New Insights and Innovations for Advanced Water Treatment

01/02/2023

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WEBINAR INFORMATION

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- The opinions, hypothesis, conclusions or recommendations contained in the presentations and other materials are the **sole responsibility of the speaker(s)** and do not necessarily reflect IWA opinion.

WEBINAR INFORMATION

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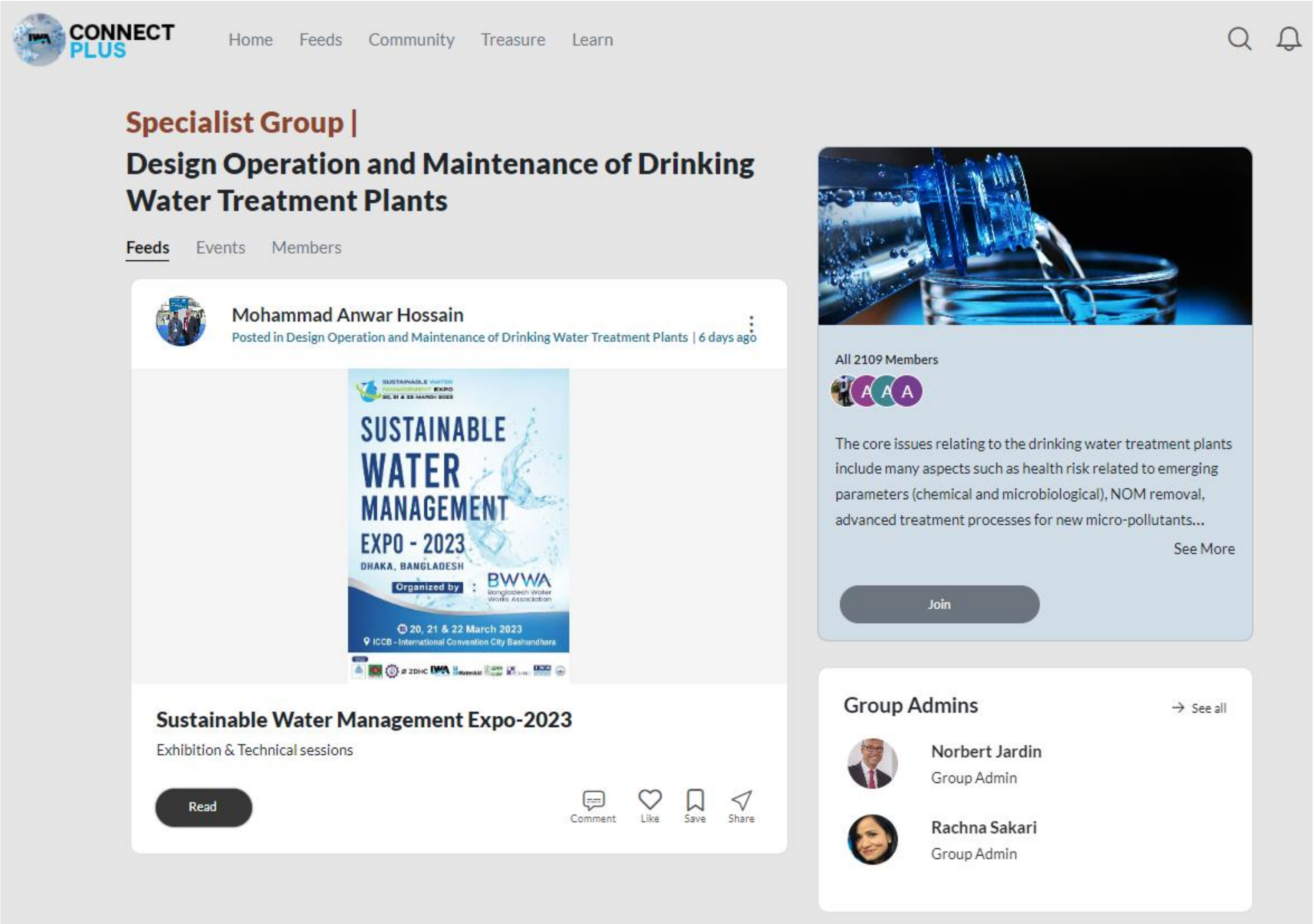
- **'Chat' box**: please use this for general requests and for interactive activities.
- **'Q&A' box**: please use this to send questions to the panelists.
  (We will answer these during the discussions)

***Please Note:** Attendees' microphones are muted. We cannot respond to 'Raise Hand'.*

IWA DESIGN, OPERATION AND MAINTENANCE OF DRINKING WATER TREATMENT PLANTS SG



Join the IWA SG on IWA Connect+

This SG aims to enhance networking and exchange of practices and experience on operational issues for those involved in the design and operation of drinking water treatment plants, and contribute to better understand the operational needs (ex. in terms of Training) and help solving operational problems.

www.iwaconnectplus.org/group/feeds?CommunityKey=a0M4K0000027gbSUAQ

IWA "DESIGN, OPERATION AND MAINTENANCE OF DRINKING WATER TREATMENT PLANTS" Specialist Group

The core issues related to the drinking water treatment plants：

- Health risk related to emerging parameters (chemical and microbiological)
- NOM removal
- Advanced treatment processes for new micro-pollutants removal
- Application and case studies solving operational issues
- Smart tools for analyzing plant data

IWA “DESIGN, OPERATION AND MAINTENANCE OF DRINKING WATER TREATMENT PLANTS” Specialist Group

- **Prof. Jun Ma**, Harbin Institute of Technology, China (Committee Chair)
- **Dr. Yeek Chia Ho**, Universiti Teknologi PETRONAS, Malaysia (Committee Vice Chair)
- **Prof. Qianhong She**, Nanyang Technological University, Singapore
- **Dr. Inês Breda**, Silhorko-Eurowater A/S, Denmark
- **Dr. Zdravka Do-quang**, Suez Environment, France
- **Jacob Kwasi Amengor**, Ghana Water Company Limited, Ghana
- **Rui Sancho**, Water Safety Plan, Portugal

哈爾濱工業大學 HARBIN INSTITUTE OF TECHNOLOGY

UNIVERSITI TEKNOLOGI PETRONAS

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

SILHORKO A GRUNDFOS COMPANY

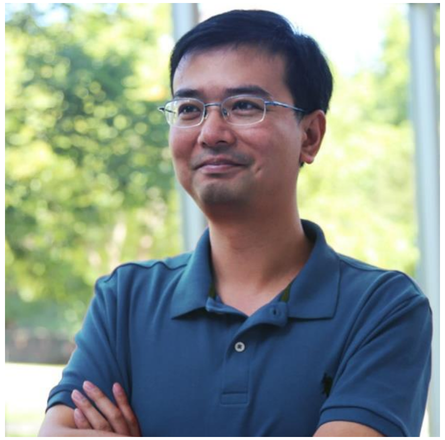
EUROWATER A GRUNDFOS COMPANY

GHANA WATER COMPANY LIMITED

suez environnement

MODERATOR & SPEAKERS

Yumeng Zhao
Harbin Institute of Technology, China
(Moderator)



Xing Xie
Georgia Institute of Technology, USA

Urs von Guten
Eawah/EPFL, Switzerland

Rhea Verbeke
Ku Leuven, Belgium

AGENDA

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- Welcome, housekeeping rules, introduction
  Yumeng Zhao, Harbin Institute of Technology (moderator)
- Application of chemical oxidants for enhanced water treatment
  Urs Von Guten, Eawag/EPFL
- Locally enhanced electric field treatment (LEEFT) for drinking water disinfection
  Xing Xie, Georgia Institute of Technology
- Recent advances and scale up challenges in oxidants production by electrochemical processes for water disinfection
  Rhea Verbeke, KU Leavem
- Q&A Discussion
  Speakers & Moderator
- Final remarks and conclusion
  Yumeng Zhao, Harbin Institute of Technology

Application of chemical oxidants for enhanced water treatment

URS VON GUNTEN

EAWAG, SWISS FEDERAL INSTITUTE OF AQUATIC SCIENCE AND TECHNOLOGY

EPFL, ECOLE POLYTECHNIQUE FEDERALE, LAUSANNE

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ENHANCED WATER TREATMENT

APPLICATION OF CHEMICAL OXIDANTS FOR MICROPOLLUTANT ABATMENT

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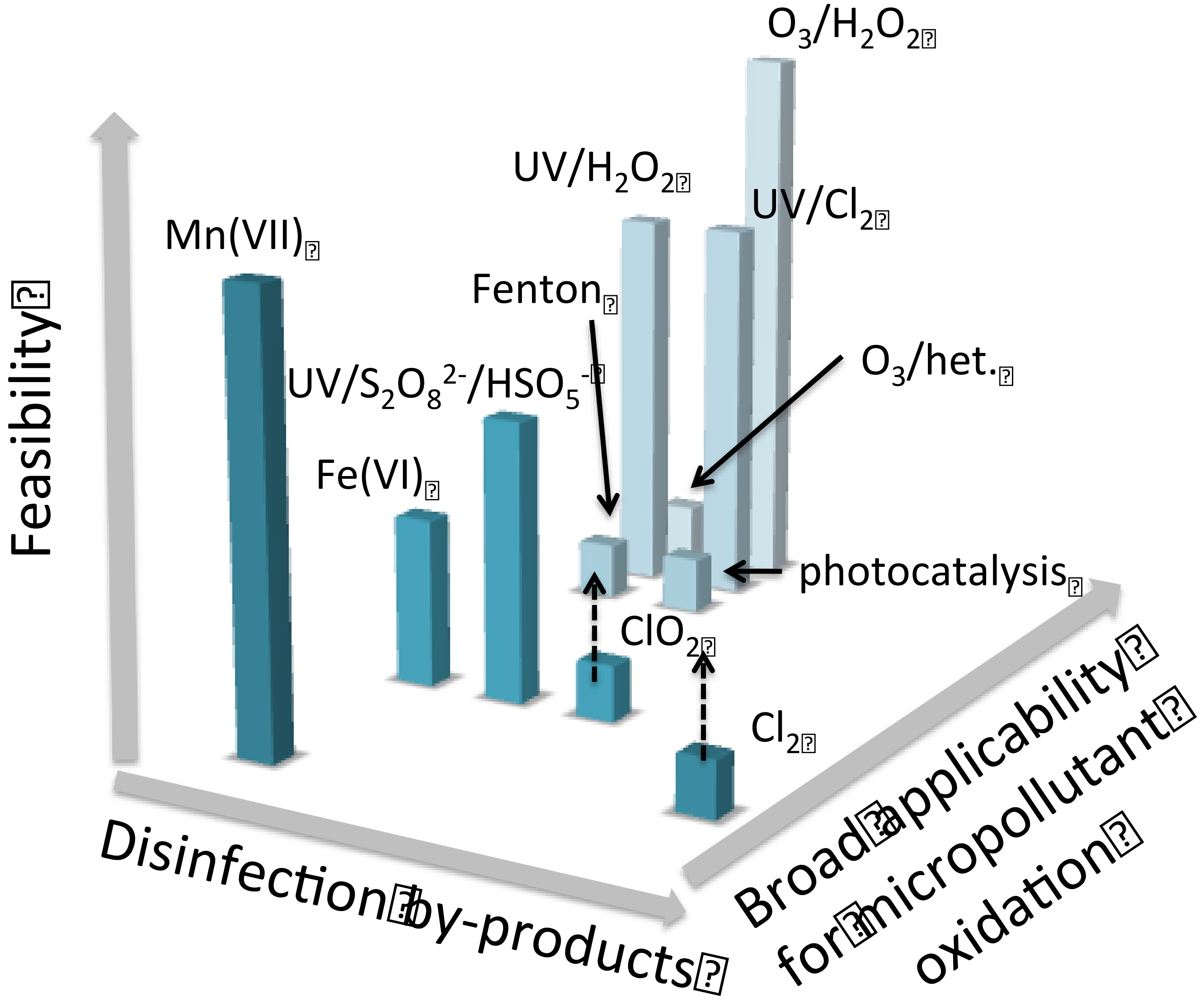
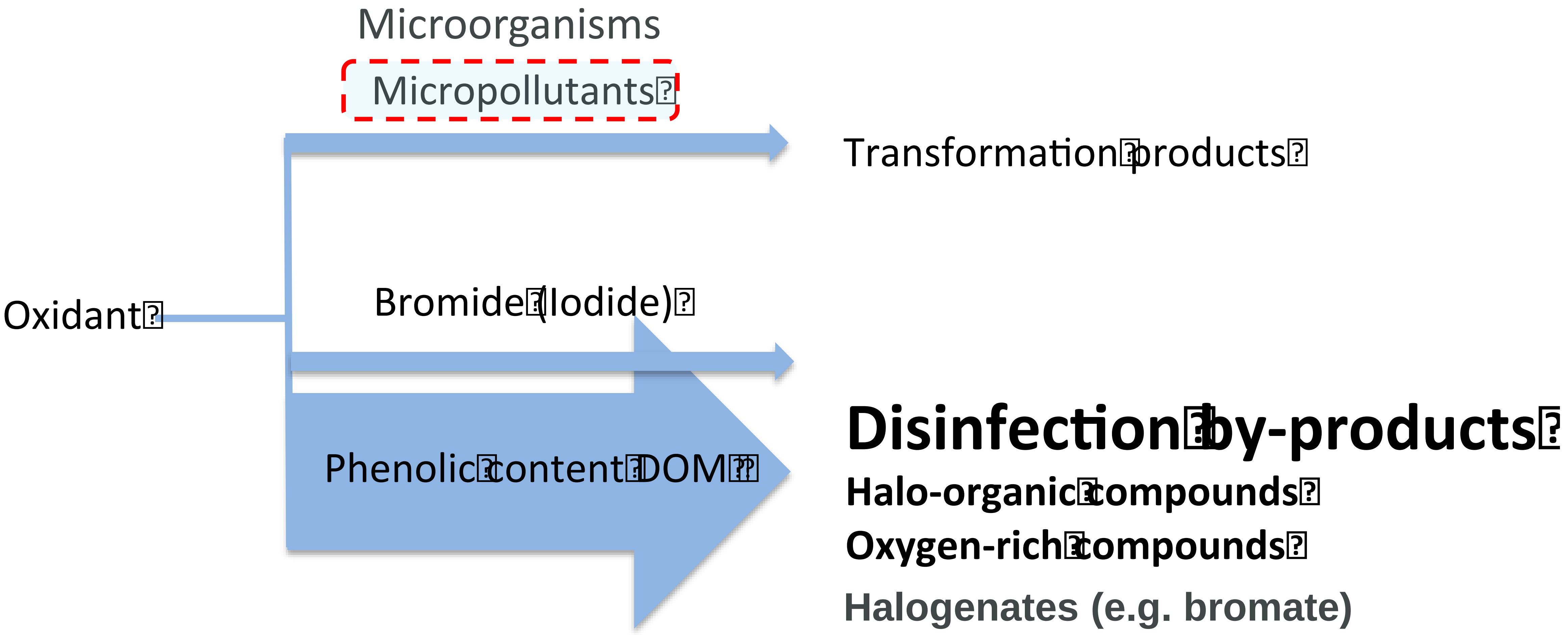
- Initial success story!
- Application to drinking water
- Inorganic compounds (sulfide, nitrite, iron(II), manganese(II))
- Taste and odor compounds, color
- Organic contaminants:
  - Biologically active compounds are **abated** but what happens to them?
  - Application to wastewaters (enhanced wastewater treatment, water reuse): Role of matrix components?

SEARCH FOR A PERFECT OXIDANT: DECADES OF RESEARCH



von Gunten, ES&T, 2018

OXIDATION REACTIONS WITH MICRO-ORGANISMS/POLLUTANTS AND MATRIX COMPONENTS



von Gunten, ES&T, 2018

OXIDATION OF MICROPOLLUTANTS

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Micropollutants → **Transformation products**

Kinetics
Mechanisms

Tools:
Laboratory experiments
Quantum chemical computations

Tools:
LC-UV/FL
LC-HRMS/MS
GC-MS/MS
IC-MS
Pathway prediction tools

Toxicity

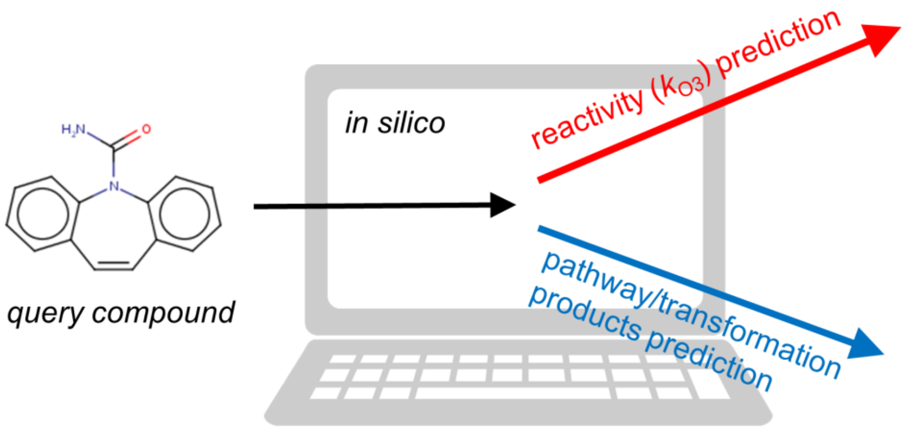
Tools:
Bioassays
In silico toxicity evaluation

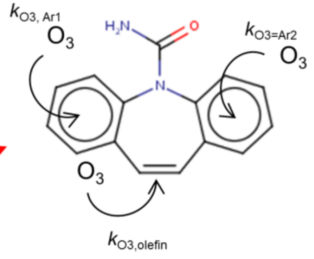
Biodegradability

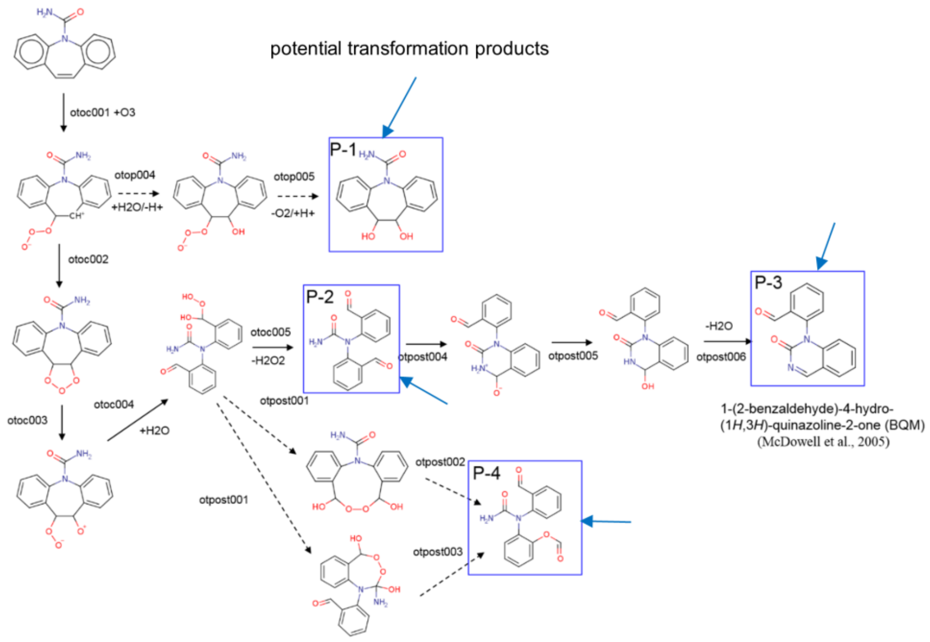
Tools:
Culture experiments
Biofiltration (pilot-, full-scale)
Biodegradability models

