The Big Problem

In Situ Bioremediation Strategies to Destroy PFAS

Keith B. Rapp - PG, RG, CPG

Jonna Spanier - PE

Brendan McShane - CHMM

MGWA Conference
November 19, 2024

Problem

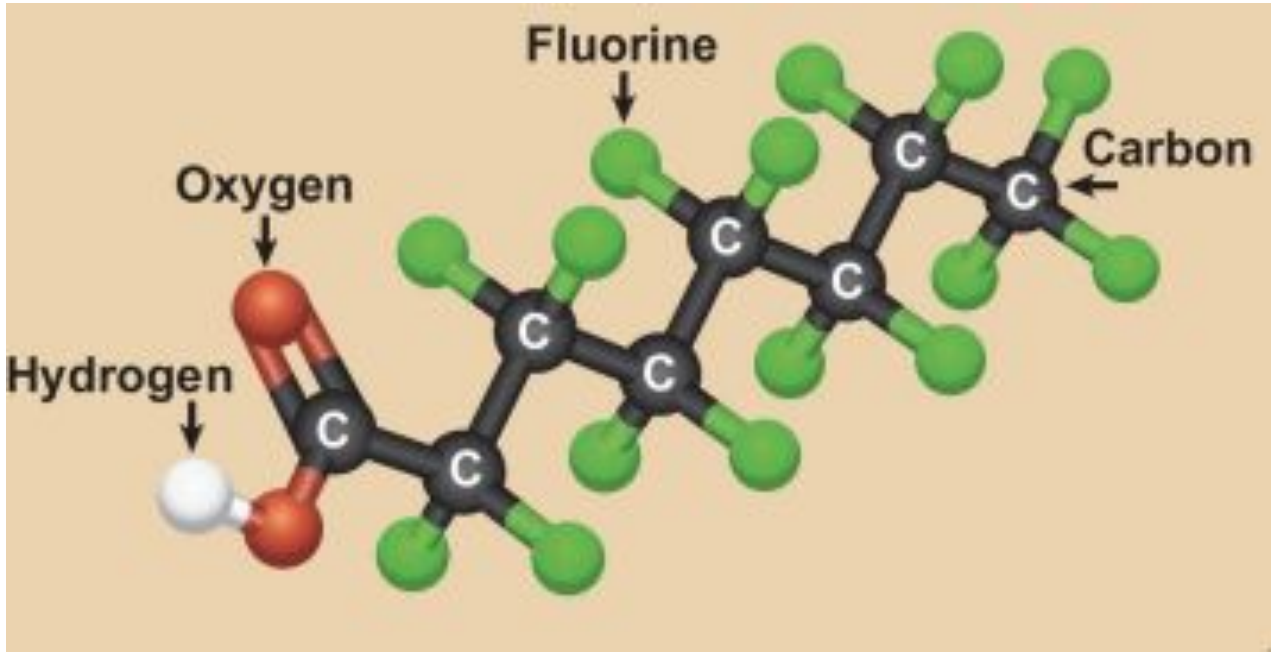
use, extent, exposure routes, persistence, limited remediation alternatives, foreverness

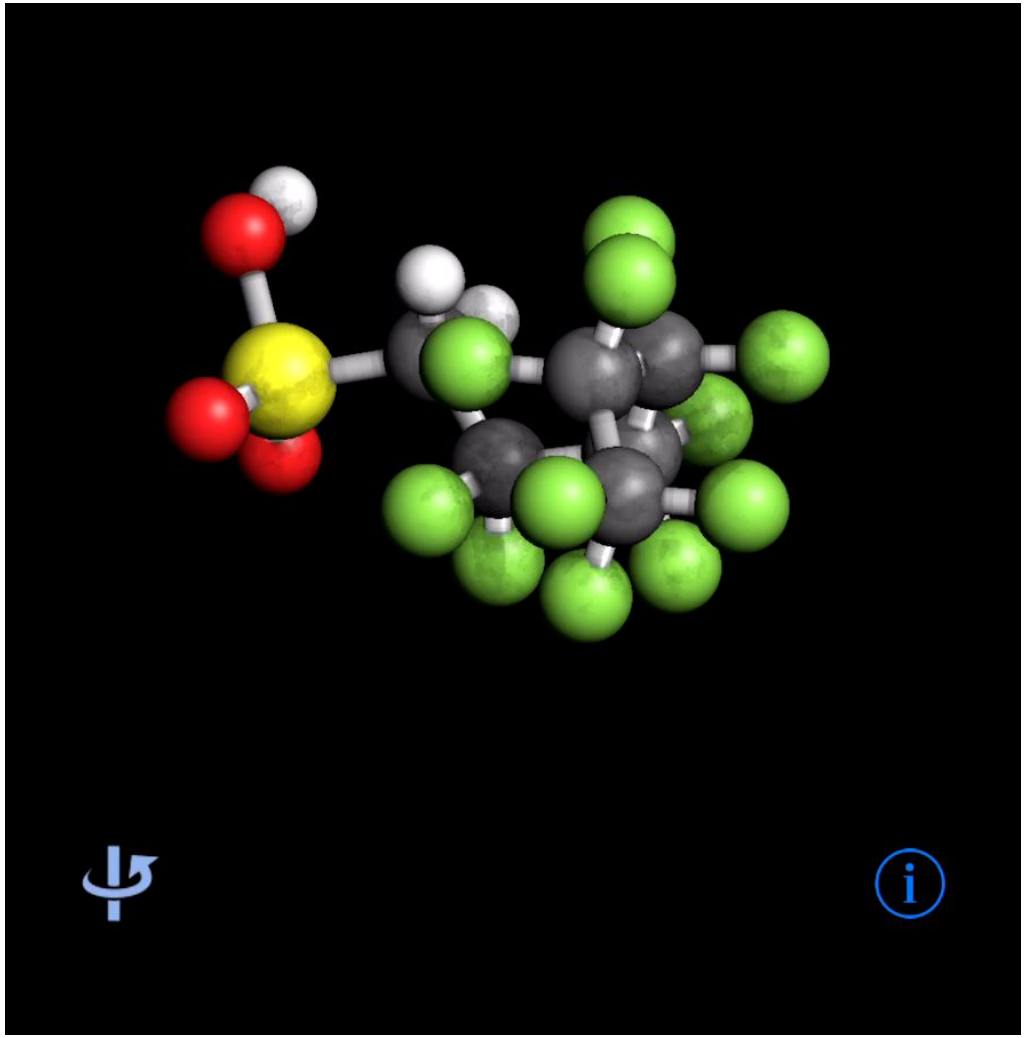
Questions

bioaccumulation, toxicity, remedial options, waste management, alternatives

PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)

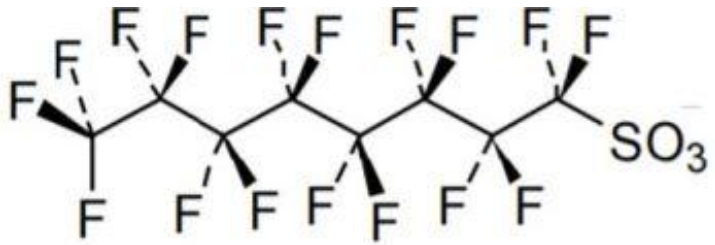
All PFAS contain a chain of carbon atoms bonded to fluorine atoms



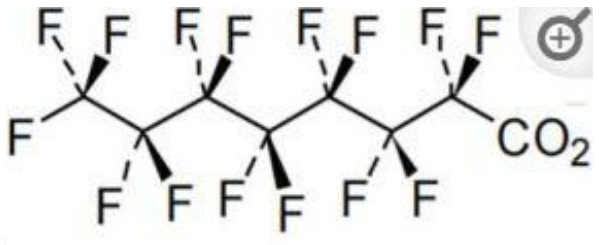


Structure of PFAS - (i) PFOS, (ii) PFOA, (iii) PFHxS

Perfluoroalkyl substances - short and long carbon chains (C_2-C_{13}^+), fluorine atoms attach to all bonding sites except for the last carbon group

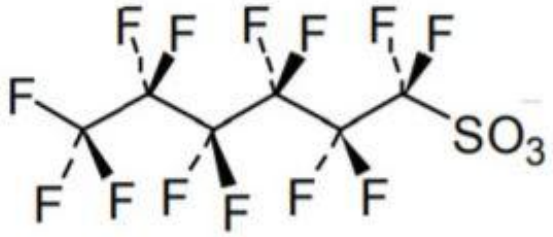


(i)



(ii)

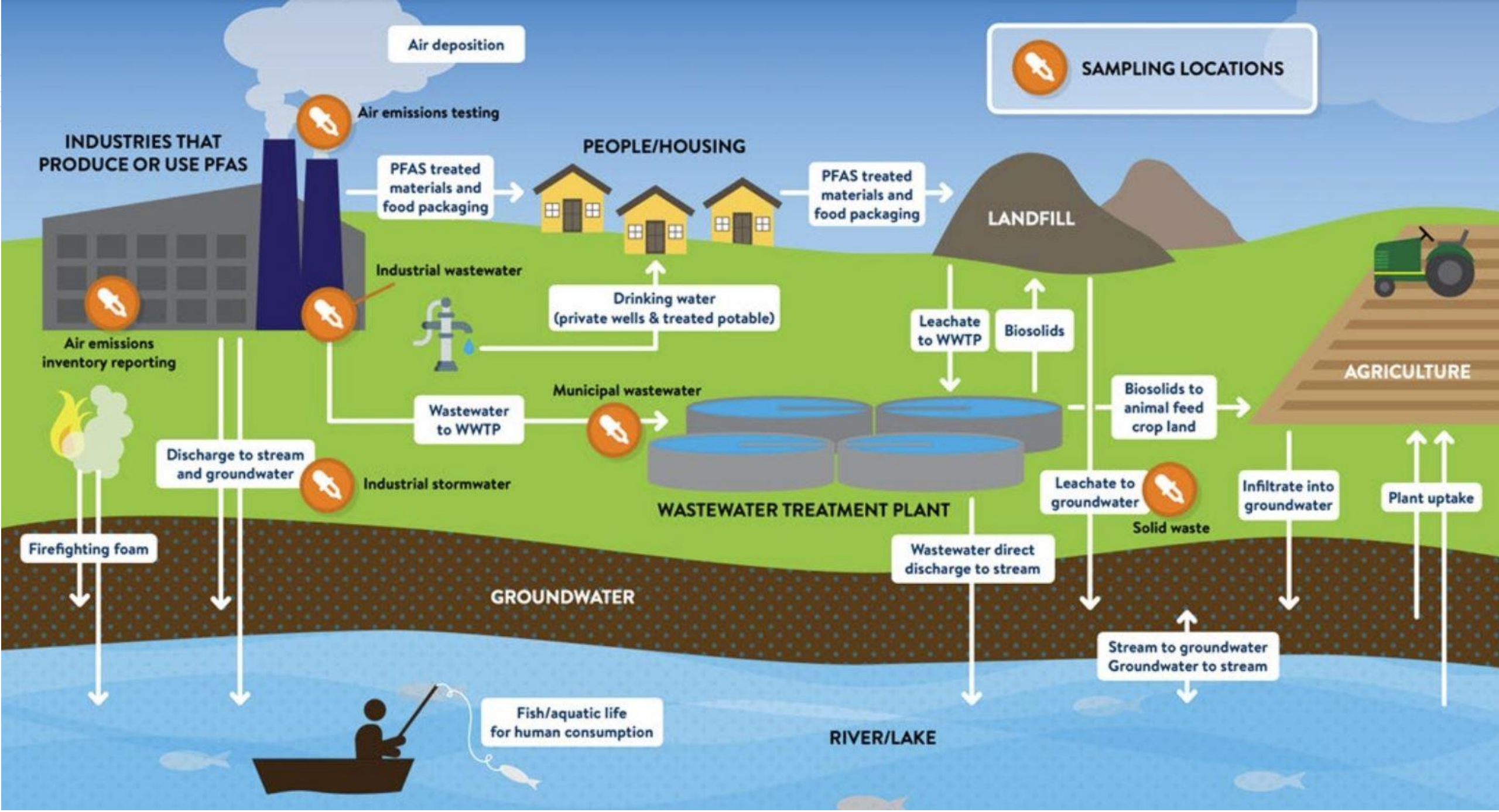
Polyfluoroalkyl substances are not fully fluorinated, and have at least one lapse in the chain not a fluorinated atom



(iii)

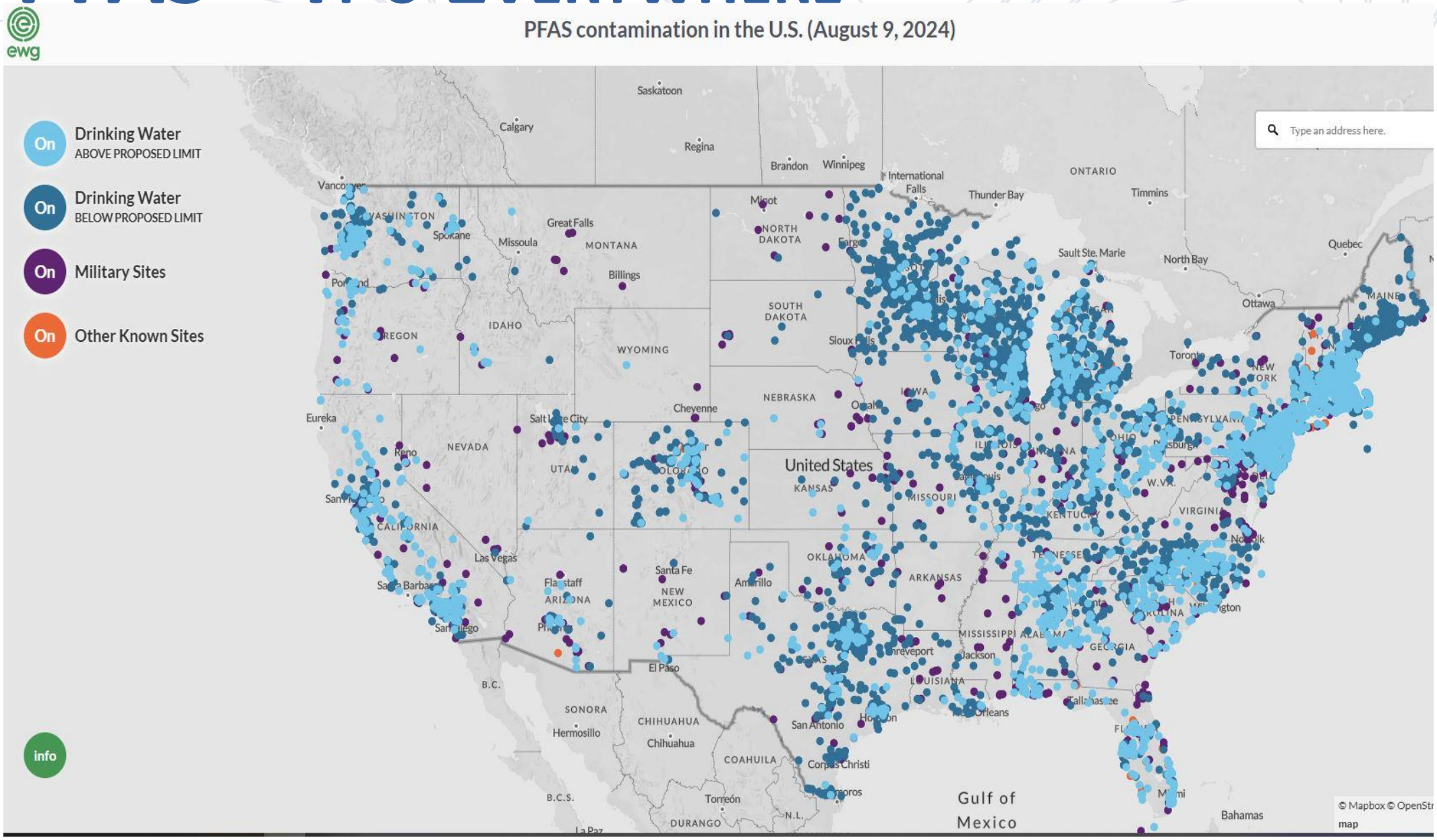
PFAS are a group of nearly 15,000 synthetic chemicals

(Buck et al. Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins. 2011.)



