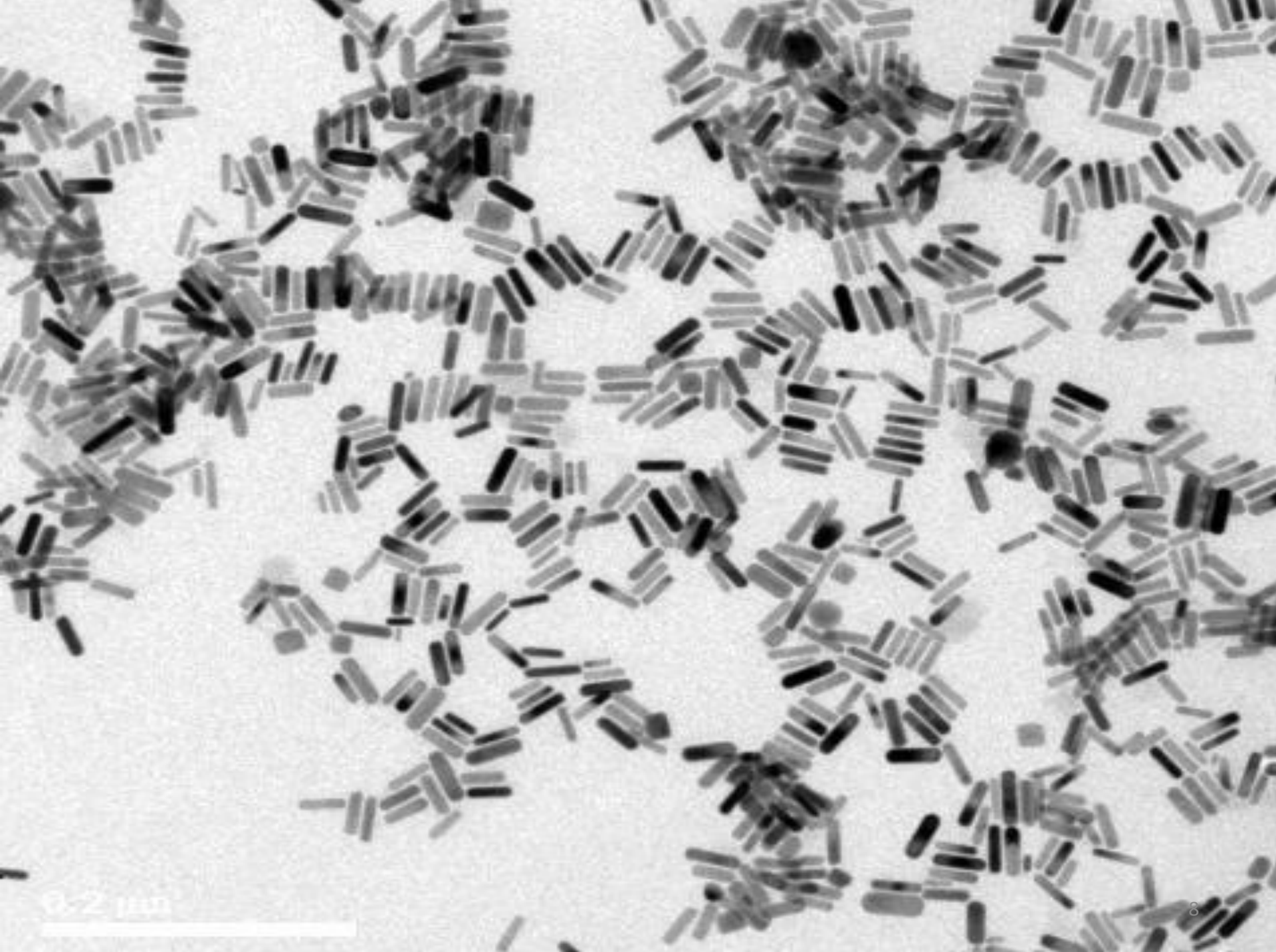
Co-founder
InnoDI Water Technologies Pvt. Ltd.
An IIT Madras Incubated Company

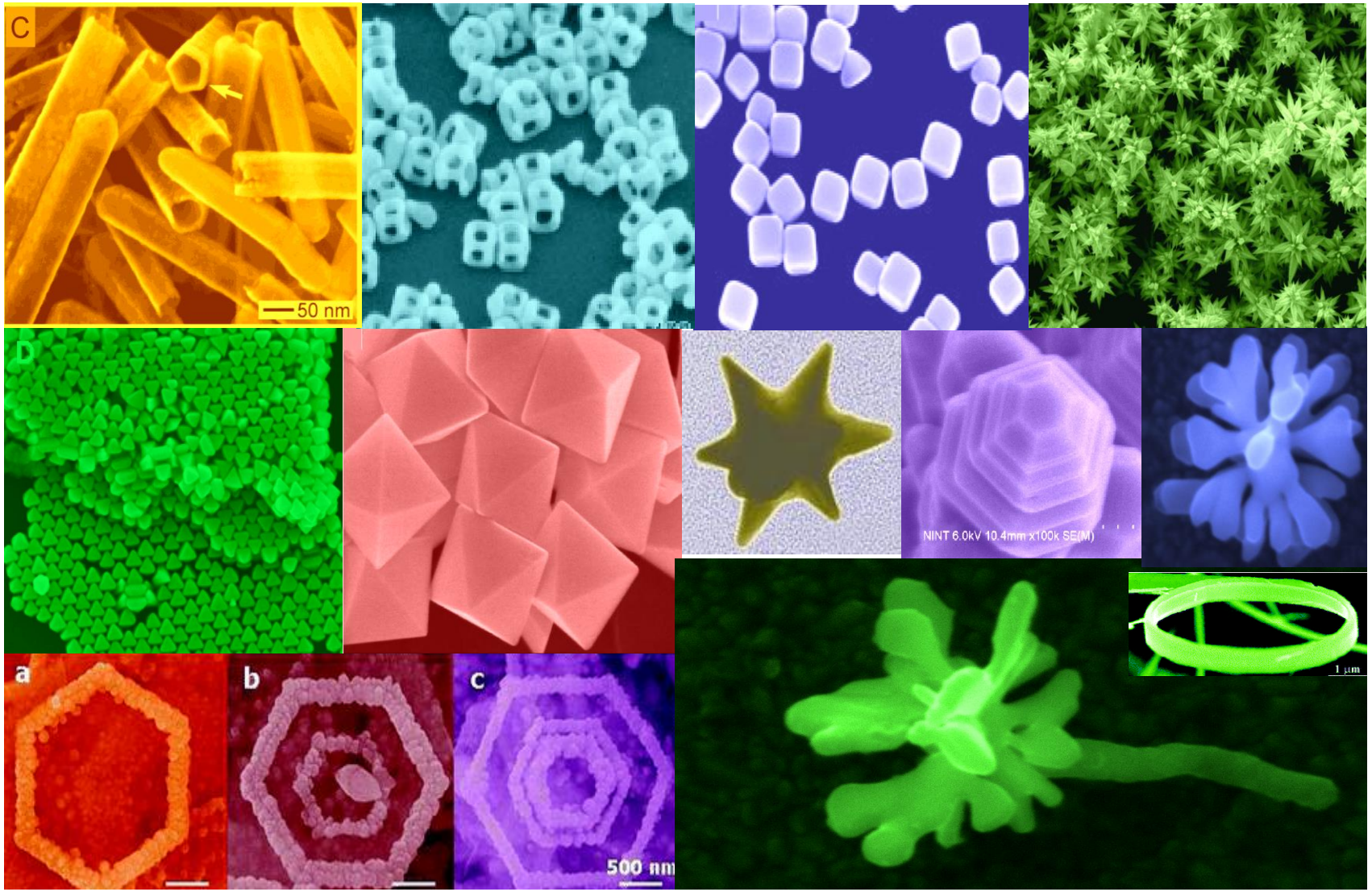
ACS Sustainable Chemistry & Engineering Editorial, December 2016

सत्यमेव जयते

mpany

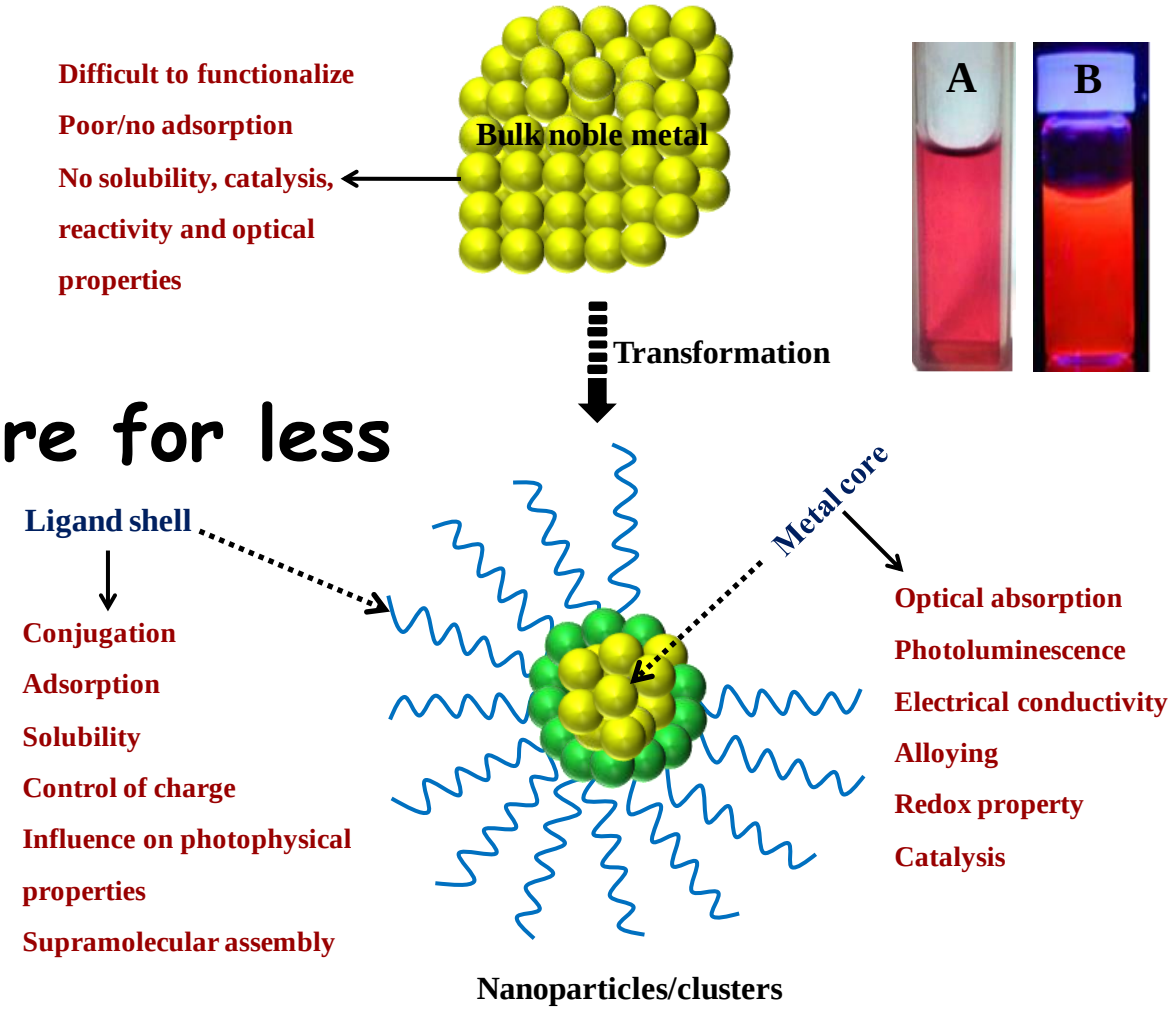
Nano 10^{-9}


0.2 μm



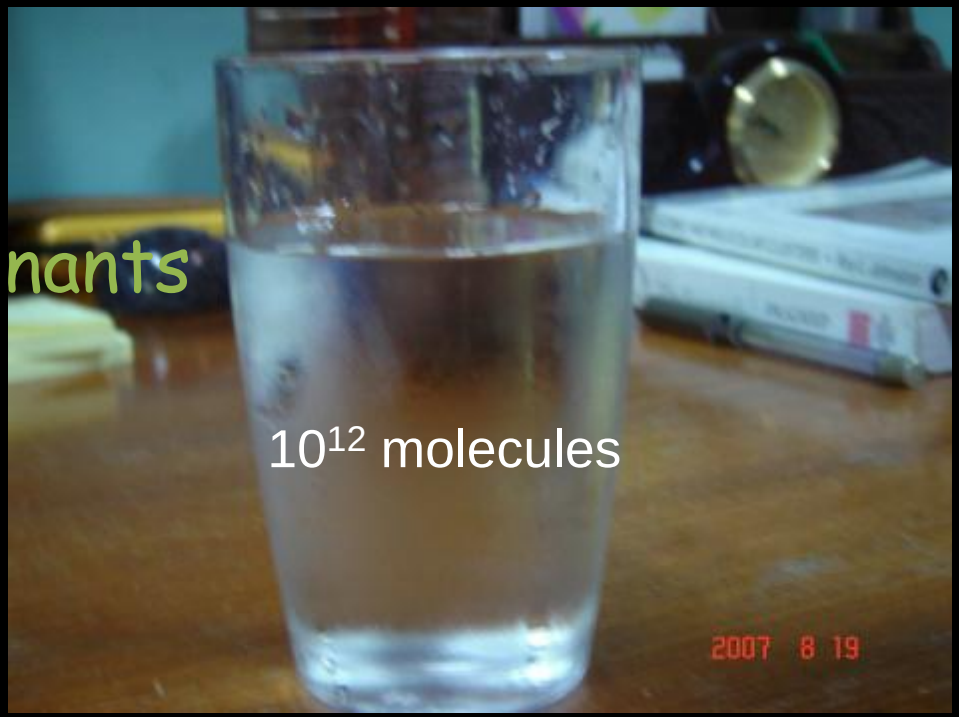
Sajanlal and Pradeep, Kirk-Othmer Encyclopedia, 2012

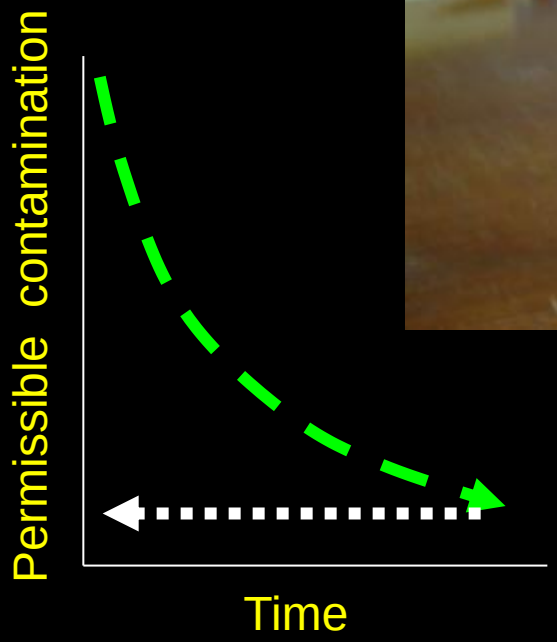
1. More for less



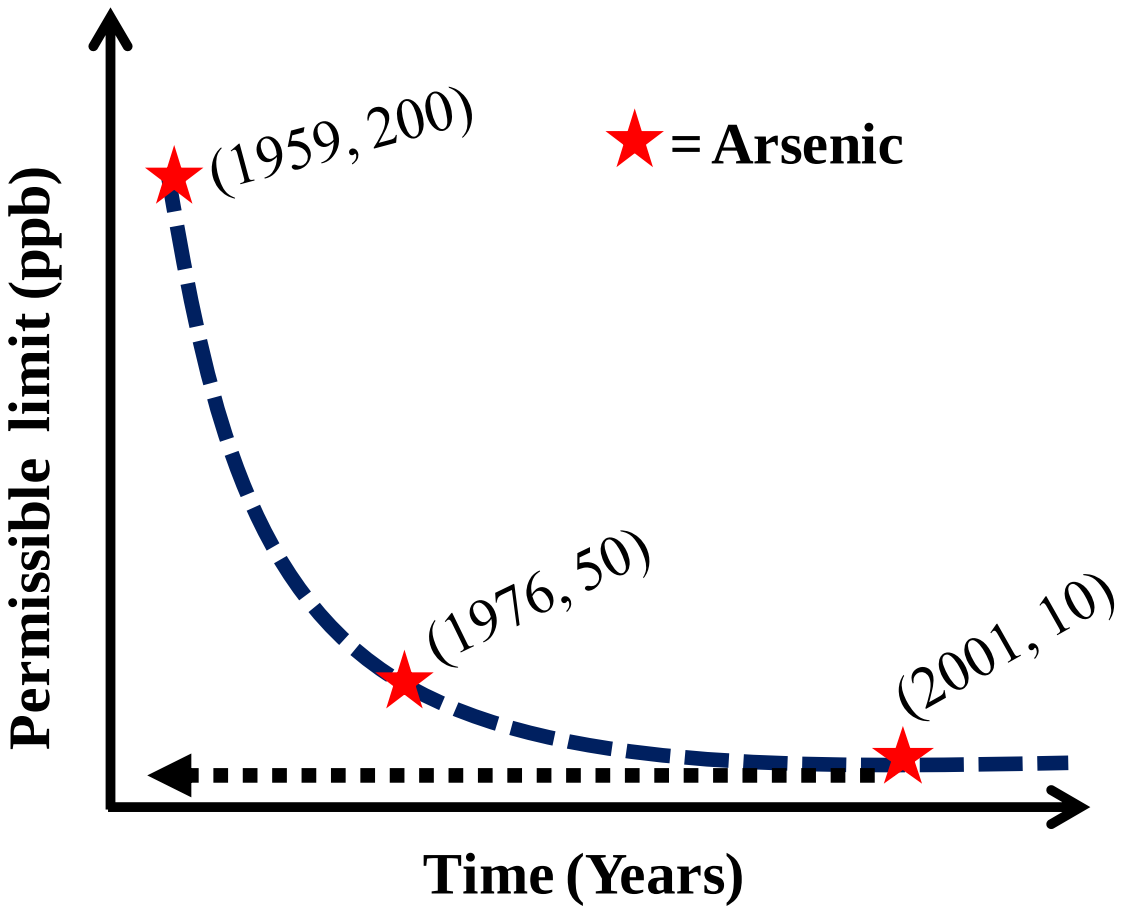
Variation in properties originating from ligand shell and metal core as bulk noble metals transform to nanoparticles/clusters. Sizes are not to scale. New properties such as color and photoluminescence arise in such size regime. Photographs of Au@citrate nanoparticles (inset A) showing intense absorption of visible light and Au@SG (SG corresponds to glutathione thiolate) clusters (inset B) showing intense photoluminescence upon ultraviolet irradiation (from the author's work).

2. Limits of contaminants



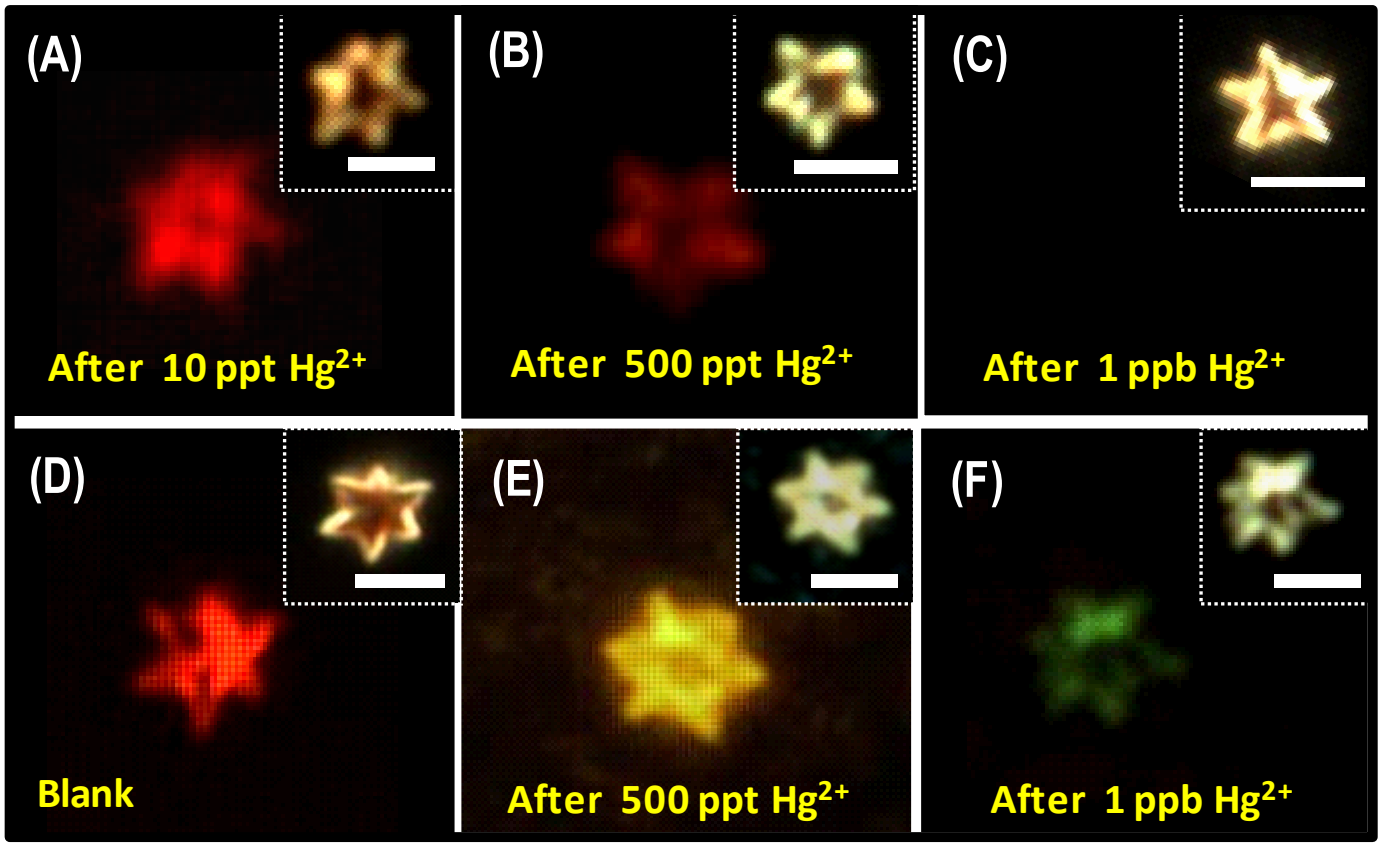


Permissible contamination reaches limits of detection



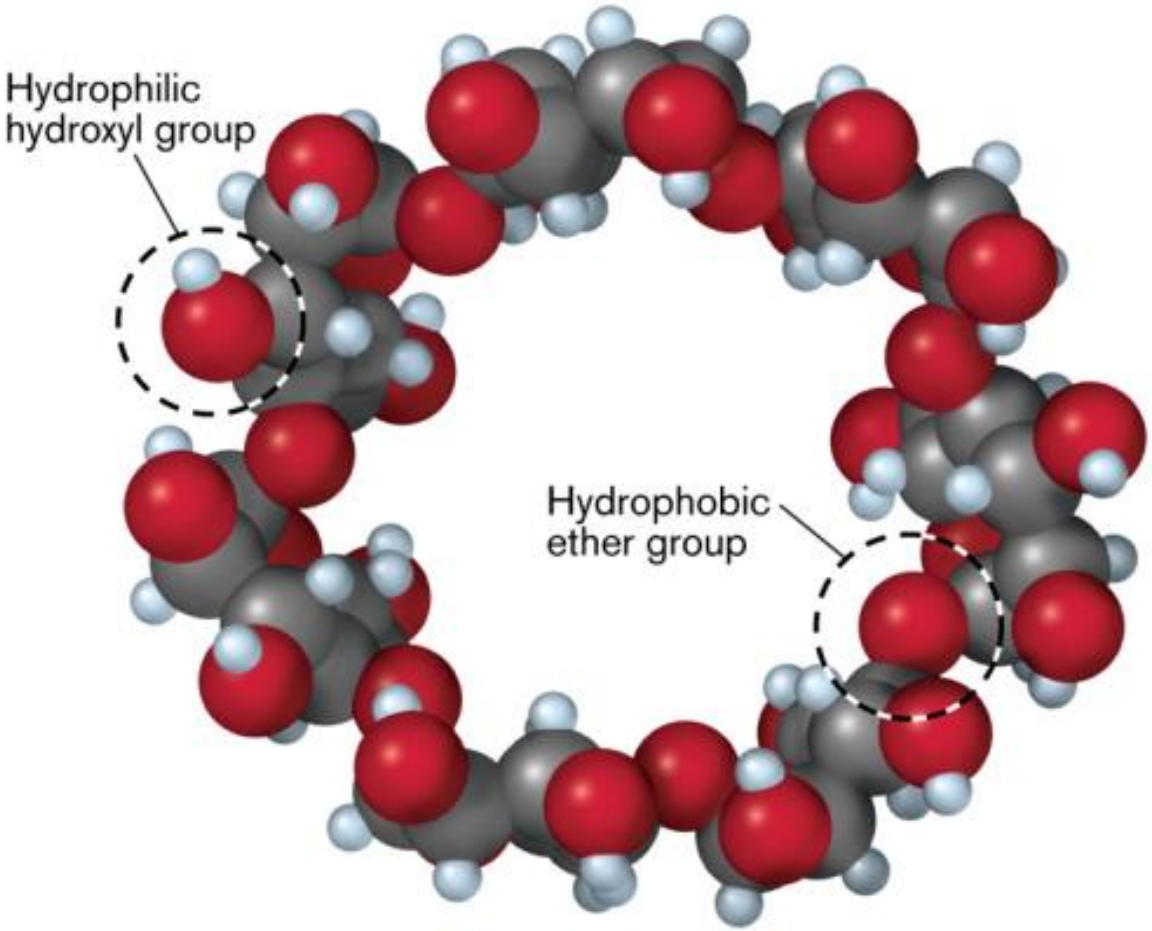
Decrease in the permissible limit of arsenic in drinking water, according to US EPA, with time. The graph indicates a general trend.