PLATFORM FOR PREDICTION OF TRANSFORMATION PRODUCTS FORMATION DURING OZONATION

Quantum chemical computations
QSAR







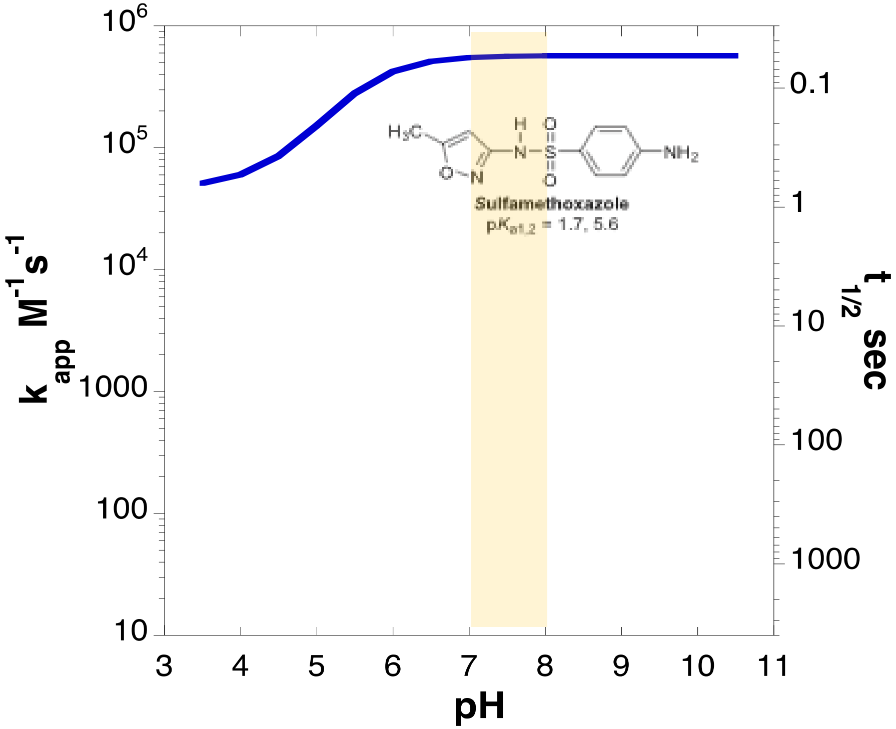
> 100 reaction rules
Critical evaluation of literature

Lee et al., ESPI, 2017

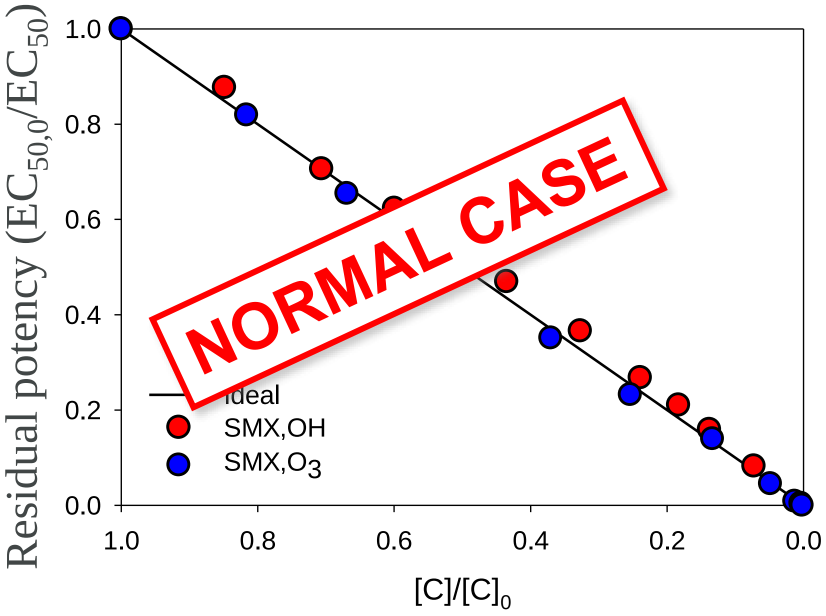
LOSS OF PRIMARY BIOLOGICAL ACTIVITY CAUSED BY THE PARENT COMPOUND

OXIDATION OF SULFAMETHOXAZOLE BY OZONE AND ·OH

Ozone oxidation kinetics



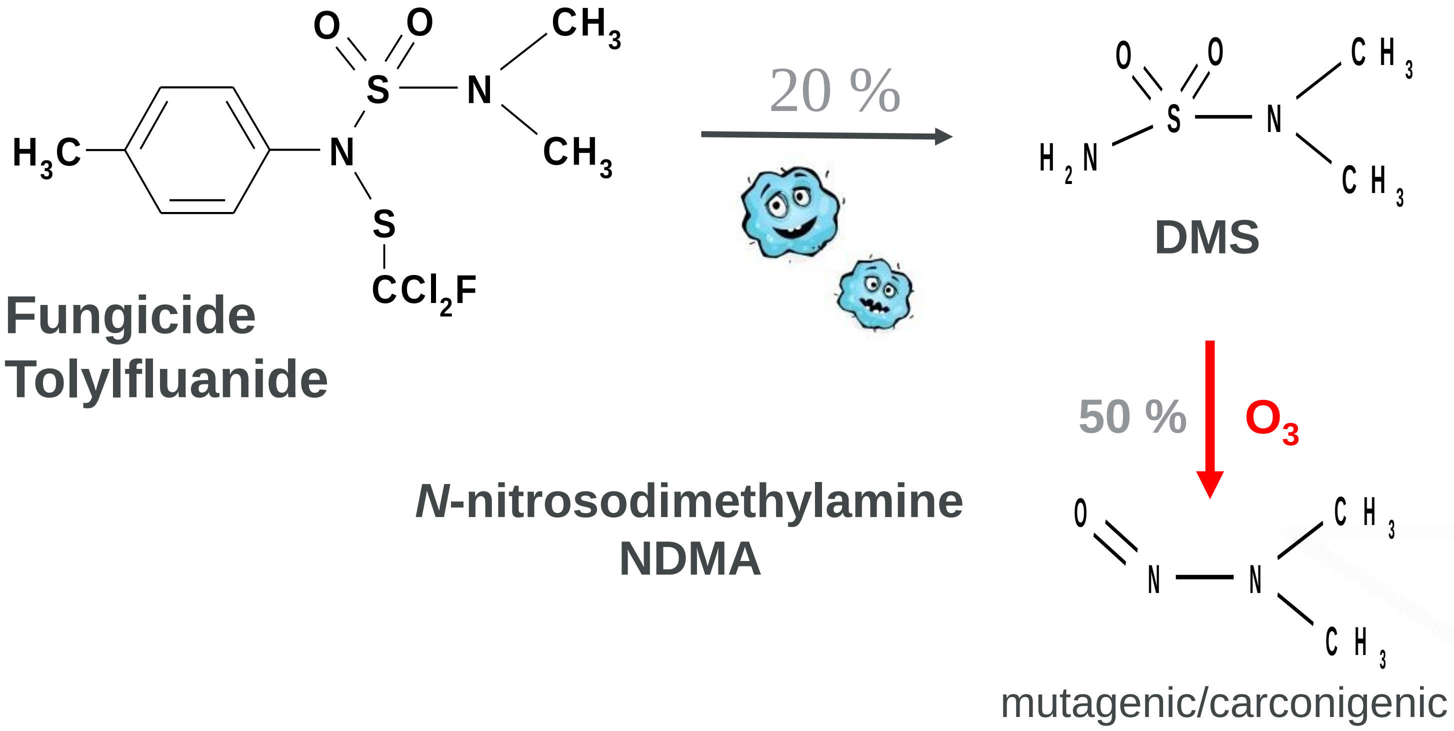
Antimicrobial activity as a function of transformation



Huber et al., ES&T, 2003, Dodd et al., ES&T, 2006, Dodd et al. ES&T, 2009

TRANSFORMATION PRODUCTS OF BIOLOGICALLY ACTIVE/NON-ACTIVE MICROPOLLUTANTS

COMPOUNDS WITH HIGHER TOXICITY THAN THE PARENT COMPOUND

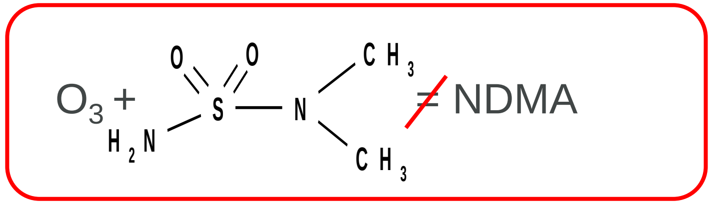


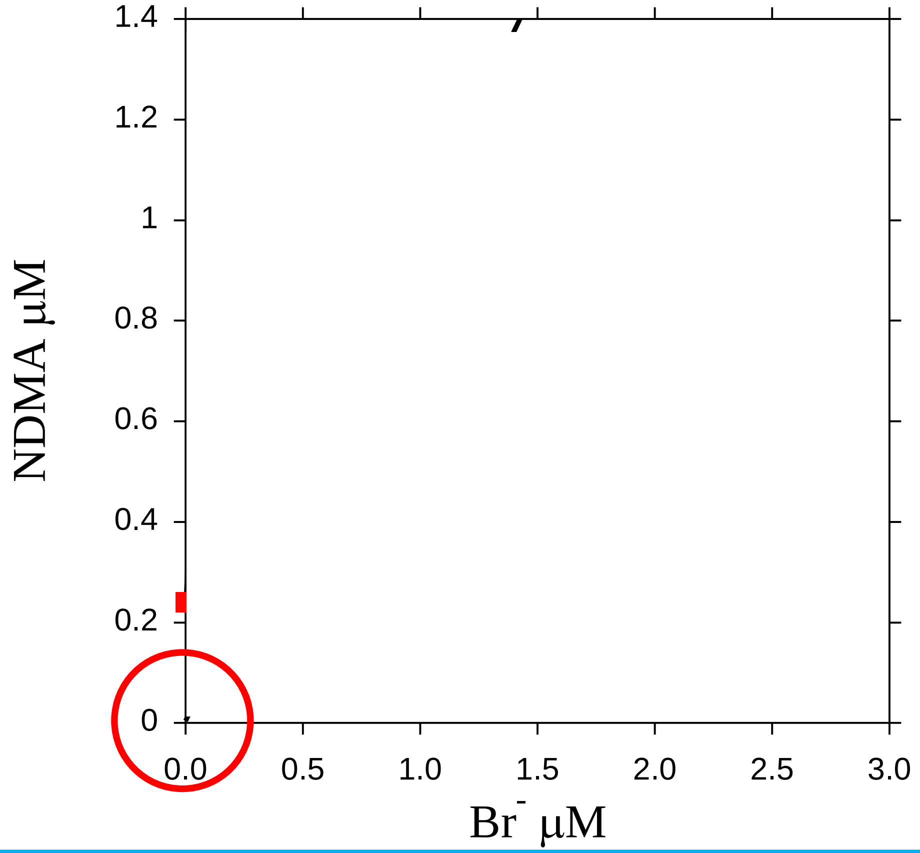
- Ozonation of drinking water
- DMS in low µg/L levels ⇒ several 100 ng/L NDMA in drinking water
- Shutdown of ozonation
- Ban of tolylfluanide in most European countries

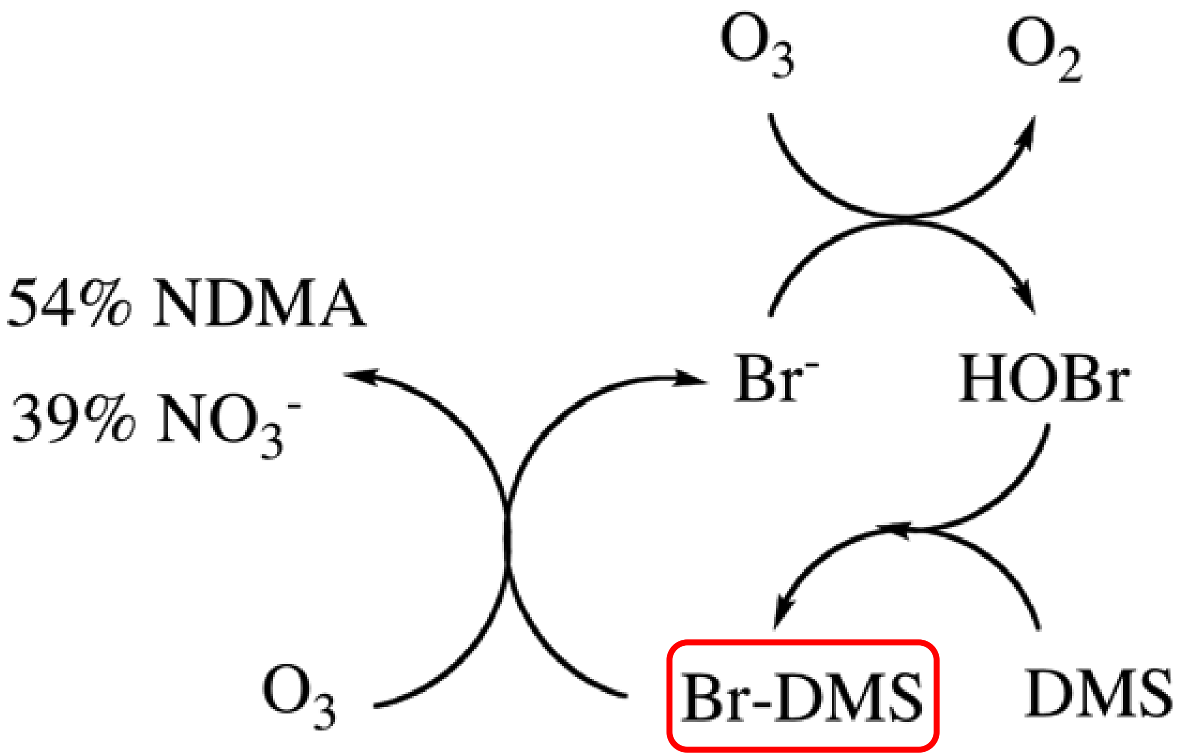
Schmidt and Brauch,ES&T, 2008

NDMA FORMATION DURING OZONATION OF DMS

ROLE OF BROMIDE

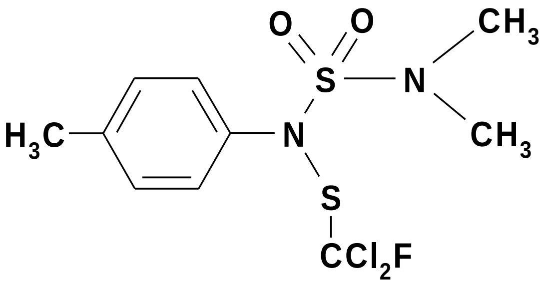


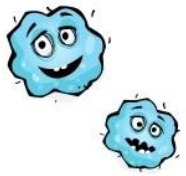




von Gunten et al., ES&T, 2010

AN UNPREDICTABLE COCKTAIL





Br^-

O_3

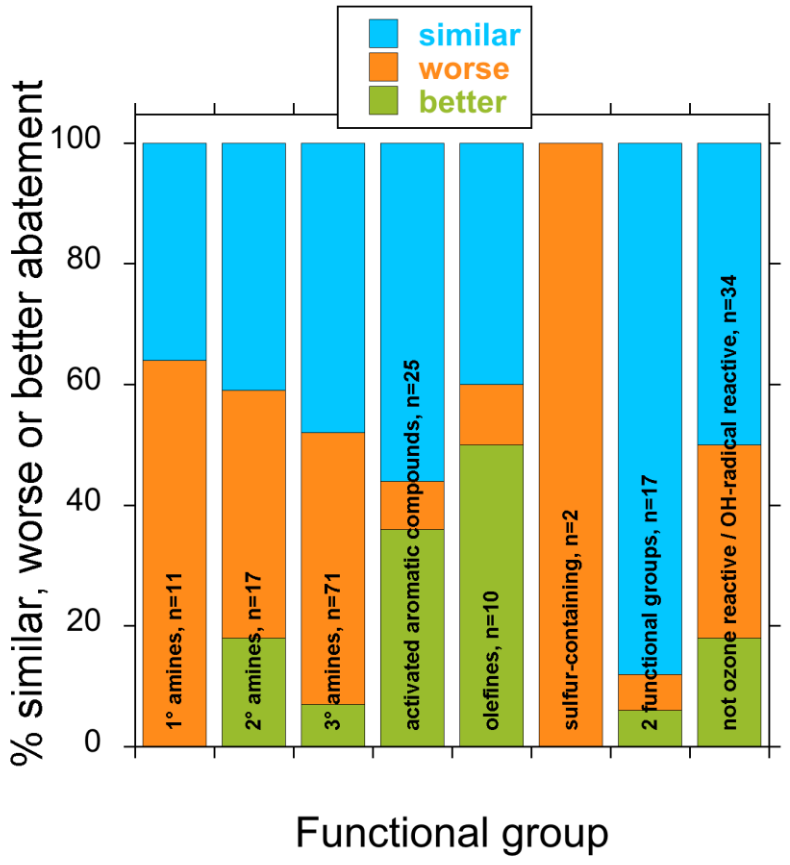
OZONATION-SAND FILTRATION OF LAKE WATER

BIODEGRADABILITY OF TRANSFORMATION PRODUCTS RELATIVE TO THE PARENT COMPOUNDS

TP measurement with LC-HRMS/MS (pos./neg. mode)

- 51 compounds spiked
- 187 TP: 143 (76%) stable, 35 (19%) abatement, 9 (5%) formation
- Abated structures contain: Aldehydes, carbonyls, carboxylic acids, alcohols, amides
- Formed from aromatic, olefinic, aliphatic functional groups
- 24 (13%) of TPs were better biodegradable than the parent compounds

51 compounds spiked, TPs from 39



Gulde et al., Water Res., 2021

OXIDATION REACTIONS WITH MATRIX COMPONENTS

DISSOLVED ORGANIC MATTER (DOM)

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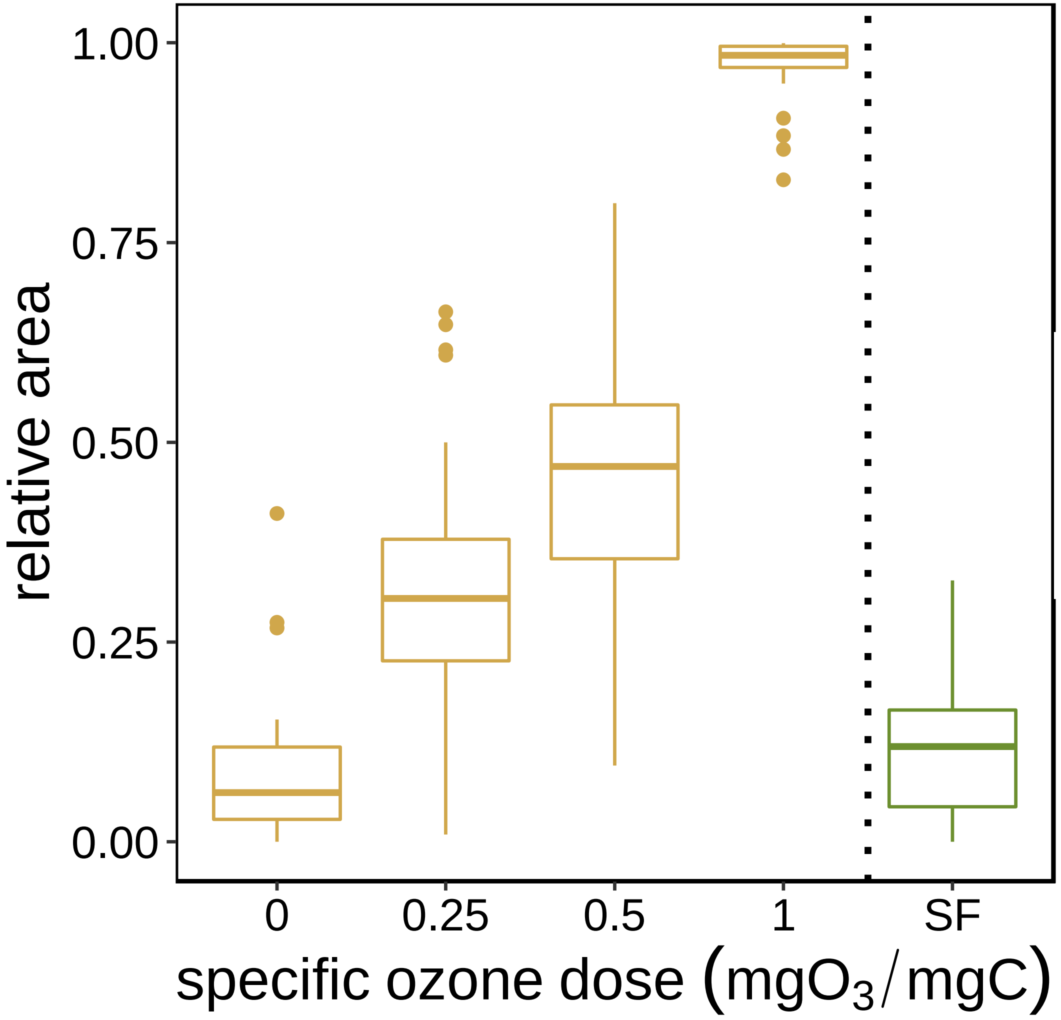
- DOM is the main consumer of oxidants
- Phenolic moieties (1-2 mmol/gDOC): 10 µM for 5 mg/L DOC
- Sum of micropollutant concentrations (WW effluent):