Source: *Minnesota Pollution Control Agency • PFAS Monitoring Plan: Initial findings and next steps*

PFAS – It's Everywhere



Environmental Working Group, 2024. https://www.ewg.org/interactive-maps/pfas_contamination/

HUBRIS

PFAS costs $50 - $1,000 per pound, but $2.7 - $18 million per pound to remove and destroy from environment

Removing and destroying PFAS from MN water and biosolids
$14 - $28 billion over 20 years

New “*short-chain*” PFAS are more difficult and up to 70% more expensive than old “*long-chain*” PFAS

Treatment Technologies v. Remediation Strategies

Treatment technologies exploit a contaminant's chemical and physical properties to immobilize, separate and concentrate, or destroy the contaminant. **Point source solution**

Remediation strategies holistically address the entirety of environmental conditions, exposures, environmental media and corrective action options to eliminate mechanisms and conditions in environmental contamination. **Field scale solution**

Treatment Technologies (Point Source)

Separation technologies

- Ion exchange resin
- Colloidal/granular activated carbon
- Nanofiltration
- Reverse osmosis
- Foam fractionation

Destructive technologies

- Electrochemical oxidation
- Plasma
- Photocatalysis
- Sonolysis
- Supercritical water oxidation
- Thermal degradation/incineration

Meegoda et al. A Review of PFAS Destruction Technologies. 2022.

Treatment Technologies (SAFF)

1. injects air into contaminated water, concentrating PFAS in foam

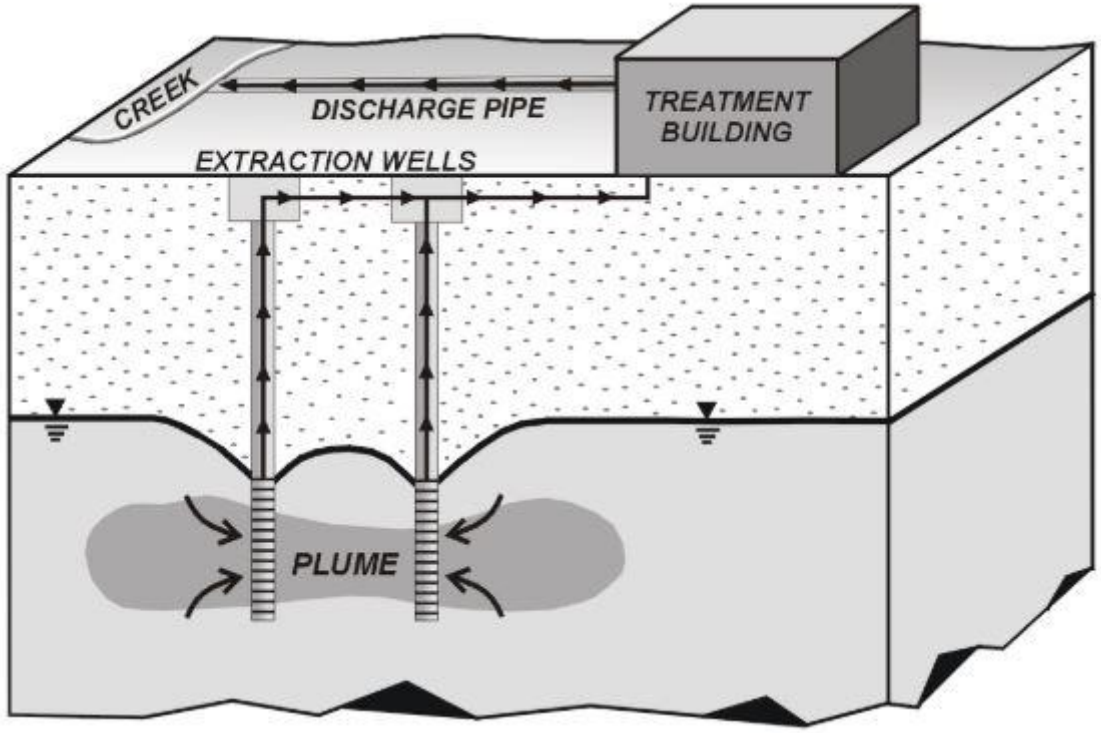
2. foam is removed

Minnesota is the first state government in U.S. to use this combination of innovative technologies to address "forever chemicals."

MPCA - 2022. https://www.pca.state.mn.us/news-and-stories/mpca-brings-cutting-edge-technology-to-minnesota-to-remove-pfas-from-water

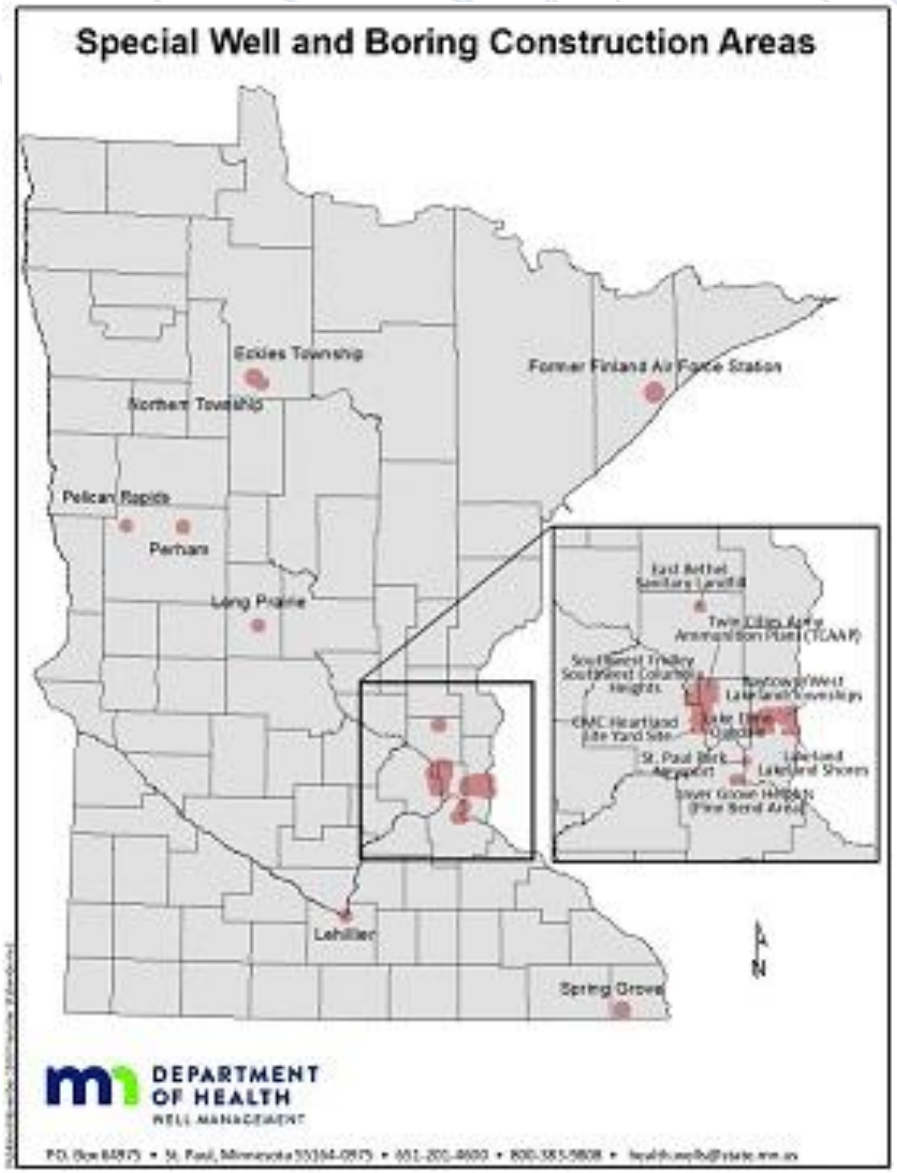
Remediation Strategies

?



Groundwater
pump & treat (P&T)

In Situ Sorption (sequestration)



A plume of PFAS chemicals under the east metro is moving. The state has a plan to stop it.

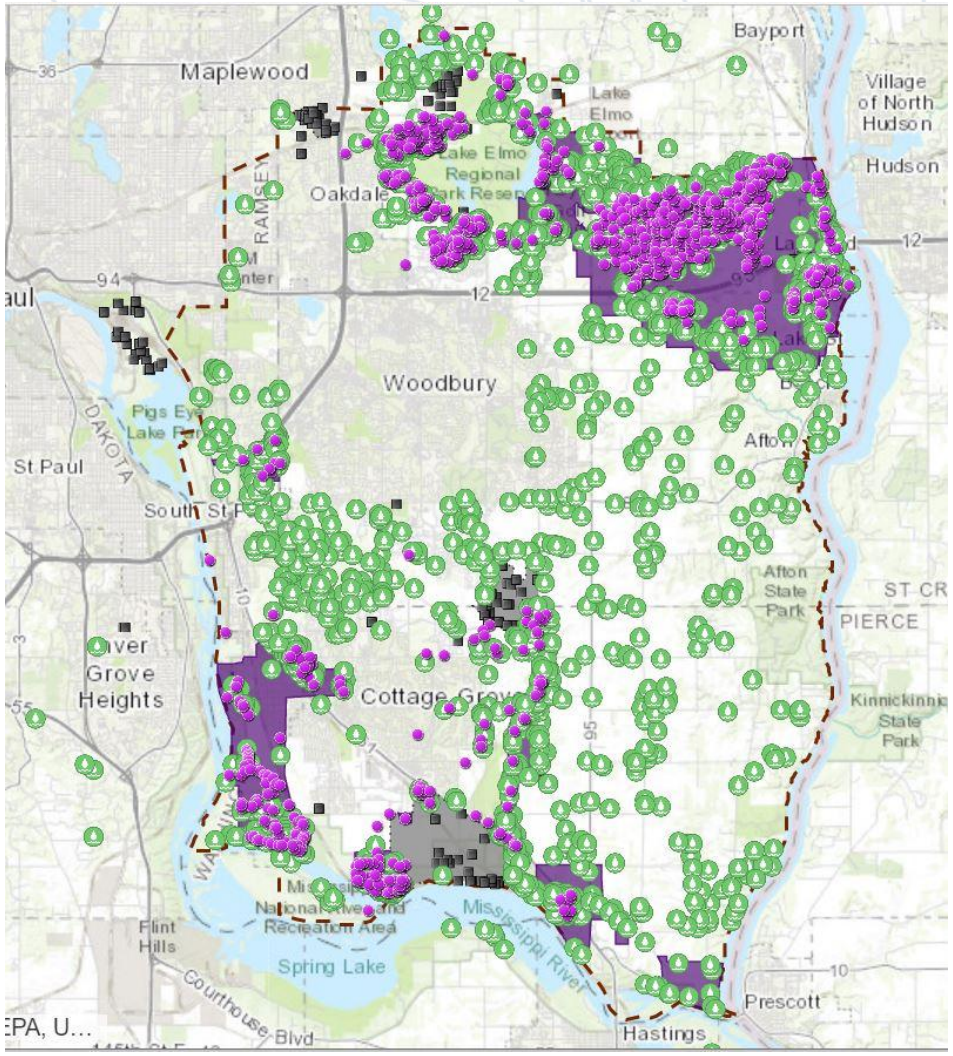
Preliminary plans would include a broad and complex system of wells to control the underground flow.

By Chloe Johnson Star Tribune | APRIL 19, 2024 — 6:00AM

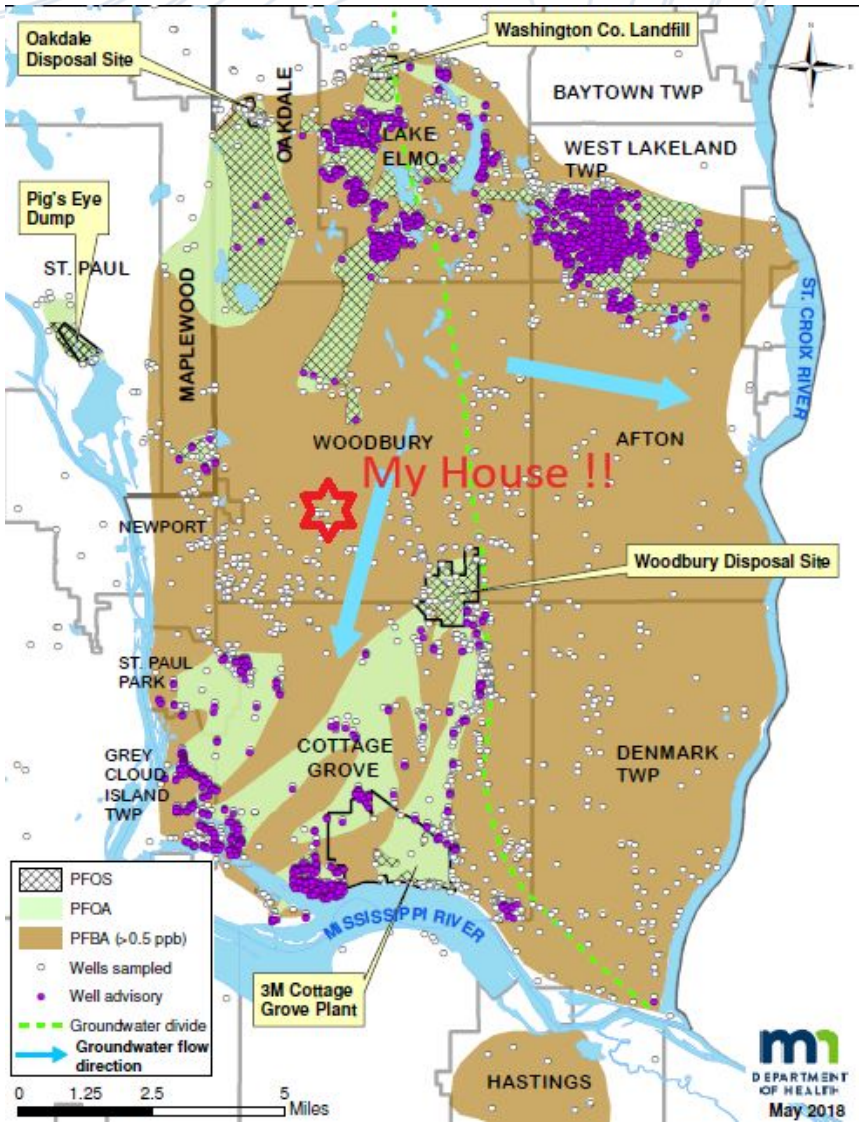
DAVID JOLES, STAR TRIBUNE

3M dumped PFAS sludge in the Washington County landfill for years. It's one of two sites that seeded underground chemical pollution that state officials now say is migrating.