3. Can we reach limits?



(A)–(C) Dark field fluorescence images of $Au@SiO_2@Ag_{15}$ MFs showing the gradual disappearance of luminescence with increasing Hg^{2+}. (D)–(F) Fluorescence images showing variation in color during the addition of Hg^{2+} of different concentrations to $Au@SiO_2$-FITC$@Ag_{15}$ MFs. Insets in all images show the corresponding optical images of the MFs; scale bars are 3 µm.

Cavities, channels, imprints, assemblies, fibres, …



Nanotechnology research in clean water

New adsorbents

Nanoparticles, nanotubes, graphene, polymers, 2D materials

New sensors

Colorimetric, fluorescence, FRET, DNA, assembly, biosensors

New catalysts

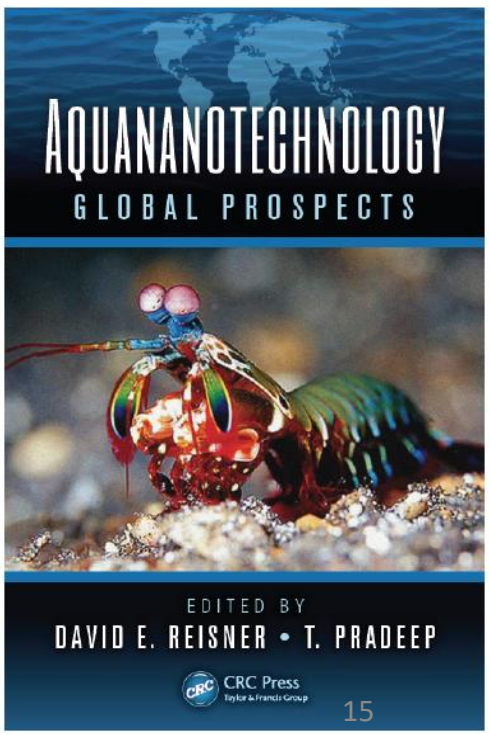
Emerging toxins, heterojunctions

Novel phenomena

Graphenic analogues, nanopores, aquaporins

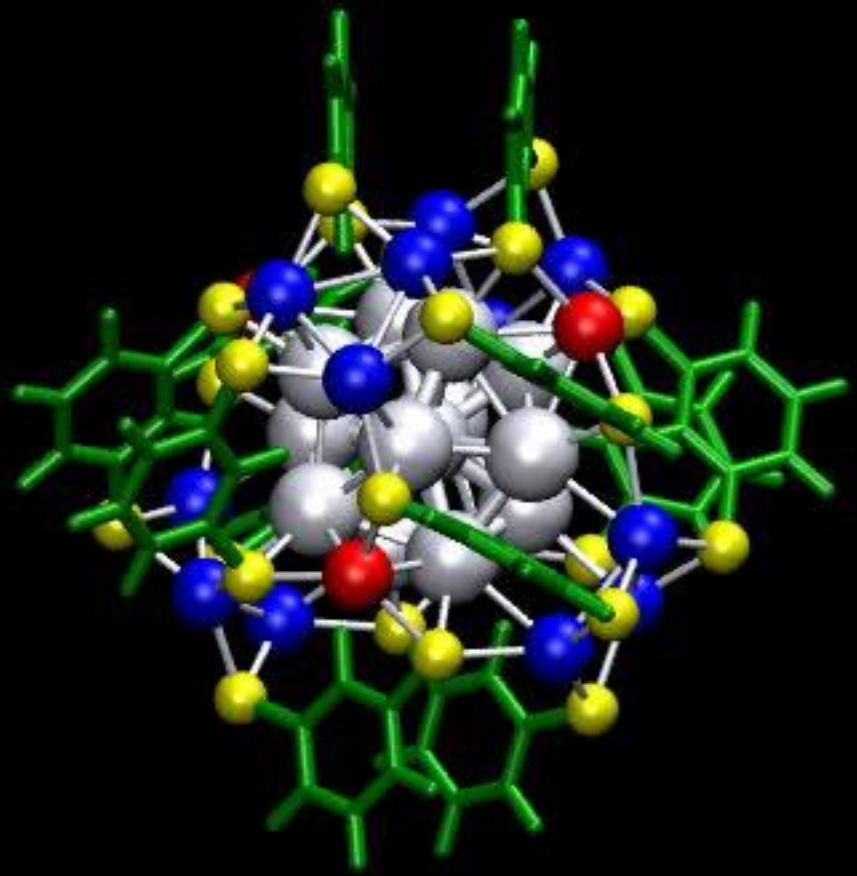
New devices

CDI, atmospheric water capture, novel membranes

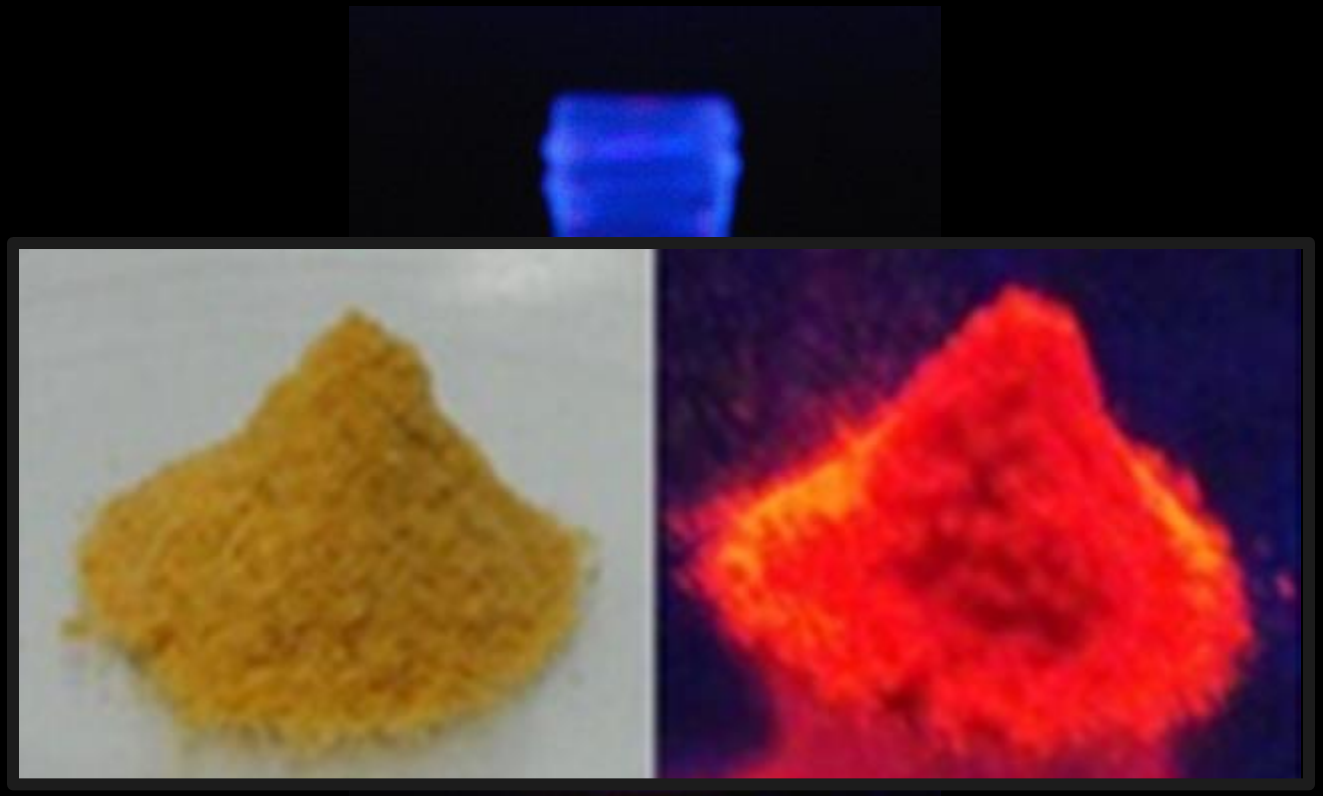


Contents

Clusters



Science of nanomaterials has advanced tremendously in the recent past.



Shibhu, Habeeb, Uday, Kamalesh, Lourdu, Ammu, Ananya, Indranath, Atanu, Krishnadas, Shridevi, Papri, Esma, Debasmita, Abhijit, Amrita, Jyoti, Sugi, Bodi, Paulami, ….

CHEMICAL REVIEWS

Review

pubs.acs.org/CR

Atomically Precise Clusters of Noble Metals: Emerging Link between Atoms and Nanoparticles

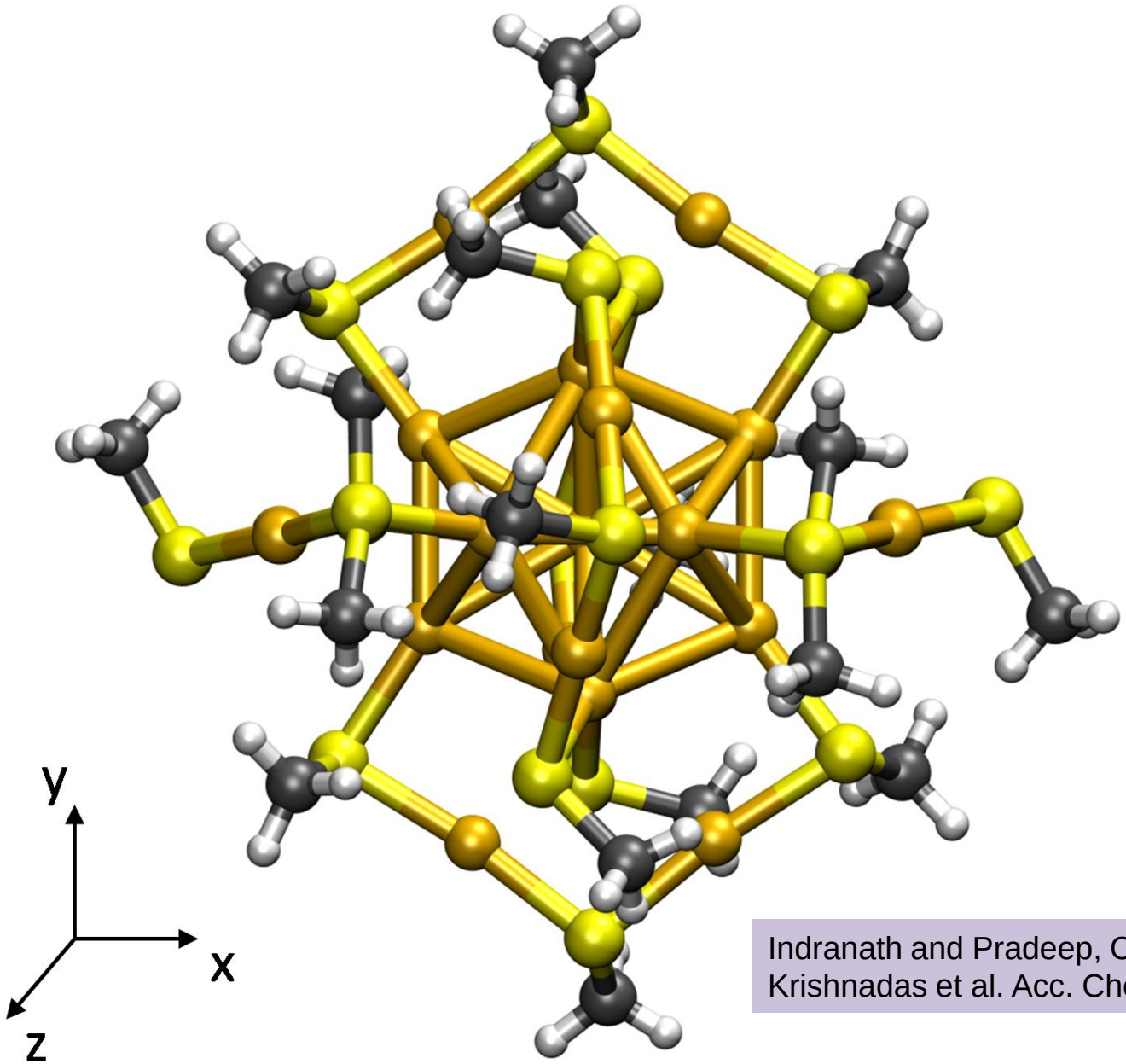
Indranath Chakraborty[†] and Thalappil Pradeep[*]

DST Unit of Nanoscience (DST UNS) and Thematic Unit of Excellence, Department of Chemistry, Indian Institute of Technology Madras, Chennai 600036, India

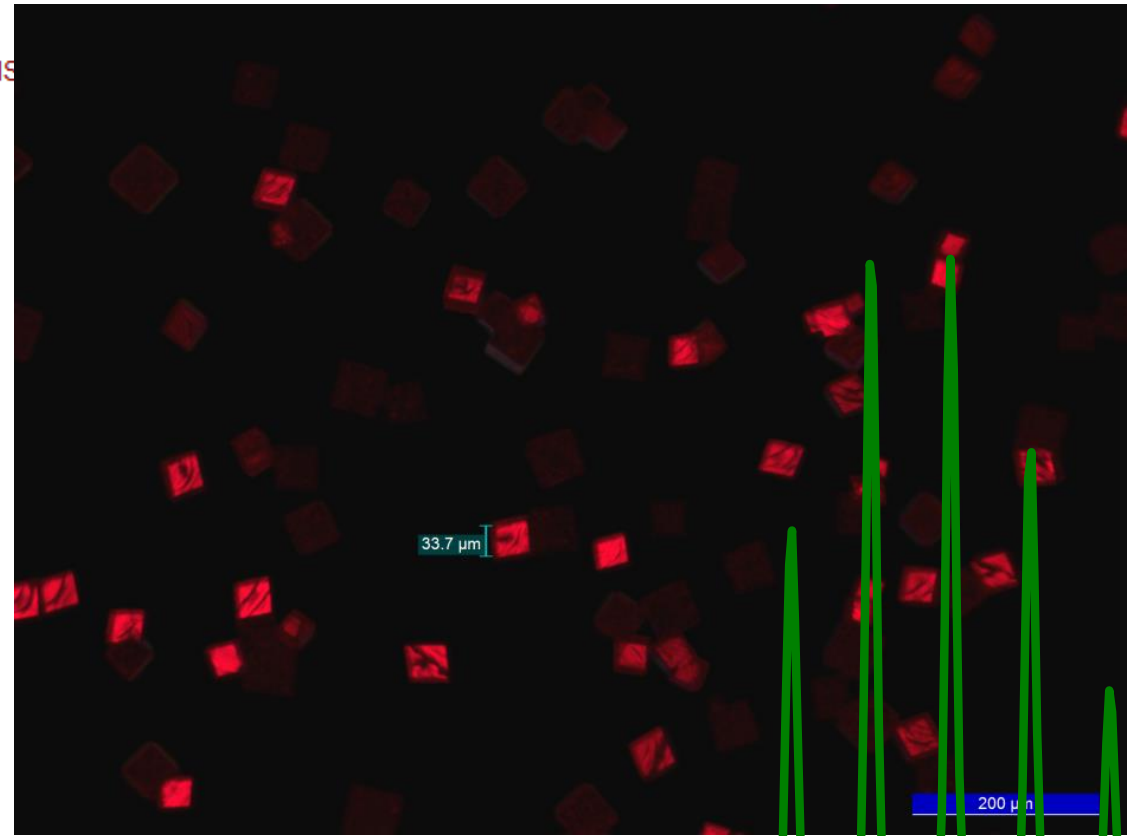
Supporting Information

ABSTRACT: Atomically precise pieces of matter of nanometer dimensions composed of noble metals are new categories of materials with many unusual properties. Over 100 molecules of this kind with formulas such as $Au_{25}(SR)_{18}$, $Au_{38}(SR)_{24}$, and $Au_{102}(SR)_{44}$ as well as $Ag_{25}(SR)_{18}$, $Ag_{29}(S_2R)_{12}$, and $Ag_{44}(SR)_{30}$ (often with a few counterions to compensate charges) are known now. They can be made reproducibly with robust synthetic protocols, resulting in colored solutions, yielding powders or diffractable crystals. They are distinctly different from nanoparticles in their spectroscopic properties such as optical absorption and emission, showing well-defined features, just like molecules. They show isotopically resolved molecular ion peaks in mass spectra and provide diverse information when examined through multiple instrumental methods. Most important of these properties is luminescence, often in the visible−near-infrared window, useful in biological applications. Luminescence in the visible region, especially by clusters protected with proteins, with a large Stokes shift, has been used for various sensing applications, down to a few tens of molecules/ions, in air and water. Catalytic properties of clusters, especially oxidation of organic substrates, have been examined. Materials science of these systems presents numerous possibilities and is fast evolving. Computational insights have given reasons for their stability and unusual properties. The molecular nature of these materials is unequivocally manifested in a few recent studies such as intercluster reactions forming precise clusters. These systems manifest properties of the core, of the ligand shell, as well as that of the integrated system. They are better described as protected molecules or *aspicules*, where *aspis* means shield and *cules* refers to molecules, implying that they are "shielded molecules". In order to understand their diverse properties, a nomenclature has been introduced with which it is possible to draw their structures with positional labels on paper, with some training. Research in this area is captured here, based on the publications available up to December 2016.

Also the pioneering work of R. W. Murray, Robert L. Whetten, Uzi Landman, Tatuya Tsukuda, Yuichi Negishi, Hannu Hakkinen, R. Jin, Nanfeng Zheng, Terry Bigioni, Osman Bakr, Kornberg, Jianping Xie, C. M. Aikens, Thomas Buergi, Amala Dass, …. A. W. Castleman Jr., H. Schmidbauer, …



Indranath and Pradeep, Chem. Rev. 2017
Krishnadas et al. Acc. Chem. Res. 2017



7390.5718
7391.5850
7388.5825
7392.5610
7387.5693
7393.5747
7394.5508

7385
7390
7395

00 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000

mass/charge

K. R. Krishnadas et al., J. Am. Chem. Soc. 2016

Contents

Inquisitive science
Technology
Translation
What next?