  20 µg/L ≈ 0.2 µM (Bourgin et al. WR, 2018)
- Ozone: << 2% reaction with micropollutants
- ·OH: <<0.5% reaction with micropollutants
- Products of reactions of DOM with O_3 and ·OH have to be considered!
- Phenolic moieties are important precursors for DBPs

FORMATION OF CARBONYL COMPOUNDS DURING OZONATION OF A WASTEWATER

- Full-scale ozonation of wastewater effluent
- Carbonyl compounds formed from aromatic (EDC), olefinic, aliphatic functional groups
- Derivatization of samples to detect carbonyl compounds with *p*-toluenesulfonyl-hydrazine (TSH)
- 46 carbonyl formulas detected (data with clear formation trend)
- Formation proportional to ozone dose
- Degradation during biological sand filtration



Houska et al. Water Res. 2023, Manasfi et al. Water Res. 2023

OUTLOOK

- Development of predictive reaction tools for kinetics and product formation
- Combination of experimental studies with quantum chemical computations
- Coupling of prediction tools with *in silico* toxicity evaluation and biodegradation tools
- Better understanding of DOM by tailored chemical approaches (selective titrations, derivatization, tagging)
- Improved tools for interpretation of non-target MS data
- Use of stable isotopes to elucidate reaction mechanisms

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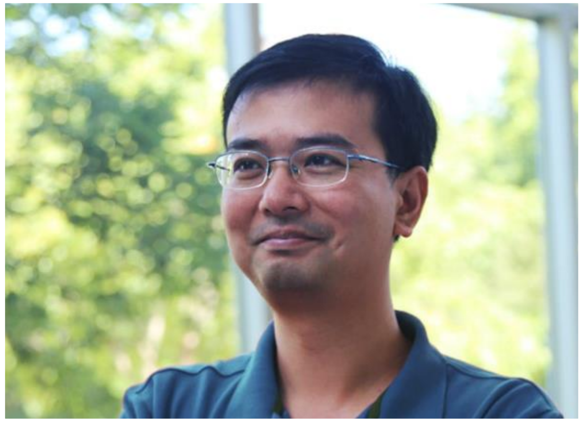
Locally Enhanced Electric Field Treatment (LEEFT) for Drinking Water Disinfection

XING XIE, GEORGIA INSTITUTE OF TECHNOLOGY



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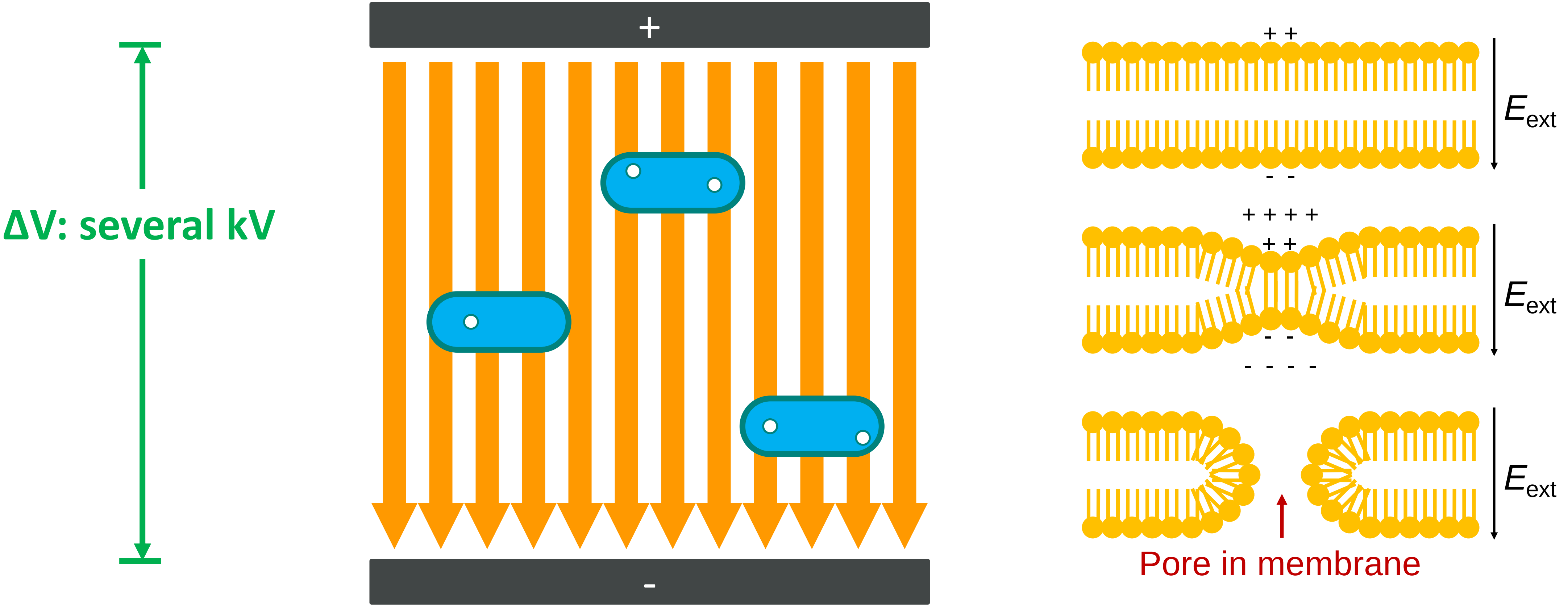
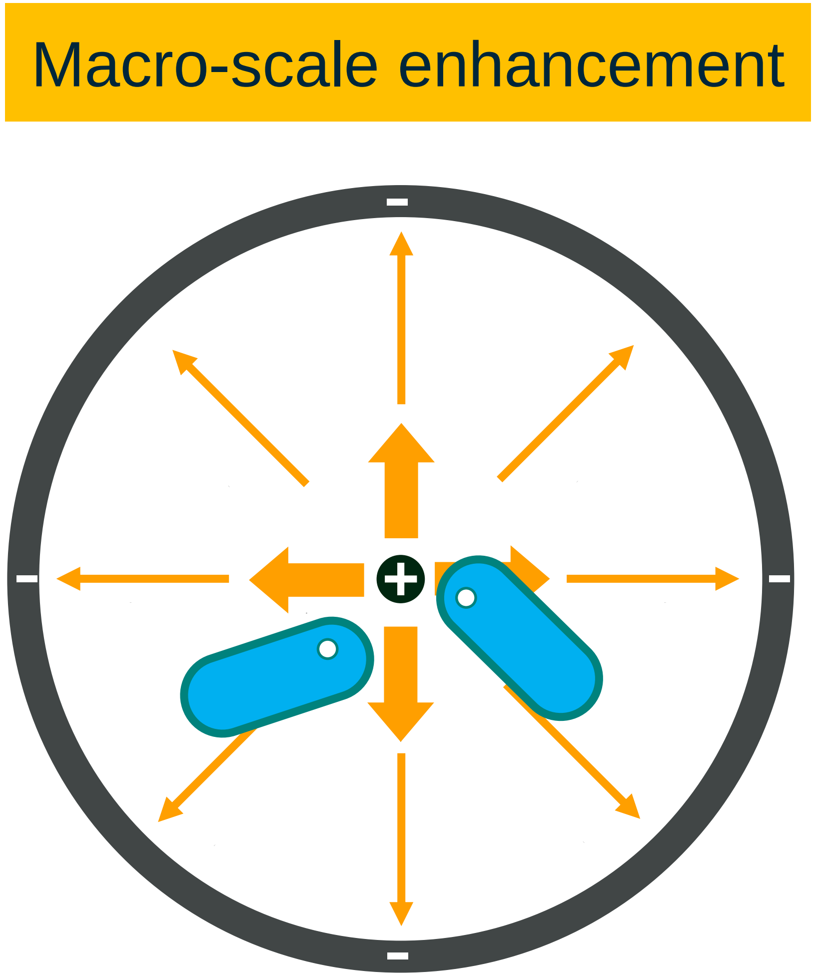
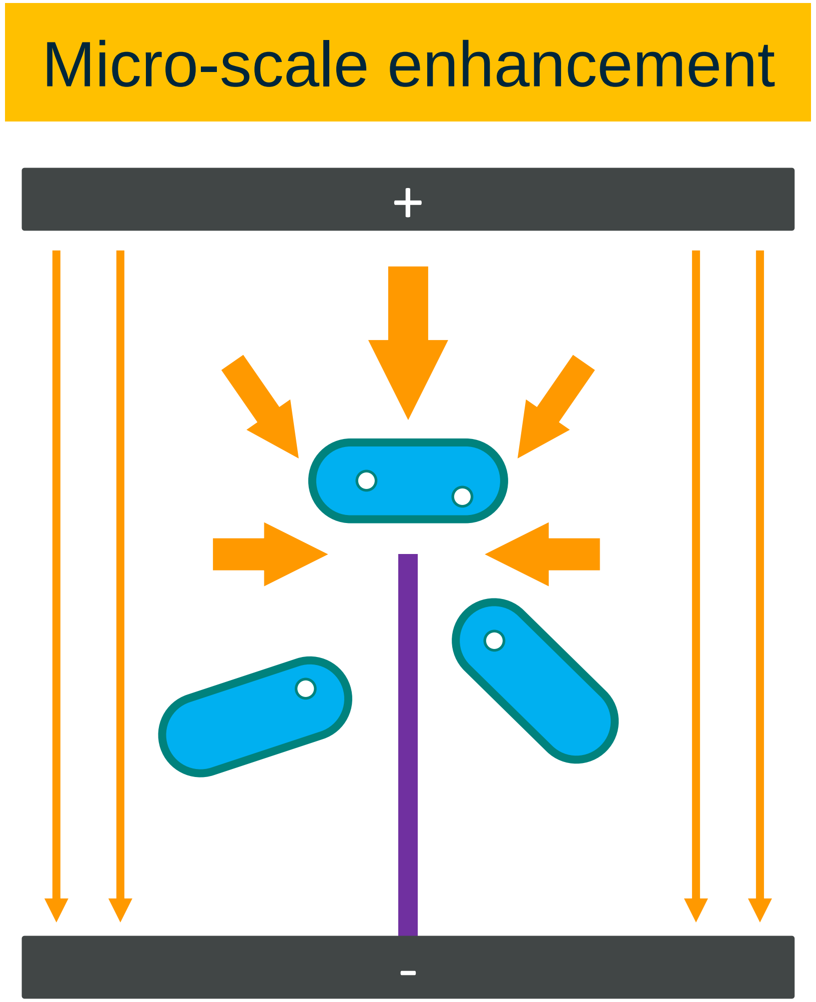
ELECTRIC FIELD TREATMENT (EFT)



LOCALLY ENHANCED ELECTRIC FIELD TREATMENT (LEEFT)

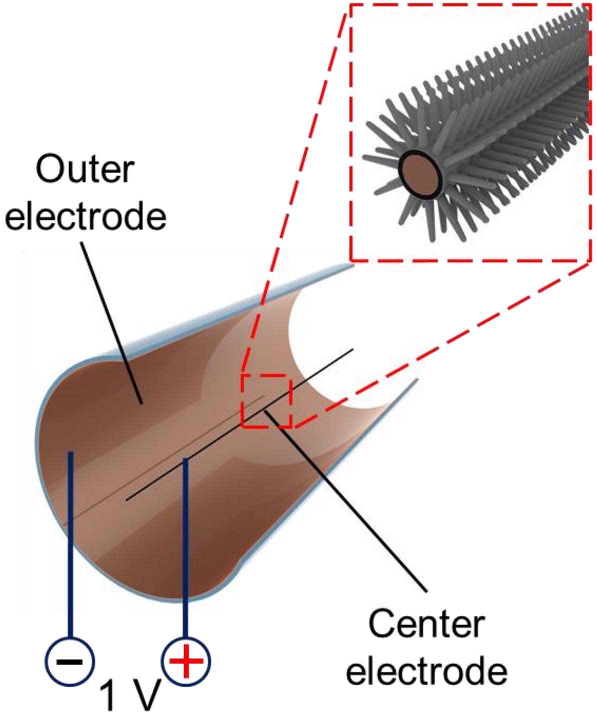




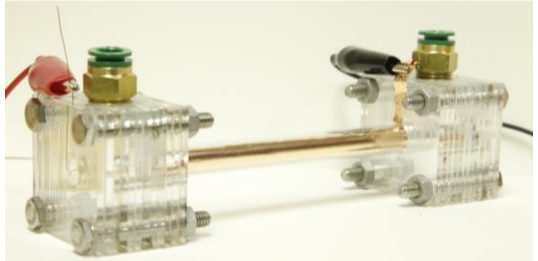
J. Zhou, et al. *Front. Environ. Sci. Eng.* 2020, 14(5): 78, J. Zhou, et al. Environ. Sci. Nano. 2020, 7 (2), 397-403

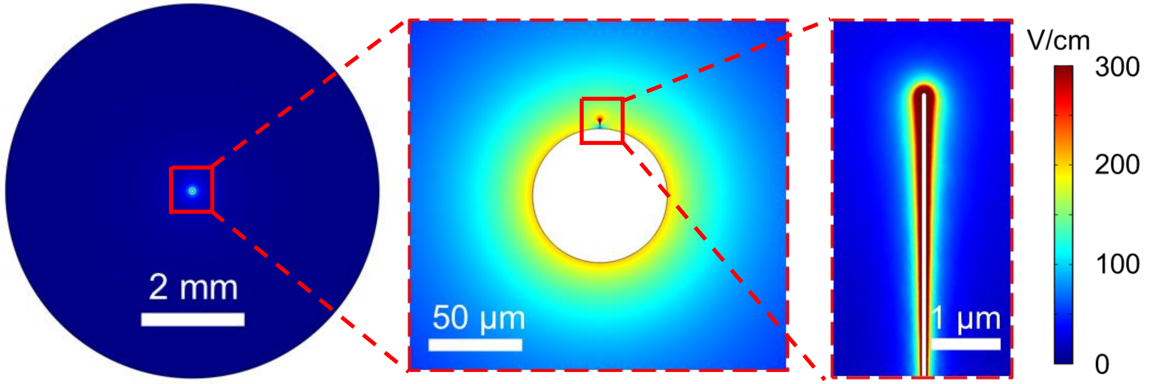
TUBULAR COAXIAL-ELECTRODE LEEFT

- Combine Macro- & Micro-scale enhancement
- **Tubular coaxial-electrode** configuration
  - **Two levels** of electric field enhancement



Length: ~12 cm
Diameter: ~1 cm

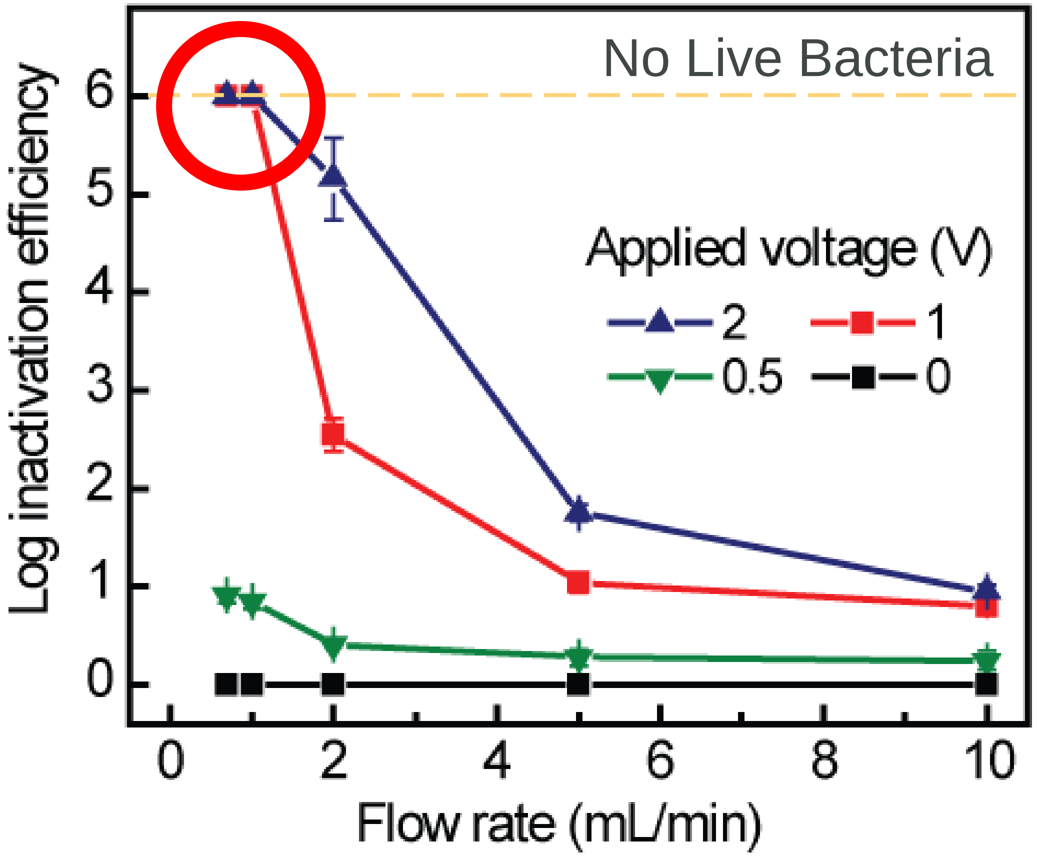




Electric field simulation

TUBULAR COAXIAL-ELECTRODE LEEFT

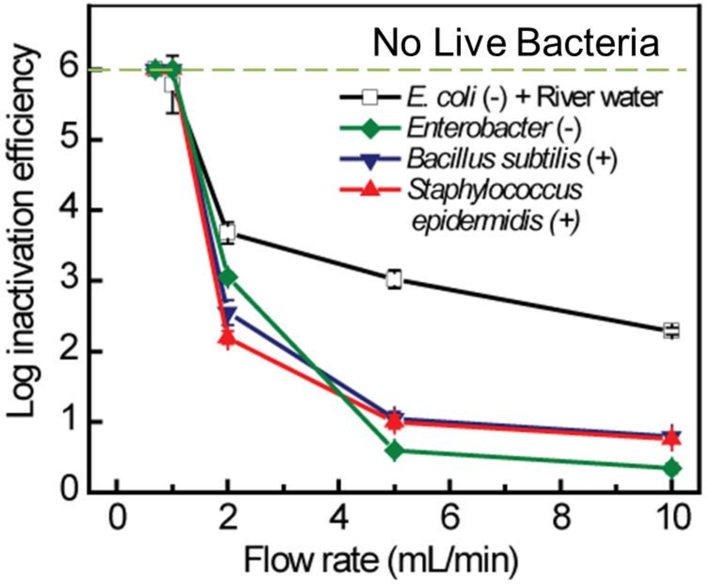
- Water disinfection performance (*E. coli*)
  - **99.9999%** inactivation with **1 V**