S. Washington County, MN

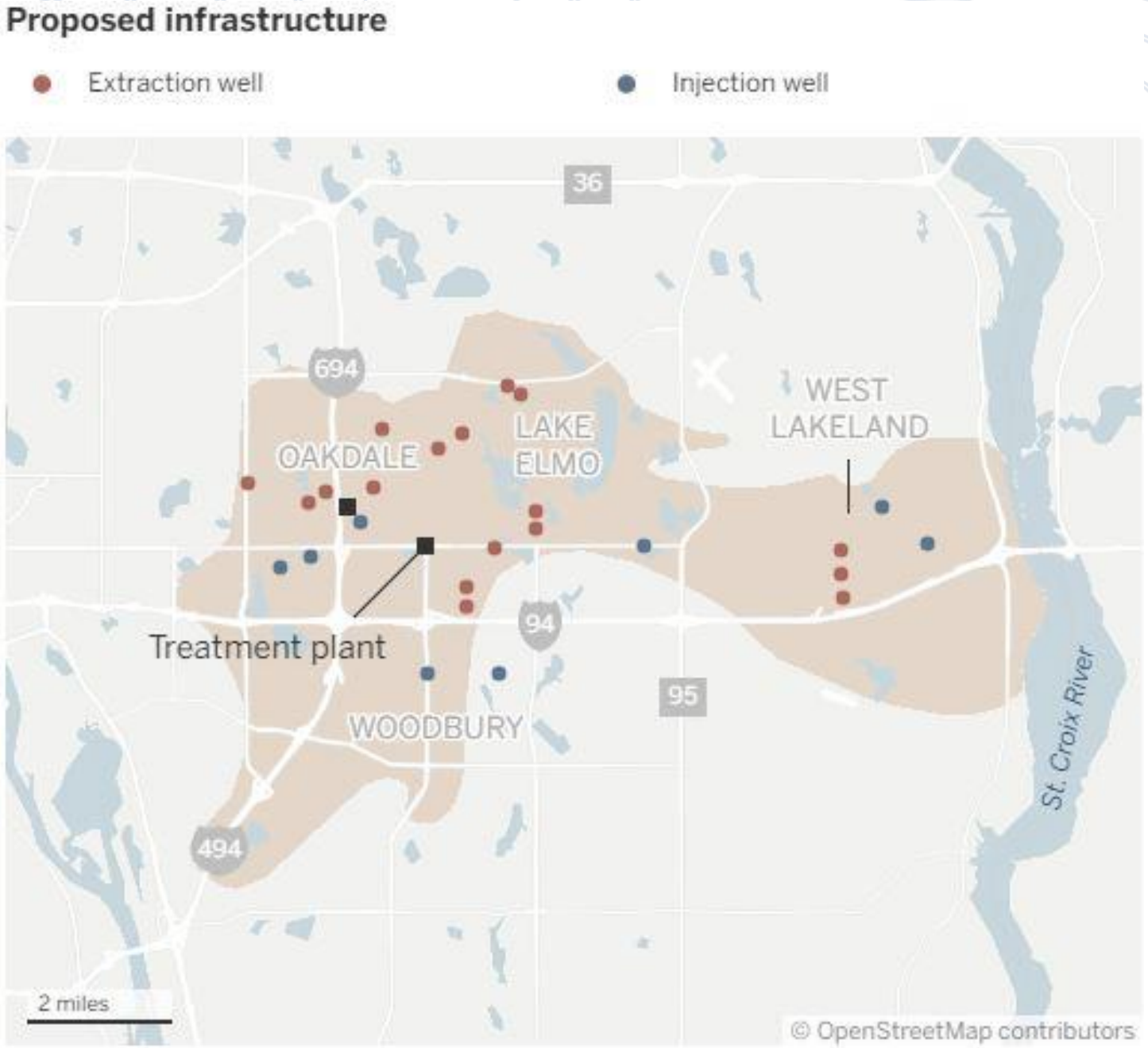


15 miles



MN Moat

Minnesota studying "*moat*" concept – network of extraction wells to pump PFAS-contaminated groundwater, treat it, and re-inject



Jake Steinberg, Star Tribune • Source: Minnesota Pollution Control Agency, AECOM

Economic Competition

"Pump & Treat is remediation in perpetuity"

(*Makay & Cherry, 1989*)

ELSEVIER

Science of The Total Environment

Volume 918, 25 March 2024, 170600

Editorial

Rethinking pump-and-treat remediation as maximizing contaminated groundwater

Kenneth C. Carroll [a], Mark L. Brusseau [b], Geoffrey R. Tick [c], Mohamad R. Soltanian [d]

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https://doi.org/10.1016/j.scitotenv.2024.170600

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Abstract

For over half a century, the United States has developed water quality regulations (e.g., Safe Drinking Water Act), which has been accompanied by innumerable advances in contaminant transport and fate, site characterization, and remediation. Since the "pump-and-treat" techniques have been the most

contamination remedi

The Fallacy of Pumping to Remove PFAS from Aquifers

Proven Advantage of In Situ Remediation

REGENE

ELSEVIER

Journal of Contaminant Hydrology

Volume 164, August 2014, Pages 16-24

Assessing contaminant-removal conditions and plume persistence through analysis of data from long-term pump-and-treat operations

Mark L. Brusseau, Zhilin Guo

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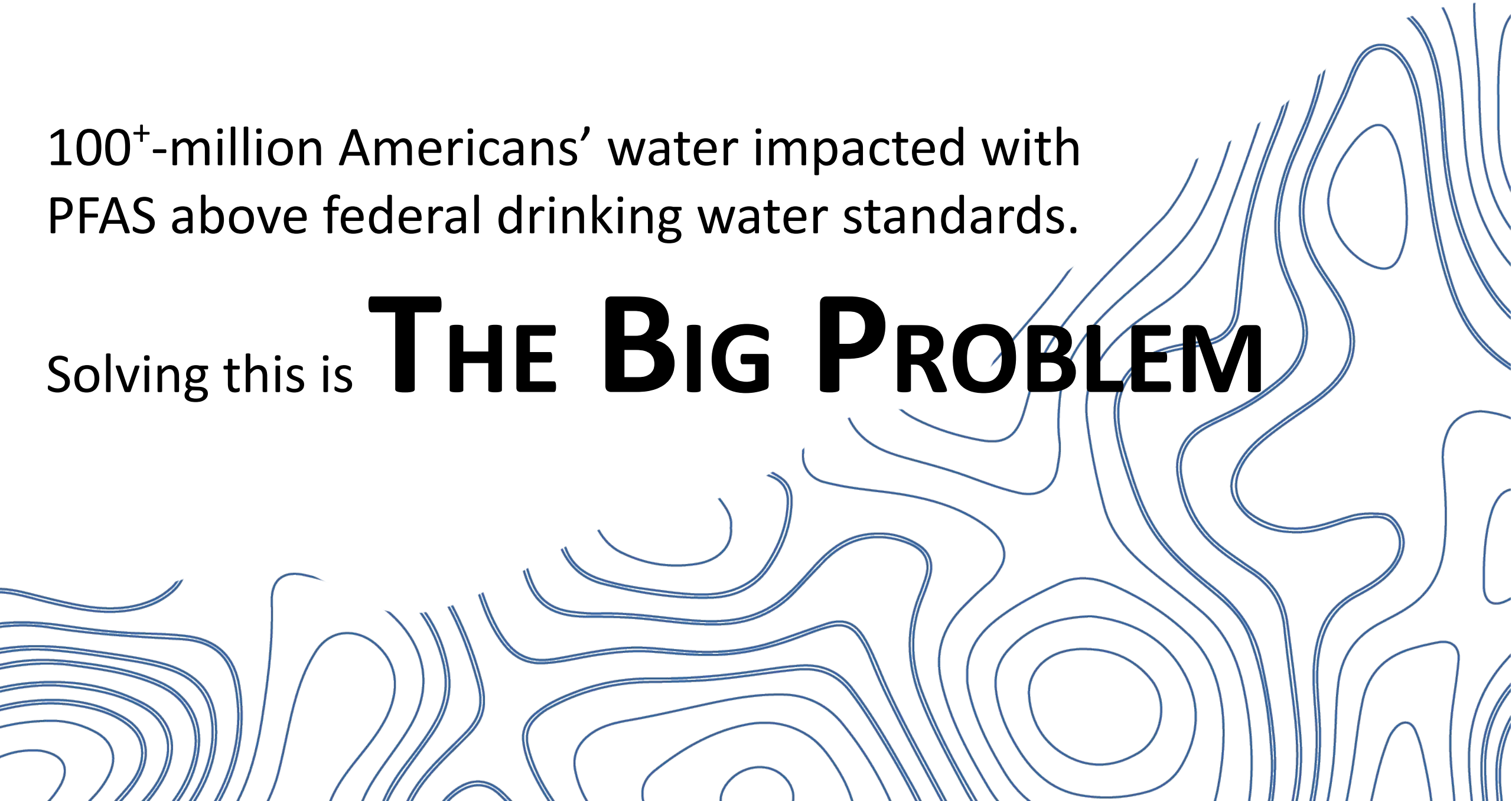
100^{+}-million Americans' water impacted with PFAS above federal drinking water standards.

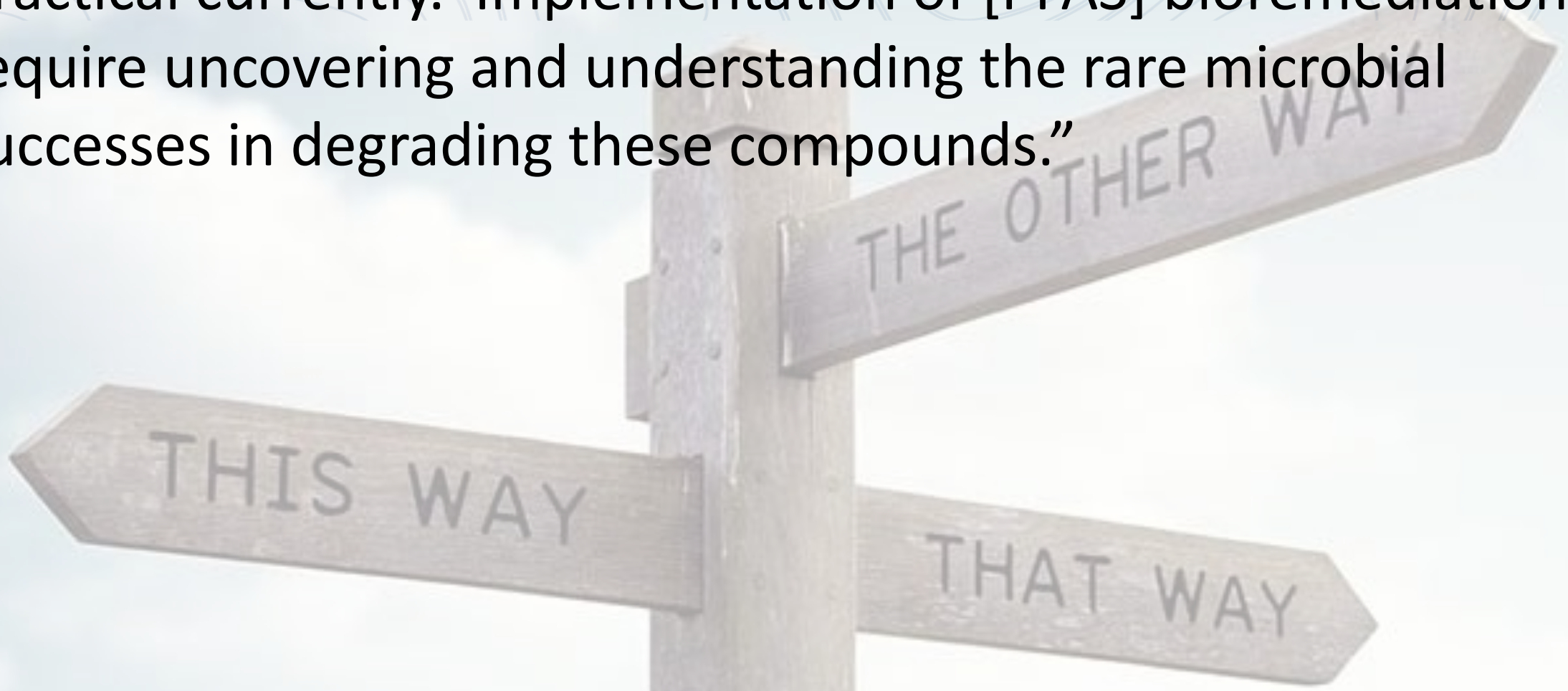
Solving this is **THE BIG PROBLEM**



BIOREMEDIATION

Use of naturally occurring or deliberately introduced microorganisms or other life forms to consume or breakdown environmental pollutants

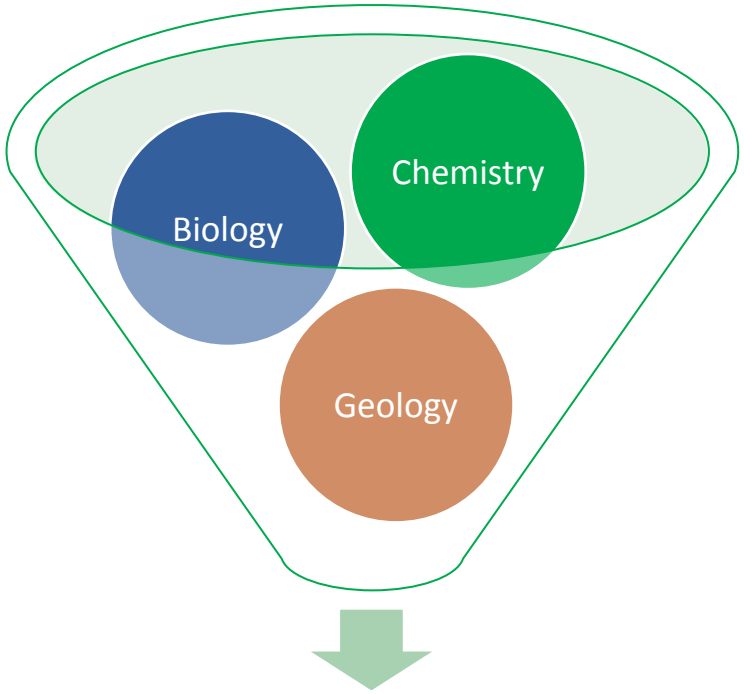
“Environmental cleanup by bioremediation is not considered practical currently. Implementation of [PFAS] bioremediation will require uncovering and understanding the rare microbial successes in degrading these compounds.”



*L.P. Wackett, et.al. – 2021. Microbial Biotechnology, 15, 773–792

HydroGeoMicroBioChemistry

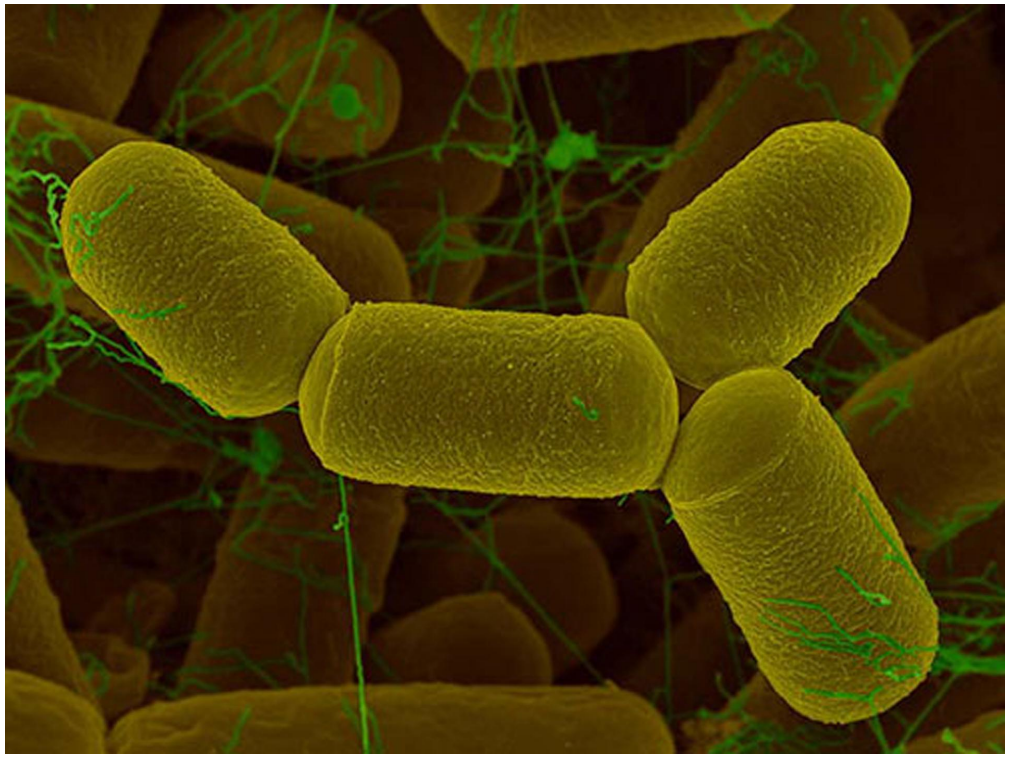
Interaction of chemistry, biology (micro), geology, soil, sediment, rock and groundwater contamination

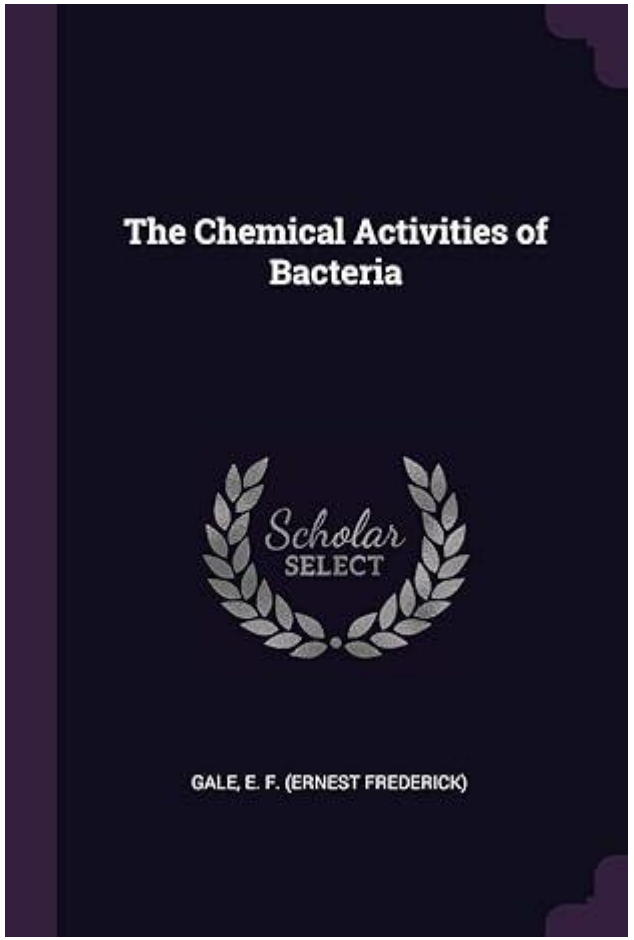


Bioremediation

Microbial Infallibility Hypothesis

"……if there is energy to be gained from a compound [contaminant], a microorganism will figure out how to extract it and create a niche for itself."