PNAS PNAS PNAS

Biopolymer-re nanocomposit water purifica

Mohan Udhaya Sankar[1], Saha Kamalesh Chaudhari, and Tha

Unit of Nanoscience and Thematic Uni

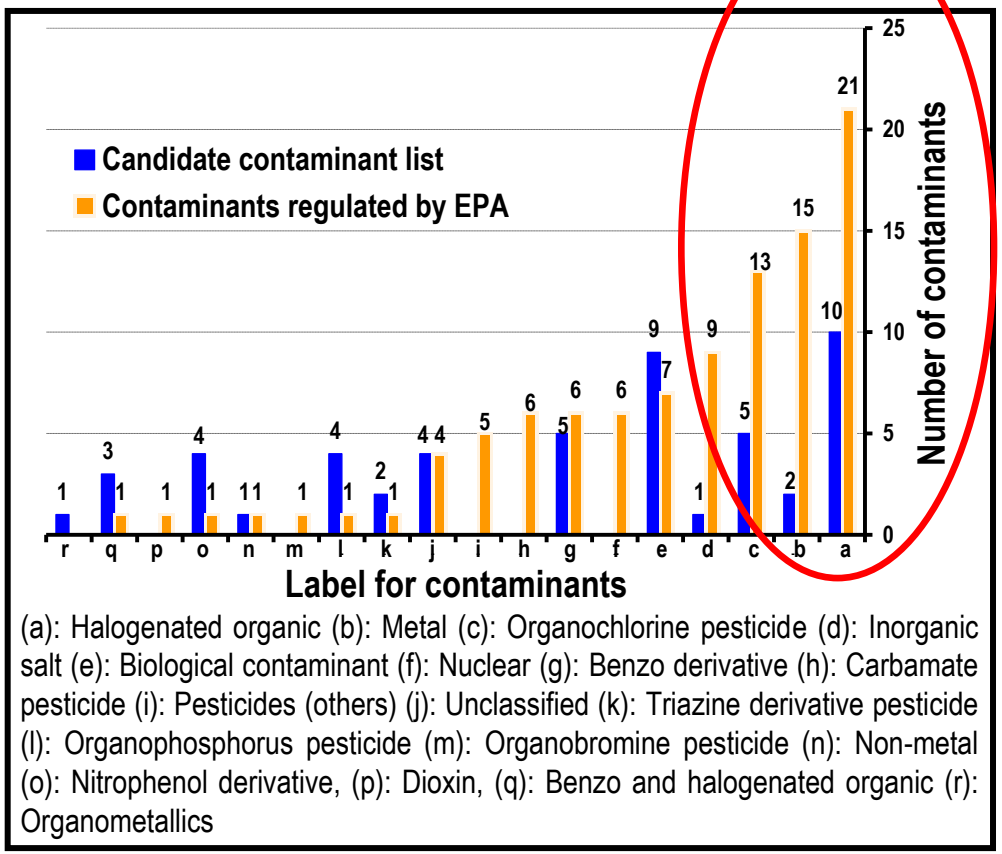
Edited by Eric Hoek, University of Calif

Creation of affordable materials fo water is one of the most promising drinking water for all. Combinin composites to scavenge toxic sp other contaminants along with t affordable, all-inclusive drinking without electricity. The critical p synthesis of stable materials tha uously in the presence of comp drinking water that deposit and surfaces. Here we show that suc be synthesized in a simple and effe out the use of electrical power. T sand-like properties, such as highe forms. These materials have beer water purifier to deliver clean drin ily. The ability to prepare nanos ambient temperature has wide water purification.

hybrid | green | appropriate technolog

Featured in:
The Guardian, UK
The Hindu, Telegraph, Times of India, etc.
Scientific American
New Scientist
and many others

Future of water purification: An enigma with some pointers



(a): Halogenated organic (b): Metal (c): Organochlorine pesticide (d): Inorganic salt (e): Biological contaminant (f): Nuclear (g): Benzo derivative (h): Carbamate pesticide (i): Pesticides (others) (j): Unclassified (k): Triazine derivative pesticide (l): Organophosphorus pesticide (m): Organobromine pesticide (n): Non-metal (o): Nitrophenol derivative, (p): Dioxin, (q): Benzo and halogenated organic (r): Organometallics

Category-wise distribution of contaminants regulated by USEPA and future contaminants

Noble metal nanoparticles for water purification: A critical review, T. Pradeep and Anshup, Invited critical review, Thin Solid Films, 517 (2009) 6441-6478 (DOI: 10.1016/j.tsf.2009.03.195).

World's first nanochemistry-based water purifier

RSC | Advancing the Chemical Sciences

Chemistry World

Pesticide filter debuts in India

20 April 2007

Kilugudi Jayaraman/Bangalore, India

A domestic water filter that uses metal nanoparticles to remove dissolved pesticide residues is about to enter the Indian market. Its developers at the Indian Institute of Technology (IIT) in Chennai (formerly Madras) believe it is the first product of its kind in the world to be commercialised.

Mumbai-based Eureka Forbes Limited, a company that sells water purification systems, is collaborating with IIT and has tested the device in the field for over six months. Jayachandra Reddy, a technical consultant to the company, expects the first 1000 units to be sold door-to-door from late May.

'Our pesticide filter is an offshoot of basic research on the chemistry of nanoparticles,' Thalappil Pradeep who led the team at IIT Chennai told *Chemistry World*. He and his student Sreekumaran Nair discovered in 2003 that halocarbons such as carbon tetrachloride (CCl_4) completely break down into metal halides and amorphous carbon upon reaction with gold and silver nanoparticles[1].

Pradeep said this prompted them to extend their study to include organochlorine and organophosphorous pesticides, whose presence in water is posing a health risk in rural India. In research funded by the Department of Science and Technology in New Delhi, his team found[2,3] that gold and silver nanoparticles loaded on alumina were indeed able to completely remove endosulfan, malathion and chlorpyrifos - three pesticides that

water supplies.

Use and recycle

Chemistry world

First ever nanotechnology product for clean water

A plant to make supported nanomaterials for water purification; with capacity of 4.5 tons per month, 2007

1. Patents: A method of preparing purified water from water containing pesticides, **Indian patent 200767**
2. Extraction of malatheon and chlorpiryhphos from drinking water by nanoparticles , **US 7,968,493** A method for decontaminating water containing pesticides, **EP 17,15,947**

Product is marketed now by a Eureka Forbes Ltd.

Several new technologies are now available

A. Sreekumaran Nair et al. 2003

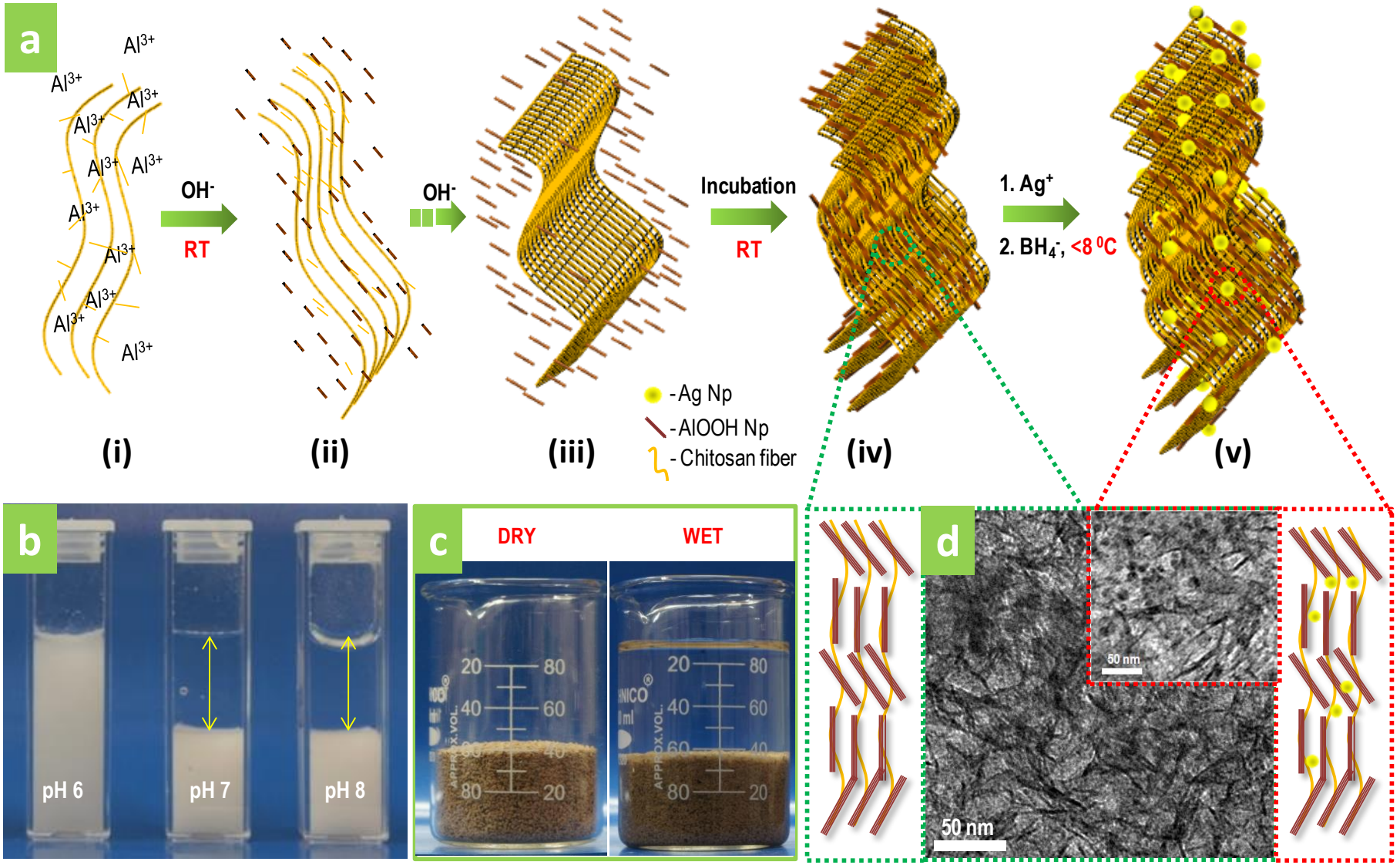
Affordable materials for water purification - Bioinspired

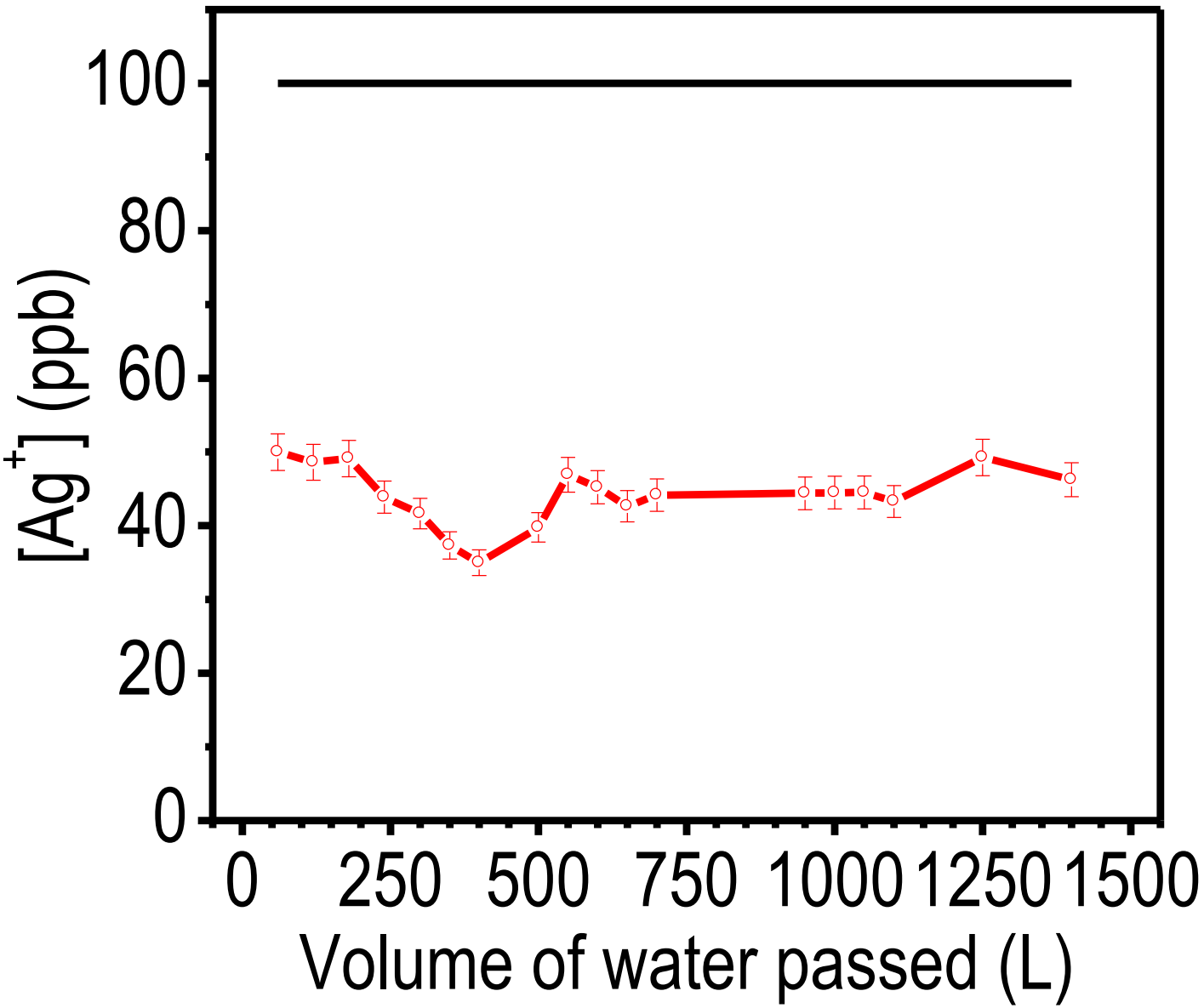
Water positive

Water-based, room temperature, water stable

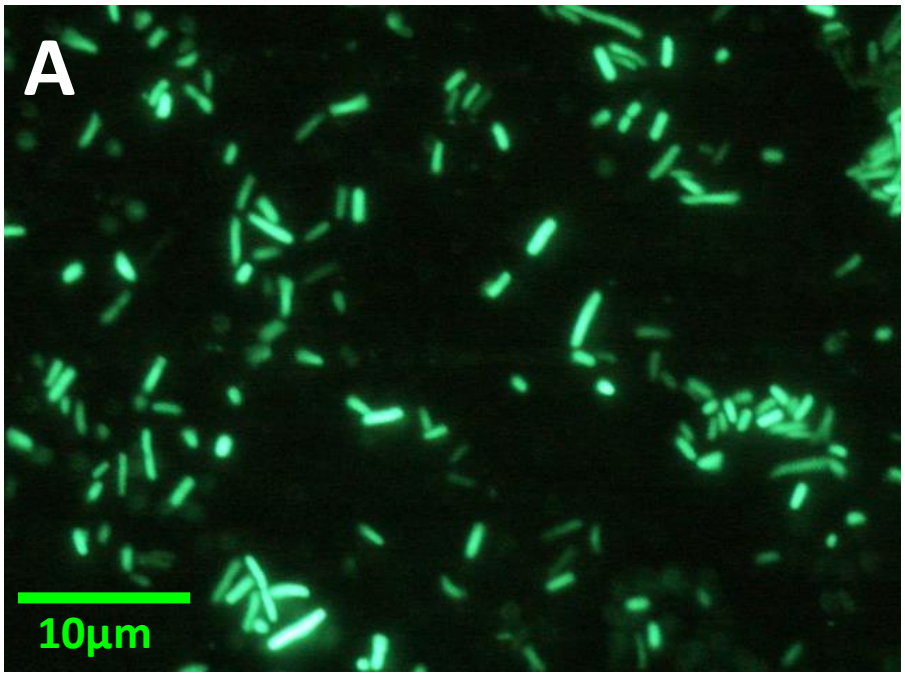
Green

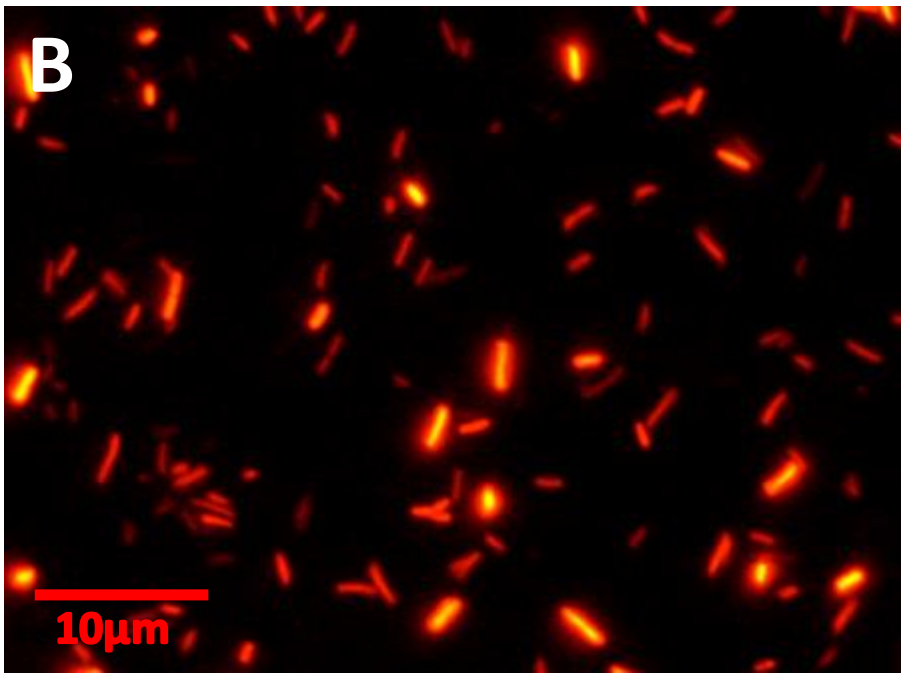
M. U. Sankar et al, PNAS 2013

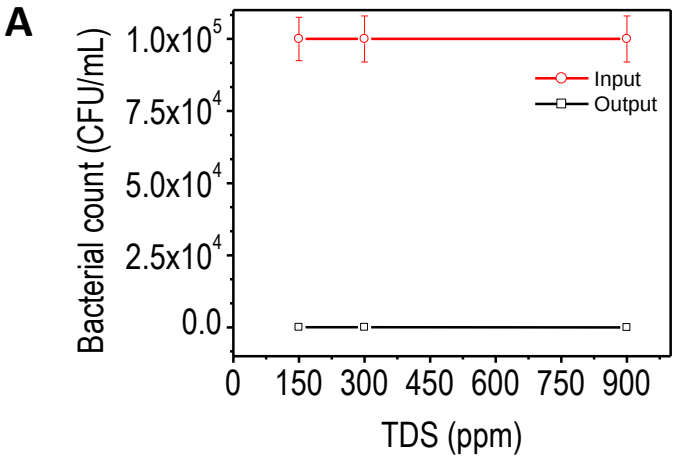

a
Al3+
OH-
RT
OH-
Incubation
RT
1. Ag+
2. BH4-, <8 0C
(i)
(ii)
(iii)
(iv)
(v)
- Ag Np
- AlOOH Np
- Chitosan fiber
b
pH 6
pH 7
pH 8
c
DRY
WET
d
50 nm
50 nm