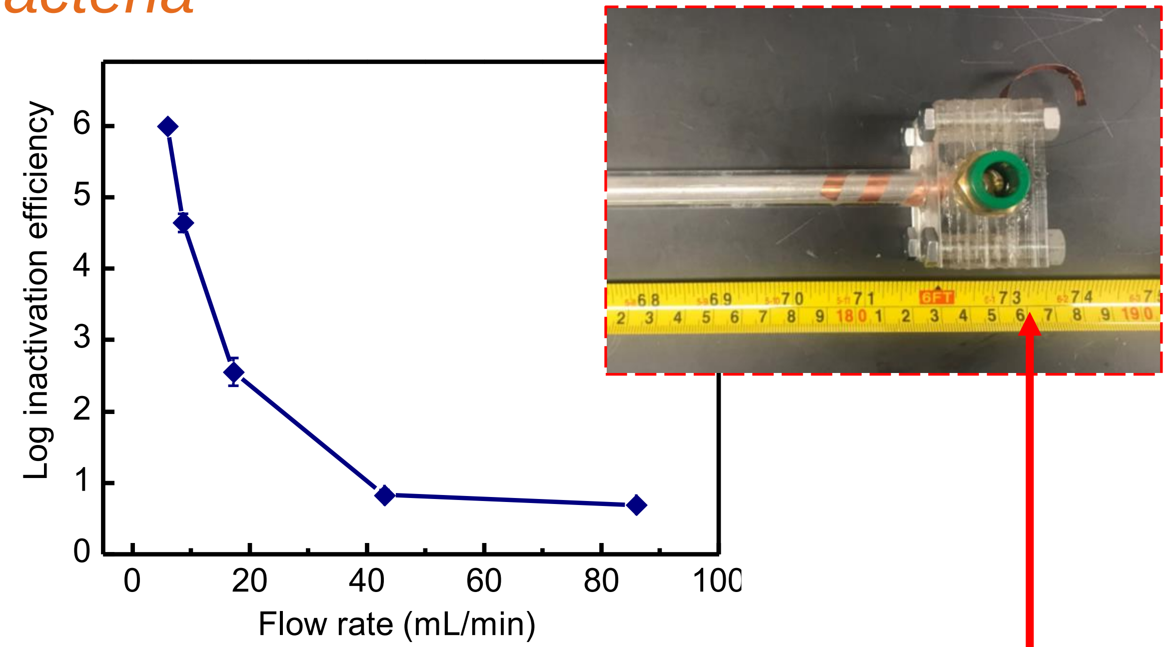


J. Zhou, et al. Environ. Sci. Nano. 2020, 7 (2), 397-403

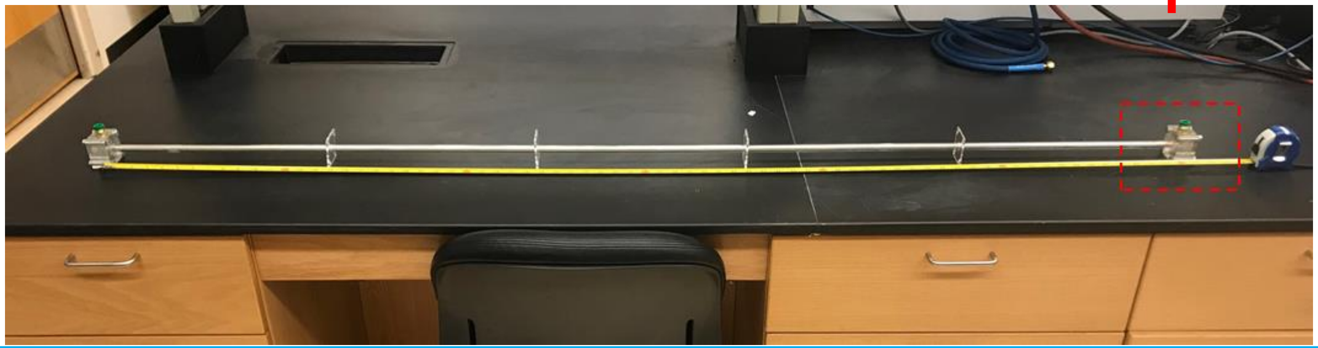
TUBULAR COAXIAL-ELECTRODE LEEFT

- Effective against *multiple strains of bacteria*





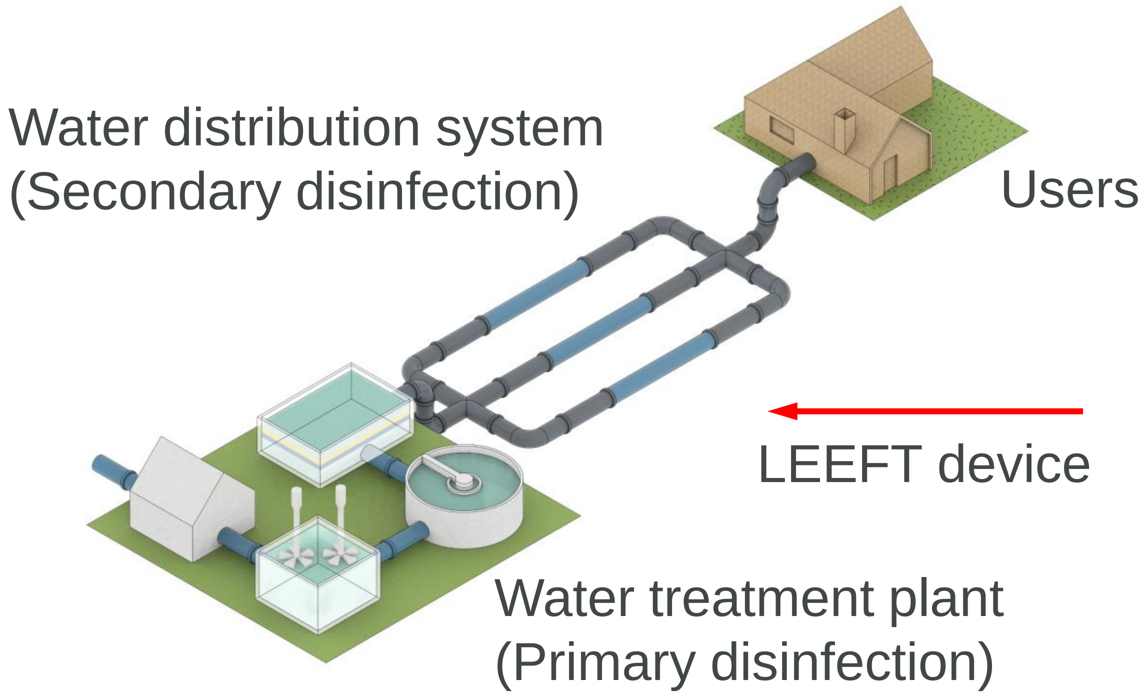
- Highly *scalable* (180 cm)

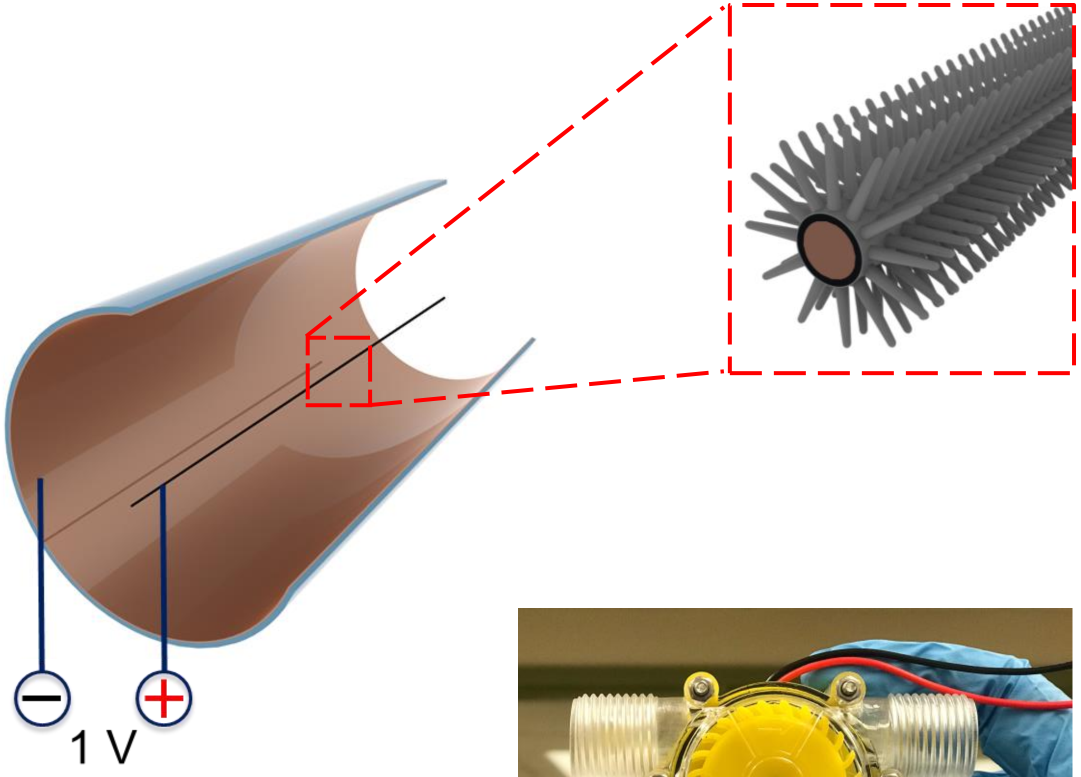


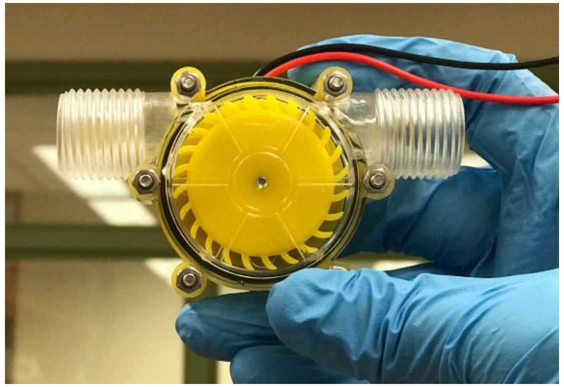
J. Zhou, et al. Environ. Sci. Nano. 2020, 7 (2), 397-403

TUBULAR COAXIAL-ELECTRODE LEEFT

- Potential application in pipelines







J. Zhou, et al. Environ. Sci. Nano. 2020, 7 (2), 397-403

DEVELOPMENT OF LEEFT

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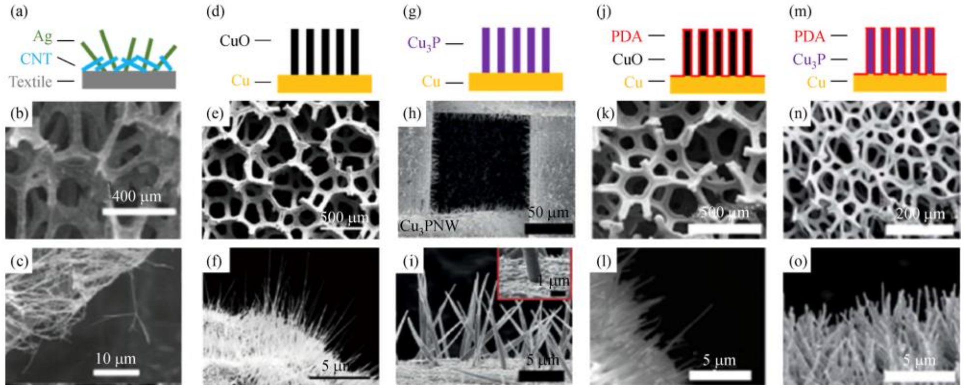
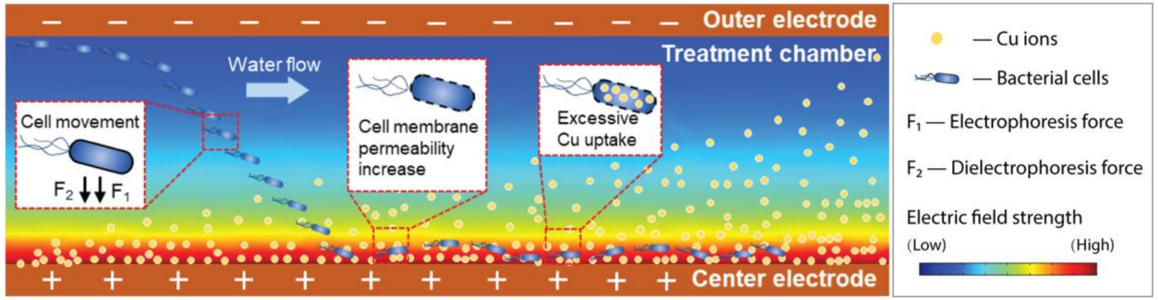


Electrodes

Power Source



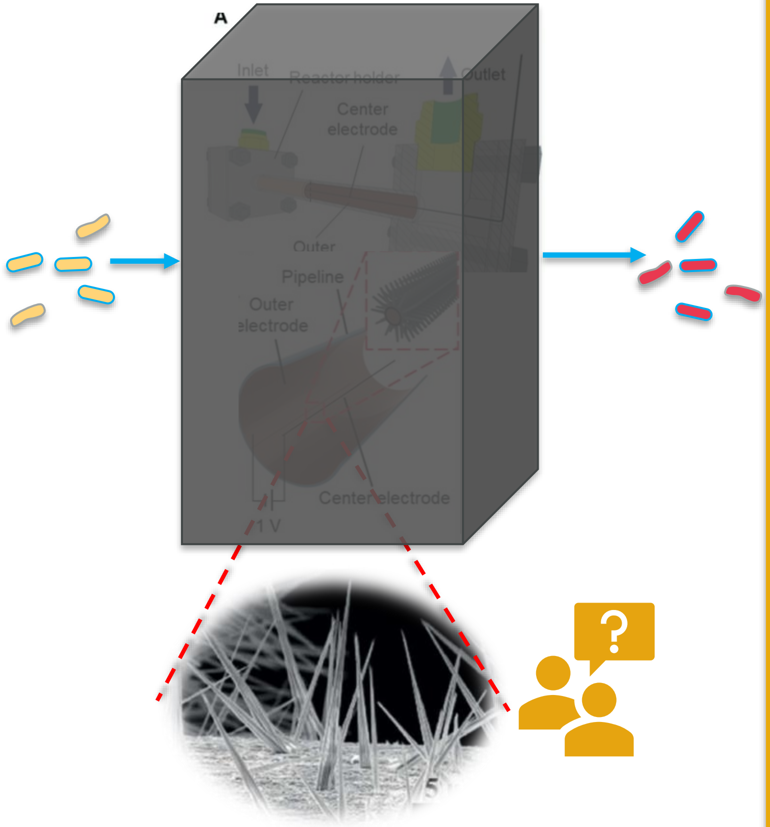
LEEFT-Cu

LEEFT-O_3

Environmental Science Technology, 2016, 50: 7641-7649
Environmental Science: Water Research & Technology, 2018, 4, 872-881
Scientific Reports, 2018, 8, 15832
Journal of Materials Chemistry A, 2018, 6, 18813-18820
Advanced Energy Materials, 2019, 1901320
Chemical Engineering Journal, 2019, 369, 1005-1013
Journal of Materials Chemistry A, 2019, 7, 7347-7354
Environment International, 2019, 128: 30-36
Environment International, 2019, 132: 105040
Environmental Science: Nano, 2020, 7: 397-403
Environmental Science: Nano, 2020, 7: 2021-2031
Environmental Science Technology, 2020, 54: 14017–14025
Frontier of Environmental Science & Engineering, 2020, 14: 78
Journal of Materials Chemistry A, 2020, 8, 12262-12277
npj Clean Water, 2020, 3(1): 1-9
Journal of Hazardous Materials, 2020, 400(5): 123320
Water Research, 2021, 207: 117817
Nano Letters, 2022, 2: 860-867
Journal of Hazardous Materials, 2023, 445(5): 130561
Nature Water, 2023, 1: 104–112

OPERANDO INVESTIGATION OF LEEFT

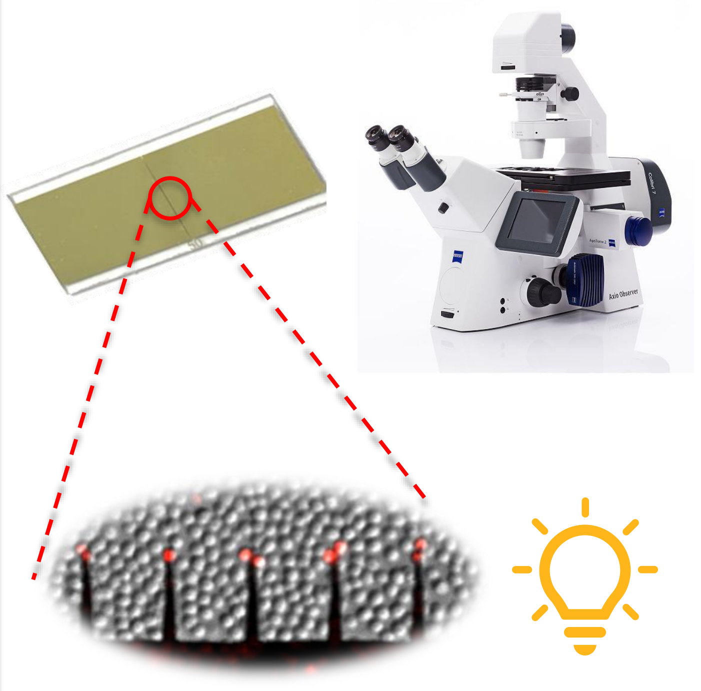
LEEFT



How are the bacteria inactivated?

Open the black box!

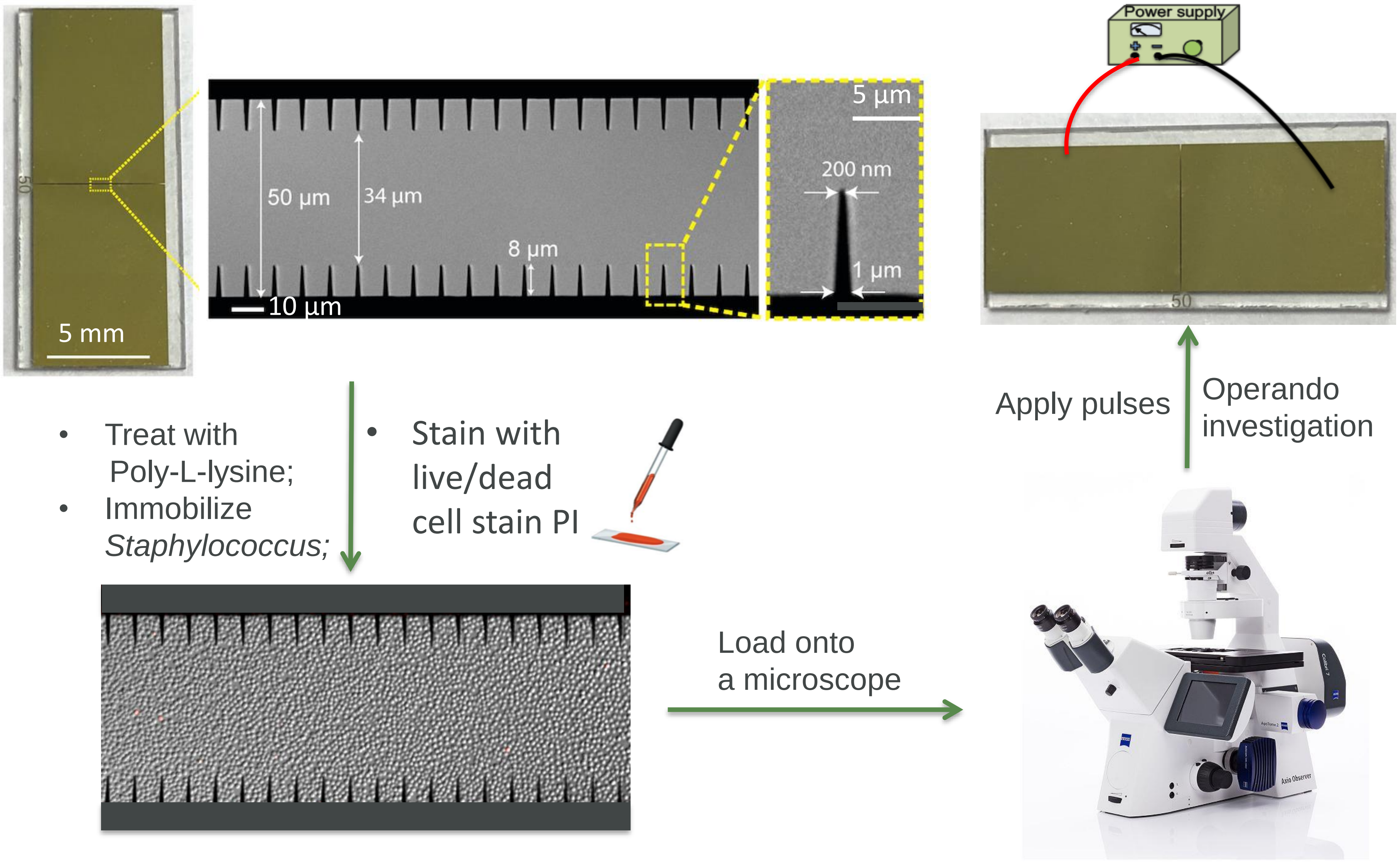
Lab-on-a-chip devices



Observe the bacteria inactivation process *in situ*!