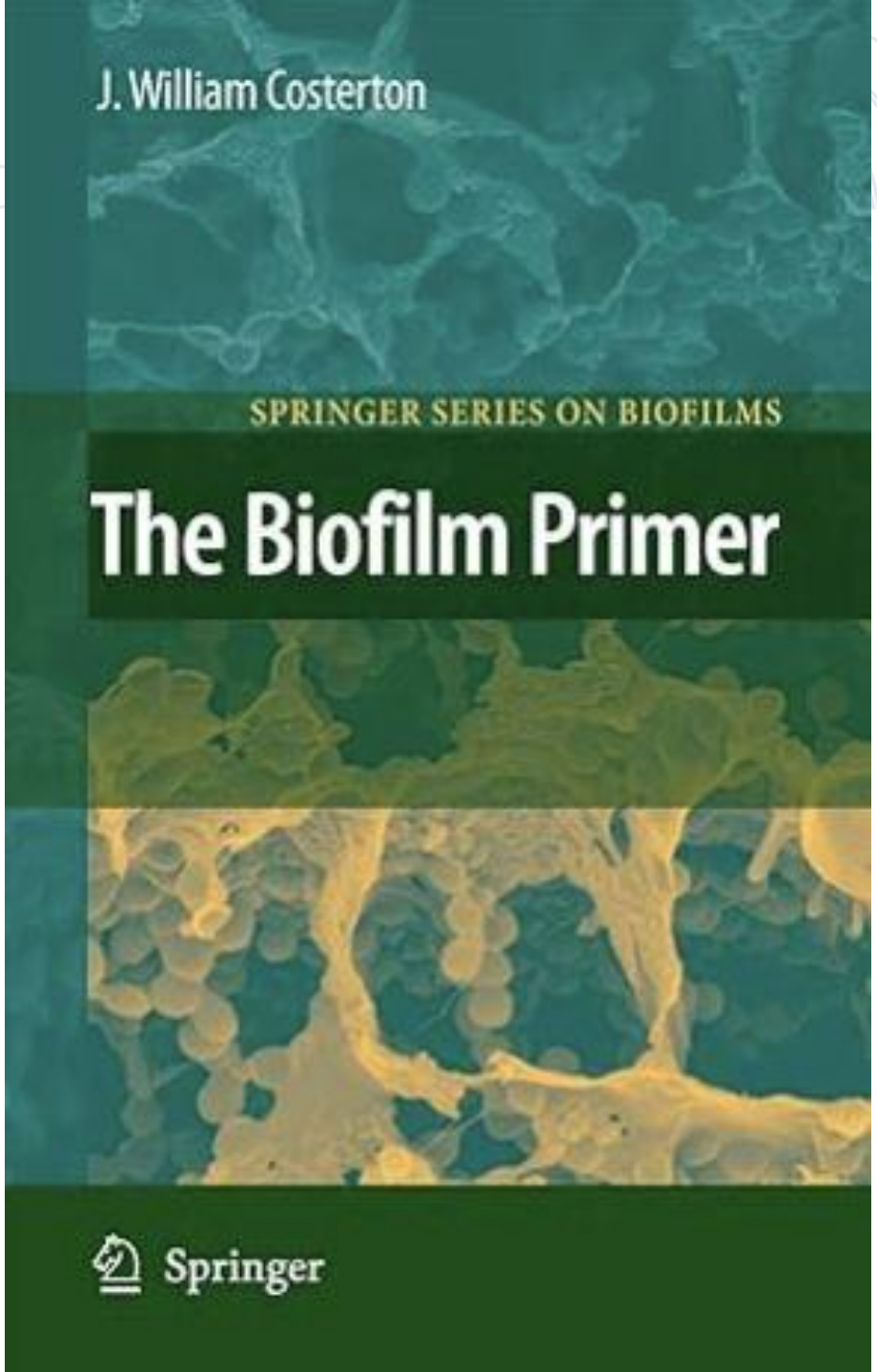
E.F. Gale, 1951 - *The Chemical Activities of Bacteria*

Biofilm Godfather

"Biofilms form in all environments with sufficient nutrients – worldwide"

Costerton (1995)

In nature, >80% of microbes exist within a biofilm

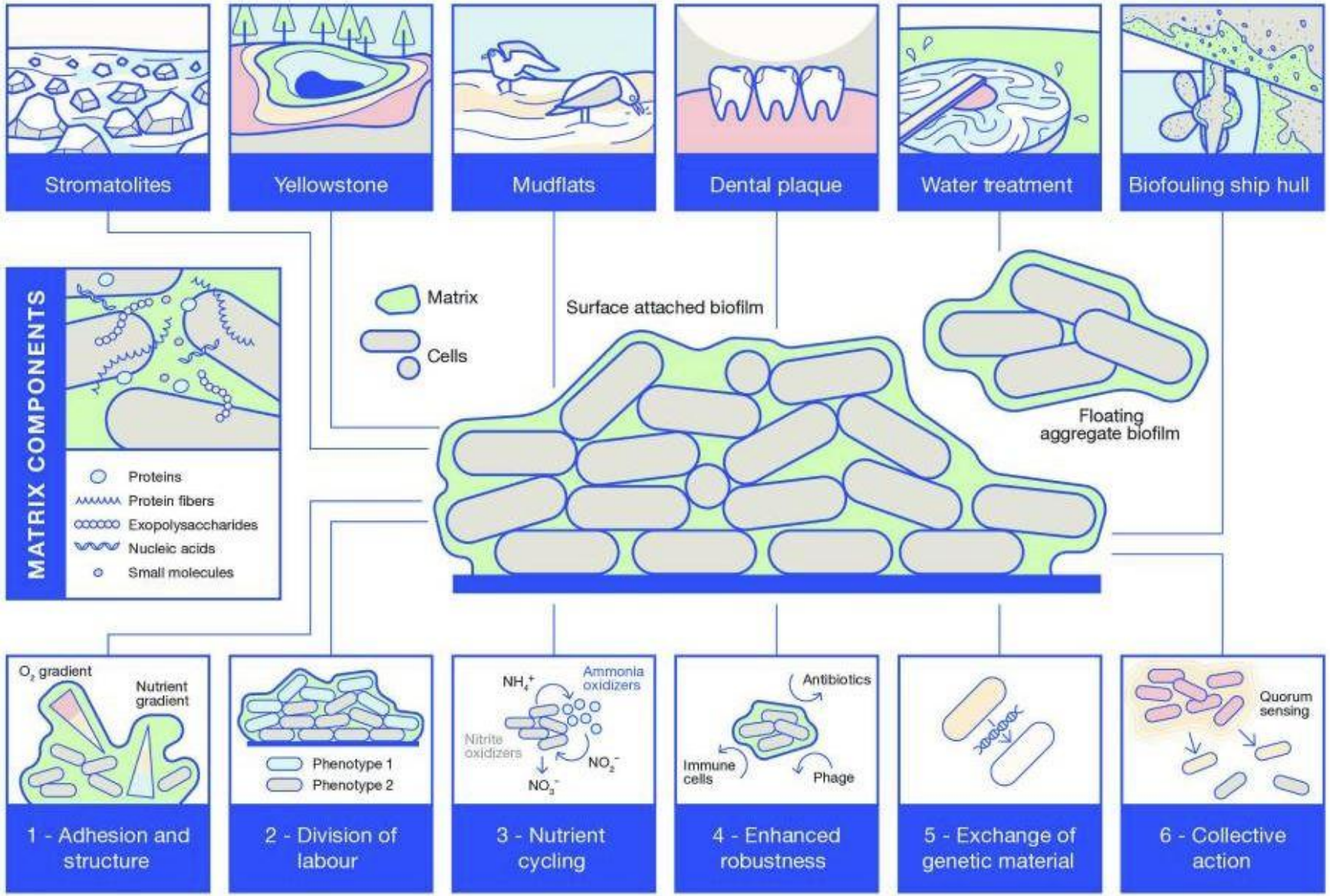


Known PFAS Biodegrading Microbes

Bacteria			
Acetobacterium sp.	*Desulfovibrio aminophilus*	*Sporomusa sphaeroides*	*Pseudomonas* sp.
Desulfovibrio aminophilus	*Sporomusa sphaeroides*	*Acidimicrobium* sp.	
Burkholderia sp.	*Thauera aromatica*	*Aliivibrio fischeri*	*Rhodopseudomonas*
Desulfococcus	*Bacillus* spp	*Rhodococcus jostii*	*Dehalobacter* sp.
Fungi			
Aspergillus niger (brown rot)	*Phanerochaete chrysosporium* (white rot)	*Phanerochaete chrysosporium*	
Archaea			
Thaumarchaeota	*Euryarchaeota*		

Biofilms execute Bioremediation

Biofilms in the World



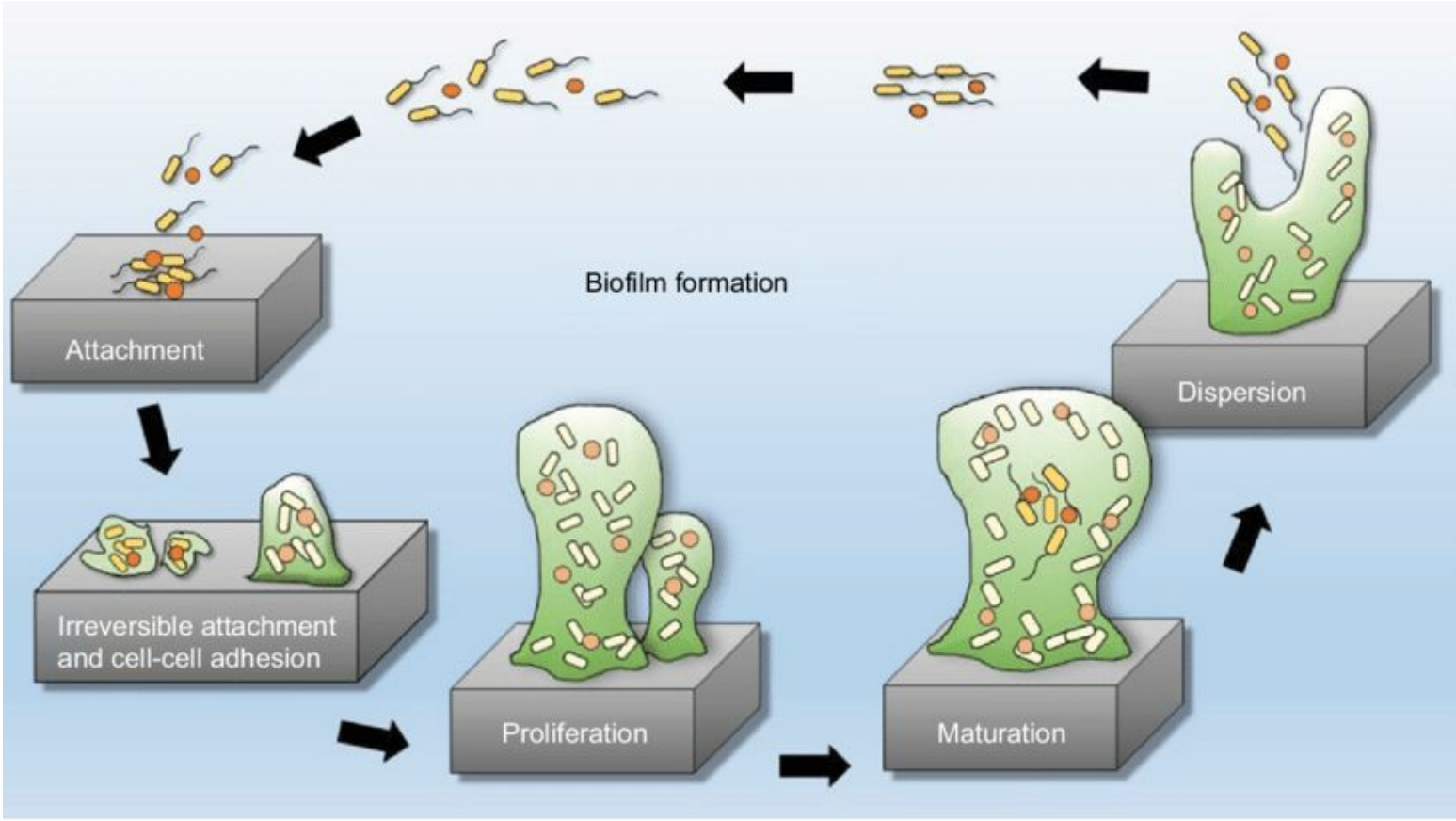
Bamford, NC, et.al., Microbial Primer: An introduction to biofilms – August 1, 2023

Biofilm Development

Biofilms form via cell-to-cell communication

Microbes form attachments to surfaces. Proteins signal nearby cells (quorum sensing)

Signaling recruits new cells, horizontal gene transfer, colony aggregates and forms a biofilm. Colony builds



Proteins signal development of exopolysaccharides (EPS), a protective layer, with channels for flow, energy transmission, and horizontal gene transfer. Biofilm matures

Biofilm Formation

Contaminant destruction occurs at surfaces – pore surfaces, fractures, boundaries.

Planktonic microbes are quickly removed, sessile microbes accomplish remediation

Volume 8, Number 9—September 2002

Perspective

Biofilms: Microbial Life on Surfaces

Rodney M. Donlan*

Author affiliation: *Centers for Disease Control and Prevention, Atlanta, Georgia, USA

Cite This Article

Abstract

Microorganisms attach to surfaces and develop biofilms. Biofilm-associated cells can be differentiated from their suspended counterparts by generation of an extracellular polymeric substance (EPS) matrix, reduced growth rates, and the up- and down- regulation of specific genes. Attachment is a complex process regulated by diverse characteristics of the growth medium, substratum, and cell surface. An established biofilm structure comprises microbial cells and EPS, has a defined architecture, and provides an optimal environment for the exchange of genetic material between cells. Cells may also communicate via quorum sensing, which may in turn affect biofilm processes such as detachment

BIOFILM COMMUNICATIONS

Biosensors and Bioelectronics 226 (2023) 115147

Contents lists available at ScienceDirect

Biosensors and Bioelectronics

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

Microbial nanowires with genetically modified peptide ligands to sustainably fabricate electronic sensing devices

Yassir Lekbach [a,1], Toshiyuki Ueki [a,1], Xiaomeng Liu [b], Trevor Woodard [a], Jun Yao [b,c,d], Derek R. Lovley [a,c,*]

[a] Department of Microbiology, University of Massachusetts, Amherst, MA, 01003, USA
[b] Department of Electrical and Comp ... University of Massachusetts, Amherst, MA, 01003, USA
[c] Institute for Applied Life Sciences (... Amherst, MA, 01003, USA
[d] Department of Biomedical Engine

ARTICLE INFO

> ChemSusChem. 2012 Jun;5(6):1039-46. doi: 10.1002/cssc.201100733. Epub 2012 May 21.

Microbial nanowires: a new paradigm for biological electron transfer and bioelectronics

Nikhil S Malvankar [1], Derek R Lovley

Affiliations + expand

PMID: 22614997 DOI: 10.1002/cssc.201100733

Abstract

The discovery that Geobac...