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

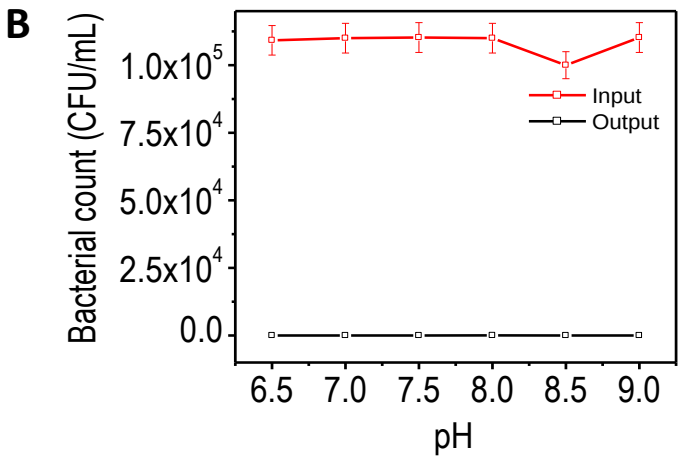
Live/dead staining experiments





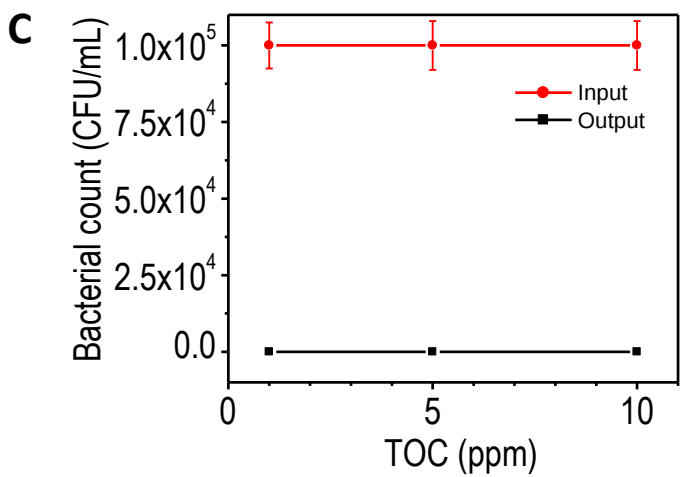


TDS

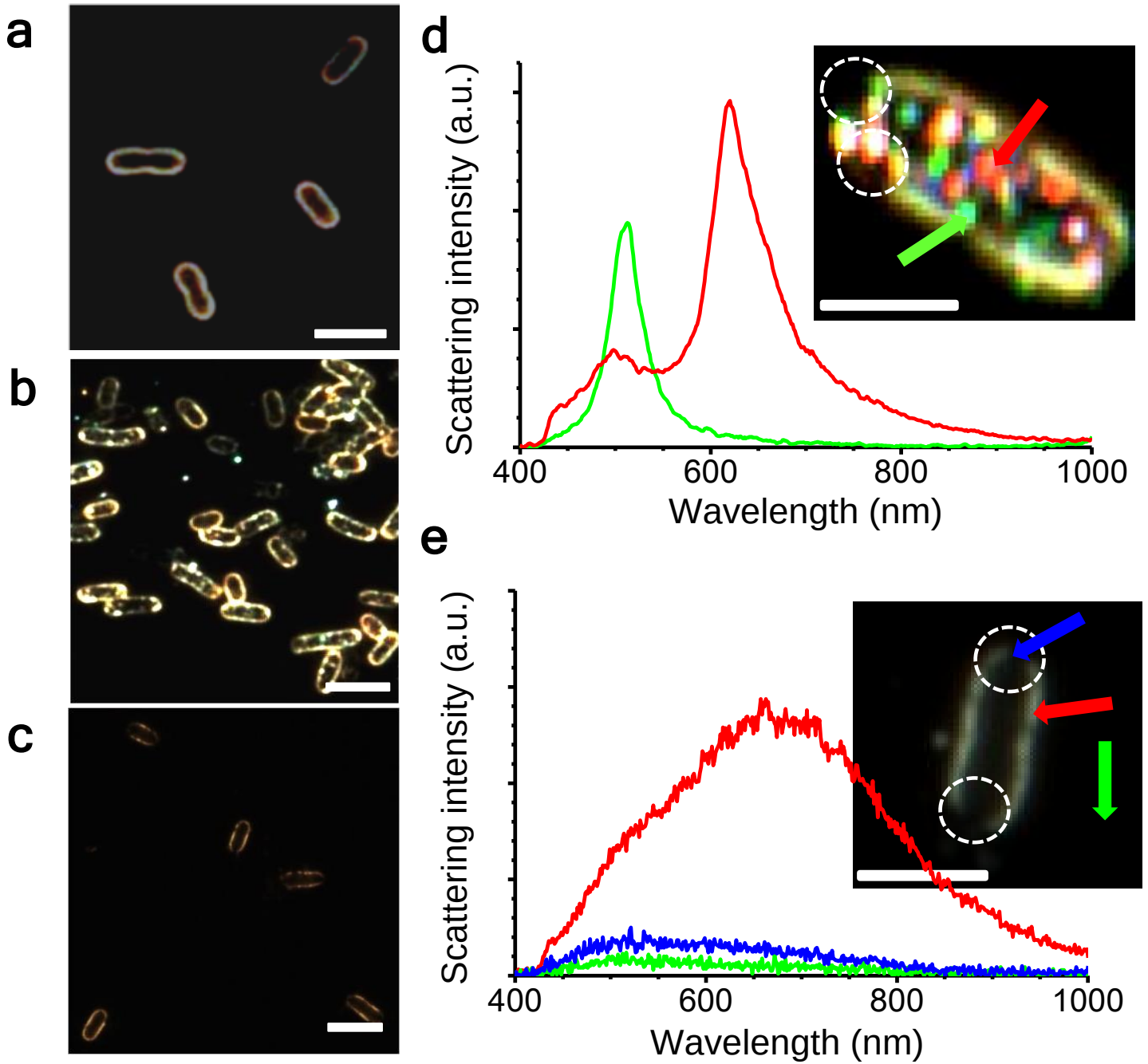


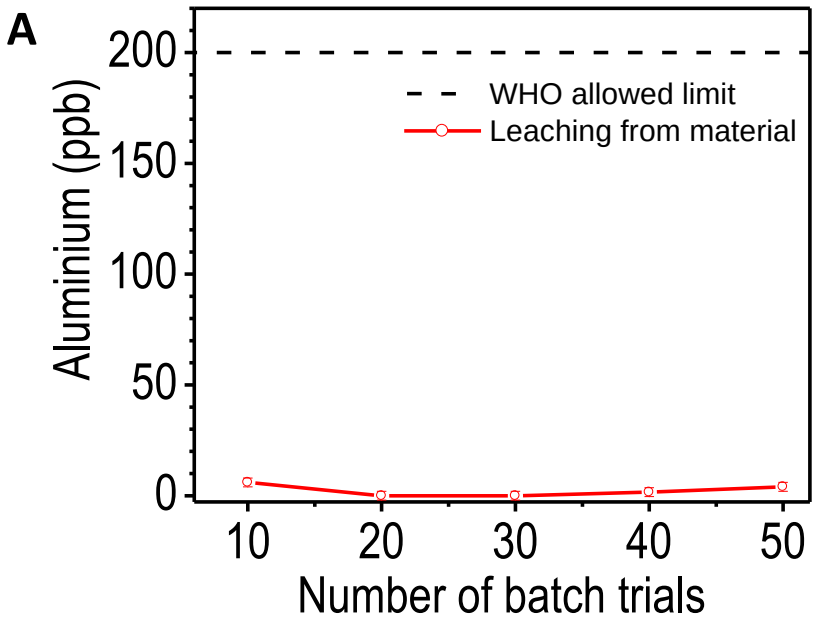
pH

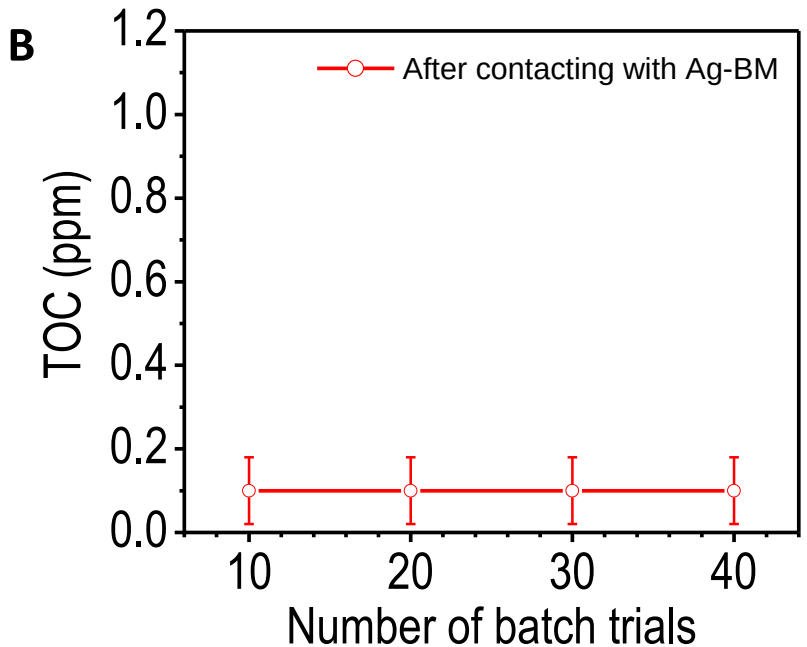
Real water experiments



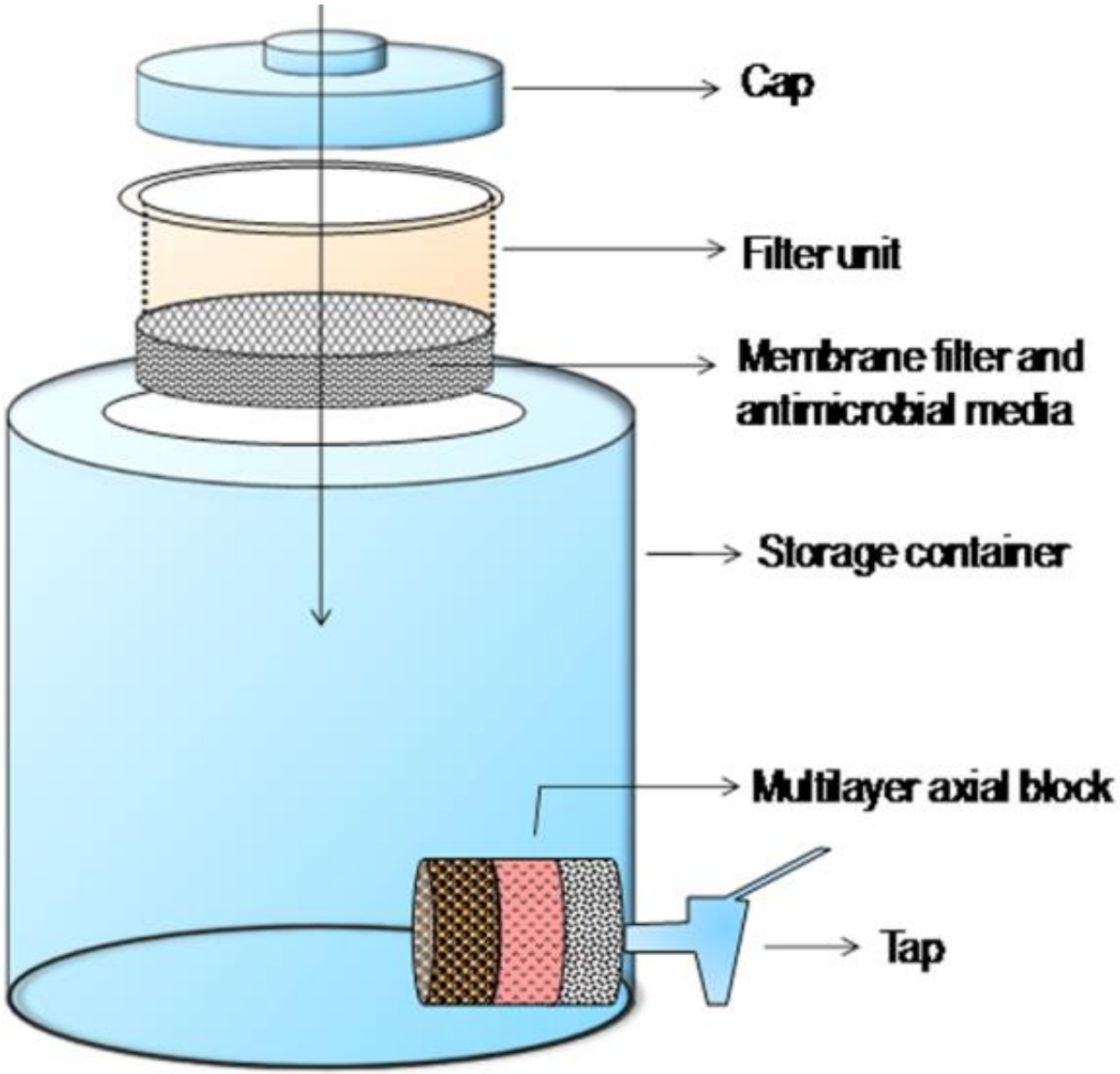
TOC – Humic acid


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)





Leaching experiments


Cap
Filter unit
Membrane filter and antimicrobial media
Storage container
Multilayer axial block
Tap

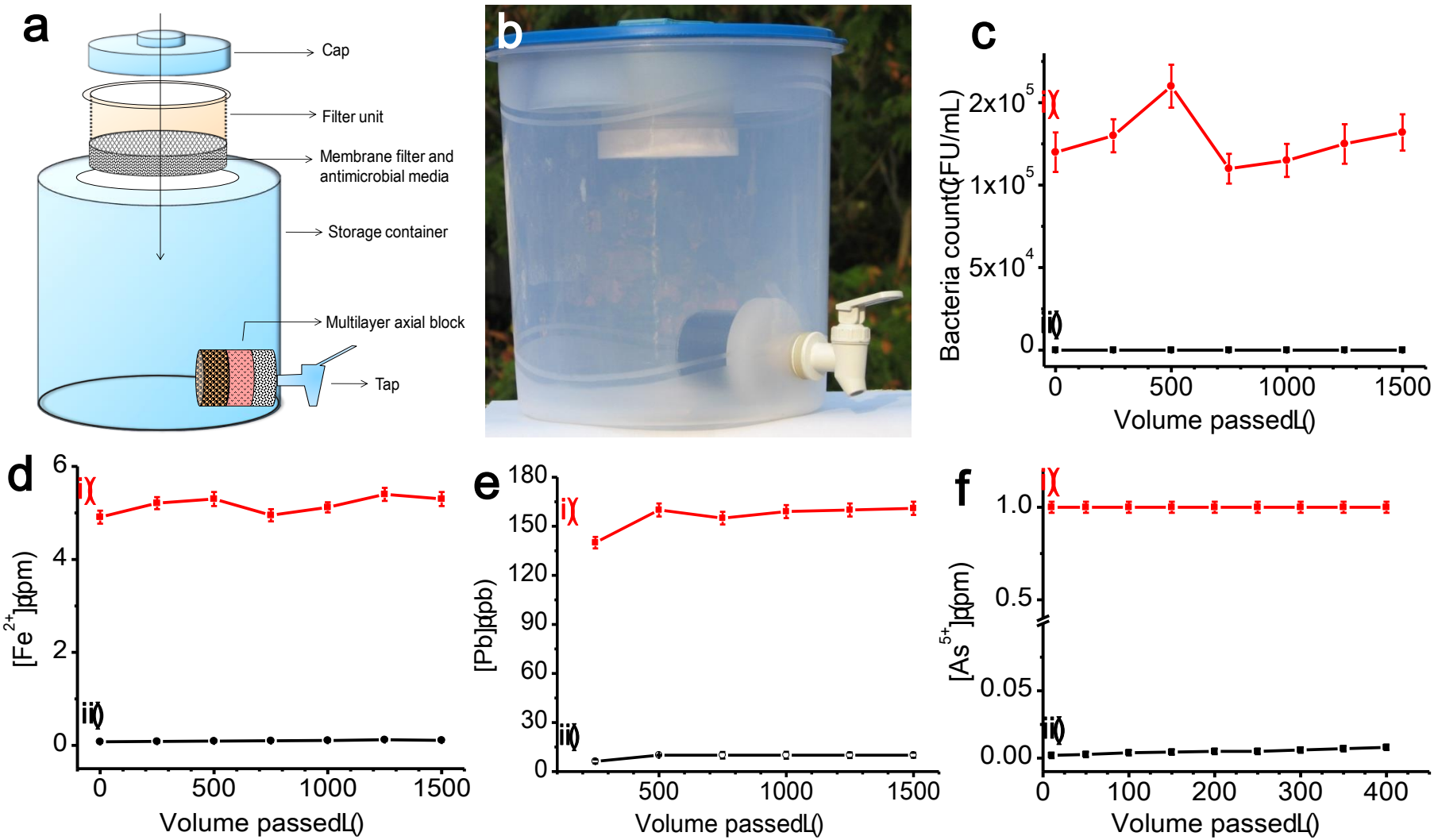
Physicochemical characteristics of influent natural drinking water

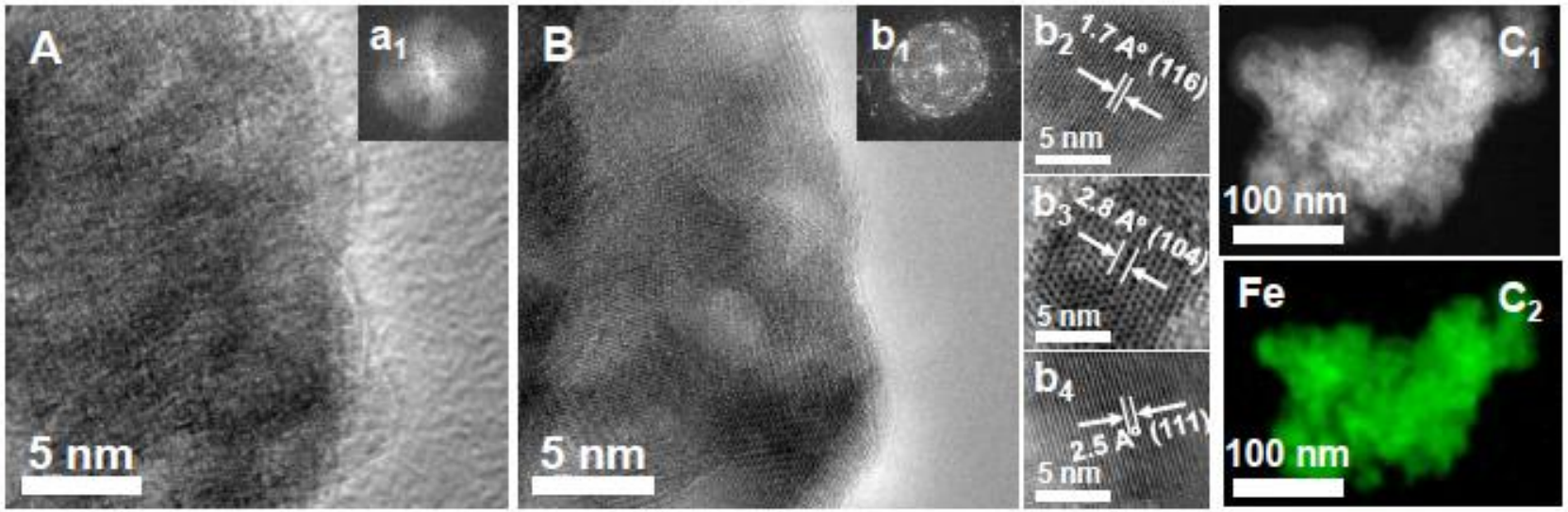
(Note: All parameters are expressed in mg L^{-1}, except for pH and conductivity)

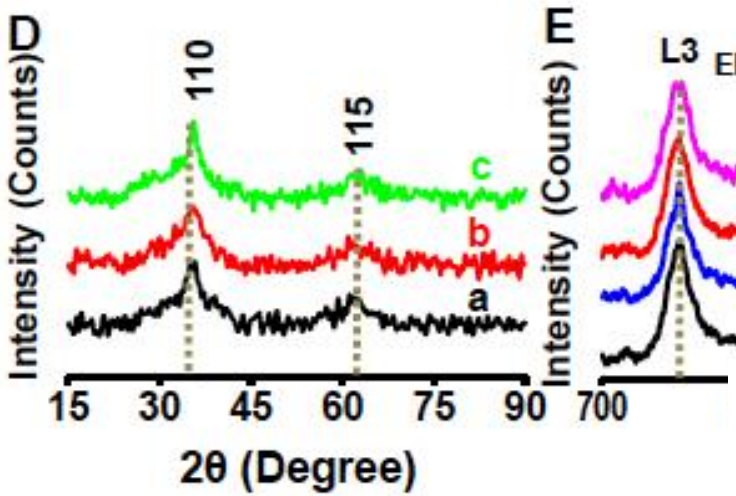
ND-not detected

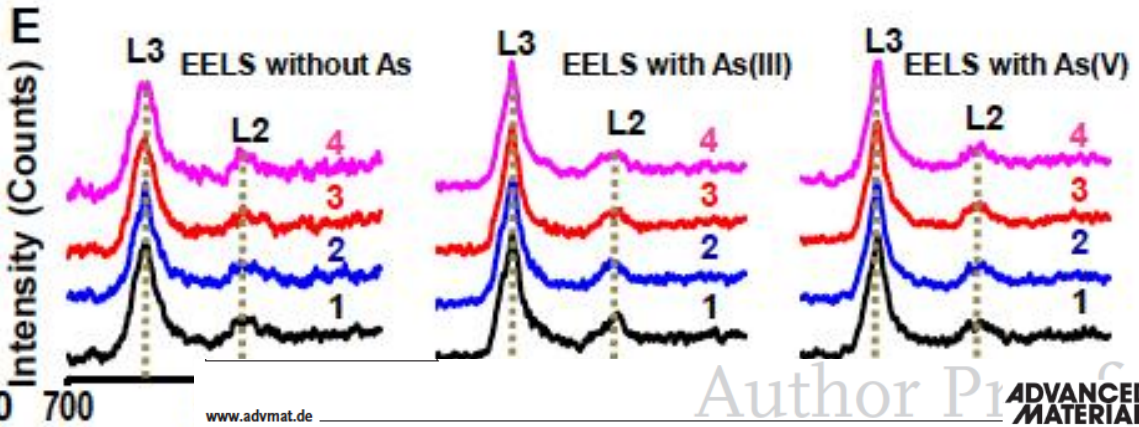
Natural drinking water (without treatment so that there is a residual bacterial count in it) was used for testing to ensure that that the material functions in the field.

Parameters	Value
Total coliforms (CFU/mL)	1-2 x 10^3
p H @25° C	7.8
Conductivity (µS/cm)	640.000
Fluoride	0.573
Chloride	86.340
Nitrate	1.837
Sulphate	32.410
Silicate	15.870
Lithium	ND
Sodium	53.740
Ammonium	ND
Potassium	2.330
Magnesium	14.340
Calcium	28.720


a
Cap
Filter unit
Membrane filter and antimicrobial media
Storage container
Multilayer axial block
Tap
b
c
Bacteria count(CFU/mL)
2x10^5
1x10^5
5x10^4
0
i)
ii)
0
500
1000
1500
Volume passedL()
d
[Fe^2+]p(pm)
6
4
2
0
i)
ii)
0
500
1000
1500
Volume passedL()
e
[Pb]p(pb)
180
150
120
90
60
30
0
i)
ii)
500
1000
1500
Volume passedL()
f
[As^5+]p(pm)
1.0
0.5
0.05
0.00
i)
ii)
0
100
200
300
400
Volume passedL()