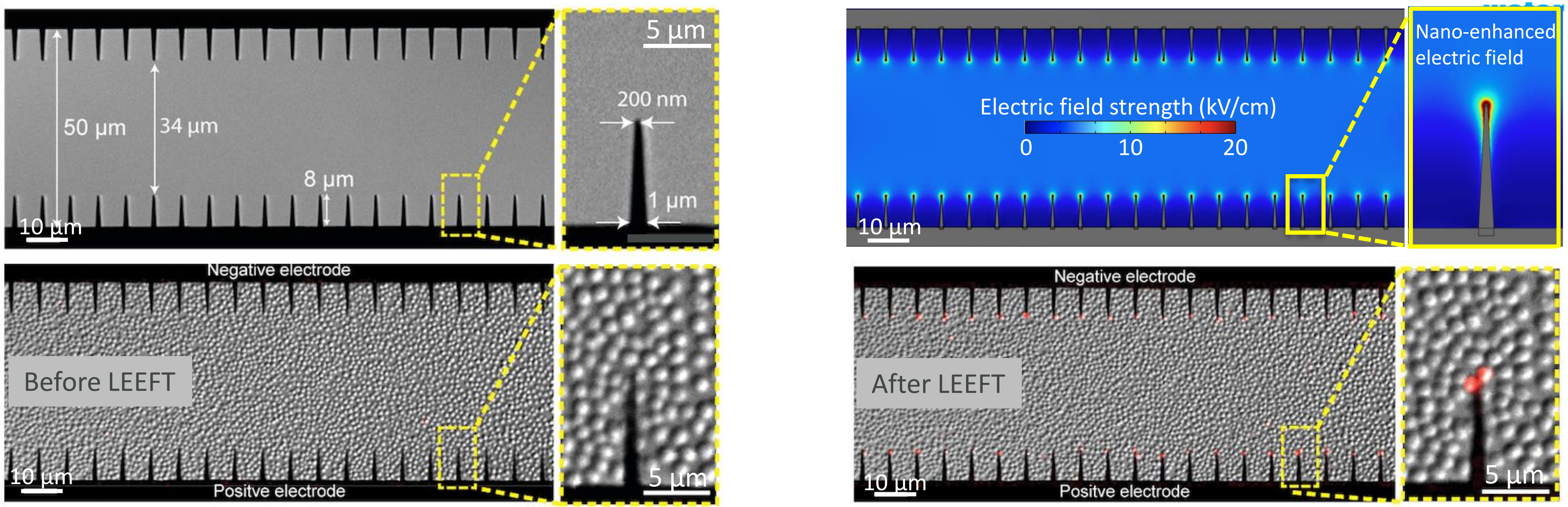
T. Wang, et al. Nano Letters, 2022, 2: 860-867; T. Wang, et al. Nature Water, 2023, 1: 104–112.

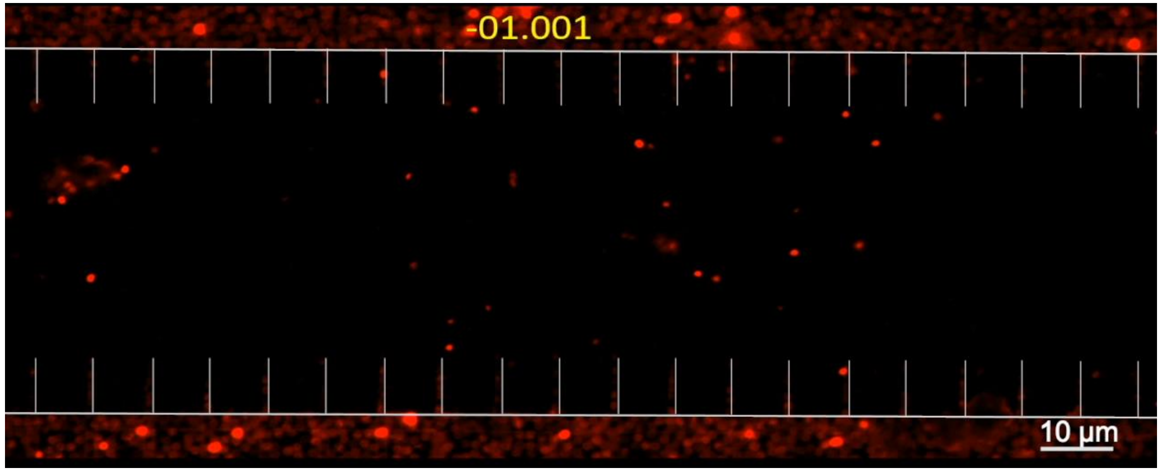
OPERANDO INVESTIGATION OF LEEFT



T. Wang, et al. Nano Letters, 2022, 2: 860-867; T. Wang, et al. Nature Water, 2023, 1: 104–112.

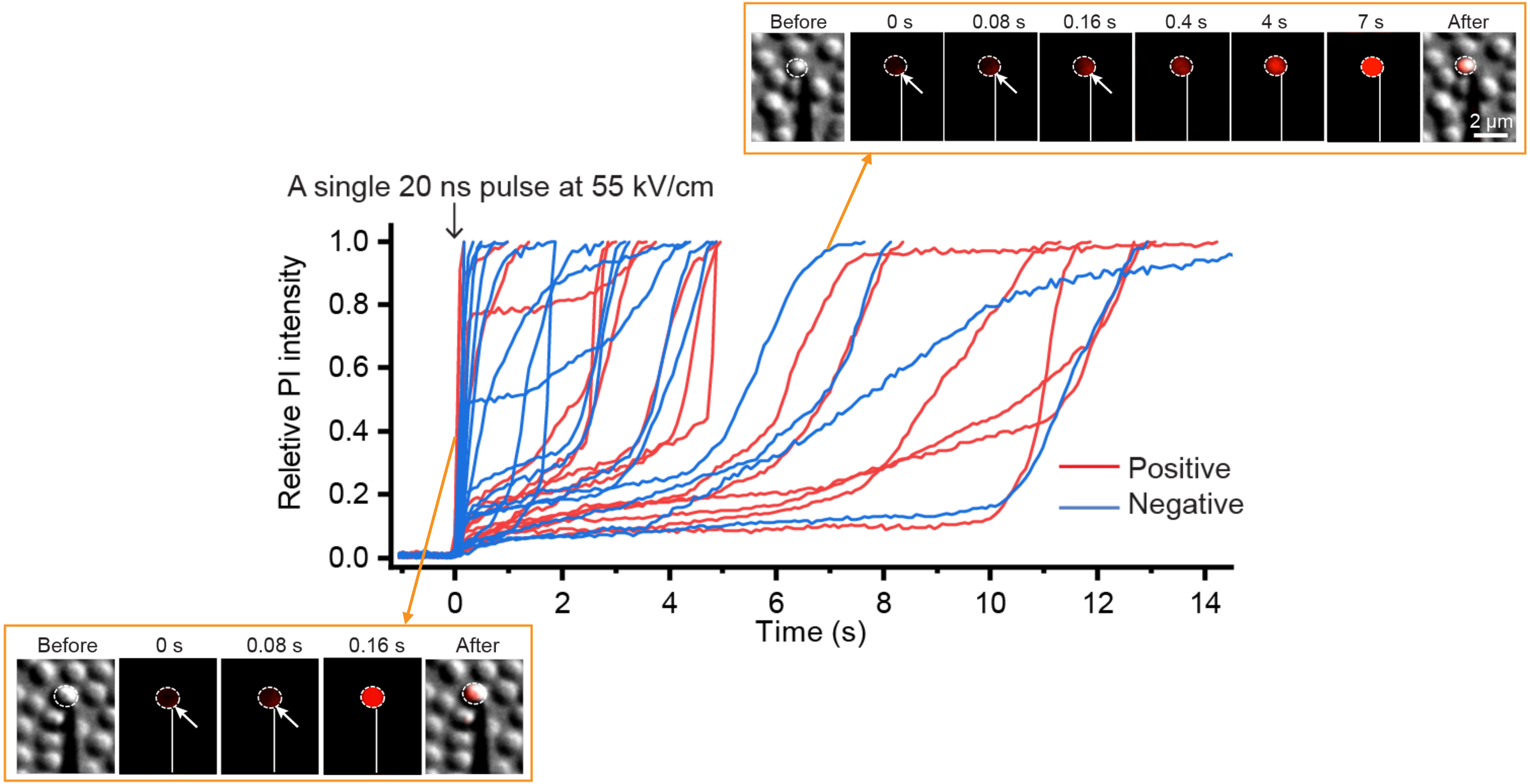
OPERANDO INVESTIGATION OF LEEFT





T. Wang, et al. Nano Letters, 2022, 2: 860-867; T. Wang, et al. Nature Water, 2023, 1: 104–112.

NANOSECOND LEEFT

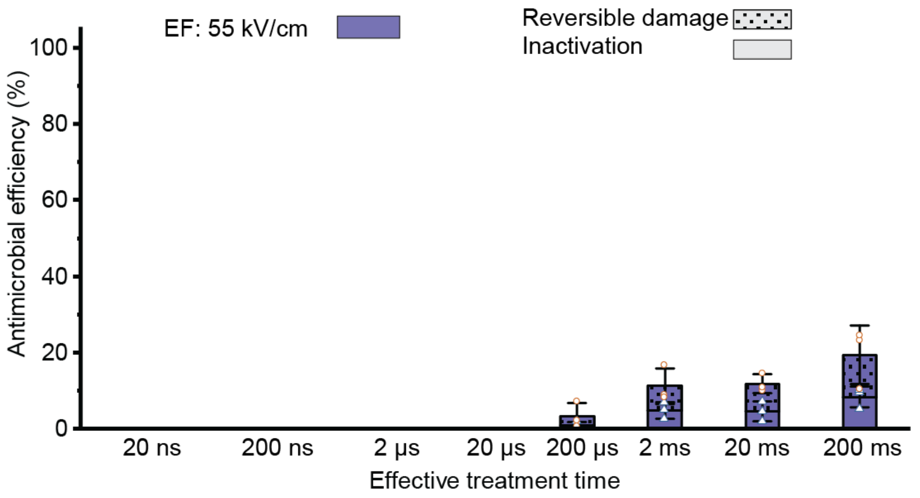


T. Wang, et al. Nature Water, 2023, 1: 104–112.

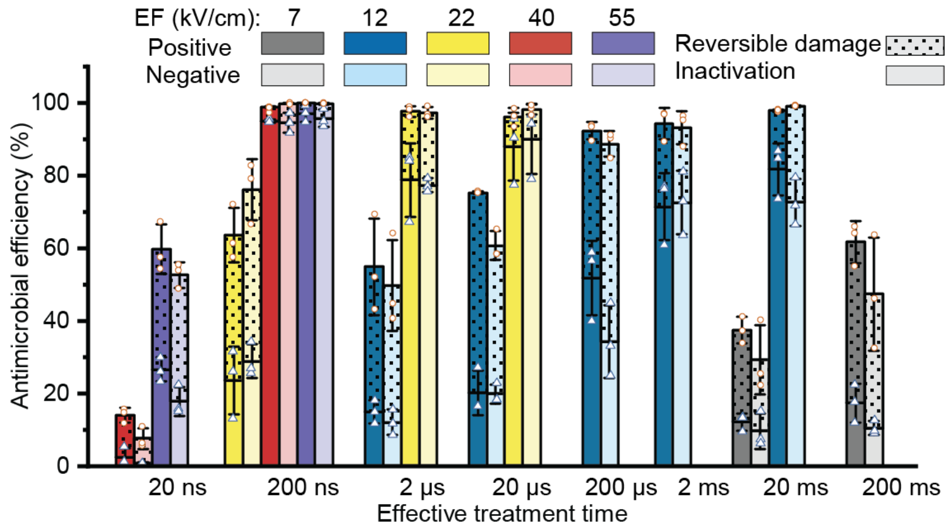
NANOSECOND LEEFT - PERFORMANCE

Fixed pulse width: 20 ns

Conventional EFT
(no nanowedges)



LEEFT



Electric field is reduced by 8 times

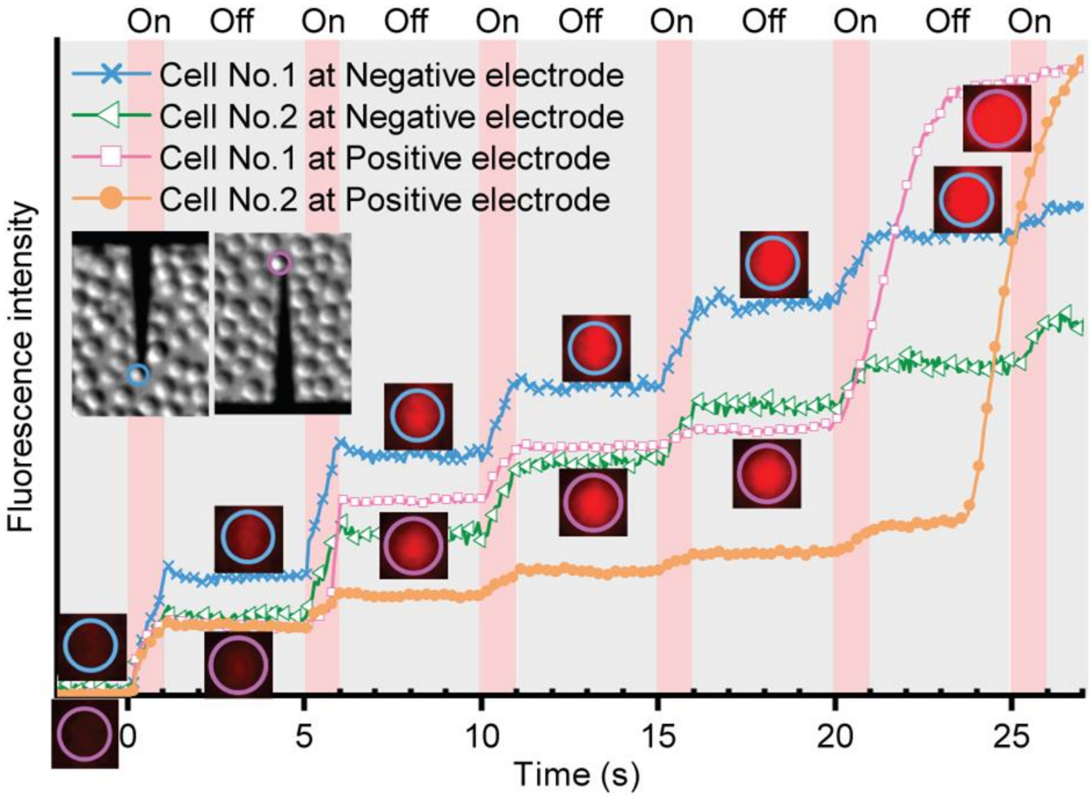
or

Treatment time is reduced by 10^6 times.

T. Wang, et al. Nature Water, 2023, 1: 104–112.

NANOSECOND LEEFT - MECHANISM

- Reversible electroporation - a unique property of electroporation.
- Quick pore closure under 20 ns pulses at 12 kV/cm.

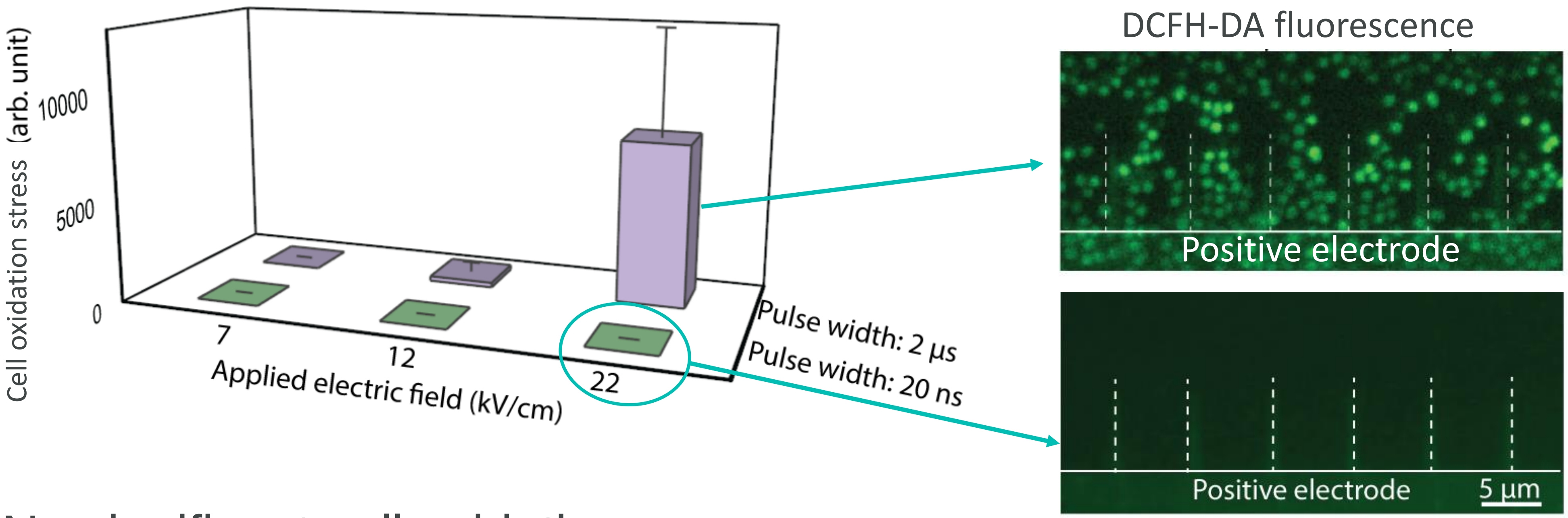


The ultrafast bacteria inactivation is induced by electroporation.

T. Wang, et al. Nature Water, 2023, 1: 104–112.

NANOSECOND LEEFT - MECHANISM

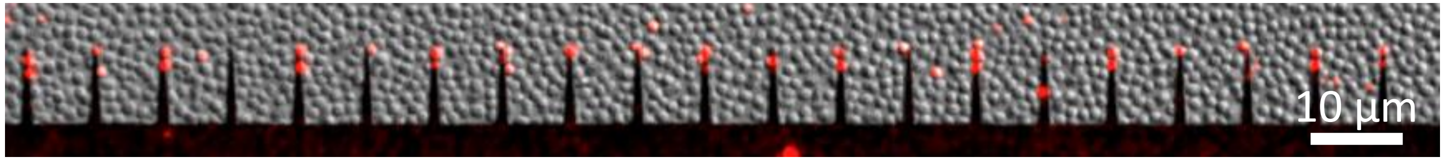
- The bacteria oxidative stress is detected using DCFH-DA.