OPINION
published: 06 June 2022
doi: 10.3389/fmicb.2022.872610

...n the Existence of Pilin-Based ...Microbial Nanowires

Derek R. Lovley*

Department of Microbiology and Institute for Applied Life Sciences, University of Massachusetts, Amherst, MA, United States

Keywords: Geobacter, e-pili, extracellular electron transfer, electromicrobiology, protein, protein nanowires

...ODUCTION

...is a debate whether *Geobacter sulfurreducens* produces electrically conductive pili (e-pili) ...its pilin monomer, PilA, a protein encoded by gene GSU 1496. *G. sulfurreducens* assembly

Dr. Bonnie Bassler (YouTube - 18:11)
https://youtu.be/KXWurAmtf78?si=JLtbt3IzhO-yS63K

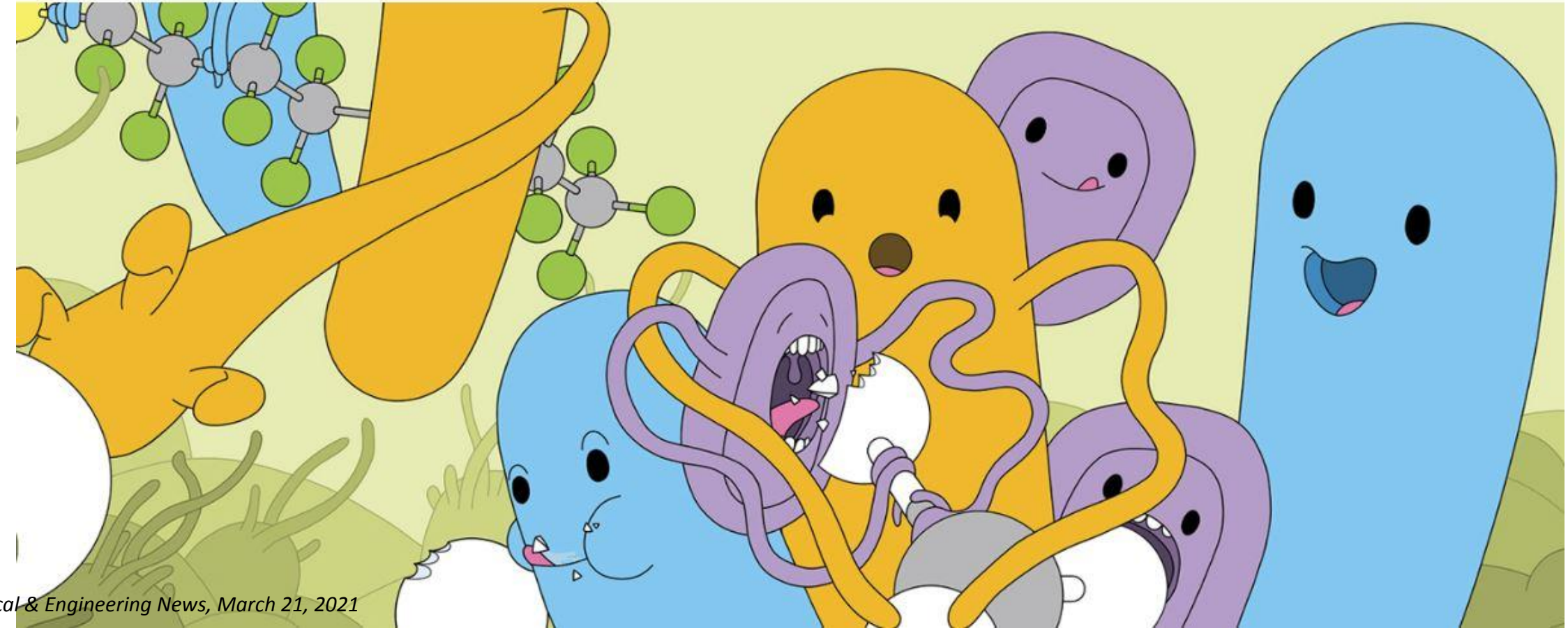
PERSISTENT POLLUTANTS

Can microbes save us from PFAS?

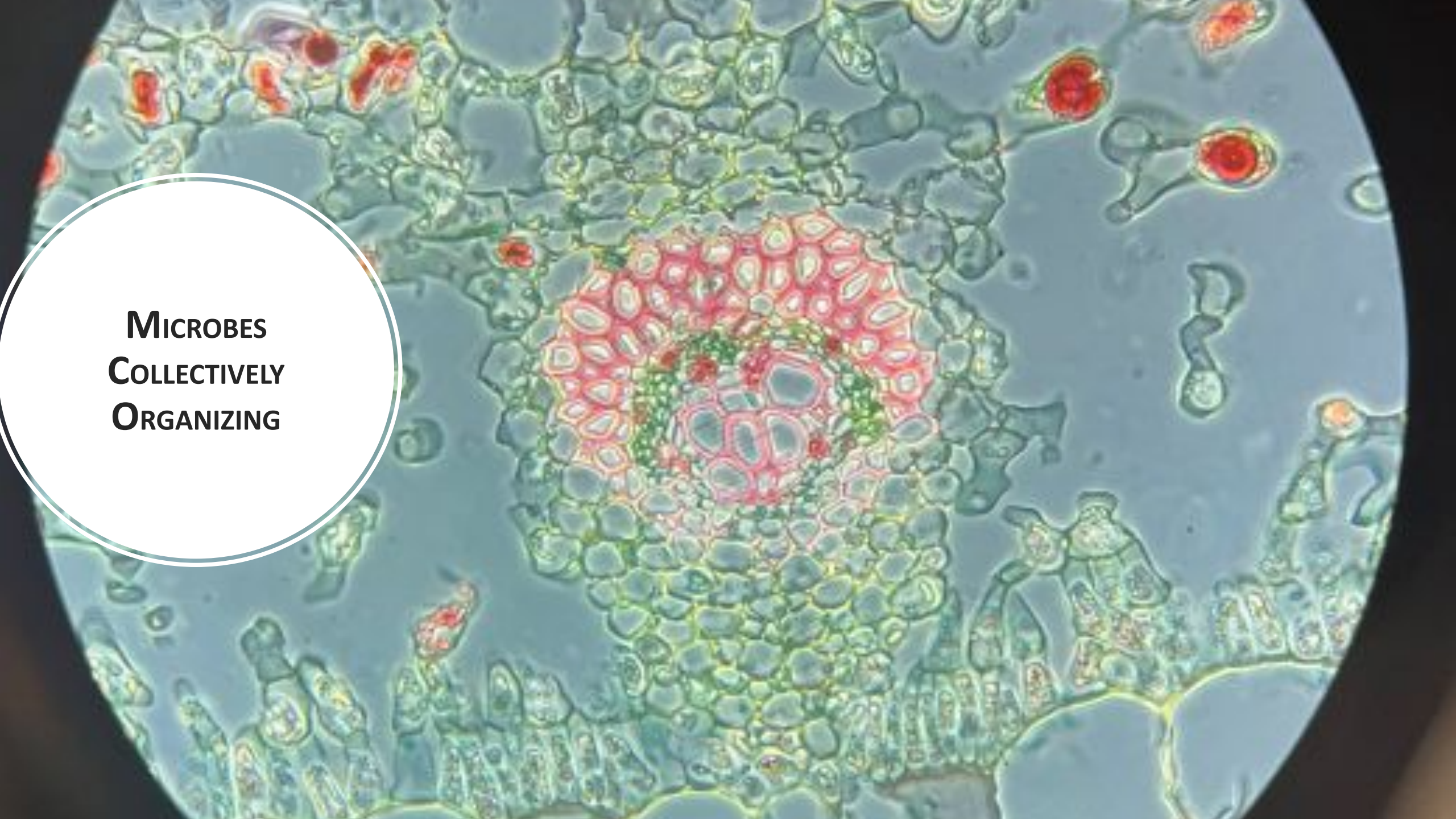
Researchers are investigating whether microbes can help break down fluorinated contaminants

by ***XiaoZhi Lim, special to C&EN***

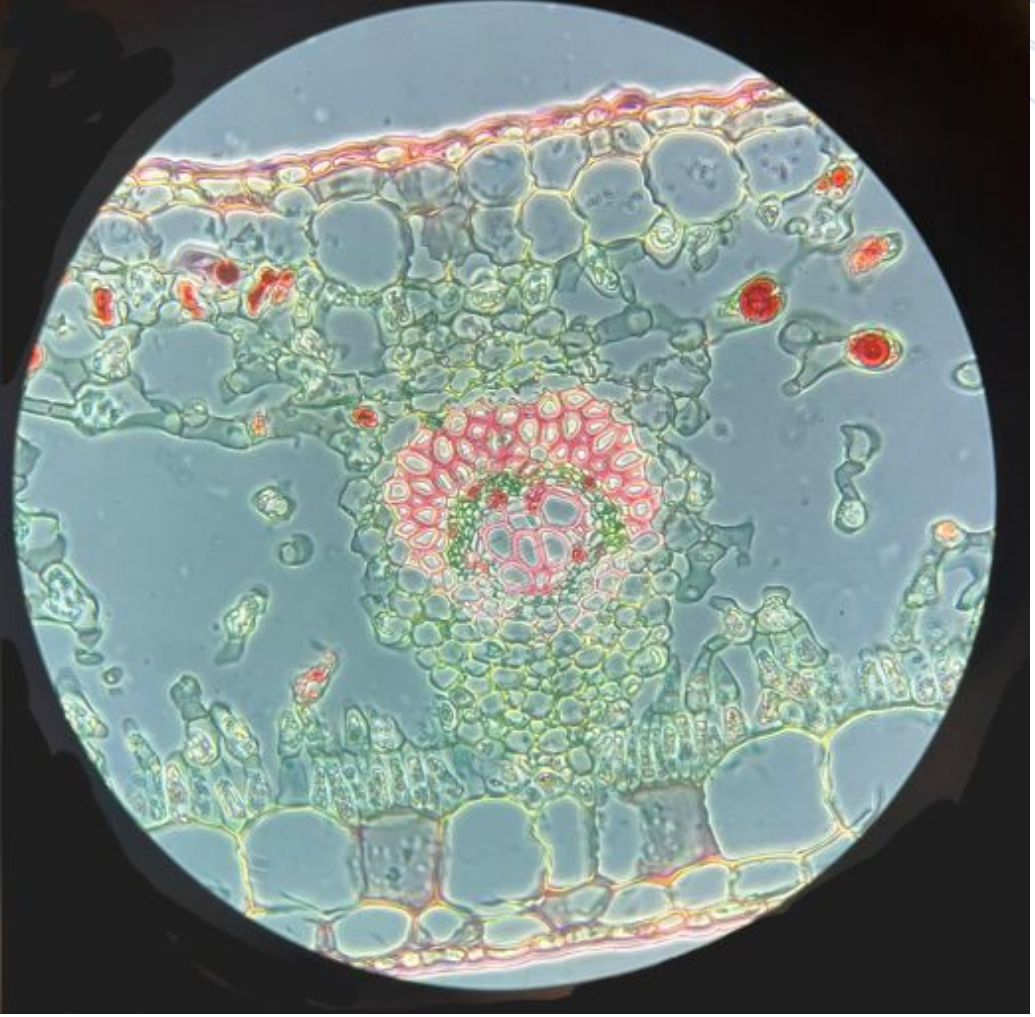
March 21, 2021 | A version of this story appeared in **Volume 99, Issue 10**



Chemical & Engineering News, March 21, 2021


MICROBES
COLLECTIVELY
ORGANIZING

Biofilm Formation



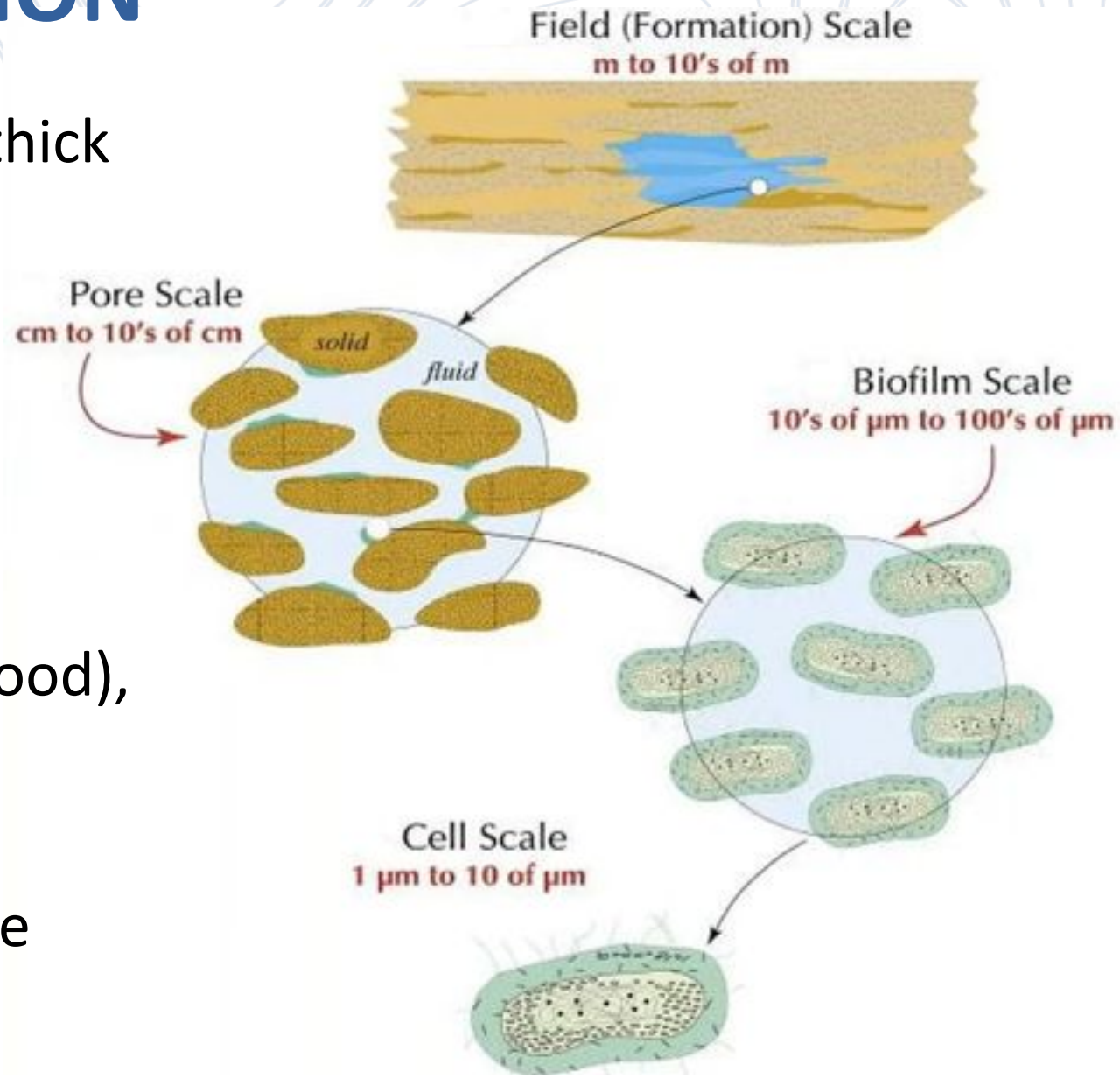
- Microbes collectively organizing

Scale & Composition

- Biofilms ~97% water, ~10 to 100 µm thick
- EPS layer ~0.2 to 1.0 µm
- EPS 65–95%, microbes 5-35%