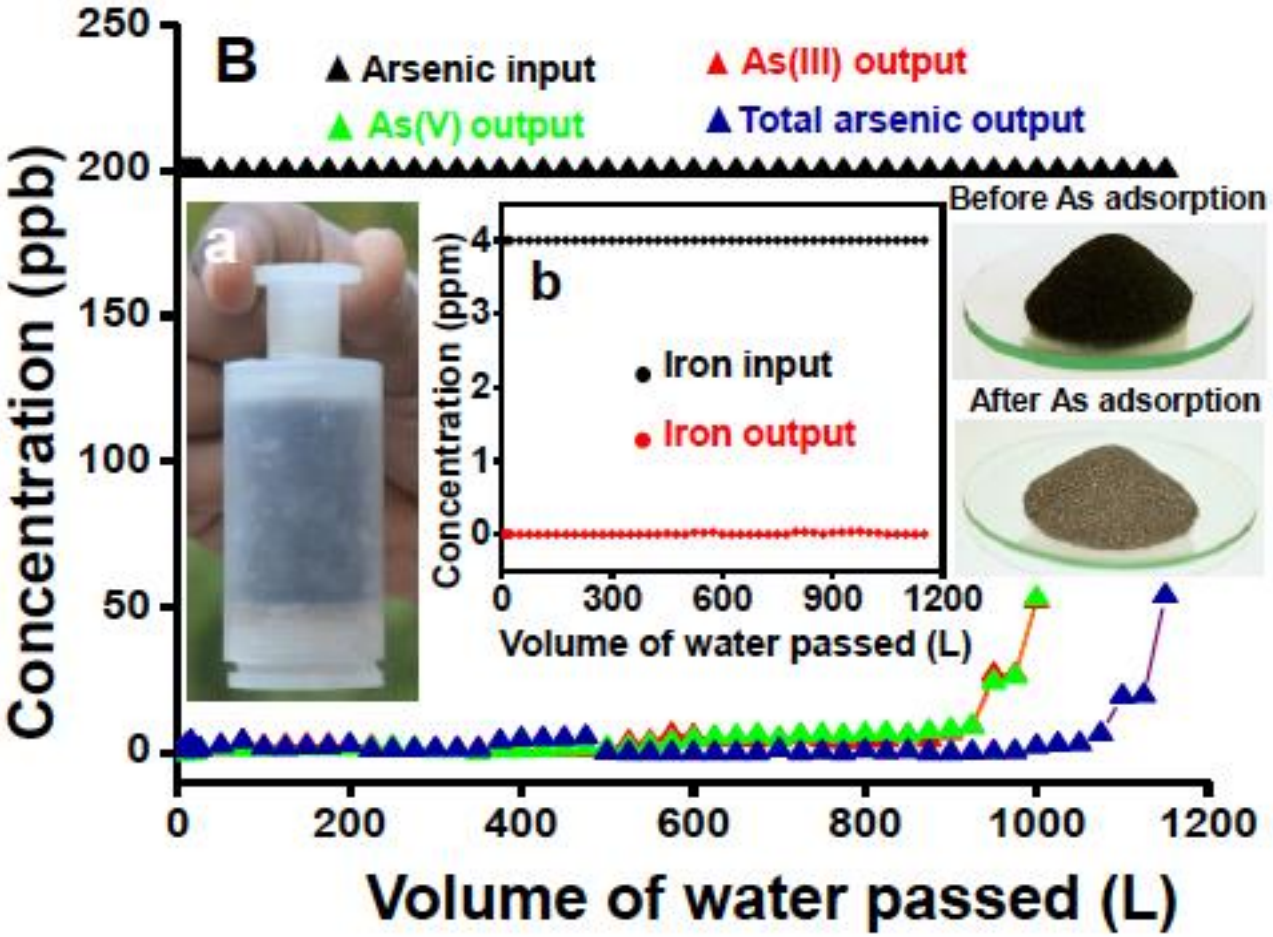




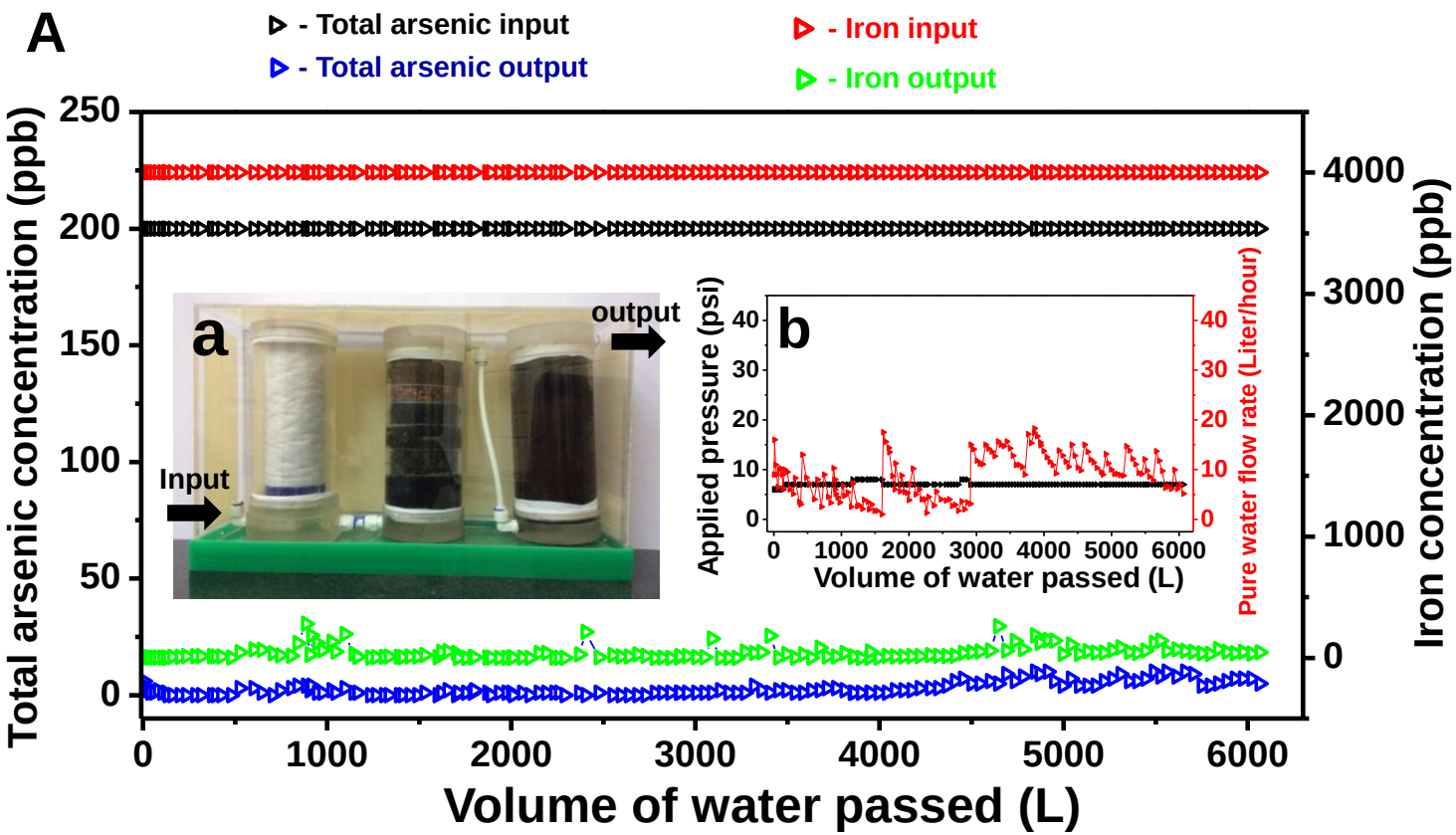
www.advmat.de
ADVANCED MATERIALS

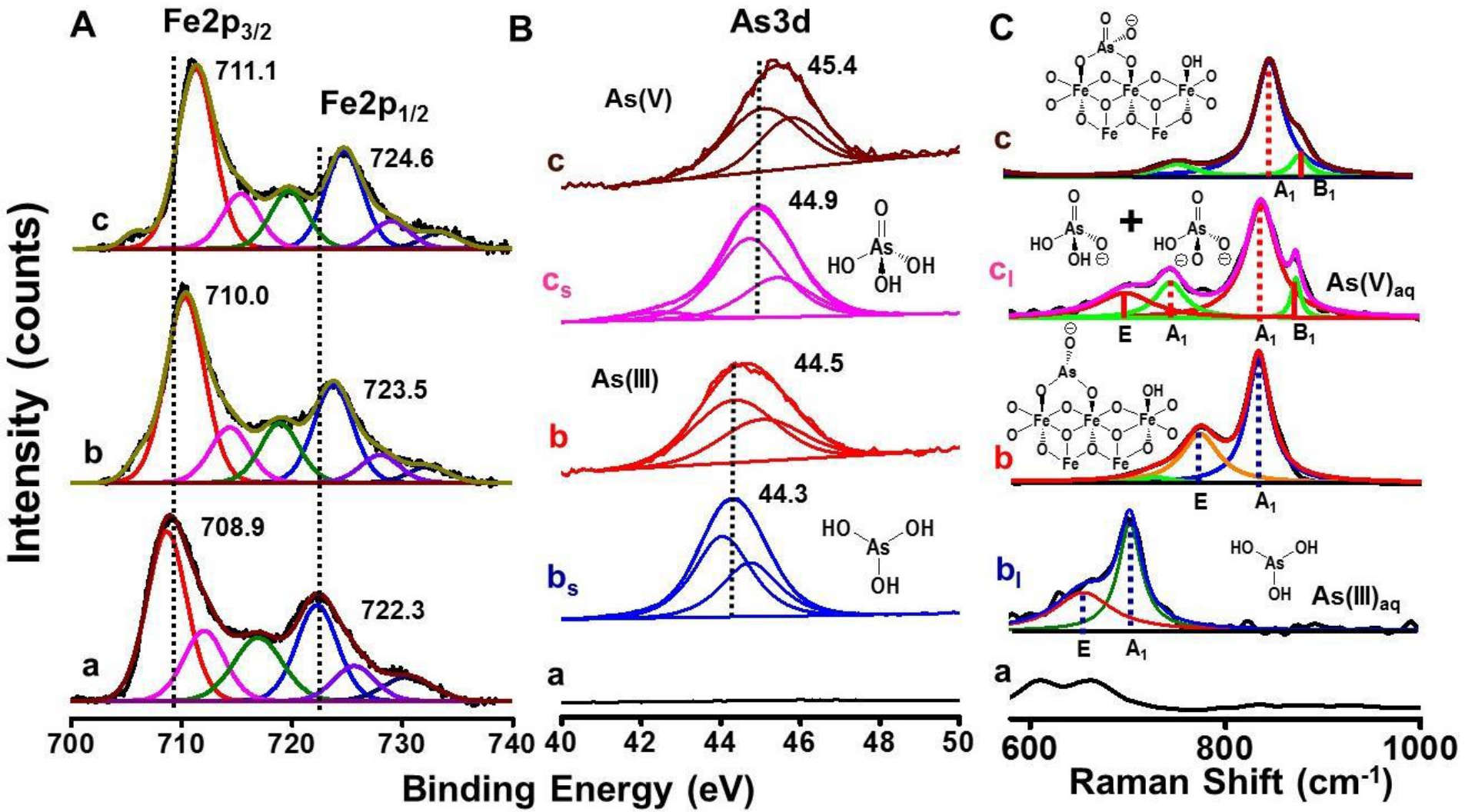
Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic Free Drinking Water

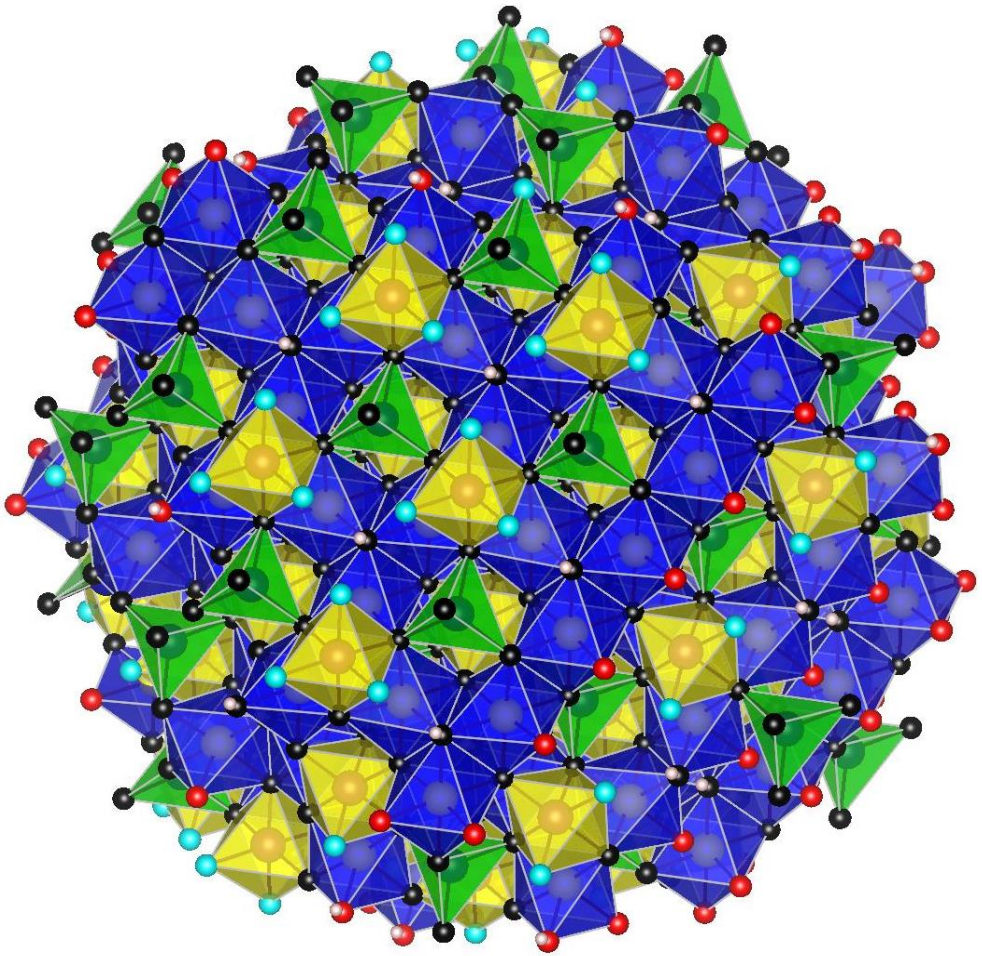
By *Avula Anil Kumar, Anirban Som, Paolo Longo, Chennu Sudhakar, Radha Gobinda Bhuin, Soujit Sen Gupta, Anshup, Mohan Udhaya Sankar, Amrita Chaudhary, Ramesh Kumar, and T. Pradeep**



A. Anil Kumar, et al. Adv. Mat. 2016

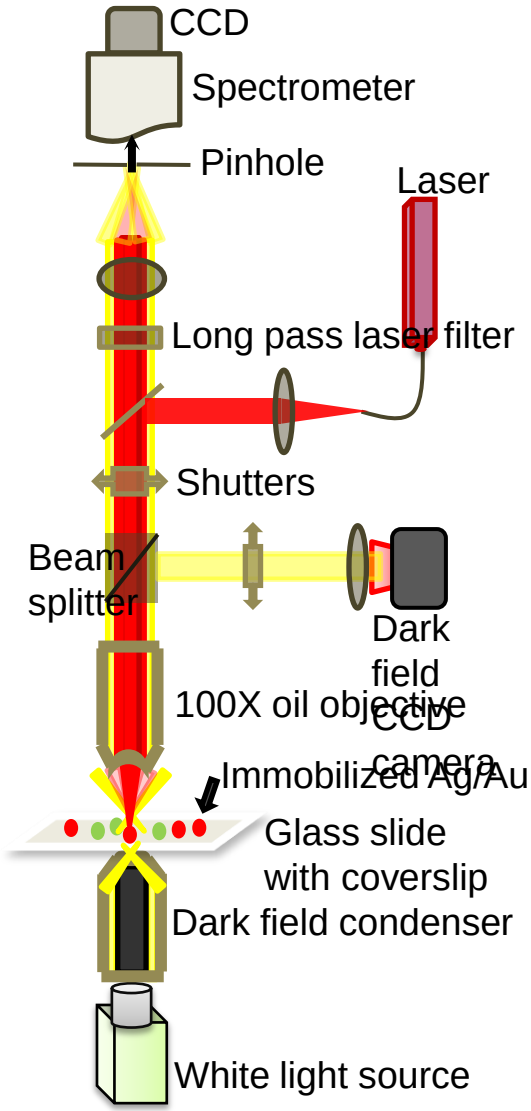

A
- Total arsenic input
- Total arsenic output
- Iron input
- Iron output
Total arsenic concentration (ppb)
Iron concentration (ppb)
Volume of water passed (L)
a
Input
output
b
Applied pressure (psi)
Pure water flow rate (Liter/hour)
Volume of water passed (L)


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
E
A1
A1
B1
As(V)aq
b
E
A1
bl
E
A1
As(III)aq
a
600
800
1000
Raman Shift (cm-1)

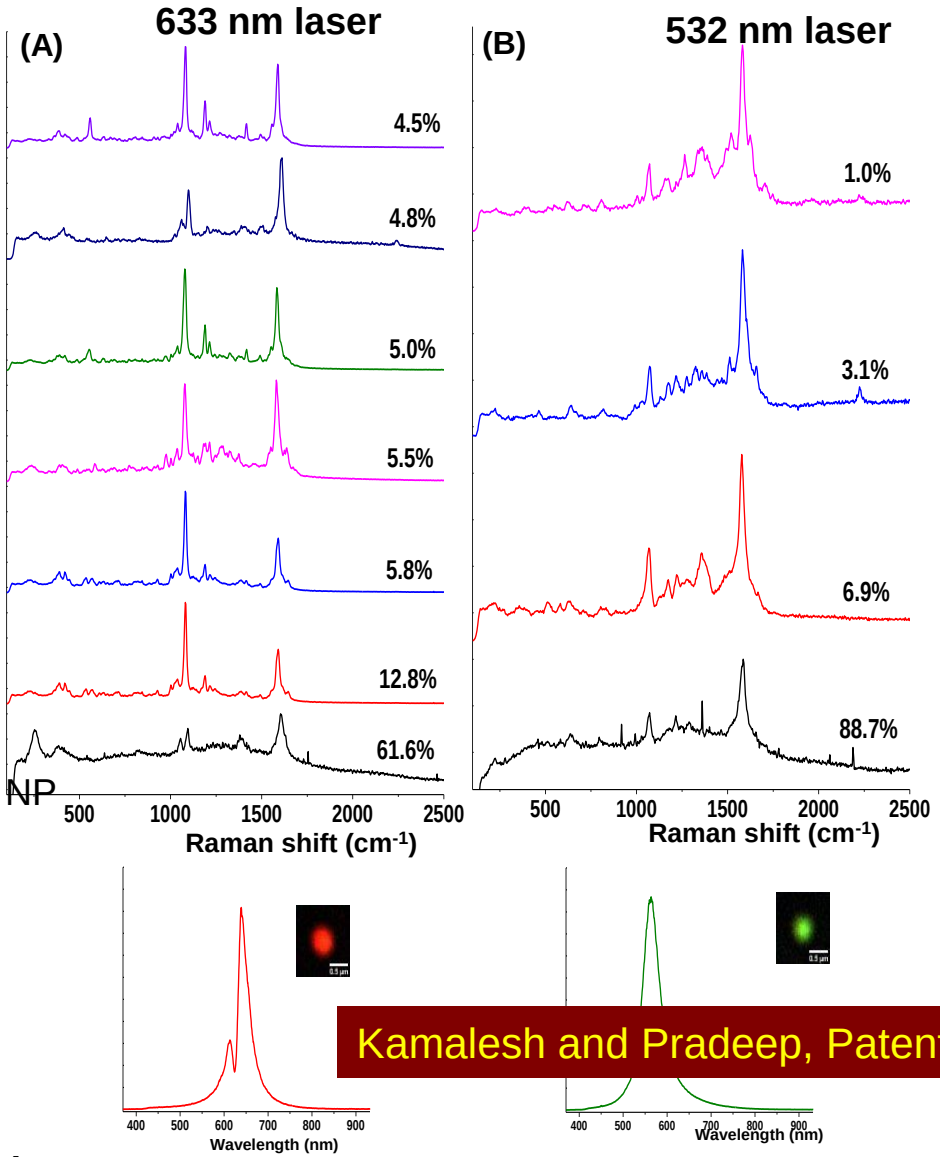


Chennu Sudhakar et al. Unpublished

Vibrational Tomography of Citrate Adsorbed on Single Isolated Silver Nanoparticles by Real Time Raman Spectroscopy

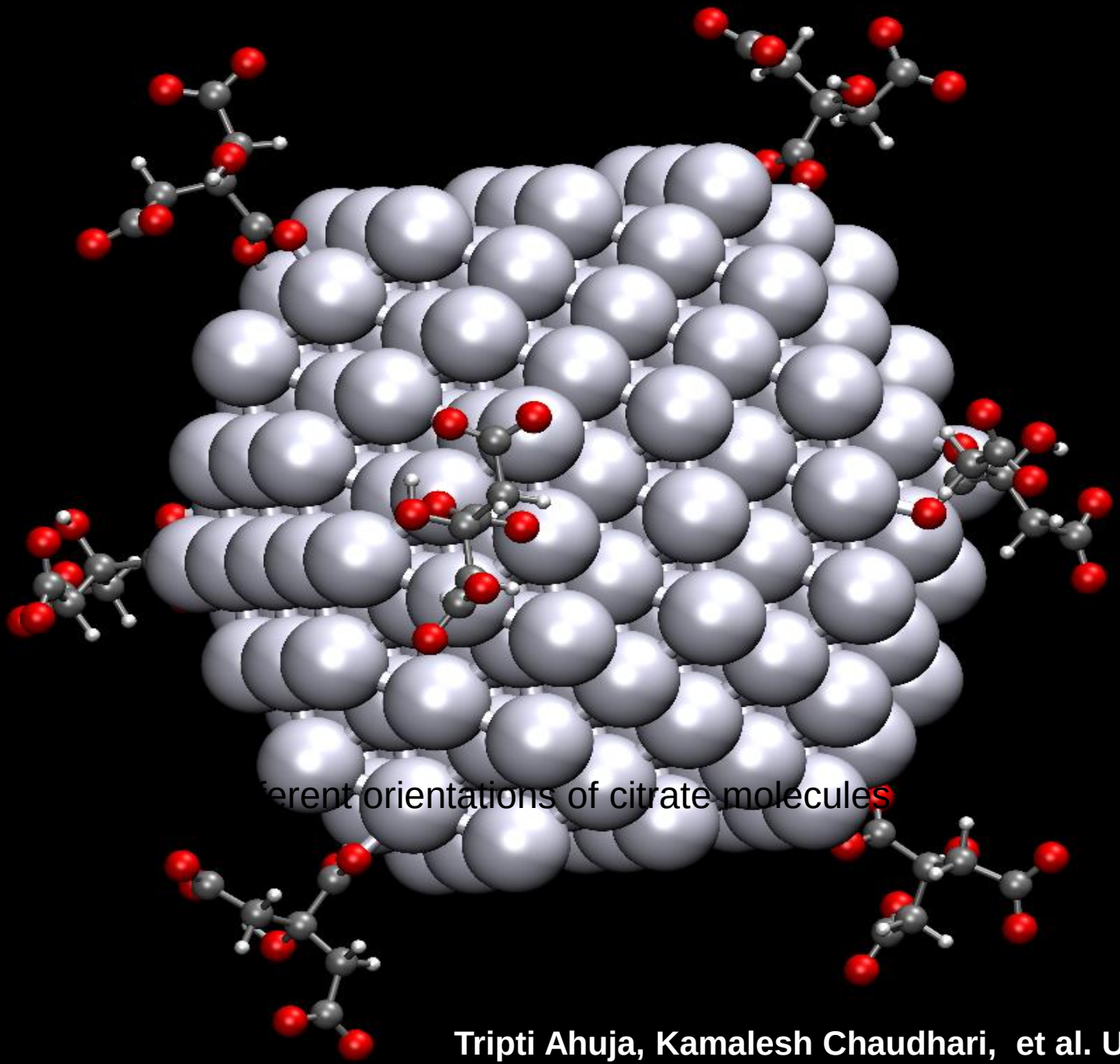


Schematic of dark field confocal Raman microspectroscopy set-up



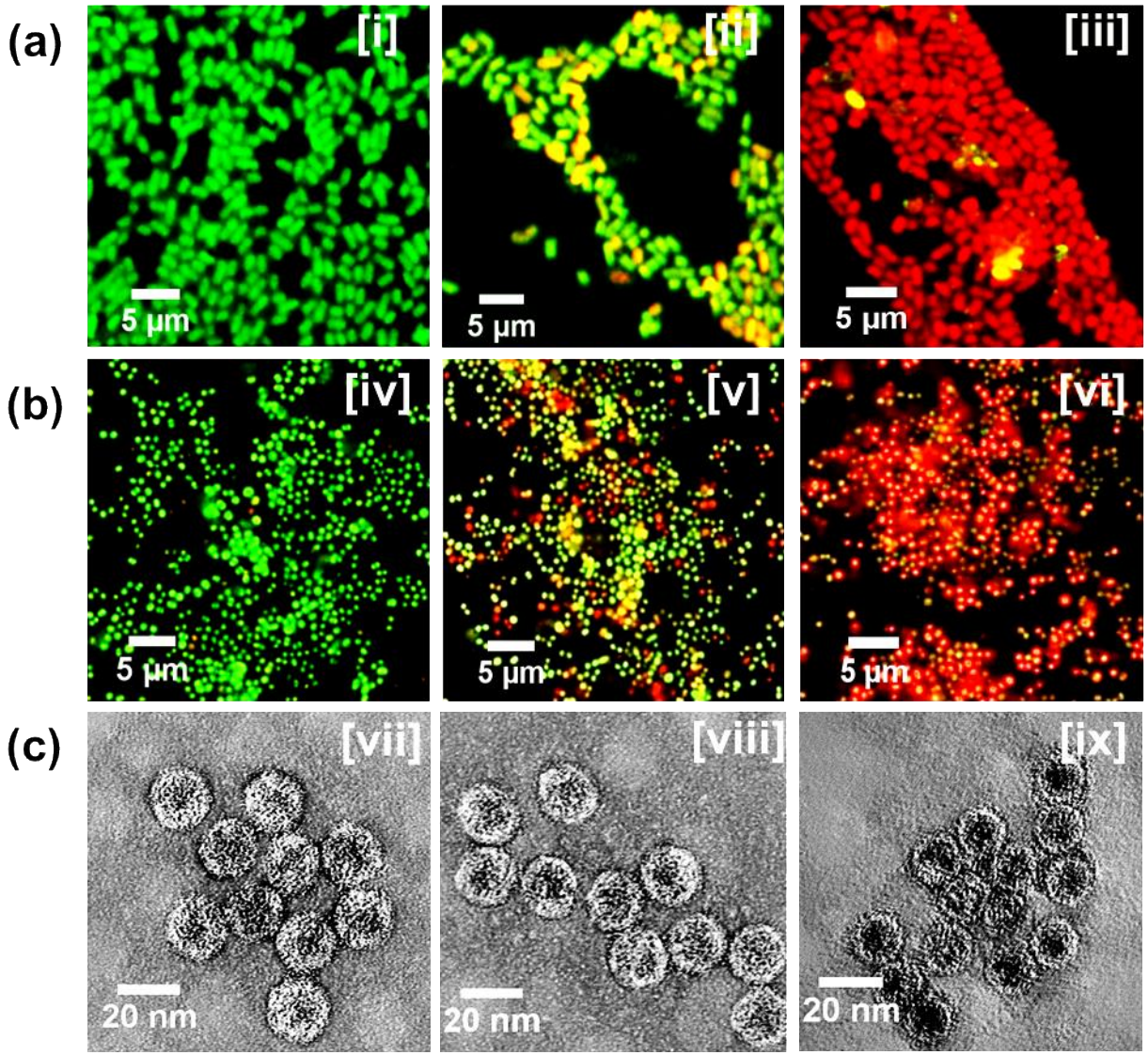
Kamalesh and Pradeep, Patent protected

Real time SERS measurements of citrate molecule adsorbed on single silver nanoparticles