2 µs pulses:
Significant oxidation

20 ns pulses:
No oxidation

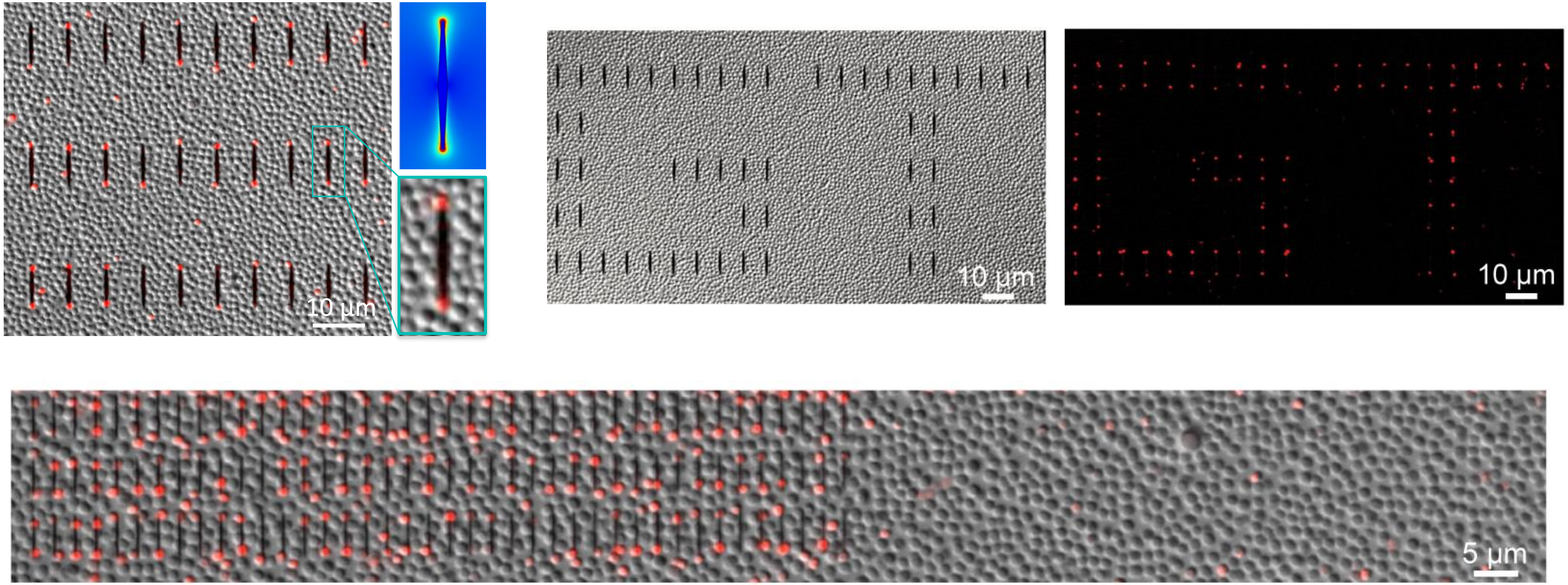
- No significant cell oxidation when 90% bacteria inactivation is achieved.



The ultrafast bacteria inactivation is not due to oxidation.

NANOSECOND LEEFT - MECHANISM

- LEEFT with non-connected electrodes



T. Wang, et al. Nature Water, 2023, 1: 104–112.

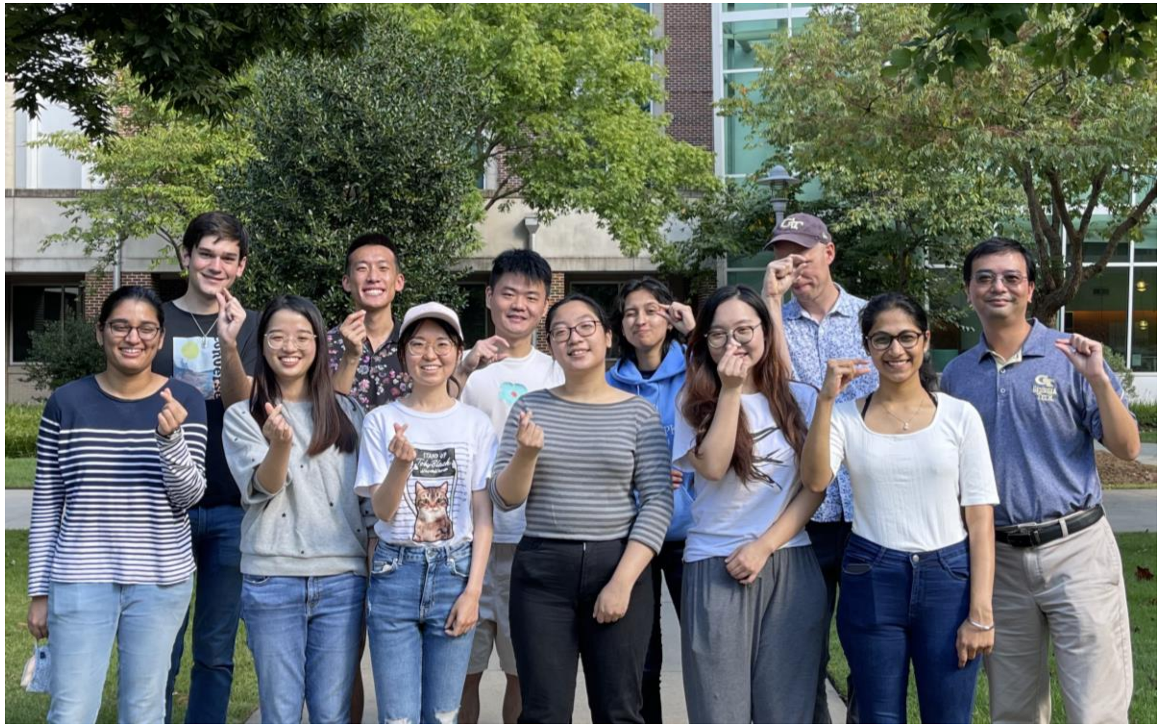
TRANSFORMATIVE WATER DISINFECTION METHOD

- Demonstrated/Potential Advantages of LEEFT
  - **High** microbial inactivation **efficiency**
  - **Broad-spectrum** effective to all pathogens
  - **Fast** treatment process
  - **Low** capital, operational, and maintenance **cost**
  - **No impact on** the physical and chemical property of the **treated water** (i.e., neither generating DBPs nor releasing toxic metals nor increasing the corrosivity)
  - Operate on electricity **without** any **chemical** consumption
  - **No overtreatment** concerns
  - **No secondary pollution** in terms of odor, sound, or light
  - **Easy to operate** and possible for automatic operation
  - Completely **safe** to operators and nearby community

ACKNOWLEDGEMENTS

the international water association

- Students
  - **Ting Wang**
  - Cecilia Yu
  - Mourin Jarin
  - Feifei Liu
  - Feiyang Mo
- Alumni
  - Zeou Dou, PhD
  - Wensi Chen, PhD
  - **Jianfeng Zhou**, PhD
  - etc.
- Visiting scholars
- Collaborators
- Lab/Administration Support



BILL & MELINDA GATES foundation

NSF

Georgia Tech | IEN Institute for Electronics and Nanotechnology

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

NWRI

BioLargo We Make Life Better

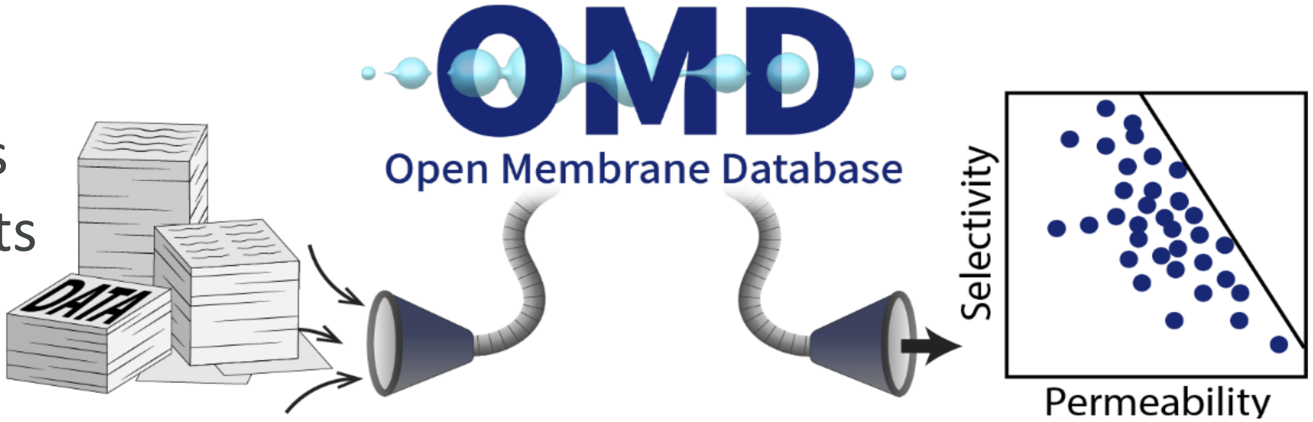
The Open Membrane Database (OMD): An open-access, user-sourced library of water purification and desalination membranes

RHEA VERBEKE, KU LEUVEN, BELGIUM

inspiring change

THE OPEN MEMBRANE DATABASE (OMD) FOR DESALINATION MEMBRANES

Peer-reviewed articles
Commercial datasheets
Patents



>1000 RO datapoints

www.OpenMembraneDatabase.org

SINCE AUGUST 2021

x 500 visitors / month

OMD ARTICLE IN THE *JOURNAL OF MEMBRANE SCIENCE*

the international water association

Contents lists available at ScienceDirect

Journal of Membrane Science

journal homepage: www.elsevier.com/locate/memsci

ELSEVIER

Check for updates

The open membrane database: Synthesis–structure–performance relationships of reverse osmosis membranes

Cody L. Ritt [a,1], Timothée Stassin [b,1], Douglas M. Davenport [b], Ryan M. DuChanois [a], Ines Nulens [b], Zhe Yang [c], Adi Ben-Zvi [d], Naama Segev-Mark [d], Menachem Elimelech [a], Chuyang Y. Tang [c], Guy Z. Ramon [d], Ivo F.J. Vankelecom [b], Rhea Verbeke [b,*]

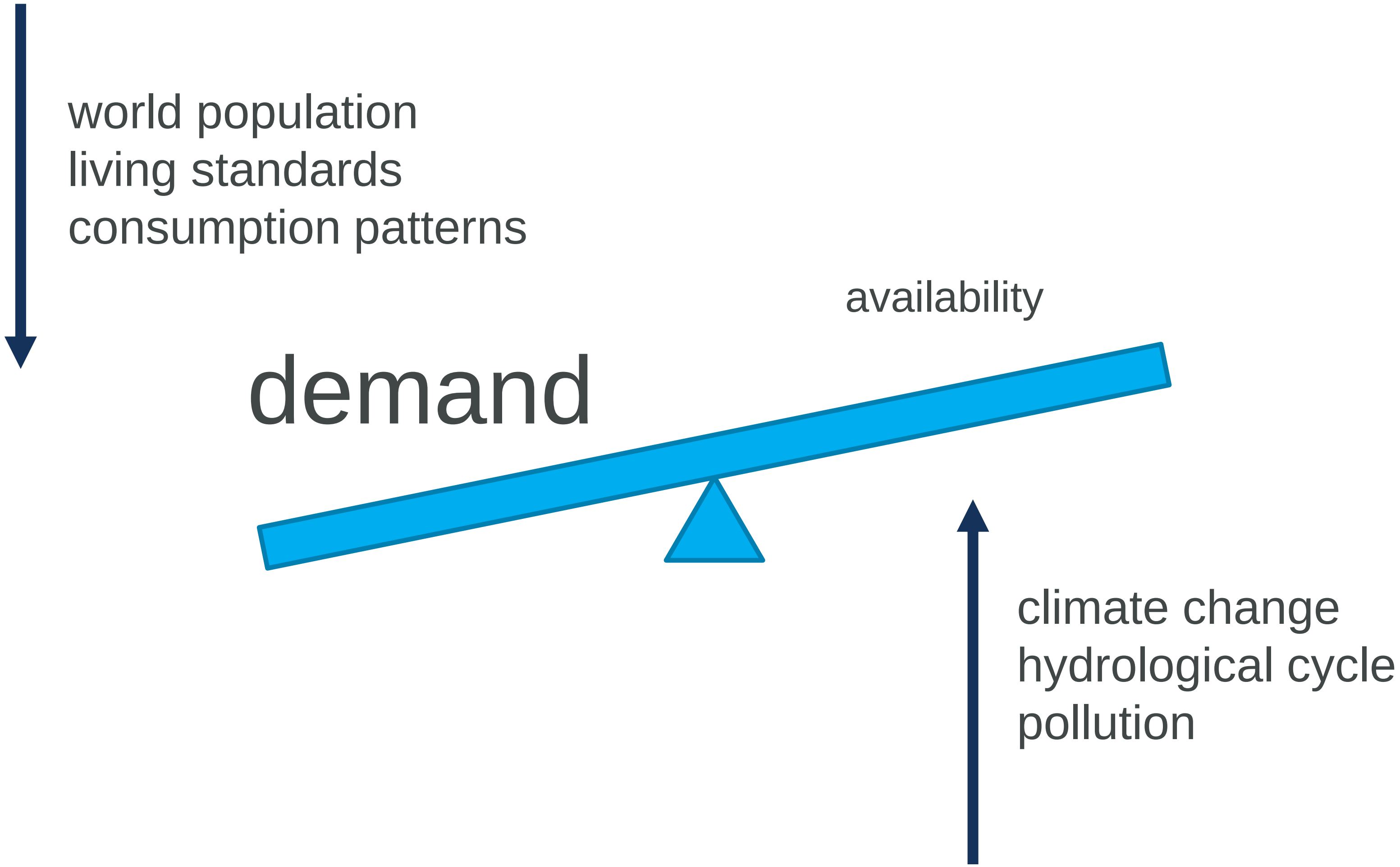
[a] *Department of Chemical and Environmental Engineering, Yale University, New Haven, CT, 06520-8286, USA*
[b] *Centre for Membrane Separations, Adsorption, Catalysis and Spectroscopy for Sustainable Solutions (cMACS), KU Leuven, Celestijnenlaan 200F Box 2454, 3001, Leuven, Belgium*
[c] *Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, SAR, PR China*
[d] *Department of Civil and Environmental Engineering, Technion—Israel Institute of Technology, Haifa, 3200003, Israel*

doi: 10.1016/j.memsci.2021.119927
Journal of Membrane Science, *641*, 119927.

TOPICS COVERED

- Water scarcity and state-of-the art membrane desalination
- Why is a database useful?
- OMD founding principles
- OMD data and constraints
- Online tools: membrane submission & calculators
- Where are we and where do we go ?

WATER SCARCITY OCCURS WHEN DEMAND EXCEEDS AVAILABILITY



COMBINED SOLUTIONS NEEDED TO FIGHT WATER SCARCITY

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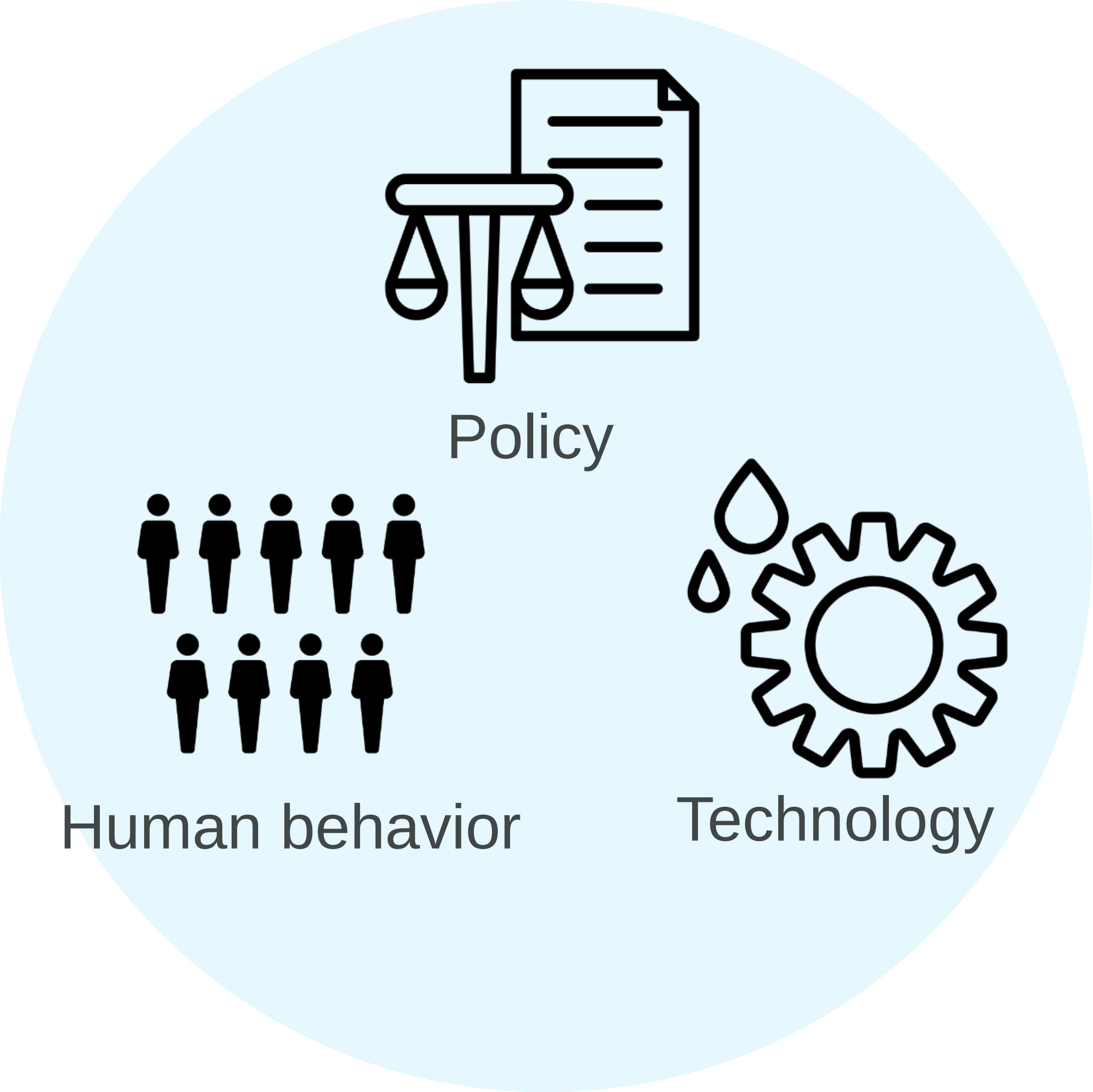
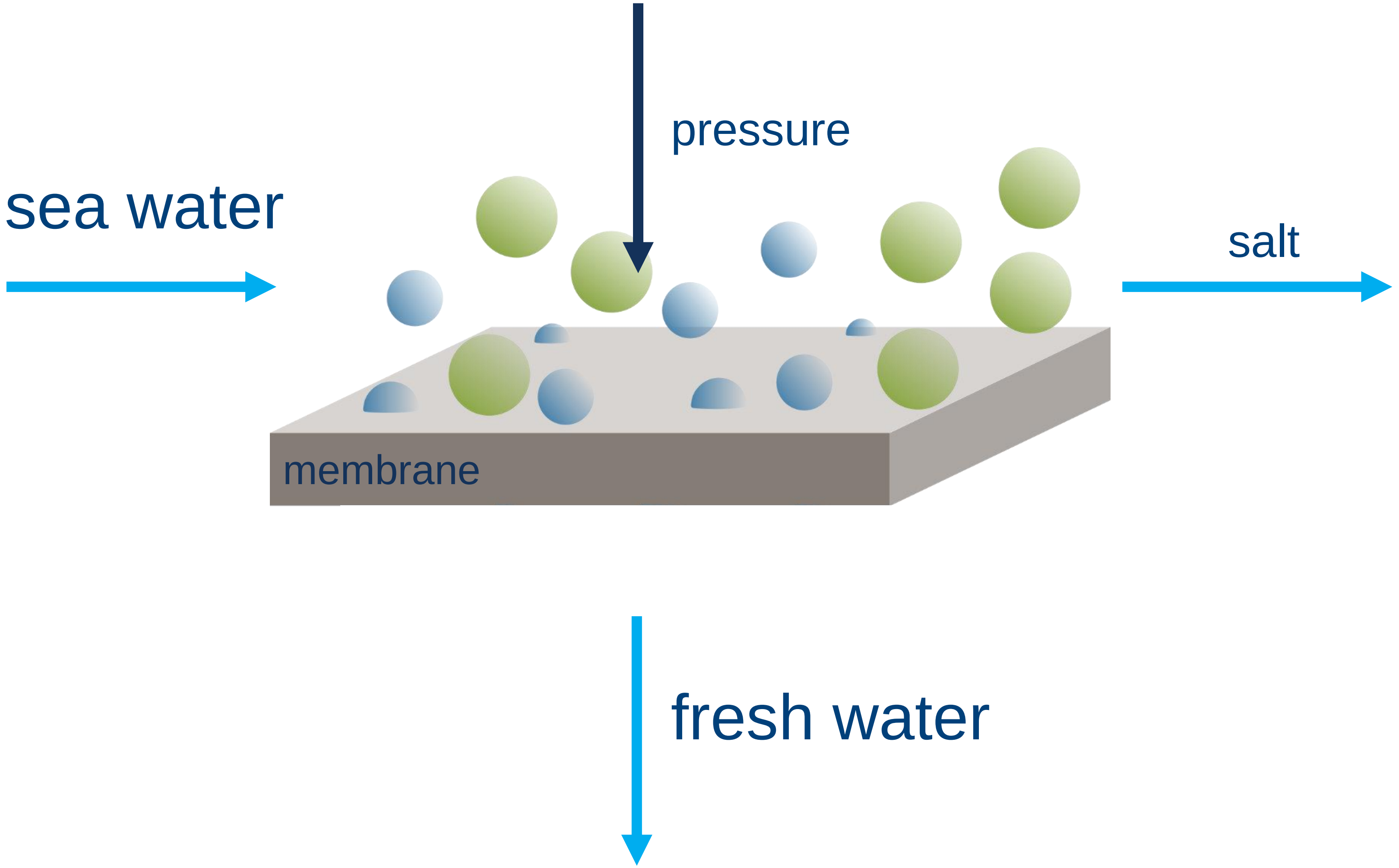
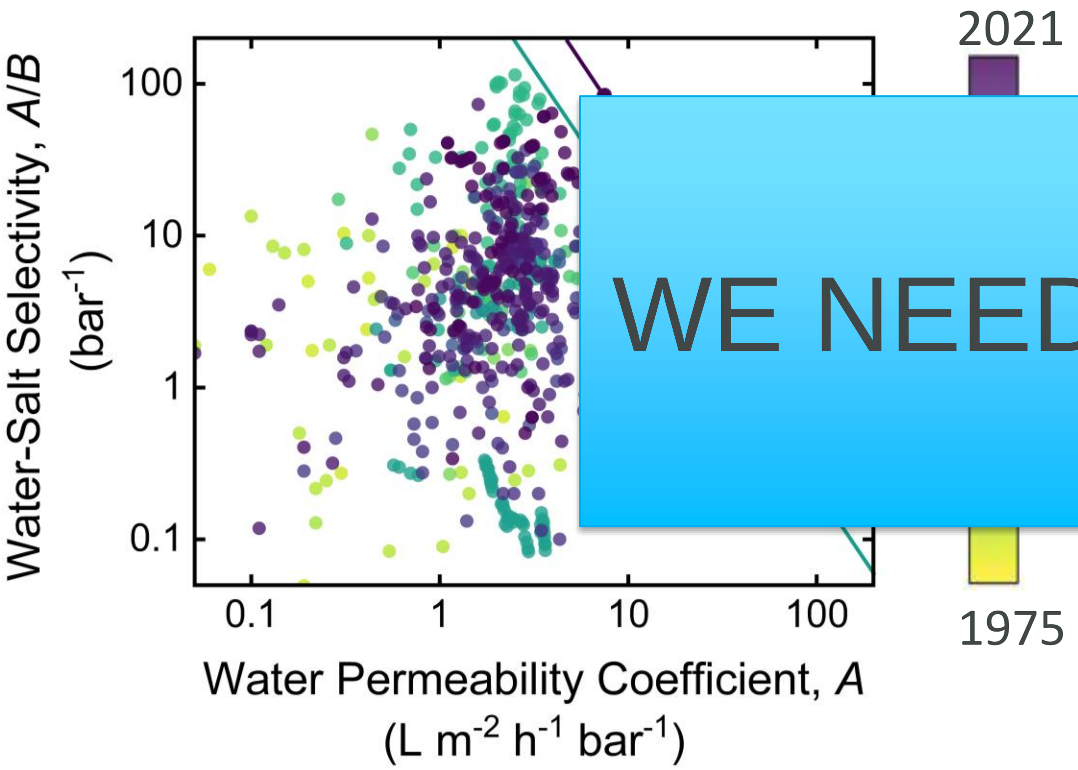