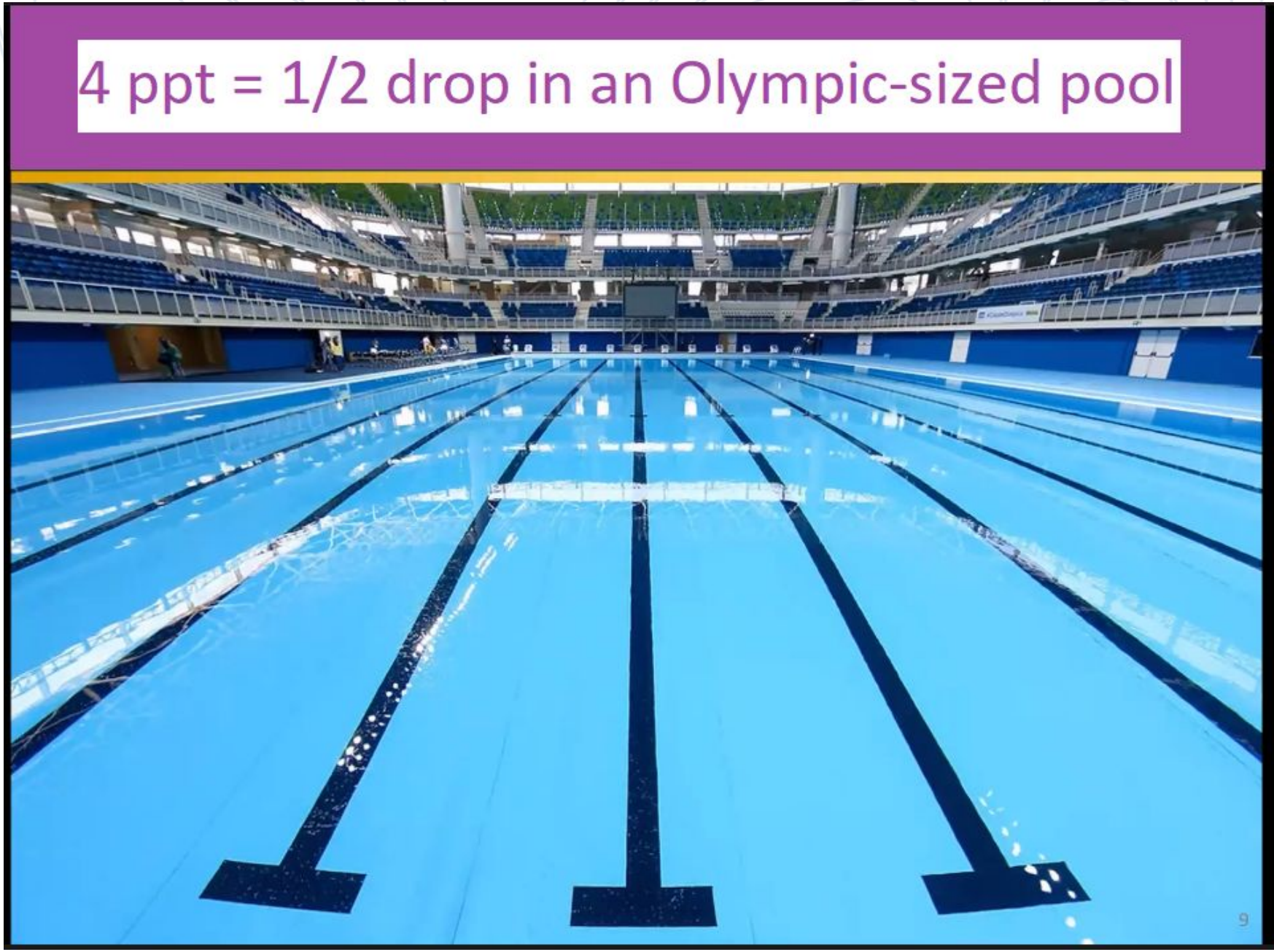
EPS composition determined by environment, growth circumstances, microbial strains (DNA-in-the-neighborhood), and nutrient supply

Lack of nutrients = biofilm cells disengage from surfaces



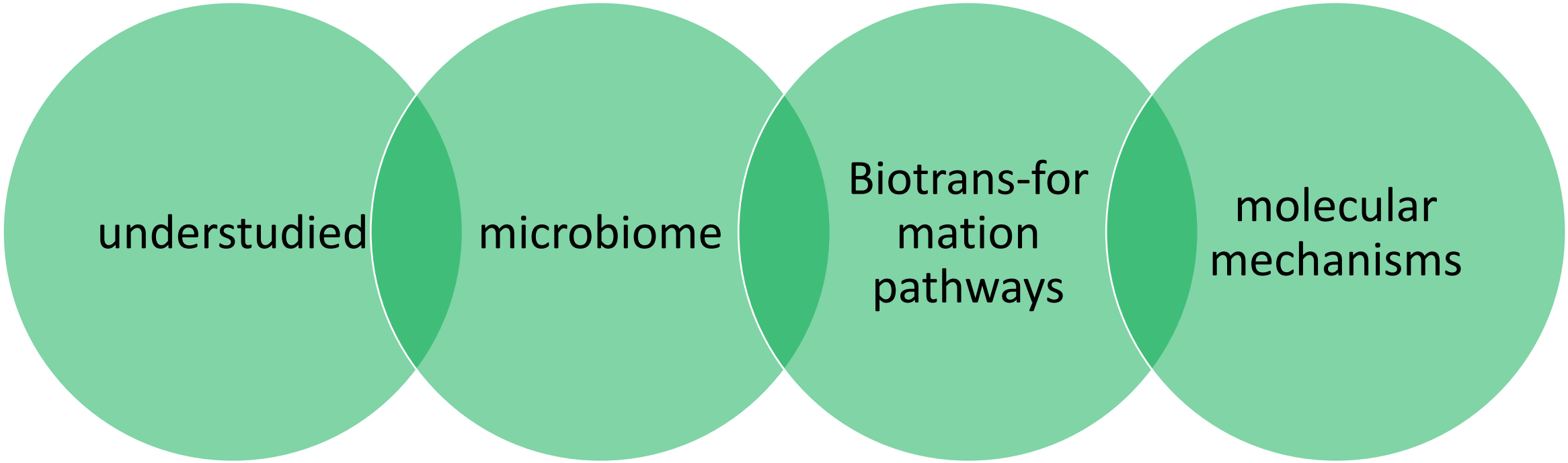
Scale

PFOA/PFOS standard is 1,000x more dilute than an equivalent TCE plume



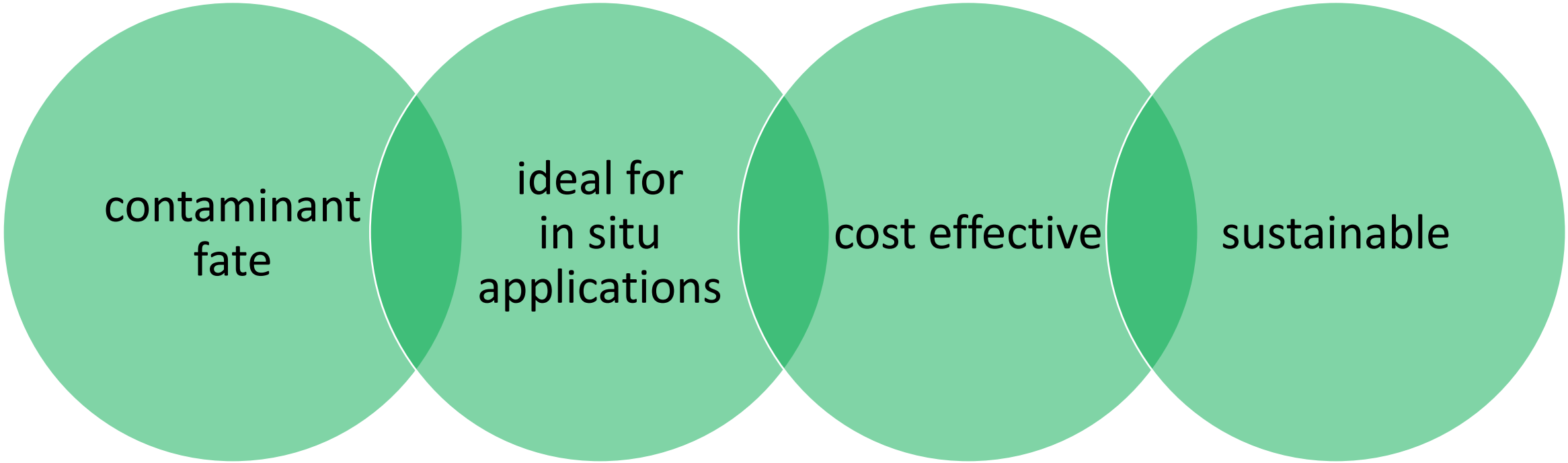
In Situ PFAS Biodegradation

UNKNOWNS



In Situ PFAS Biodegradation

BENEFITS



microbial biotechnology

Open Access

Minireview

Nothing lasts forever: understanding microbial biodegradation of polyfluorinated compounds and perfluorinated alkyl substances

Lawrence P. Wackett*
Department of Biochemistry, Molecular Biology and Biophysics, University of Minnesota, St. Paul, MN 55108, USA.

Summary

...rfluorinated chemicals, including per-...ces (PFAS), are pervasive ...act on human

Introduction

Greater than 9000 heavily f...
been synthesized f...
2021). The ...
has becon...
fluorinated ...
elements oth...
polyfluorinate...
pounds, both ...
perfluorinated ...
...ated alkyl gro...

Environmental Science Advances

TUTORIAL REVIEW

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this: Environ. Sci.: Adv., 2023, 2,

Bacterial transformation of per- and polyfluoroalkyl substances: a review for the field of bioremediation

Jessica A. LaFond, [a] Paul B. Hatzinger, [b] Jennifer L. Guelfo, [a] Kayleigh Millerick [a] and W. Andrew Jackson*[a]

Per- and polyfluoroalkyl substances (PFAS) have received gro...
potential risk and widespread extent of contam...
currently being developed to ...
where extensive ...

ROYAL SOCIETY OF CHEMISTRY

microorganisms

MDPI

Review

Strategies for the Biodegradation of Polyfluorinated Compounds

Lawrence P. Wackett

Department of Biochemistry, Molecular Biology and Biophysics and BioTechnology Institute, University of Minnesota, Minneapolis, MN 55455, USA; wacke003@umn.edu

Abstract: Many cite the strength of C–F bonds for the poor microbial biodegradability of po...
orinated organic compounds (PFCs). However, commercial PFCs almost invariably contain...
functionality than fluorine. The additional functionality provides a weak entry point for reacti...
activate C–F bonds and lead to their eventual cleavage. This metabolic activation strategy is ...
in microbial biodegradation pathways and is observed with aromatic hydrocarbons, ch...
compounds, phosphonates and many other compounds. Initial metabolic activation prece...
bond breakage and assimilation of nutrients. A similar strategy with commercial PFCs ...
initial attack at the non-fluorinated functionalities: sulfonates, carboxylates, chlorines, ...
or phosphonates. Metabolic transformation of these non-fluorinated groups can ac...
bonds, allowing more facile cleavage than a direct attack on the C–F bonds. Given t...

Biofilm Mediated PFAS Destruction in Groundwater

LCCMR Meeting -- June 26, 2024

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MN Environment and Natural Resources Trust Fund 116

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ENVIRONMENT AND NATURAL RESOURCES TRUST FUND ¶

Environment·and·Natural·Resources·Trust·Fund¶

2025·Request·for·Proposal¶

▪ General·Information¶

Proposal·ID:·2025-258¶

Proposal·Title:·Biofilm·Mediated·Destruction·of·PFAS·in·Groundwater¶

¶

▪ Project·Manager·Information¶

Name:·Keith·Rapp¶

Organization:·Bay·West·LLC¶

Office·Telephone:·(651)·291-3415¶

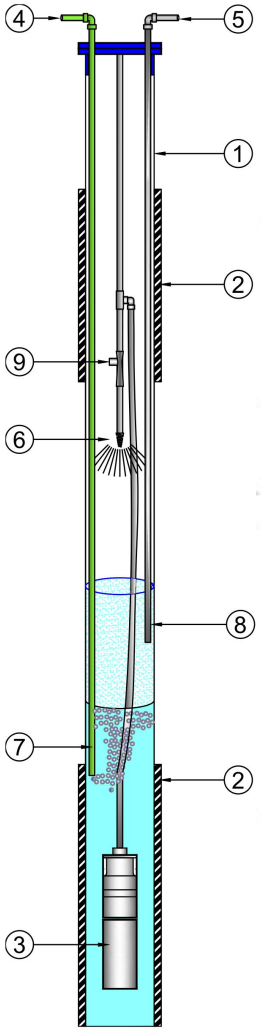
Email:·krapp@baywest.com¶

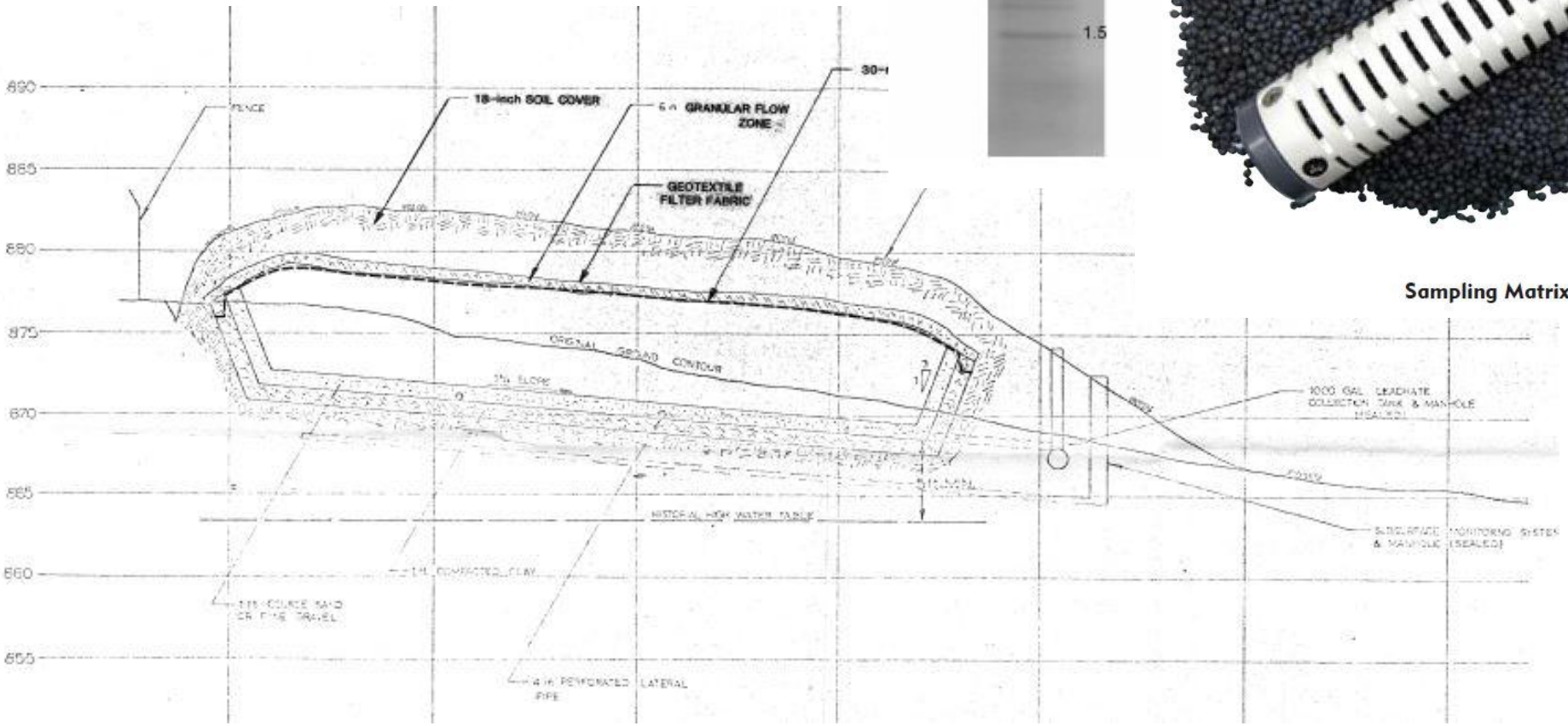
¶

▪ Project·Basic·Information¶

Project·Summary:·Microbes·control·the·attenuation·and·destruction·of·environmental·contaminants.··Biofiln