Tripti Ahuja, Kamalesh Chaudhari, et al. Unpublished

Anion effect



R. Swathy, et al. Scientific Reports, 2014

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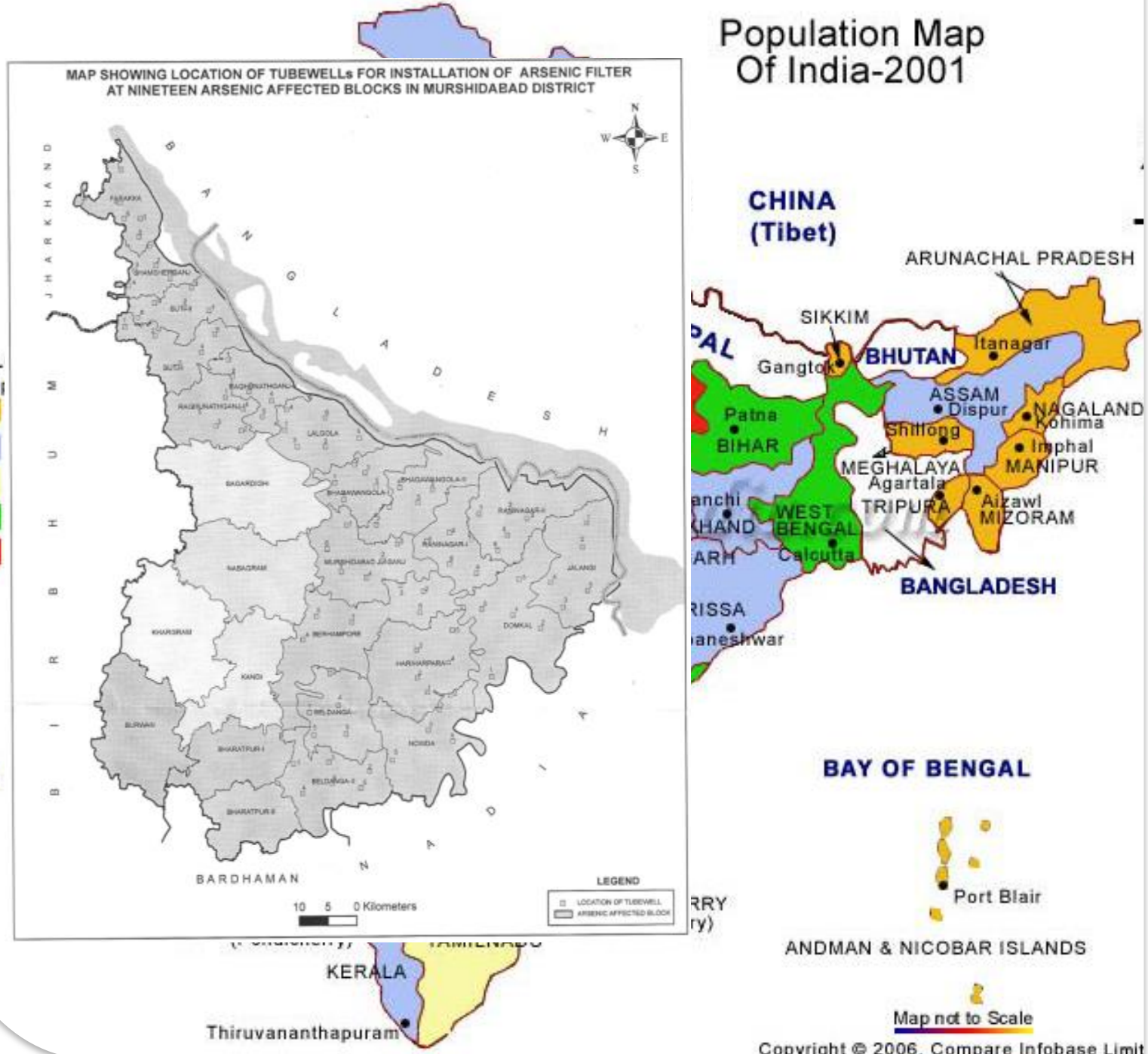
AMRIT
DRINKING WATER
ARSENIC & METAL REMOVAL BY INDIAN TECHNOLOGY
INDIAN INSTITUTE OF TECHNOLOGY MADRAS


Population Map
Of India-2001
MAP SHOWING LOCATION OF TUBEWELLs FOR INSTALLATION OF ARSENIC FILTER
AT NINETEEN ARSENIC AFFECTED BLOCKS IN MURSHIDABAD DISTRICT
JHARKHAND
BIHAR
BANGLADESH
BARDHAMAN
LEGEND
10 5 0 Kilometers
CHINA
(Tibet)
ARUNACHAL PRADESH
SIKKIM
Gangtok
BHUTAN
Itanagar
ASSAM
Dispur
NAGALAND
Kohima
Patna
BIHAR
Shillong
Imphal
MANIPUR
MEGHALAYA
Agartala
TRIPURA
Aizawl
MIZORAM
WEST
BENGAL
Calcutta
BANGLADESH
BAY OF BENGAL
Port Blair
ANDMAN & NICOBAR ISLANDS
KERALA
Thiruvananthapuram
Map not to Scale
Copyright © 2006, Compare Infobase Limit

A glimpse of performance data for installations in Murshidabad

S.No	Sample Name	Input arsenic (ppb)	Output arsenic (ppb)	Number of days running
1.	Topidanga Jumma Masjid, Bhagwangola-II	31	0	30 days
2.	Bhandahara Jumma Masjid, Bhagwangola-II	20.7	0.4	30 days
3.	Horirampur Jumma Masjid, Bhagwangola-II	37	0	45 days
4.	Dihipara Jumma Masjid, Bhagwangola-II	4.8	1.8	30 days
5.	Bahadurpur High School, Bhagwangola-I	9.4	0.2	30 days
6.	Charlabangola Higher Sec School, Bhagwangola-I	28.2	0.1	245 days
7.	Mahisasthali Girls' High School, Bhagwangola-I	0	0	30 days
8.	Orahar Girls' High School, Bhagwangola-I	0.53	0	10 days
9.	Rabindratola BN Pandey High School, Bhagwangola-I	84.3	0	245 days
10.	Karbalajamam Masjid, Berhampore	6.8	0	150 days
11.	PHED office, Berhampore	32	0	10 days
12.	Nabipur Bazar Jumma Masjid, Raninagar-II	1.3	0	60 days
13.	Rukunpur Jumma Masjid, Hariharpara	25.6	2.2	60 days
14.	Klyanpur Jumma Masjid, Domkal	64.7	0	200 days
15.	Benadaha Mondalpara Hanafi Jamat, Beldanga-I	9.04	0	180 days

Performance data from Murshidabad (continued)

S. No.	Sample Name	Input arsenic (ppb)	Output arsenic (ppb)	Number of days running
23.	Babaltali Jumma Masjid, Raninagar – II	10.7	0	180 days
24.	Sargachhi Paschimpara Jumma Masjid, Beldanga – I	1.26	0.04	180 days
25.	Pratappur Jumma Masjid, Hariharpara	27.19	0.13	180 days
26.	Fakirabad Jumma Masjid, Domkal	24.67	0	180 days
27.	Shialmari Jumma Masjid, Raninagar – II	287.5	0.09	240 days
28.	Bhabta Ahelahadis Jumma Masjid, Beldanga	8.6	5.7	240 days
1.	Dhapadia Junior Madrasah	46.5	2.15	30 days
2.	Khidirpur Shishu Shiksha Kendra	14.99	0	260 days
3.	Junior Madrasah	12.7	0	60 days
4.	Dhapana Board High School	14.96	0.6	45 days
5.	Birpur Primary School	19.56	0	90 days
6.	Bethuaduari JCM High School	4.56	0	45 days
7.	Jugnuthala Primary School	23.36	0	60 days
8.	Dahakula Primary High School	36.6	0	60 days
9.	Bargachi Primary School Nagadi	9.56	0	90 days
10.	Dahakula Primary School	22.7	0	60 days
11.	BJ Kumari Primary School	5.9	0	100 days
12.	Arijnagar Primary School	0.13	-	60 days
13	Patikpari Girls Primary School	9.6	0	60 days

Now in Punjab

InnoNano Research Pvt. Ltd.

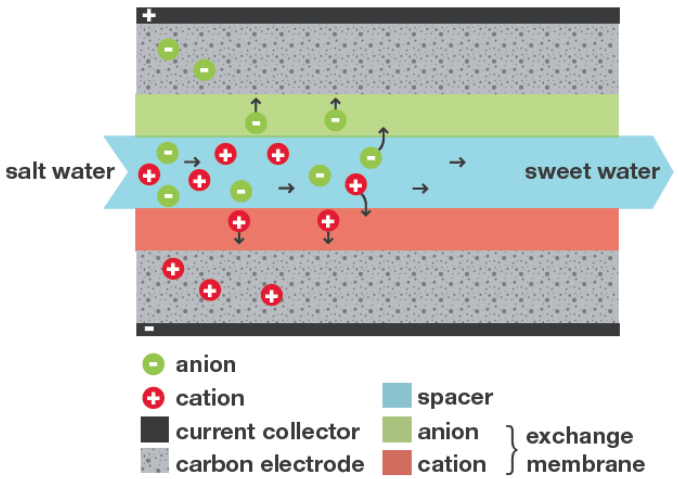
Problems in the field

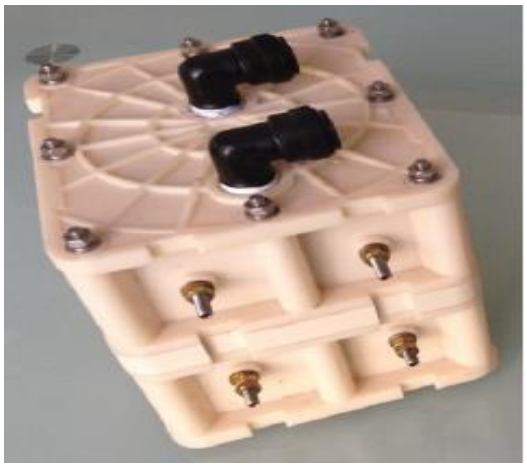
Diverse water quality
Spent media
Sludge management
Reactivation
Cost
Weather conditions, accessibility

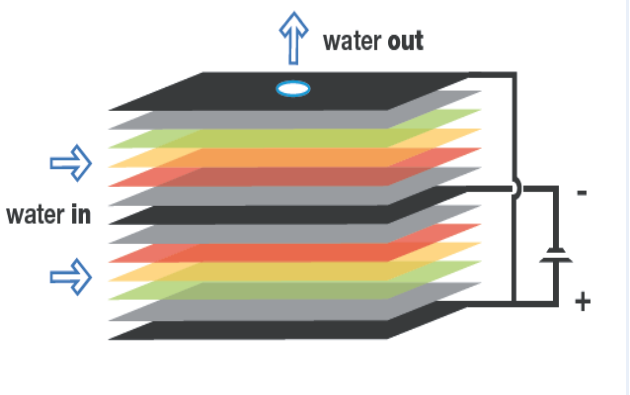
Work was featured in several journals

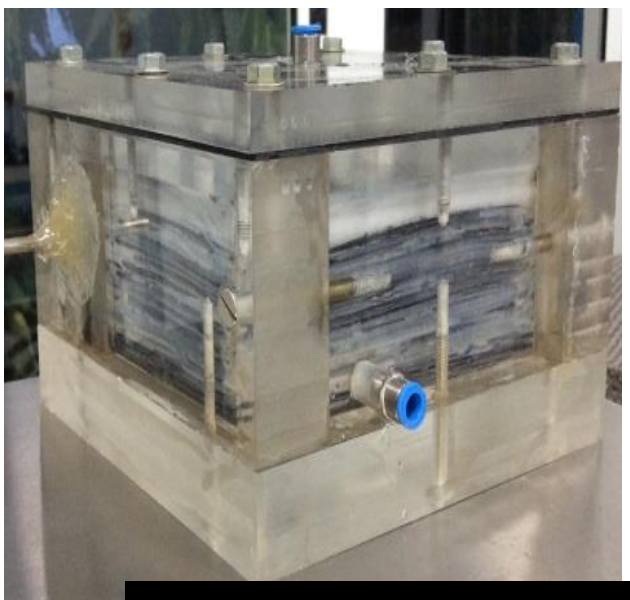
Nature Nanotechnology, July 2014 issue

Capacitive Desalination (CDI)





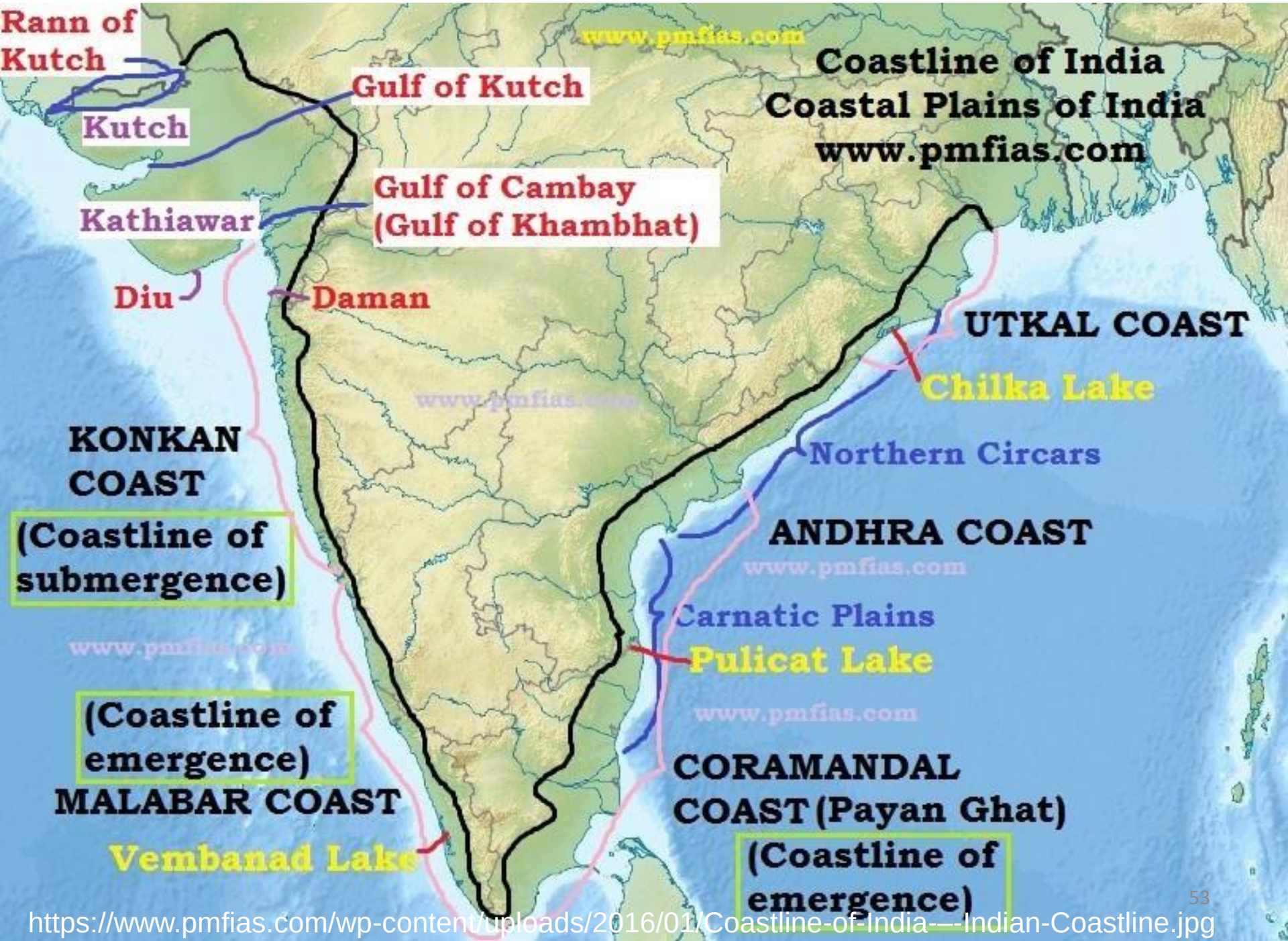




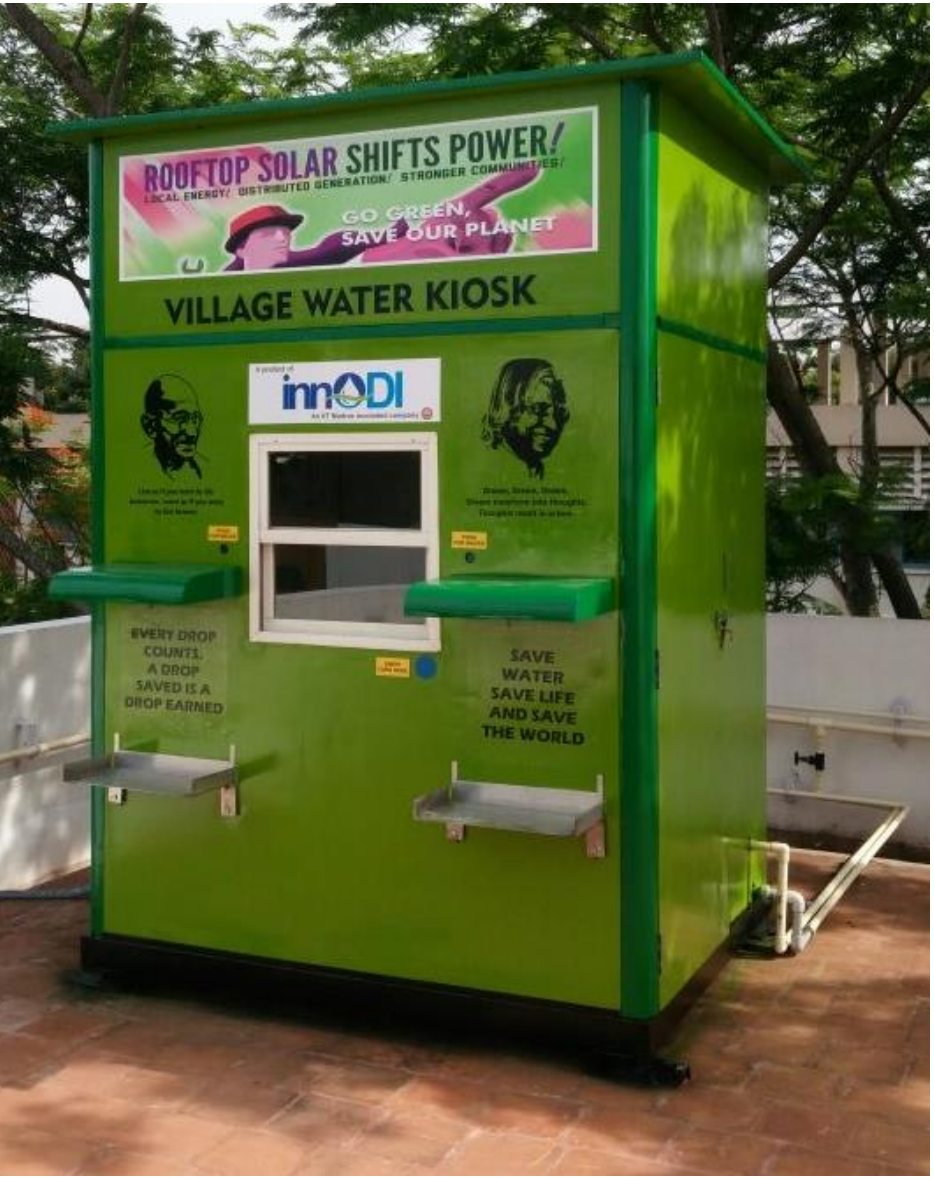
innODI

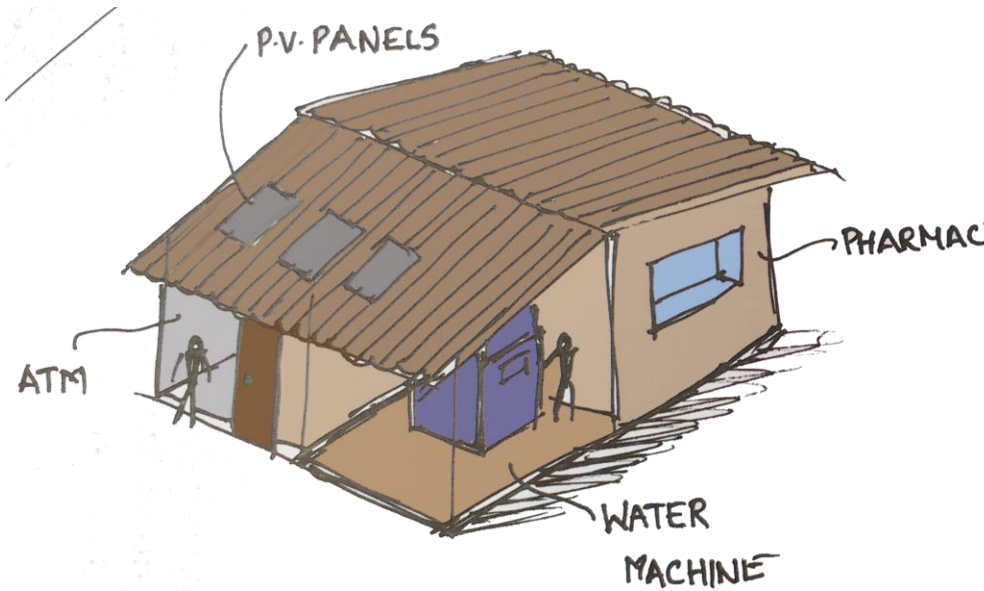
Our new company

Soujit Sengupta, Rabiul Islam and others



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





Products under implementation

Vijay Sampath, Tullio Servida

Plan for immediate future

ARSENIC TOXIC WATER

India Mark II hand water pump – most common water pump used globally

InnoNano Research's in-line arsenic removal filtration system

In-line arsenic sensor and remote data management – indicates when filtration systems require maintenance.