Desalination

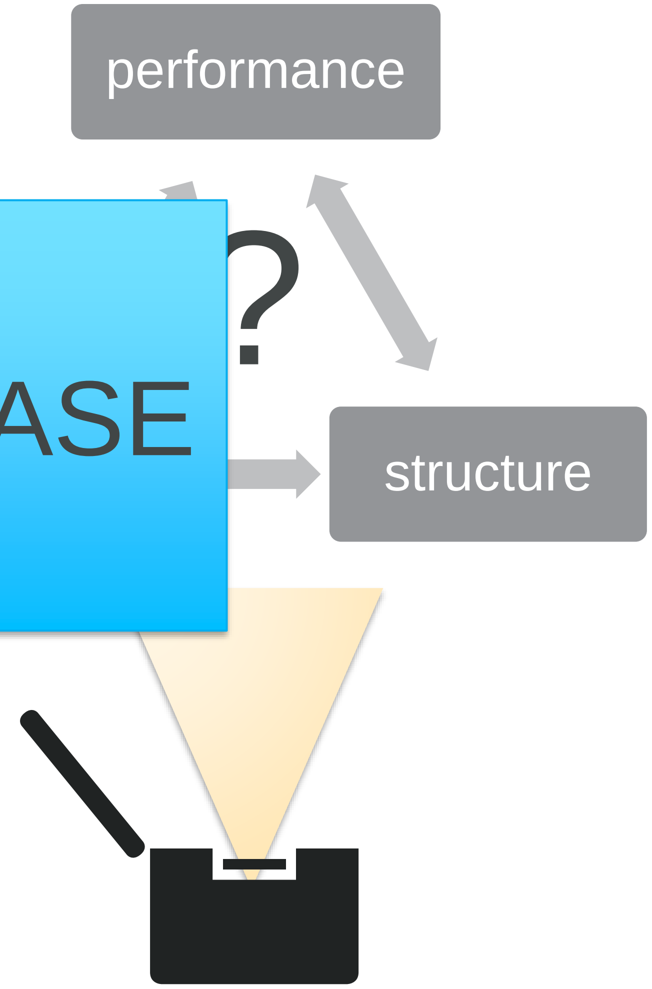
DESALINATION MEMBRANES CAN HELP INCREASE FRESH WATER AVAILABILITY



MARGINAL IMPROVEMENTS IN RO MEMBRANE PERFORMANCE IN THE LAST 30 YEARS



WE NEED A DATABASE

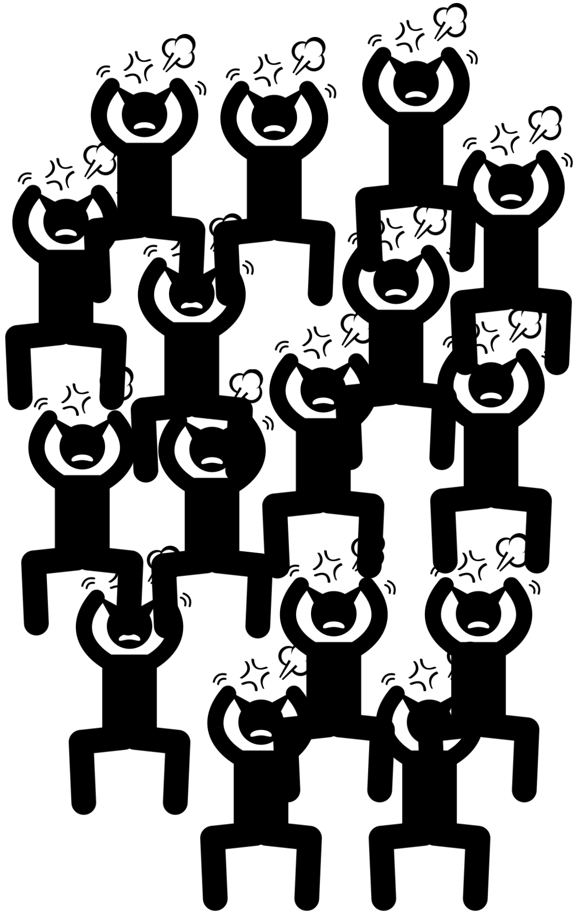


WE ALSO NEED A DATABASE TO INCREASE RESOURCE AND TIME EFFICIENCY

Data scattered

Data not readable

Data not standardized



WHY WOULD A DATABASE IMPROVE THE FIELD?

Understand

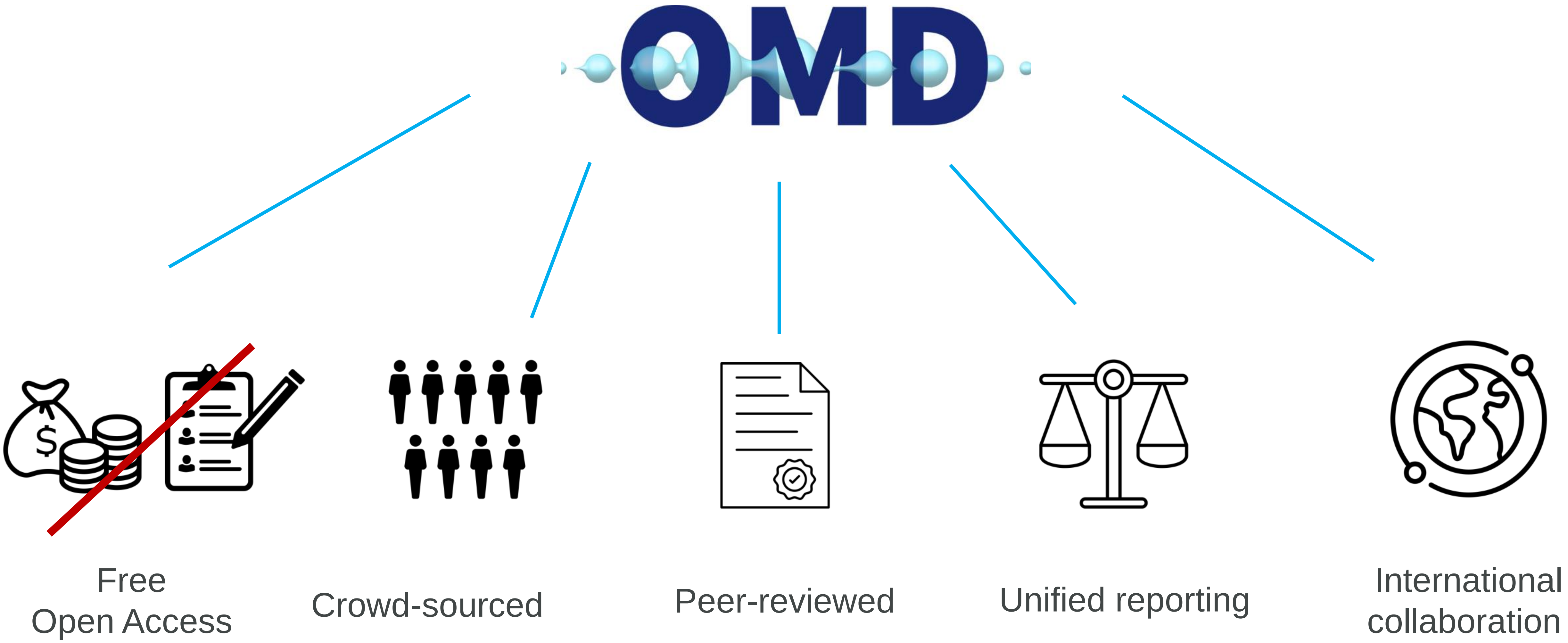
Standardize

Share

Inspiration:

- Cambridge Structural Database (since 1965): MOF explorer
- Protein Data Bank (since 1971)

THE FOUNDATIONAL PRINCIPLES OF THE OMD



ADVANTAGES OF OMD OVER STATUS QUO

Data Features	Status Quo	OMD
Update Frequency		
Data Sourcing		
Processing		
Exploration		
Accessibility		

OMD CAN HELP ADVANCE MEMBRANE TECHNOLOGY

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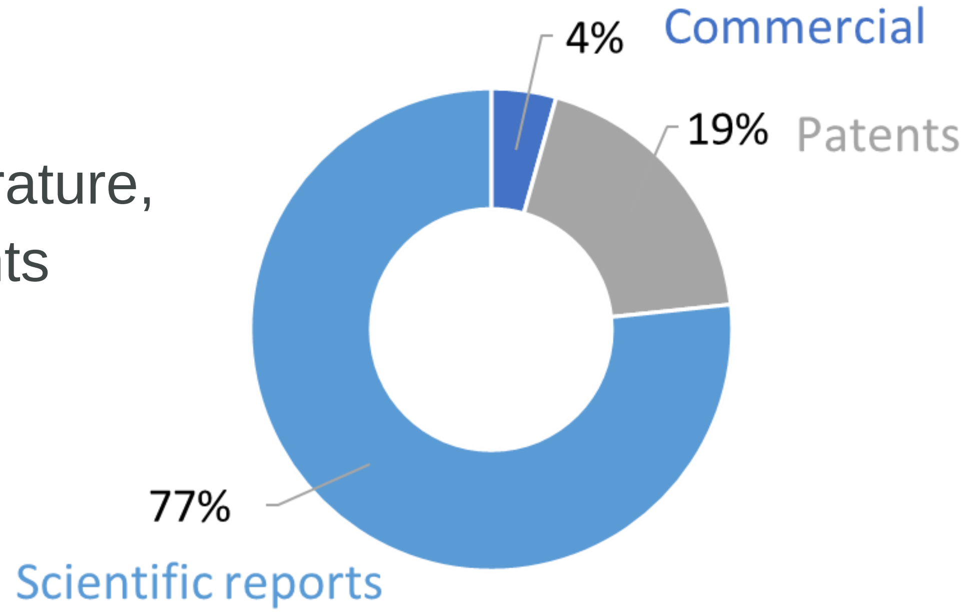
1. Benchmark novel RO membranes against the state of the art
2. Conduct meta-analysis
3. Develop membrane synthesis-structure-performance relationships
4. Calculate membrane performance, concentration polarization, osmotic pressure
5. Facilitate interdisciplinary research

OMD DATA: ORIGINS AND CONSTRAINTS

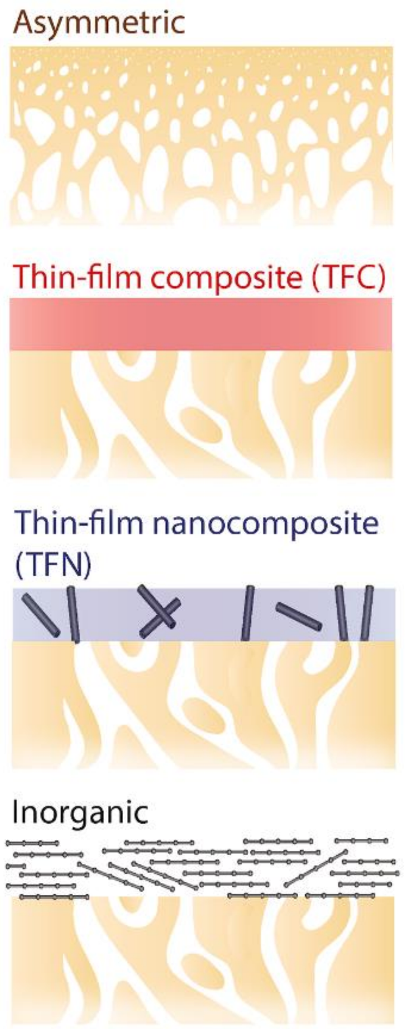
- Data only from peer-reviewed literature, commercial datasheets and patents



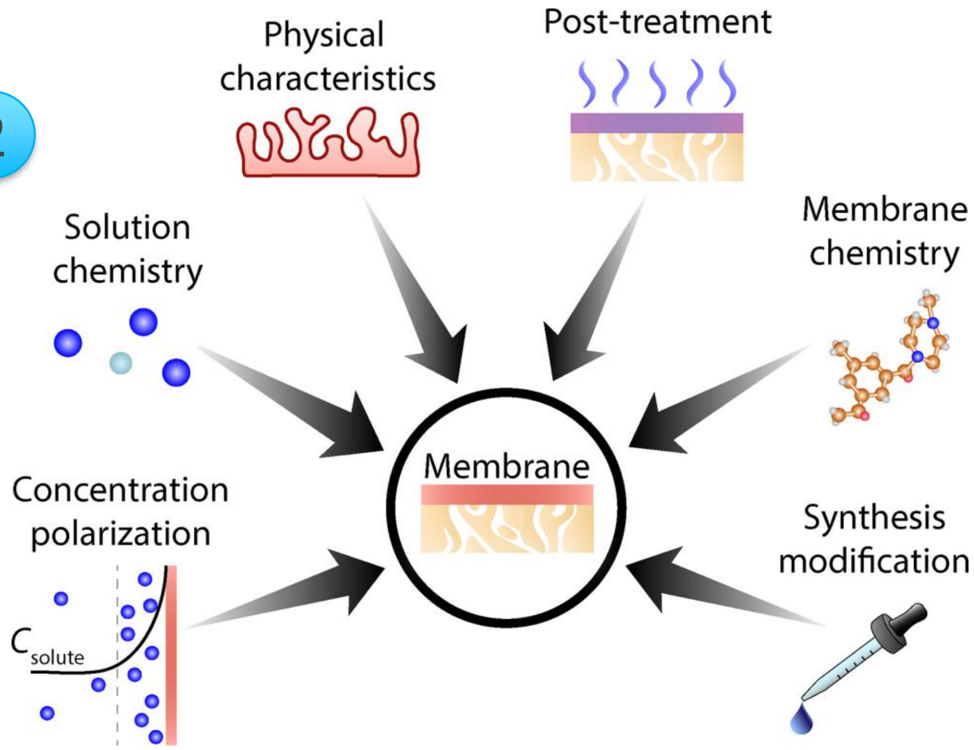
- Definition of RO membrane: R_{NaCl}> 80%
- Not only the best performing → data series

INPUT COLLECTED BY THE OMD

1



2



FUNCTIONALITY OF THE OMD

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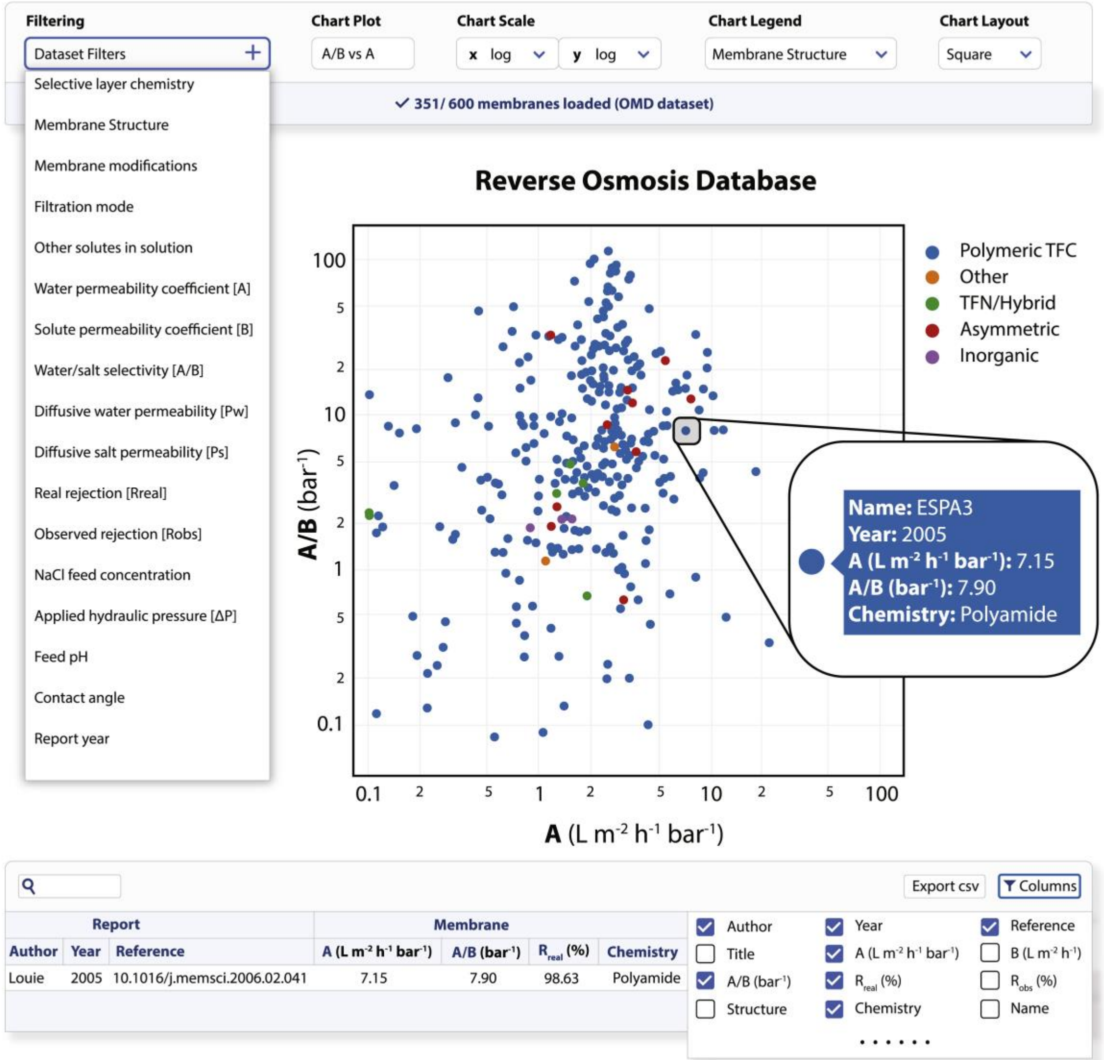