Microbe Sourcing



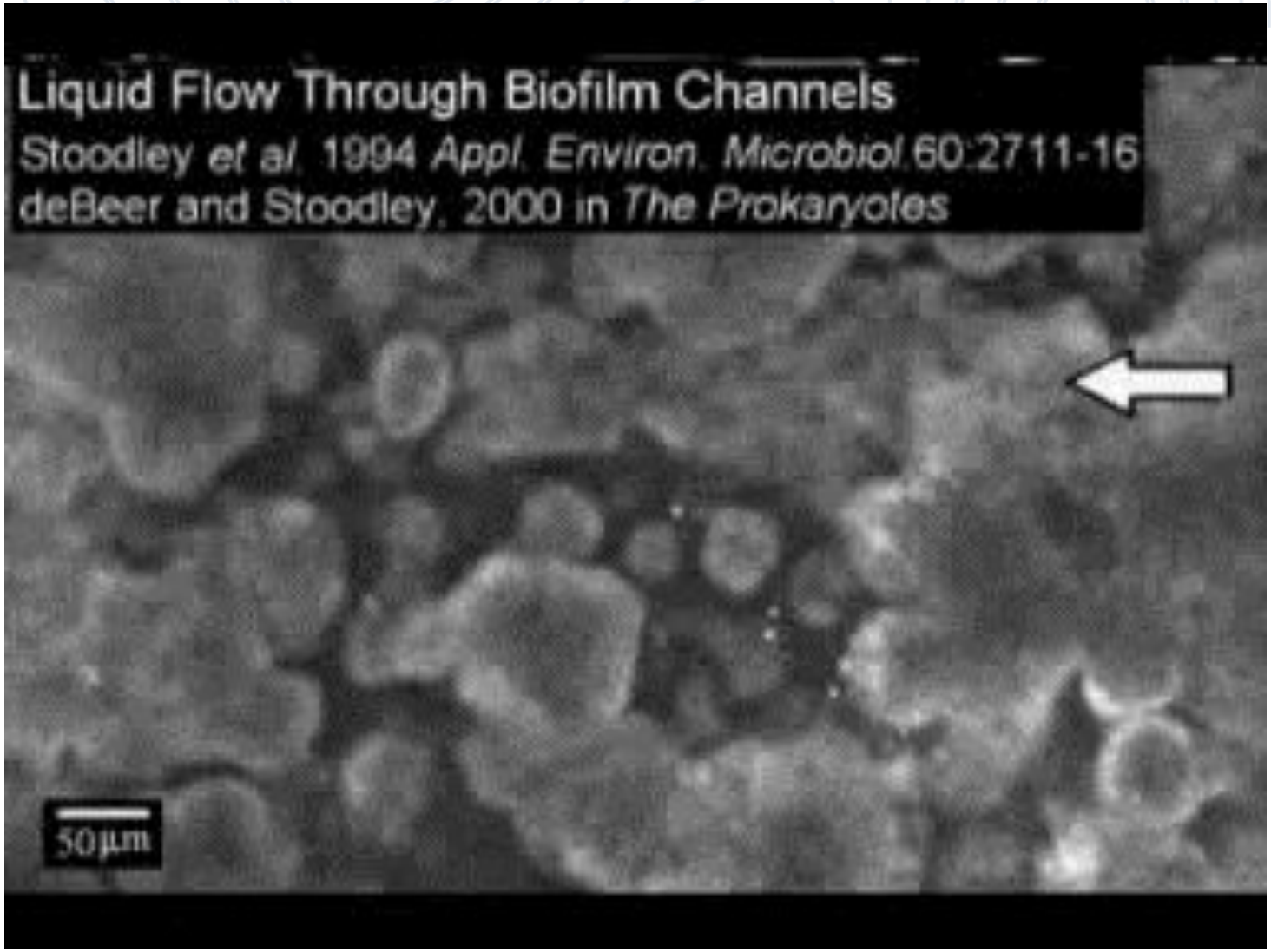


Sampling Matrix: Bio-Sep® Beads

Accelerated Remediation Technologies, Inc. - https://www.artinwell.com/about.asp

Biofilm Environment

Channel flow occurs within pores & fractures & 10 – 1,000 X faster

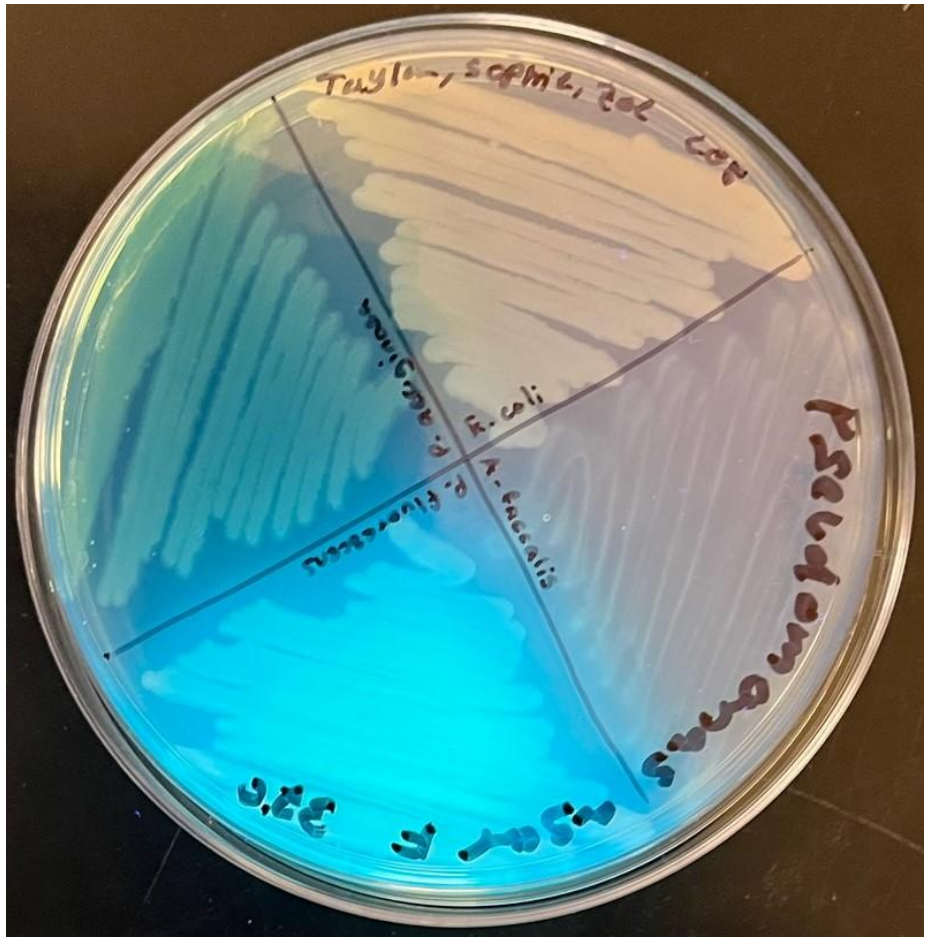


Biofilm of *Pseudomonas aeruginosa, Pseudomonas fluorescens, and Klebsiella pneumoniae*.
P. Stoodley & Z. Lewandowski (1994) - Montana State University - Center for Biofilm Engineering (CBE)

Isolates v. Consortium

New and novel testing and destructive technologies

- Stable isotope probing
- Metagenomics
- Transcriptomics
- Metabolomics
- New genes
- Carbon tagging/ biodegradation



MICROBAC®

Genomic Sequencing Report

Microbac Oak Ridge WO# **3/13/2024**

Client: Kent Armstrong

Sample Project:

Sample ID: DWH-Z

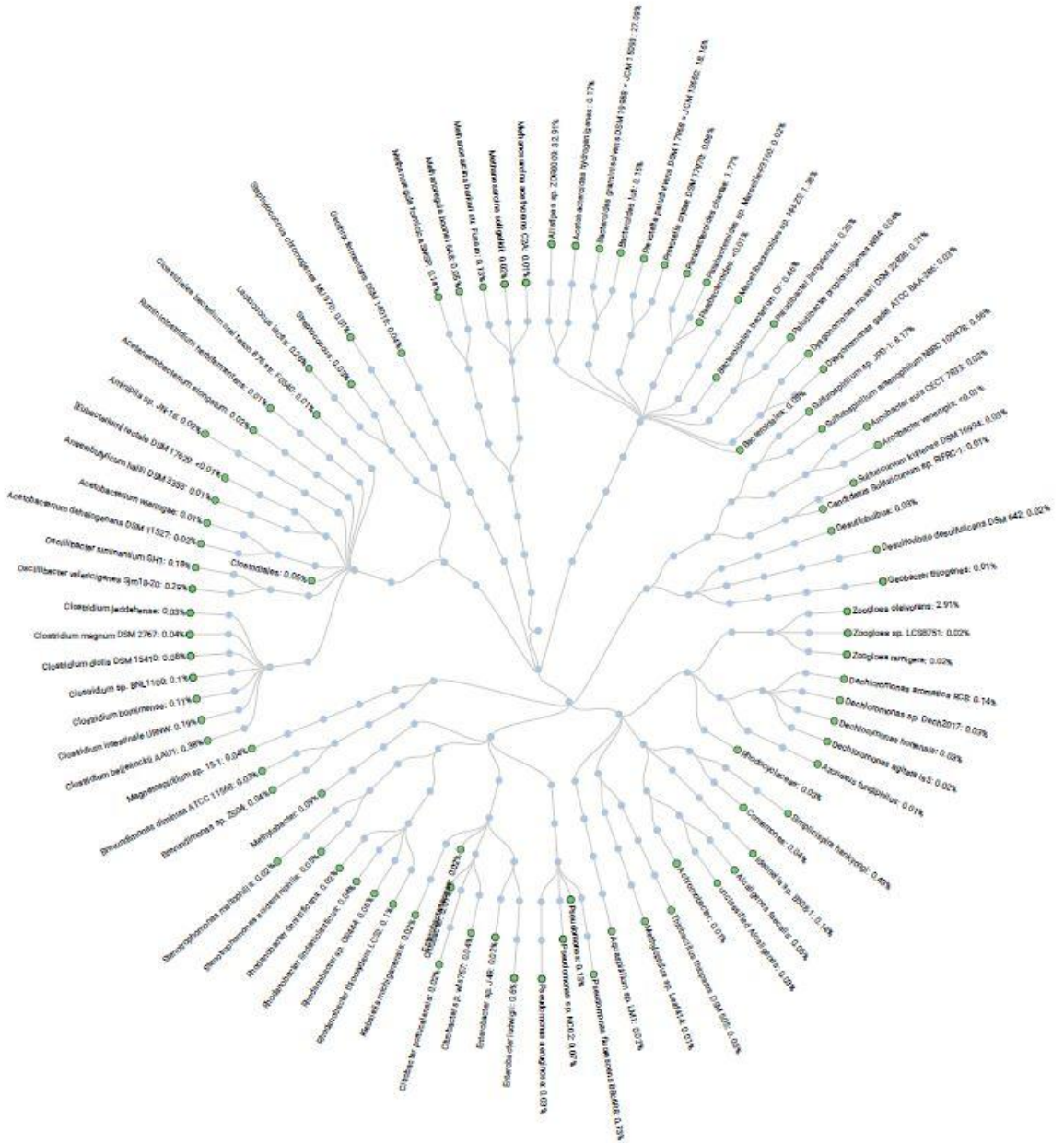
Sample Collected: 1/30/2024

Sampe 16S Biomass: 2.9 X 10^{11} gene copies/g

NCBI Taxonomy Browser to look up "Taxonomy Id"
https://www.ncbi.nlm.nih.gov/Taxonomy/Browser/wwwtax.cgi add number in "Search for" in upper left box.

Summary:

- There were 13.737 Million reads for this sample and the file size was 2.93 GB.
- There were 91 identifications (ID's) in the bacterial data set.
- There were 0 identifications in the virus data set.
- There were 4 identifications in the protists data set.
- There were 5 identifications in the fungal data set.
- There were 21 identifications in the Combined Kingdom data set.
- There were 3 identifications in the Antimicrobial Resistance data set.
- There were 22 identifications in the Virulence Factors data set.
- There were 11 identifications in the phages data set.
- There were 81 identifications in the Dark Matter (Beta) data set.



MICROBAC®

Genomic Sequencing Report

Microbac Oak Ridge WO# **3/13/2024**

Client: Kent Armstrong

Sample Project:

Sample ID: DWH-Z

Sample Collected: 1/30/2024

Sampe 16S Biomass: 2.9 X 10^{11} gene copies/g

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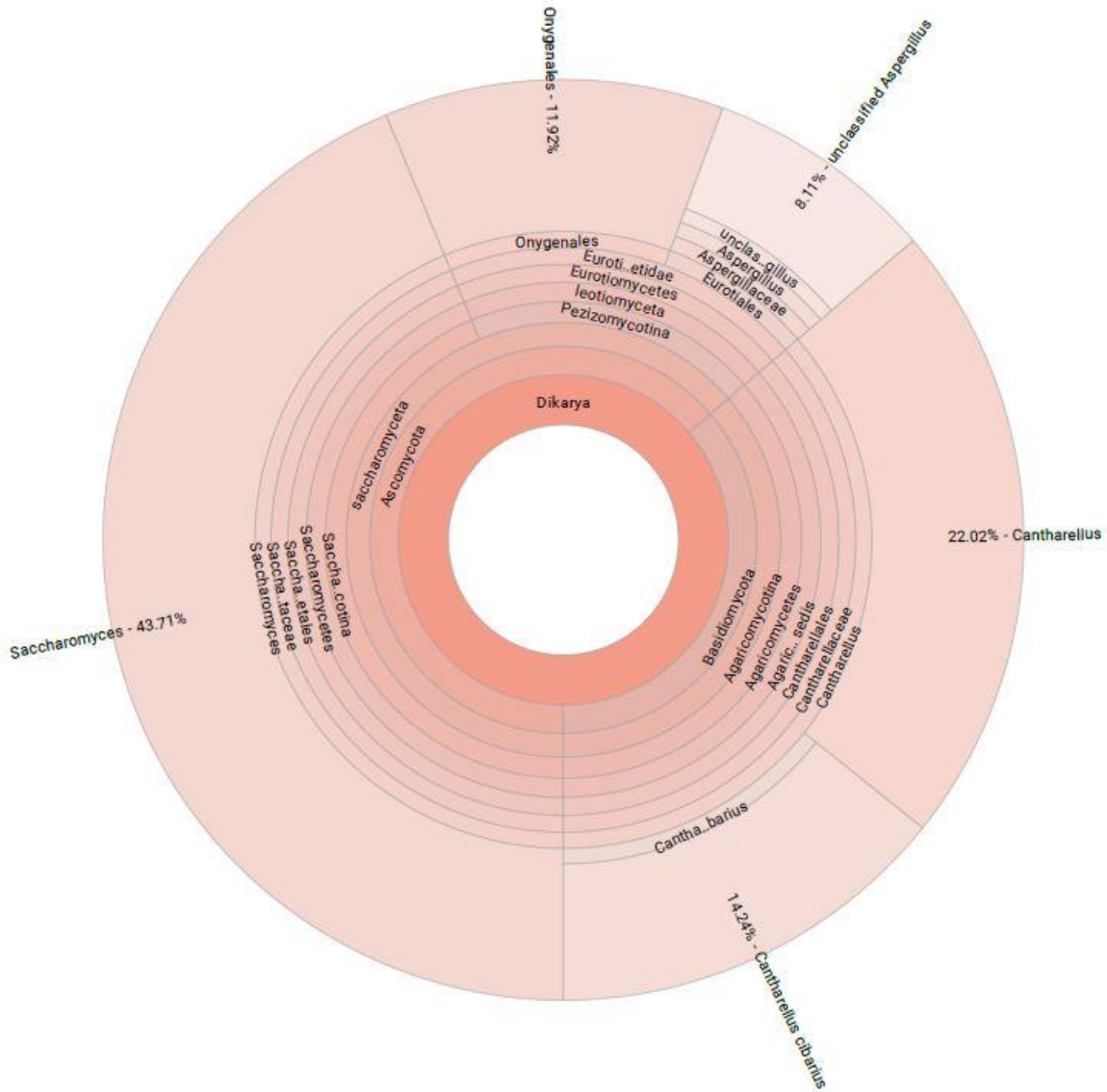
Fungi
Sunburst Chart

Taxa
Filterset: Total



Microbial Consortiums

DOI: 10.1002/rem.21645

PRACTICE NOTE

WILEY

Comparing PFAS to other groundwater contaminants: Implications for remediation

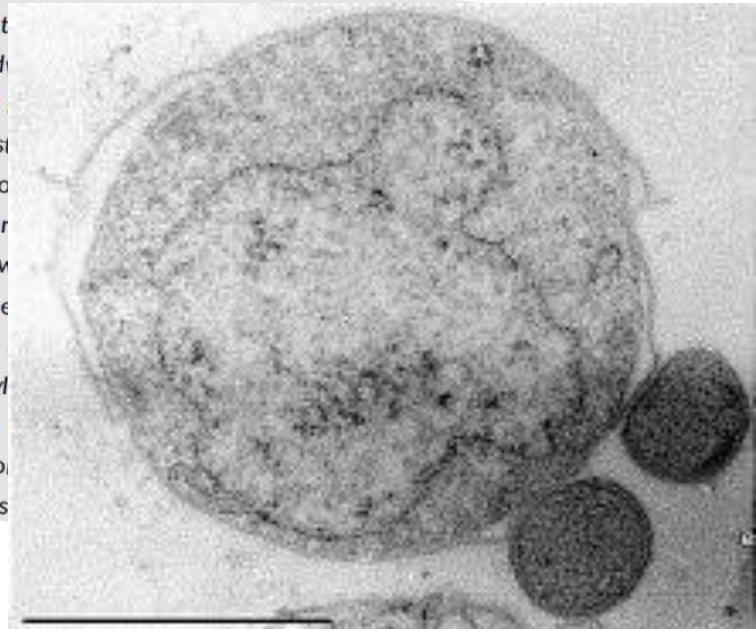
...vell[1] | David T. Adamson[1] | Poonam R. Kulkarni[1] | ...eribe[1] | Hans Stroo[2]

...ouston, Texas
...Oregon

...nmental Inc., ...uston, TX 77098.