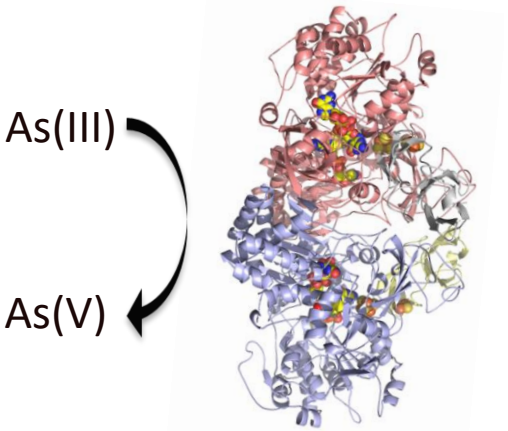
IMPROVED FILTER SUSTAINABILITY

SUSTAINABLE SOURCE OF ARSENIC FREE SAFE DRINKING WATER

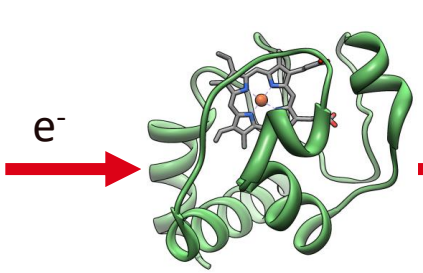
Anshup, Udhaya Sakar and Amrita

Biosensor Design

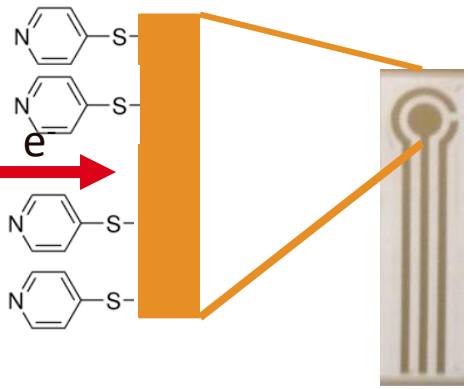
1st Generation Design (Mediated Electrochemistry)



Recombinant Arsenite Oxidase NT-26 Aio



Horse Heart Cytochrome C

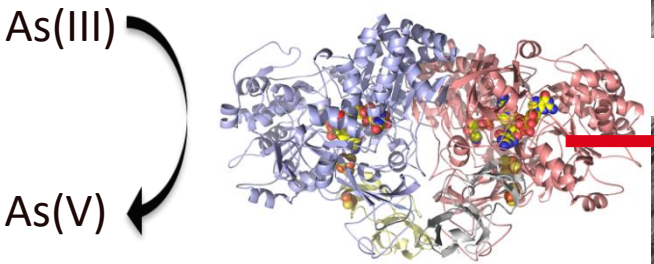


Aldrithiol

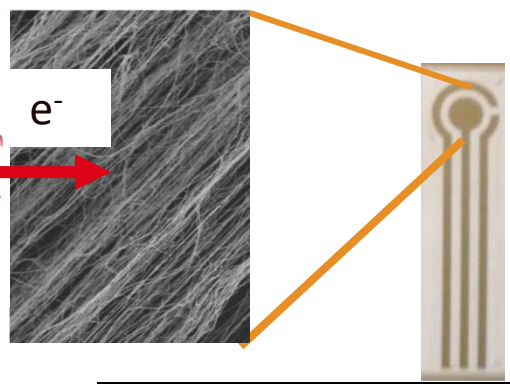
Buffer: pH 7-8

Low-cost Gold sputtered thin film on PET substrate

2nd Generation Design (Direct Electron Transfer)

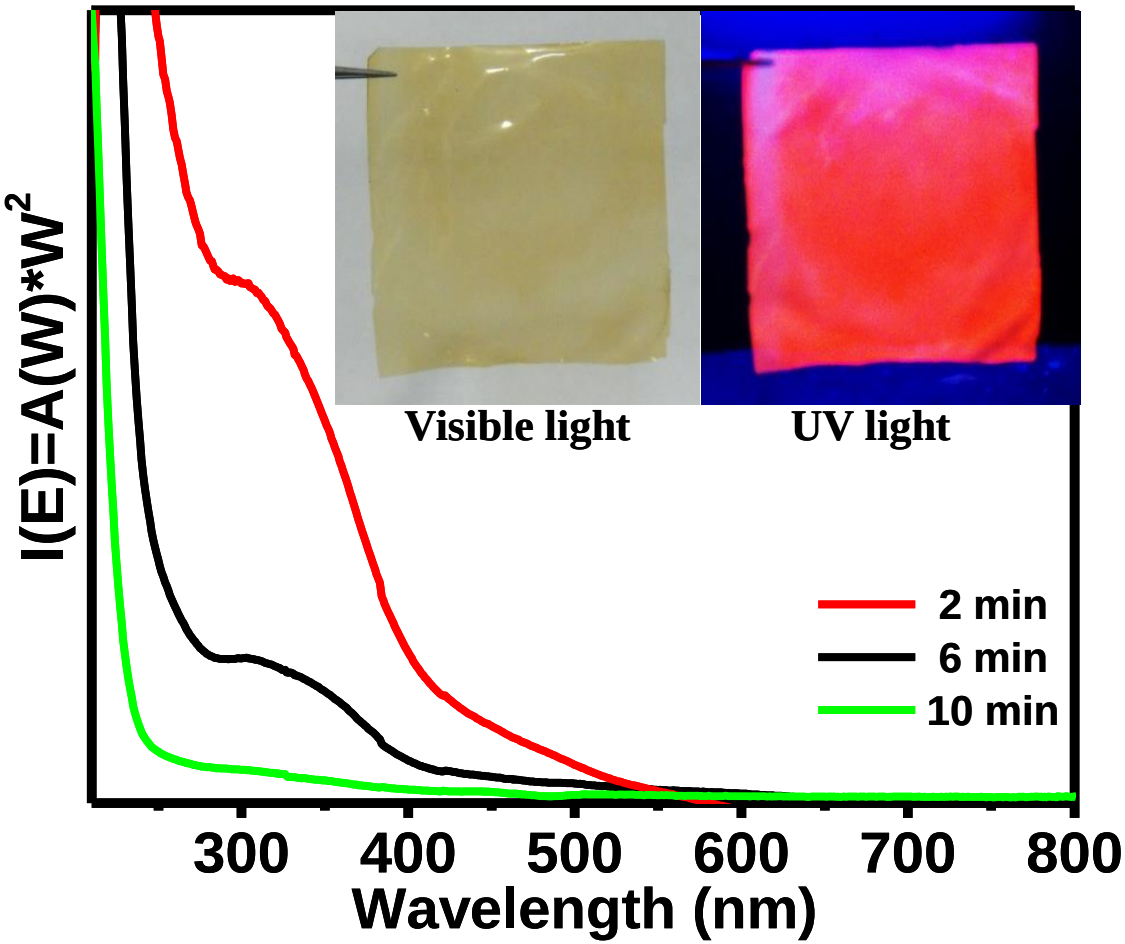


Recombinant Arsenite Oxidase NT-26 Aio



low-cost nanostructured electrodes which interact directly with enzyme (e.g. graphene or CNT).

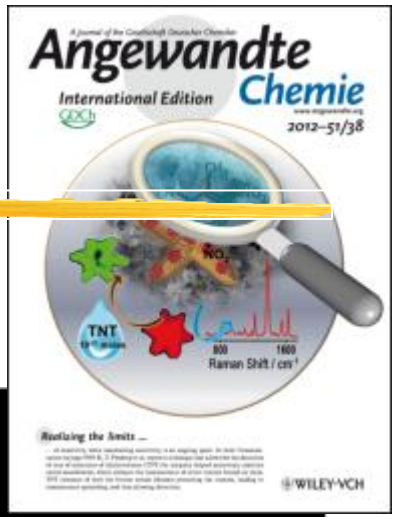
Quantum cluster based metal ion sensing paper
Large area uniform illumination using quantum cluster

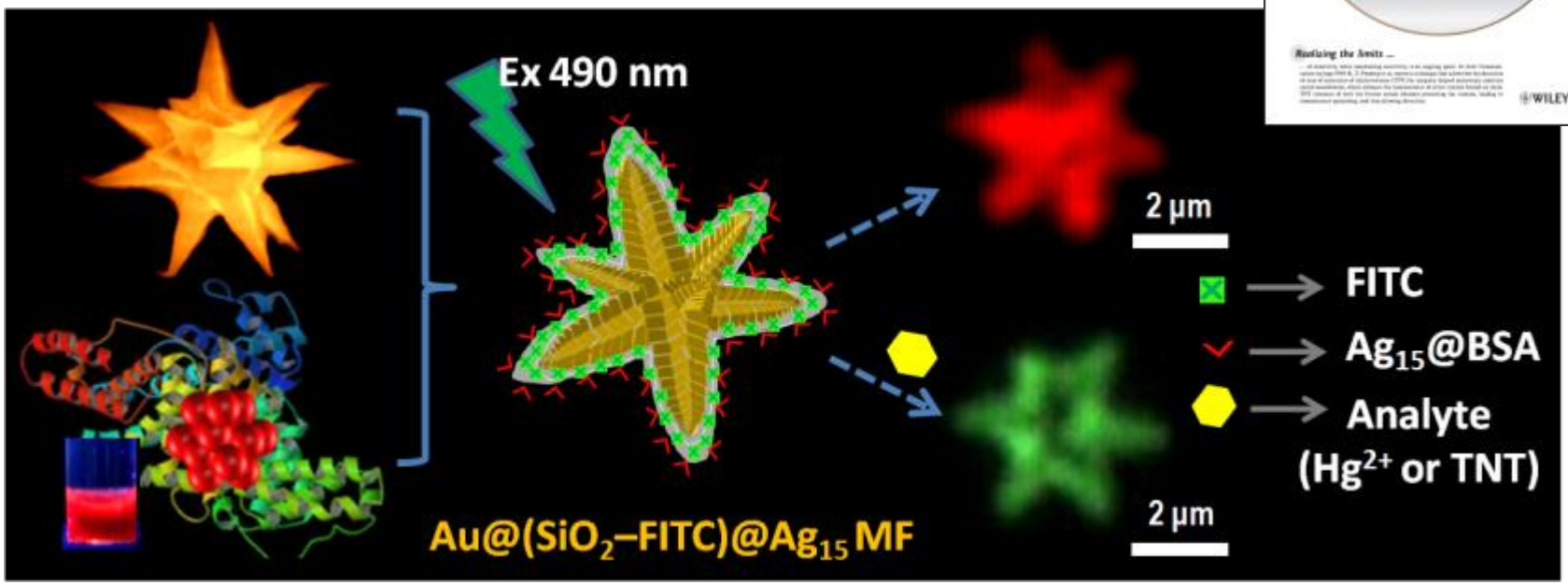


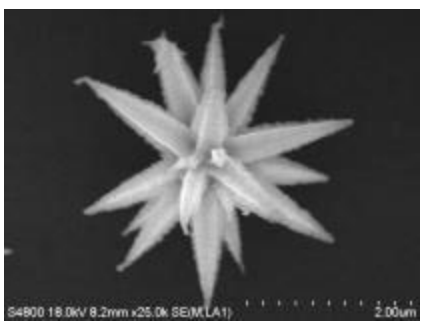
Decrease in the absorption of Au_{15} as a biofilm is dipped into the cluster solution. Inset: Free standing quantum cluster loaded film in visible light and UV light.

Anu George et al. *ACS Applied Materials & Interfaces*, 2012

Sub-zeptomolar detection







Featured in:
The Hindu, Telegraph, Times of India, etc.
C&E News
and many others

Ammu Mathew, et al. Angew. Chem. Int. Ed. 2012

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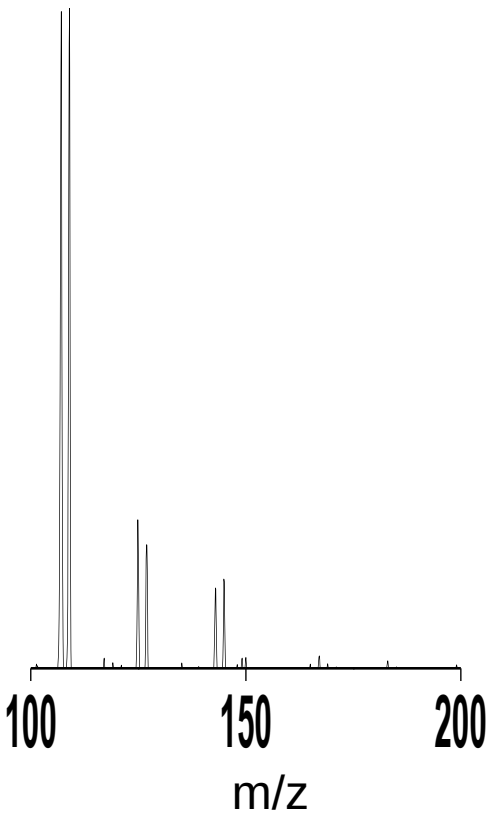
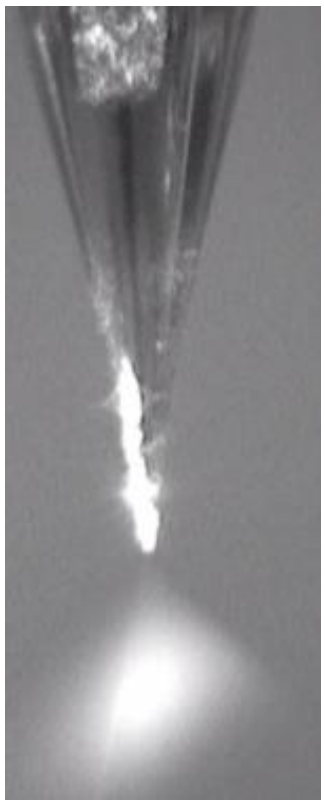
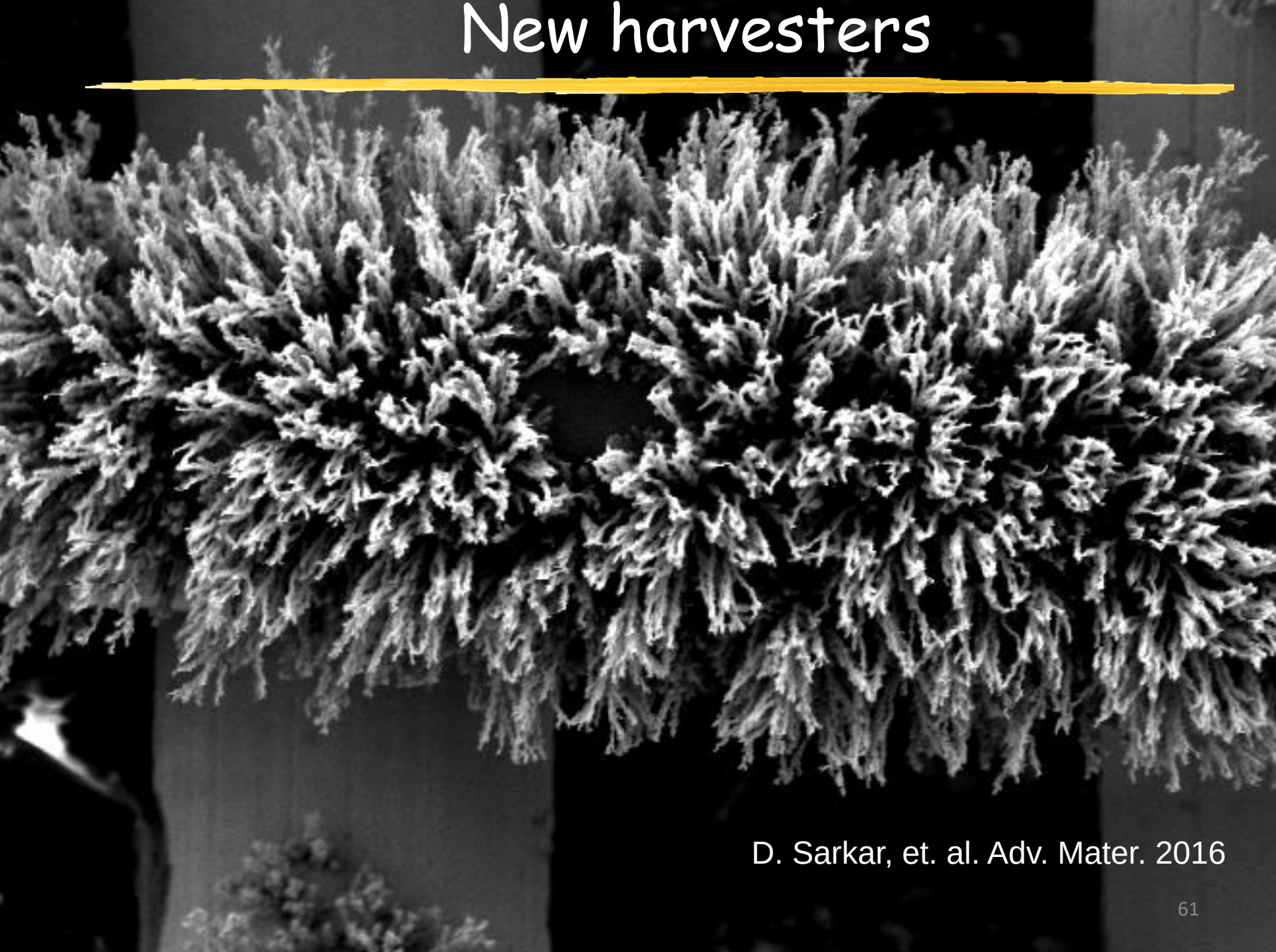
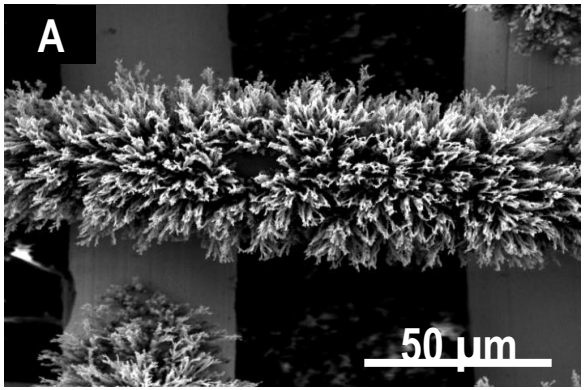