- Filtering
- Interactive chart
- Data callouts
- Tabulated details
- Data export as csv
- Figure export as png

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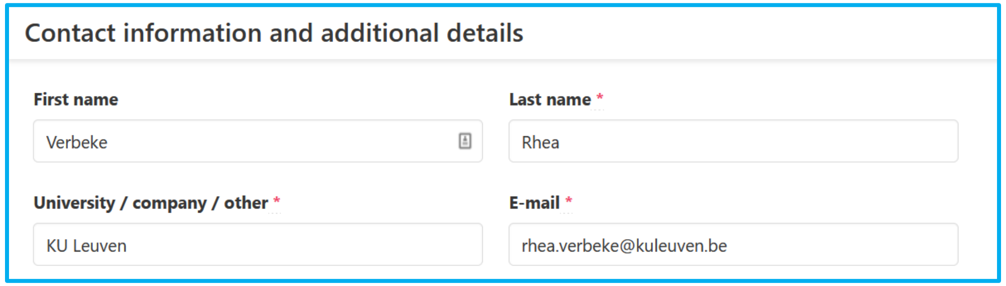
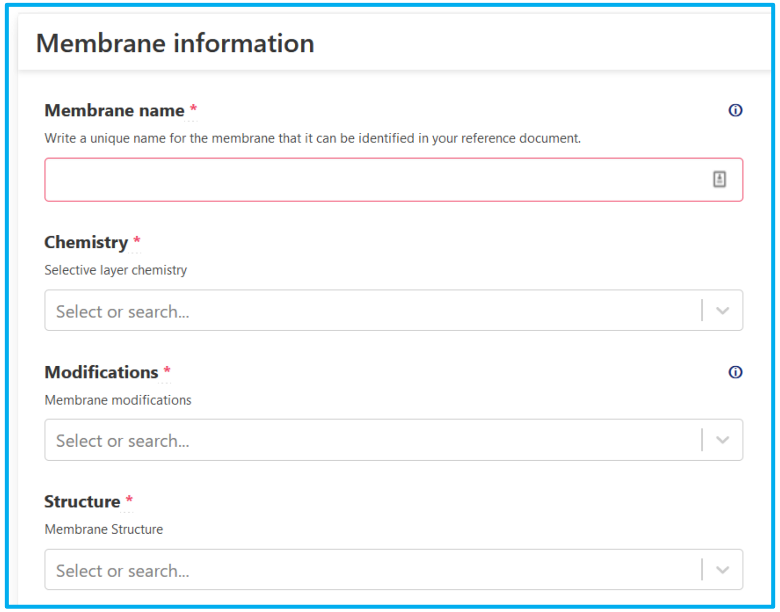
SUBMISSIONS OPEN TO EVERYONE

1. Enter report and data
2. Provide contact info



3. Submit membrane data



4. Post-submission review by OMD team
5. Upon acceptance: data directly online

ONLINE CALCULATORS TO HELP USERS

the international sociation

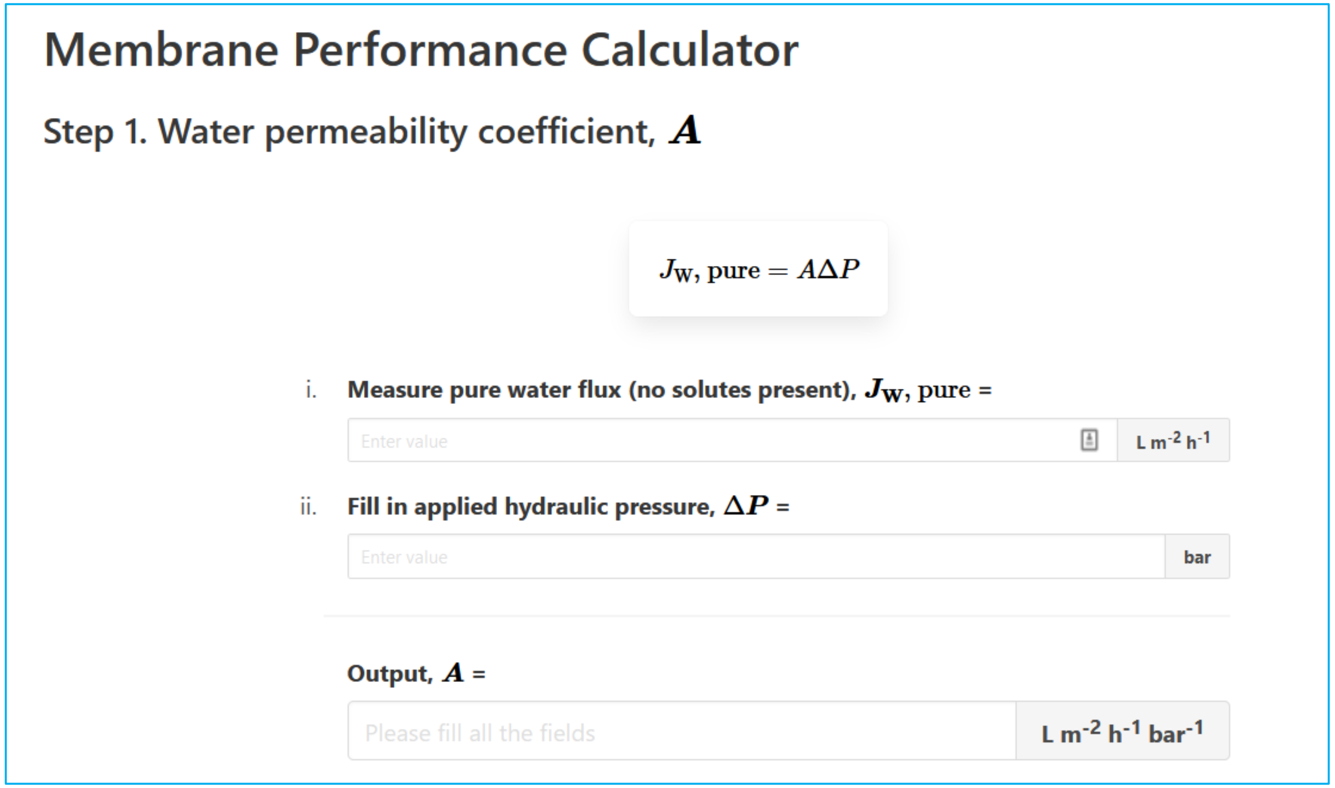
Membrane Performance Calculator

Concentration Polarization Calculator

Osmotic Pressure Calculator

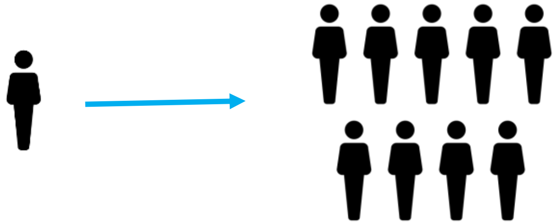
Common Unit Converters

- Facilitate accurate determination to avoid errors
- Step-by-step process



WHERE DO WE STAND NOW?

- Very positive feedback, many visitors, highly cited paper

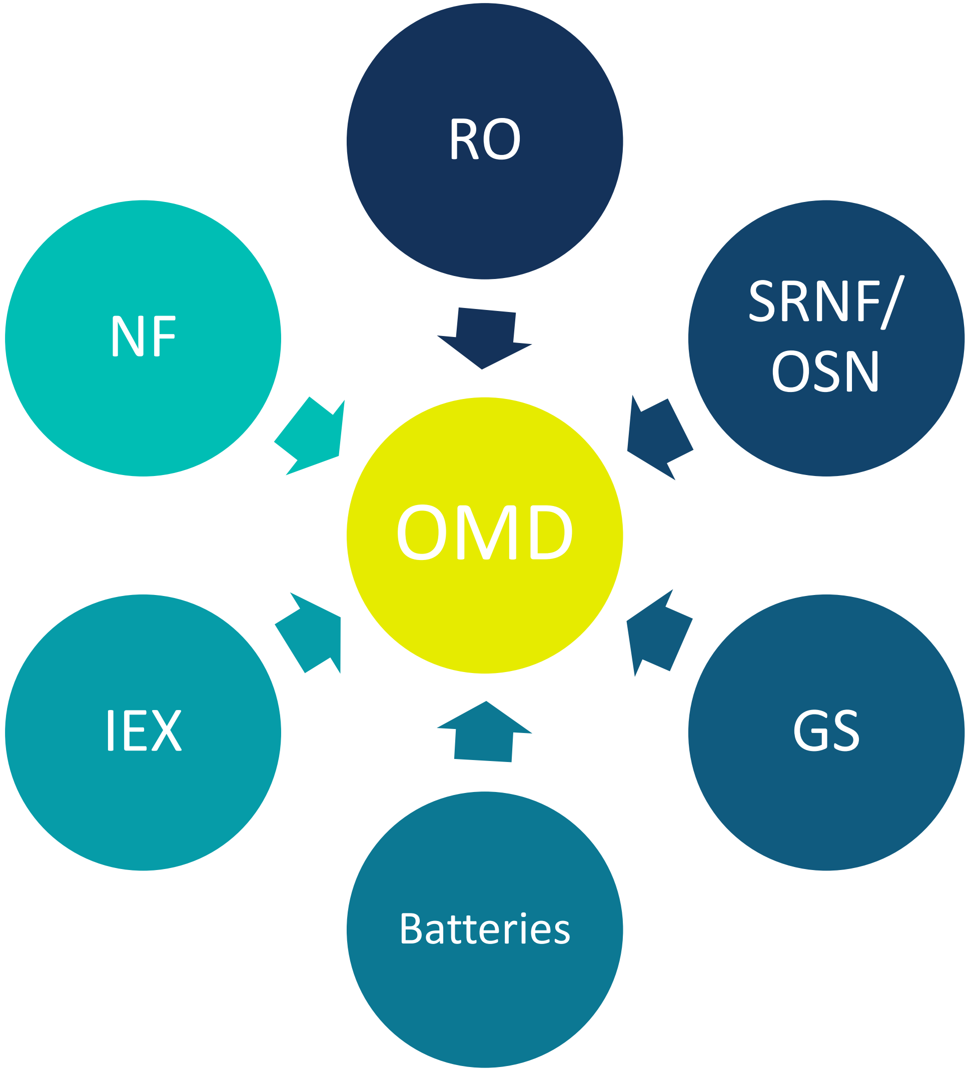


- Only 1 external submission since August 2021
- Involvement of the field needed
  - You and your colleagues !
  - Journals → open repository → OMD
  - Other ideas?

OUTLOOK OF THE OMD FOR RO

- Revisit concentration polarization assumptions
- Membranes tested under standard conditions → gold standard
- Addition of trace organic contaminants
- Include dynamic upper bound
- Establish connections with journals to facilitate automatic data transfer

LONG TERM VISION: OMD AS A DATABASE 'HUB'



COLLABORATIVE PROJECT TO ADVANCE OUR FIELD

the international water association

Submit your membrane data

More data = higher chance of a scientific breakthrough

THANK YOU TO ALL INVOLVED PARTIES

IWA
the international water association

KU LEUVEN

Yale

ISRAEL SCIENCE FOUNDATION

TECHNION
Israel Institute of Technology

香 港 大 學
THE UNIVERSITY OF HONG KONG

BSF

fwo
Research Foundation Flanders
Opening new horizons

NEWT

UGC 大學教育資助委員會
University Grants Committee

EMS 1982

MSA
MEMBRANE SOCIETY OF AUSTRALASIA

African Membrane Society
Environment Process Energie

the international water association

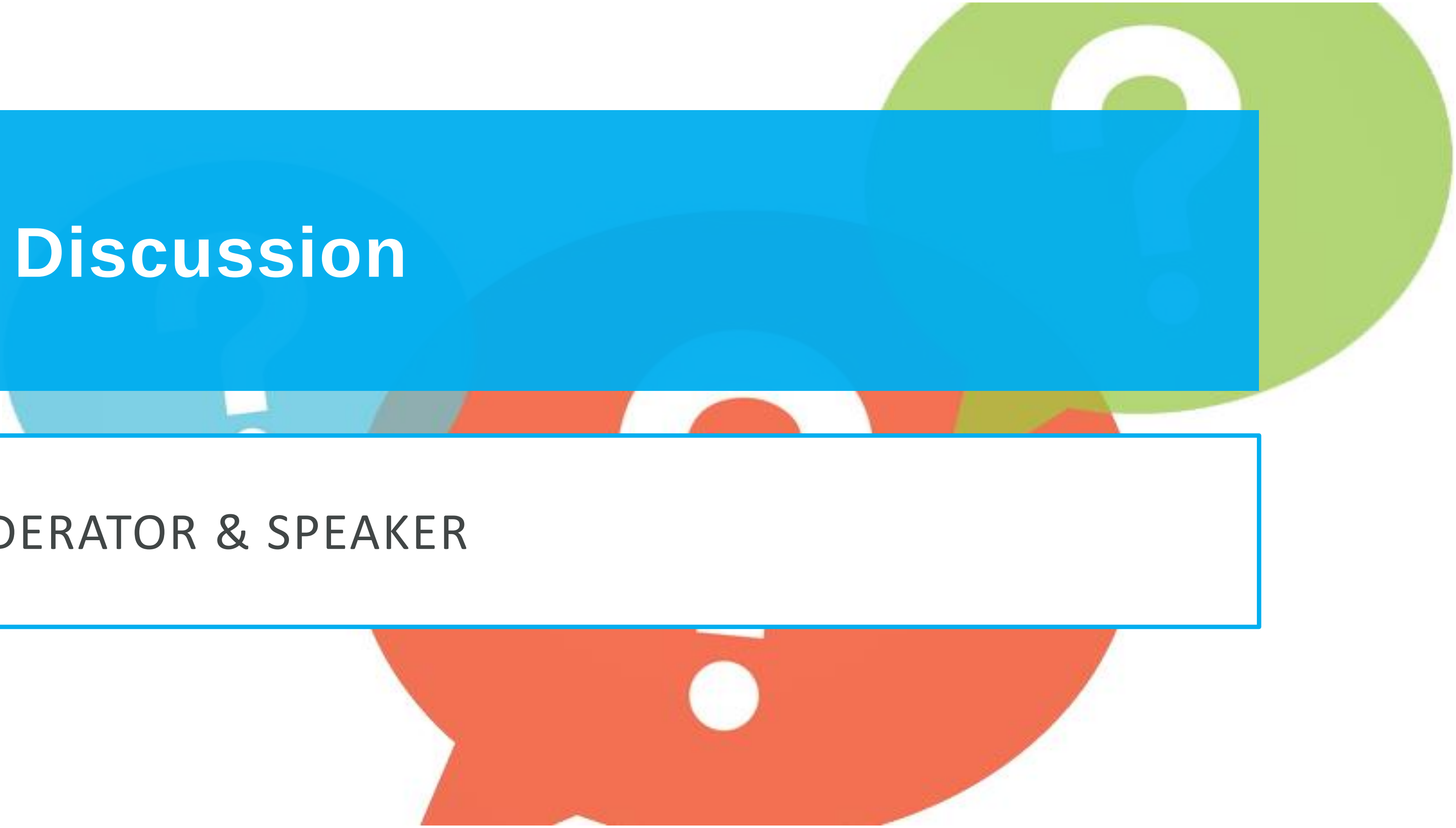
Please spread the word & get involved!

OMD
Open Membrane Database

Dr. Rhea Verbeke

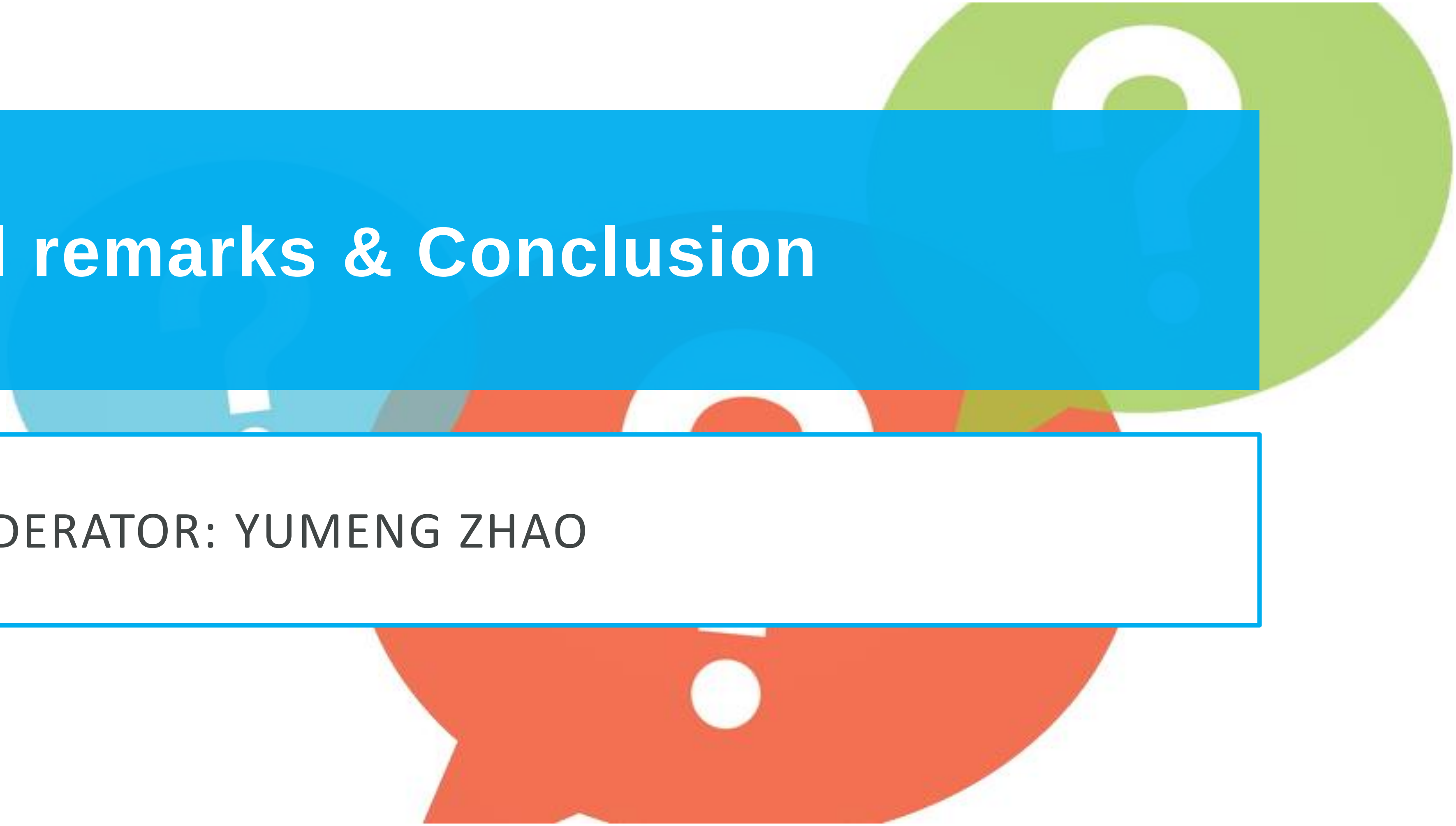
rhea.verbeke@kuleuven.be
info@openmembranedatabase.org

. codefathers



Q&A Discussion

MODERATOR & SPEAKER



Final remarks & Conclusion

MODERATOR: YUMENG ZHAO

UPCOMING WEBINARS

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