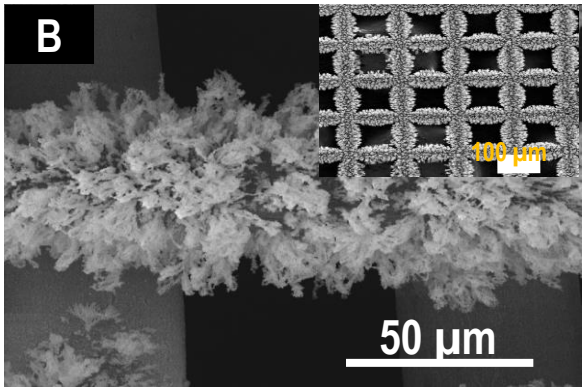


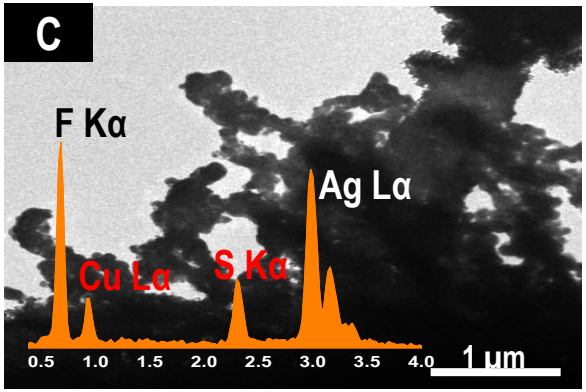
New harvesters



D. Sarkar, et. al. Adv. Mater. 2016

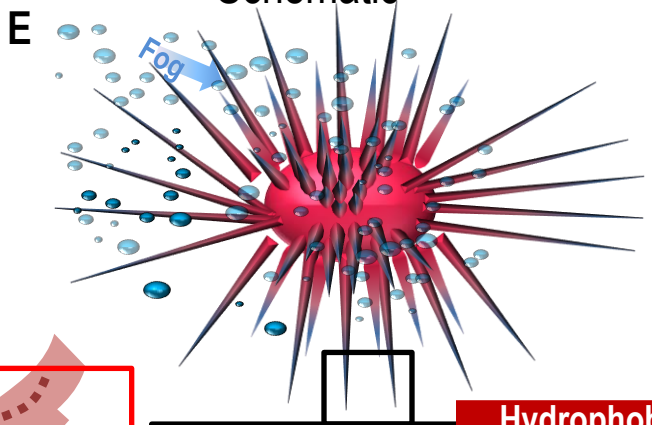




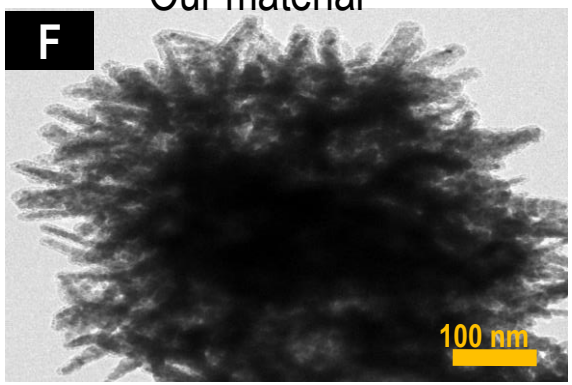


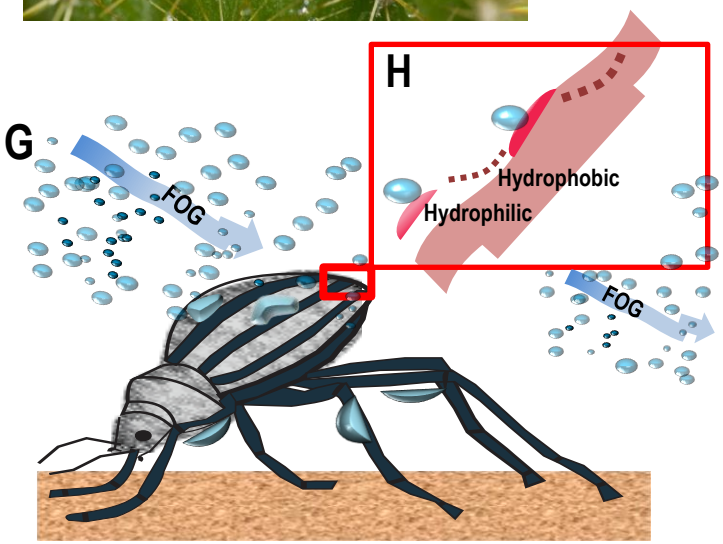
Nature

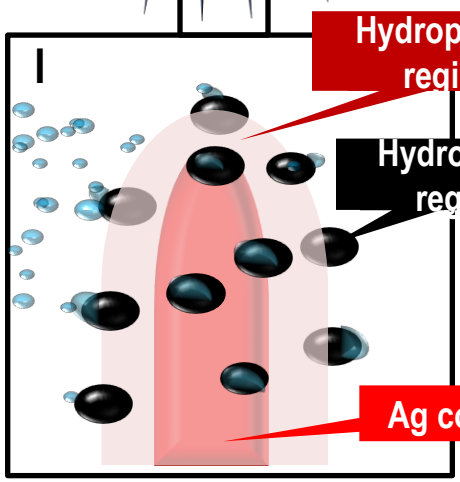
Schematic



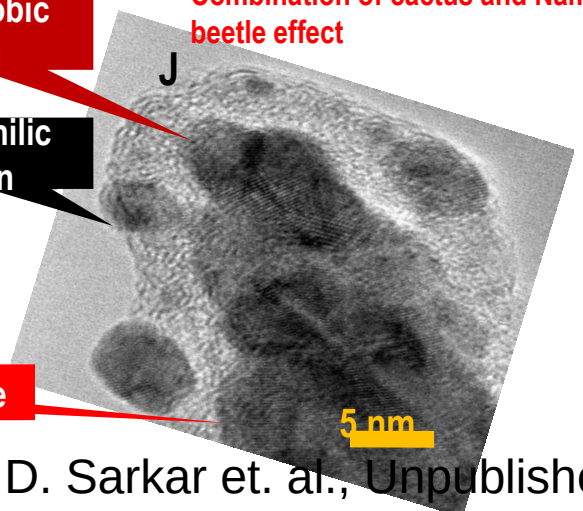
Our material



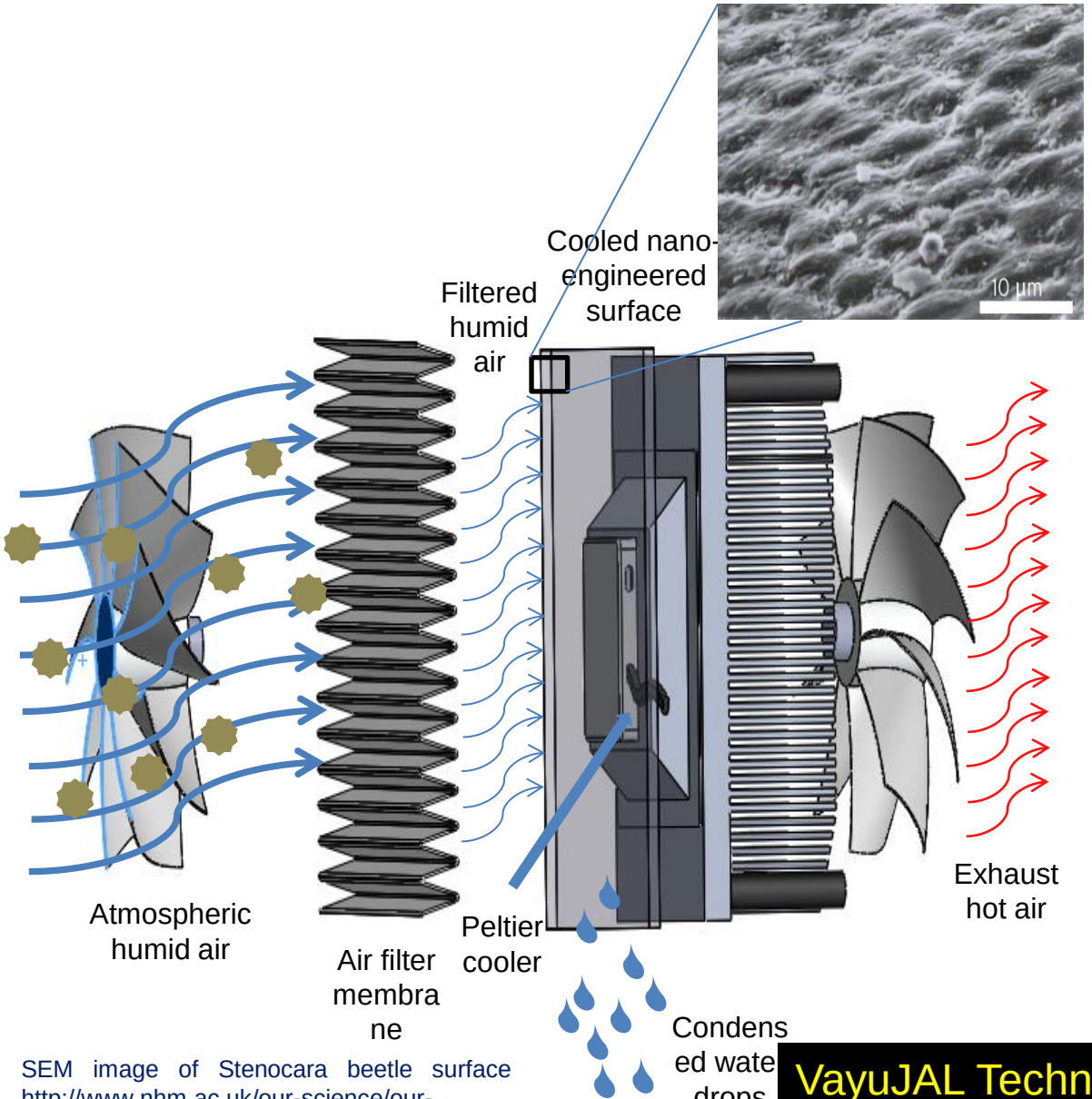




Combination of cactus and Namib des
beetle effect



D. Sarkar et. al., Unpublished

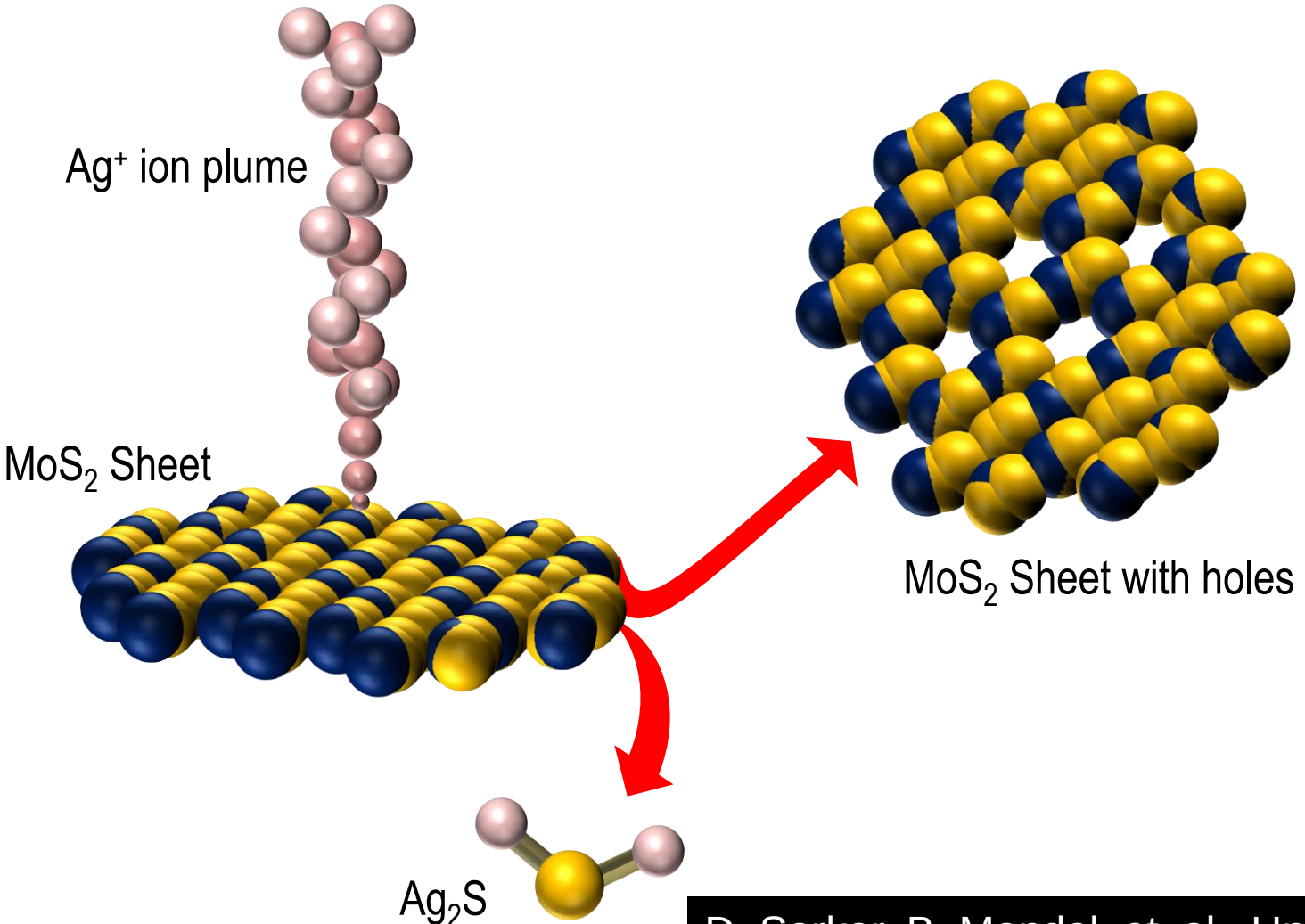


SEM image of Stenocara beetle surface http://www.nhm.ac.uk/our-science/our-work.html

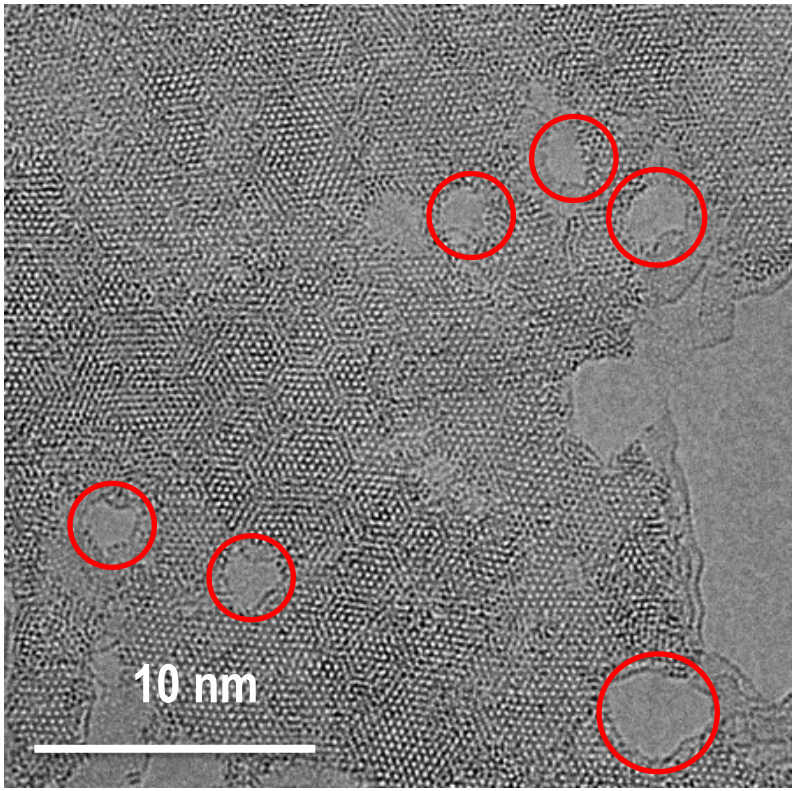
VayuJAL Technologies Pvt. Ltd.

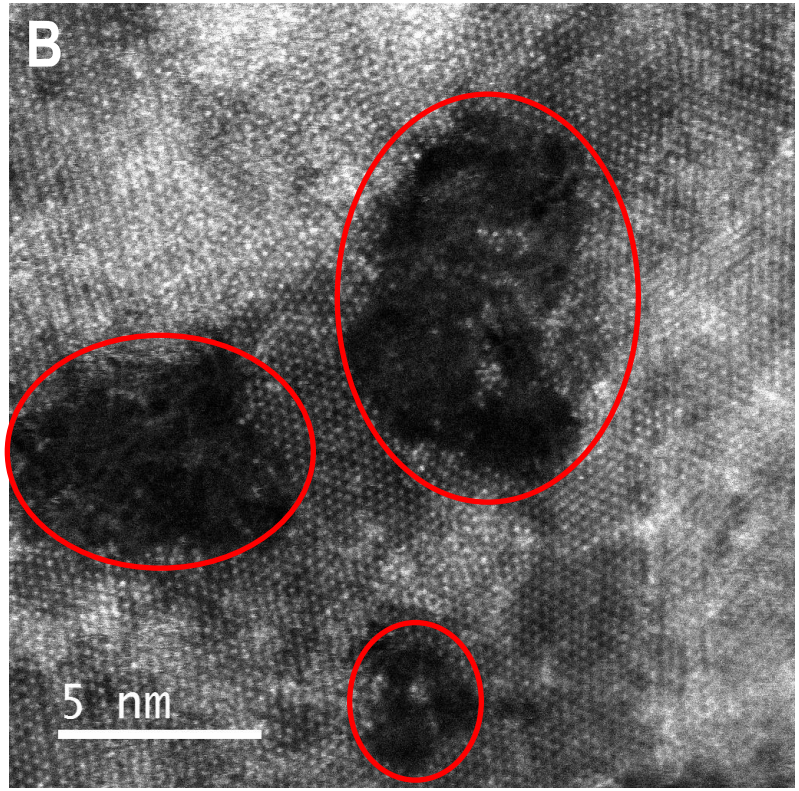
Ankit Nagar and Ramesh Kumar Soni

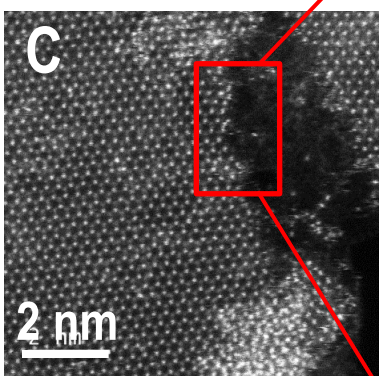
Atomically precise holes

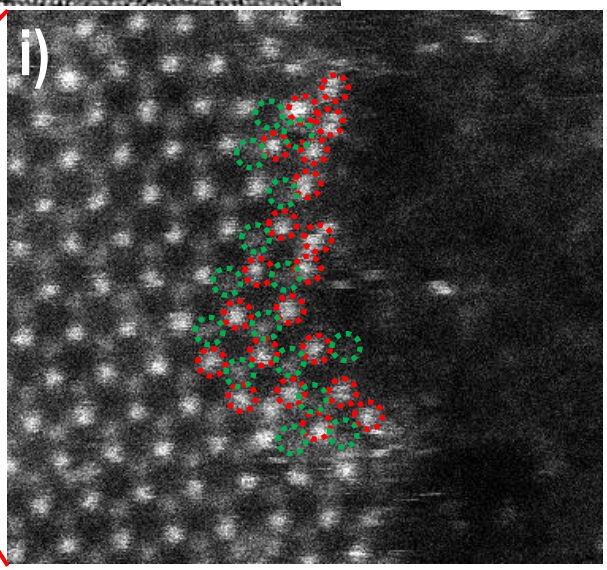


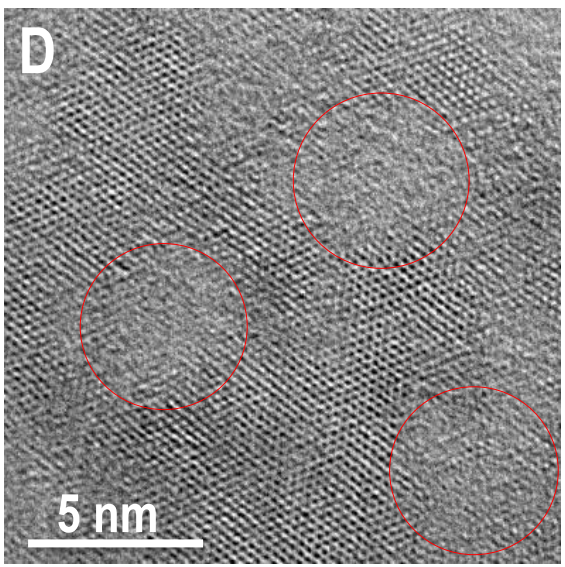
D. Sarkar, B. Mondal, et. al., Unpublished Patented

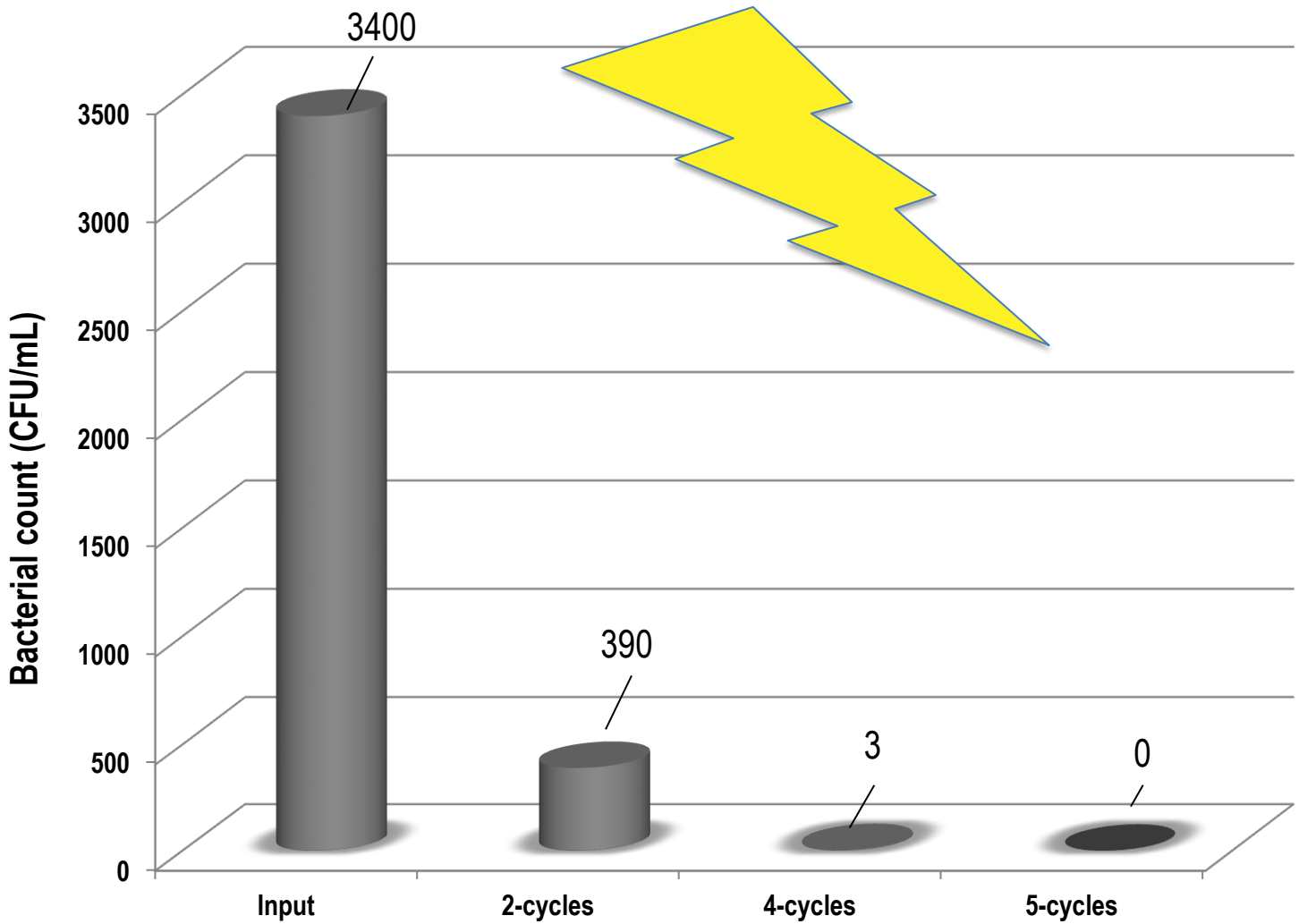

10 nm


B
5 nm


C
2 nm


i)


D
5 nm


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

Road ahead

We can solve ALL the DRINKING WATER problems affordably.

Better mechanisms of monitoring are needed to ensure that the nation stays healthy.

Affordable and sustainable solutions for water harvesting are needed.

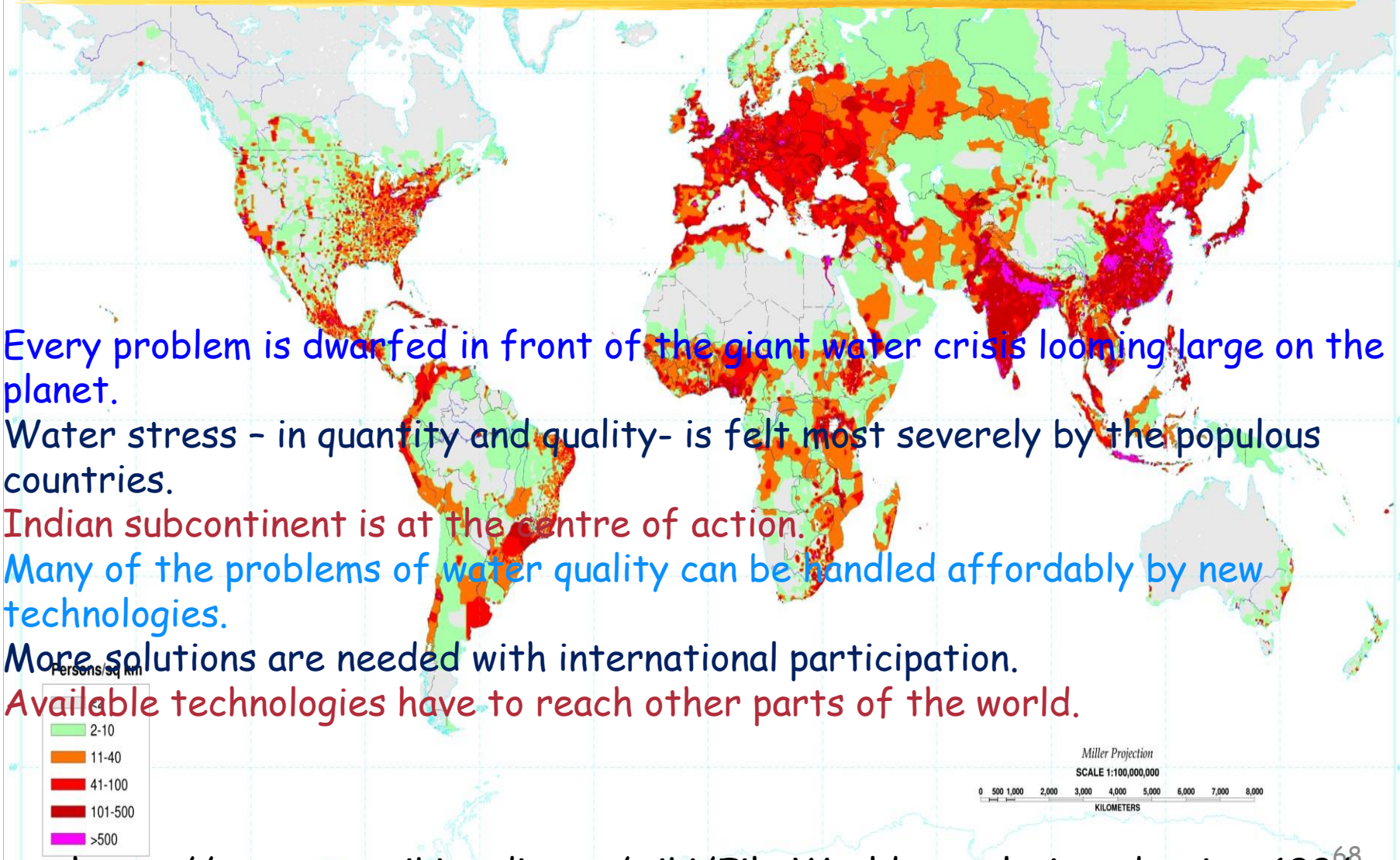
We need to create mechanisms of delivery.

Expanding to clean air, sustainable and healthy water, food

Global efforts

International centre for clean water

World population density 1994



Every problem is dwarfed in front of the giant water crisis looming large on the planet.

Water stress – in quantity and quality- is felt most severely by the populous countries.

Indian subcontinent is at the centre of action.

Many of the problems of water quality can be handled affordably by new technologies.

More solutions are needed with international participation.

Available technologies have to reach other parts of the world.

https://commons.wikimedia.org/wiki/File:World_population_density_1994.png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January 2016

Thank you


Where there is clean water, there is hope.