Abstract

Established groundwater cont... carbons have impacted ground... United States and have been ... penditures. An important quest... emerging contaminant class co... (PFAS) will be a smaller, similar... groundwater contaminants. A tw... question in this paper. First, nine... used to compare PFAS to four ... benzene, 1,4-dioxane, and methyl... prevalence of the contaminants in ... ficulty, and research intensity. Seco... remediation were evaluated to see s...



environmental microbiology

Environmental Microbiology (2022) **24**(7), 2882–2889 doi:10.1111/1462-2920.15990

Opinion

Pseudomonas: versatile biocatalysts for PFAS

Lawrence P. Wackett *

[1]*Microbial Engineering Program, University of Minnesota, Minneapolis, MN.*

[2]*Biotechnology Institute, University of Minnesota, Minneapolis, MN.*

[3]*Department of Biochemistry, Molecular Biology and Biophysics, University of Minnesota, Minneapolis, MN.*

Scope

Many believe in the concept expressed by the old saying, 'A byrd in hand – is worth ten flye at large,'

20% of new drugs and pharmaceutical compounds contain fluorine and many are polyfluorinated aromatic compounds (Han *et al*., 2021; Ogawa *et al*., 2021).

All classes of organofluorine compounds present similar challenges for microbial metabolism. Those include the chemical strength of the C-F bond, enzyme induction given that C-F compounds present different binding interactions compared to C-H and C-Cl analogues, and the inherent toxicity of fluoride following defluorination (Wackett, 2022). The lack of any known polyfluorinated natural products (Murphy *et al*., 2003; Fincker and Spormann, 2017) suggests that defluorination capabilities will be rare in nature. In laboratory studies, *Pseudomo-*

Fluoride Effect

environmental microbiology Applied Microbiology International

RESEARCH ARTICLE

Role of the CrcB transporter of *Pseudomonas putida* in the multi-level stress response elicited by mineral fluoride

Patricia Calero | Nicolás Gurdo | Pablo I. Nikel

The Novo Nordisk Foundation Center for Biosustainability, Technical University of Denmark, Kongens Lyngby, Denmark

Correspondence
Pablo I. Nikel, The Novo Nordisk Foundation Center for Biosustainability, Technical University of Denmark, 2800 Kongens Lyngby, Denmark.
Email: pabnik@biosustain.dtu.dk

Funding information
H2020 Environment, Grant/Award Number: 814418; Novo Nordisk Fonden, Grant/Award Numbers: NNF18OC0034818, NNF20CC0035580, NNF21OC0067996; Cystic Fibrosis Trust, *Strategic Research Centre Award*–2019–SRC017; Danish Council for Independent Research Natural Sciences, Grant/Award Number: 8021-00039B

Abstract
The presence of mineral fluoride (F^-) in the and anthropogenic origin, and the halide ha tually all living organisms. While the evide species supports this notion, a systemat salts on the metabolism and physiology underexplored thus far. In this work, we mechanisms deployed by the model s KT2440 against NaF. By adopting syste functional genomics and metabolomics, at different regulatory levels under co Several genes involved in halide tolera *Tn*-Seq screening—among which *crc* was shown to play the predominant metabolomics, combined with the ass lar pH values and quantitative physio

nature communications

Perspective

https://doi.org/10.1038/s41467-024-49018-1

The link between ancient microbial fluoride resistance mechanisms and bioengineering organofluorine degradation or synthesis

Received: 10 January 2024

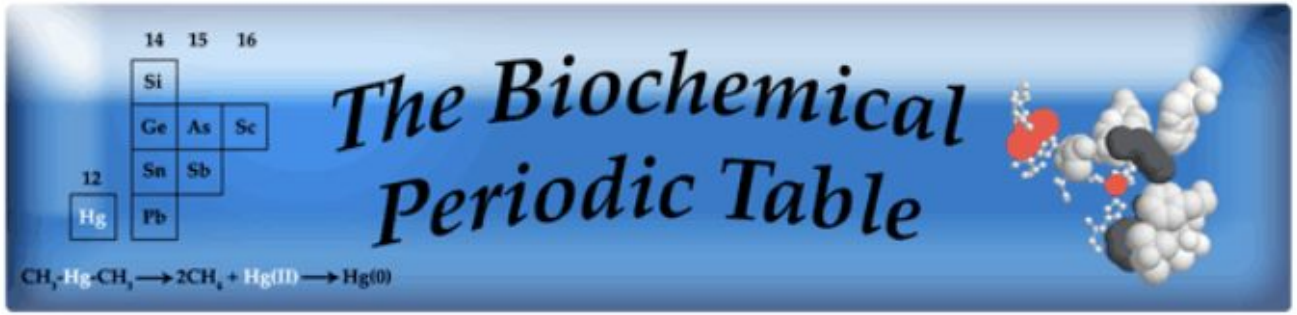
Accepted: 20 May 2024

Published online: 30 May 2024

Check for updates

Randy B. Stockbridge[1] & Lawrence P. Wackett[2]

Fluorinated organic chemicals, such as per- and polyfluorinated alkyl substances (PFAS) and fluorinated pesticides, are both broadly useful and unusually long-lived. To combat problems related to the accumulation of these compounds, microbial PFAS and organofluorine degradation and biosynthesis of less-fluorinated replacement chemicals are under intense study. Both efforts are undermined by the substantial toxicity of fluoride, an anion that powerfully inhibits metabolism. Microorganisms have contended with environmental mineral fluoride over evolutionary time, evolving a suite of detoxification mechanisms. In this perspective, we synthesize emerging ideas on microbial defluorination/fluorination and fluoride resistance mechanisms and identify best approaches for bioengineering new approaches for degrading and making organofluorine compounds.



Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra																
Lanthanoids			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
Actinoids			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

Key	Biologically relevant elements colored
	Major, essential, all life
	Major anions, all life
	Major cations, all life
	Essential, trace, all life
	Major biological transition metals
	Specialized uses, some life
	May be bound, transported, reduced, and/or methylated
	Inert or unknown biological function

Intense Financial Pressure

DoD	Investigate	Cleanup
2019	$256.5M	$245.1M
2020	$242.5M	$28.8M
2021	$174.1M	$77.3M
2022	$181.7M	$78.5M

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DRINKING WATER SMART WATER ASSET MANAGEMENT WATER UTILITY MANAGEMENT WATER REUSE RESIDENTIAL/COMMERCIAL

DRINKING WATER TREATMENT

PFAS remediation spending forecasted to triple by 2030

A new report form Bluefield Research anticipates that infrastructure investments, amid a changing regulatory env national spending on PFAS treatment systems.

May 17, 2022

[1] Current removal cost equal to rate of production estimated $20 to $7,000 trillion/yr

[2] PFAS drinking water removal $3.2 - $5.7 billion/yr

[1] A.L., Ling Univ. St. Thomas, Mar-2024
American Water Works Association [2]

PFAS Source Reduction

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NEWS 12.15.23

Minnesota's Ban on PFAS in Food Packaging Becomes Effective Jan. 1

Minnesota's ban on intentionally added per- and polyfluoroalkyl substances (PFAS) in food packaging becomes effective on January 1, 2024. (See Minn. Stat. § 325F.075.) The ban was included in an omnibus environment, natural resources, and tourism bill that was signed into law on June 29, 2021. We previously reported on the law here.

This PFAS-in-food packaging law defines "food package" as "a container applied to or providing a means to market, protect, handle, deliver, serve, contain, or store a food or beverage." The Minnesota [illegible] takes a broad view of the scope of products encompa[illegible]

SECTIONS | StarTribune

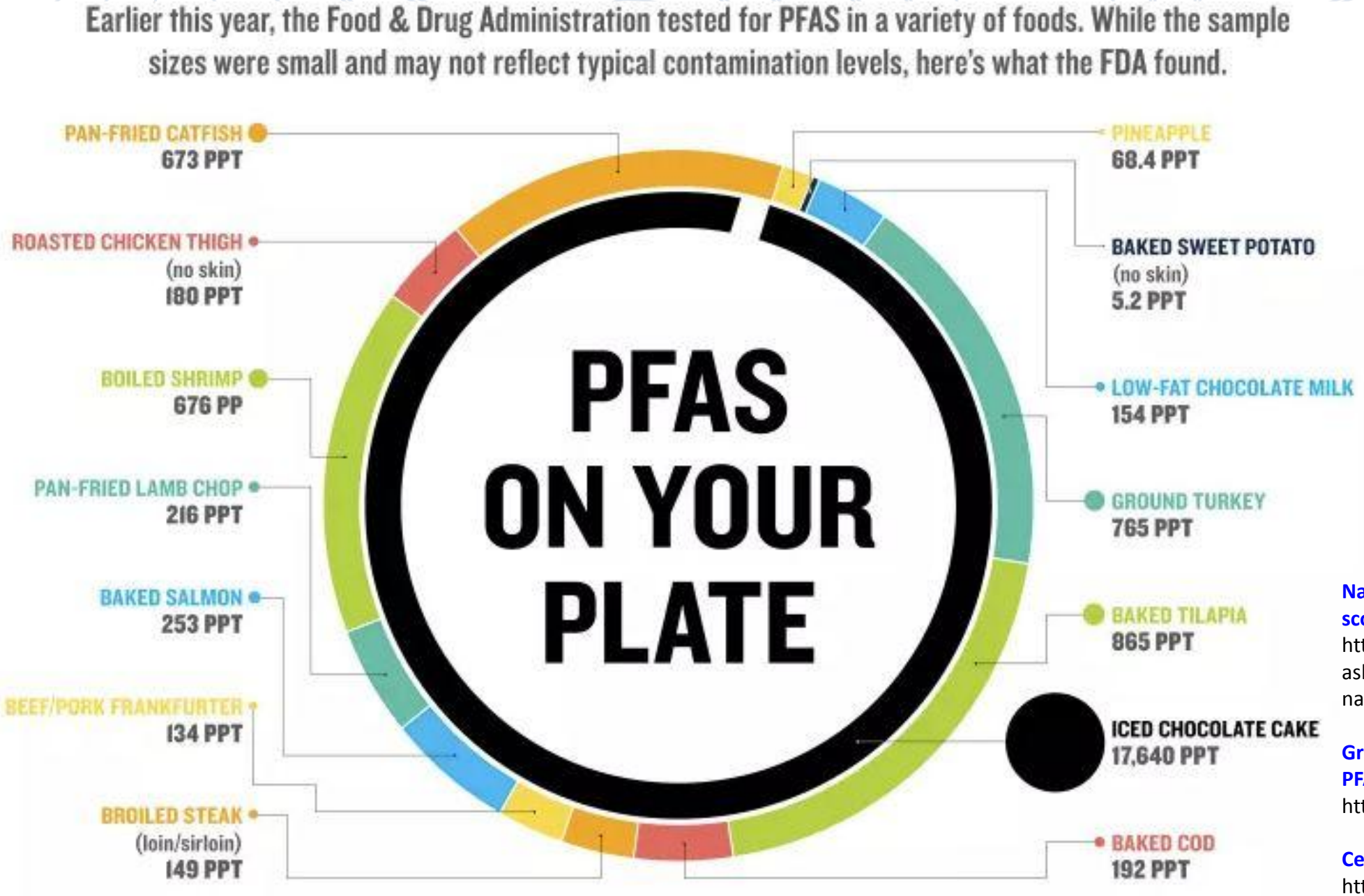
LOCAL

By 2032, almost anything you buy in Minnesota will come in recyclable, compostable or reusable packaging. Here's why.

Environmental groups and Twin Cities leaders say requiring packaging be recyclable is key to reducing the growing amount of waste.

By Christopher Magan Star Tribune | JUNE 4, 2024 — 9:29AM

ELIZABETH FLORES, STAR TRIBUNE



Natural Resources Defense Council scorecard (Apparel)
https://www.nrdc.org/resources/going-out-fashion-us-apparel-manufacturers-must-eliminate-pfas-from-their-supply-chains

Green Science Policy Institute (Corporate PFAS evaluation)
https://pfascentral.org/pfas-free-products/

Center for Environmental Health (Foodware)
https://ceh.org/wp-content/uploads/2021/08/foodware.jpg

NOTHING LASTS FOREVER

QUESTIONS

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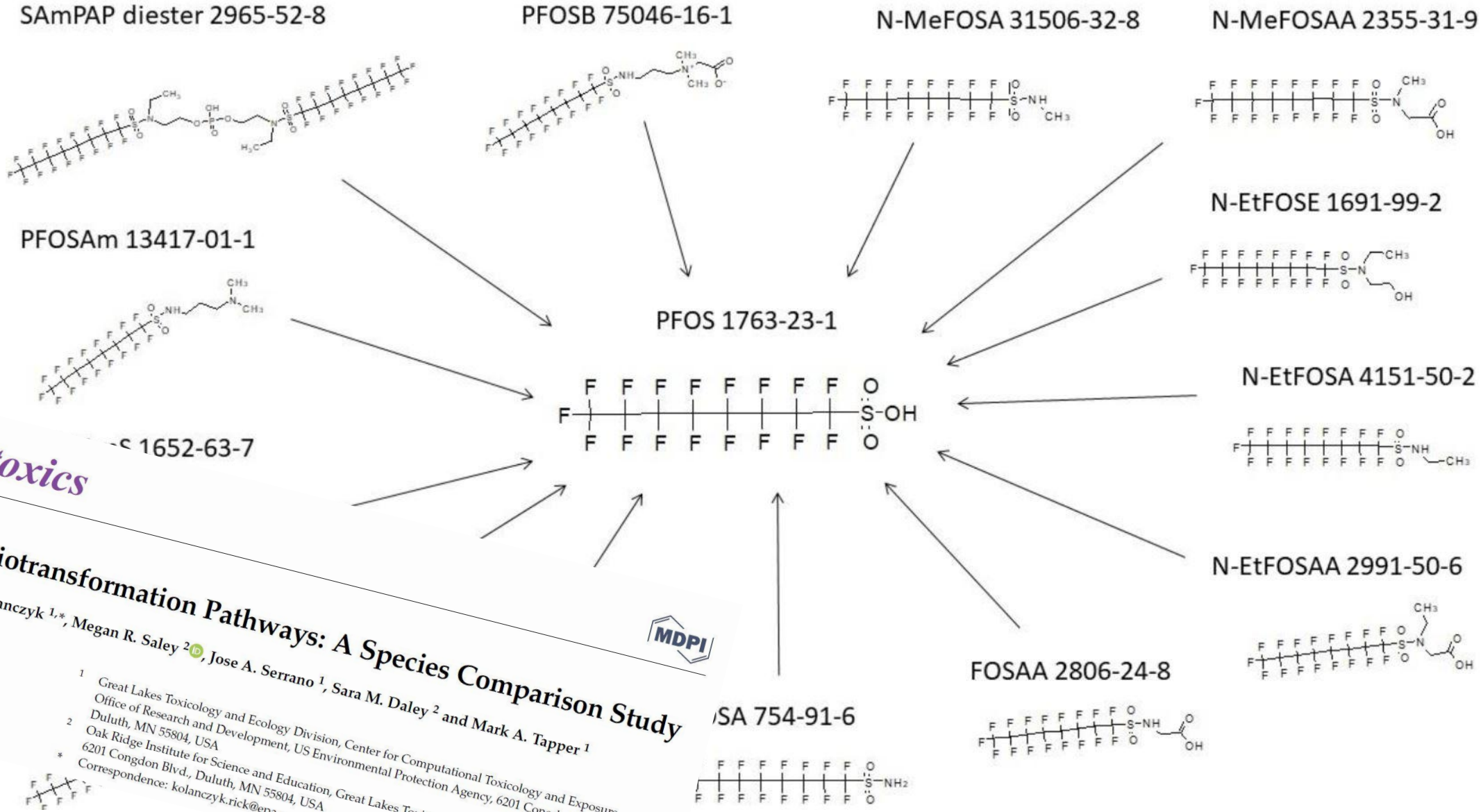
Bay West

Biotransformation Pathways



toxics
Article

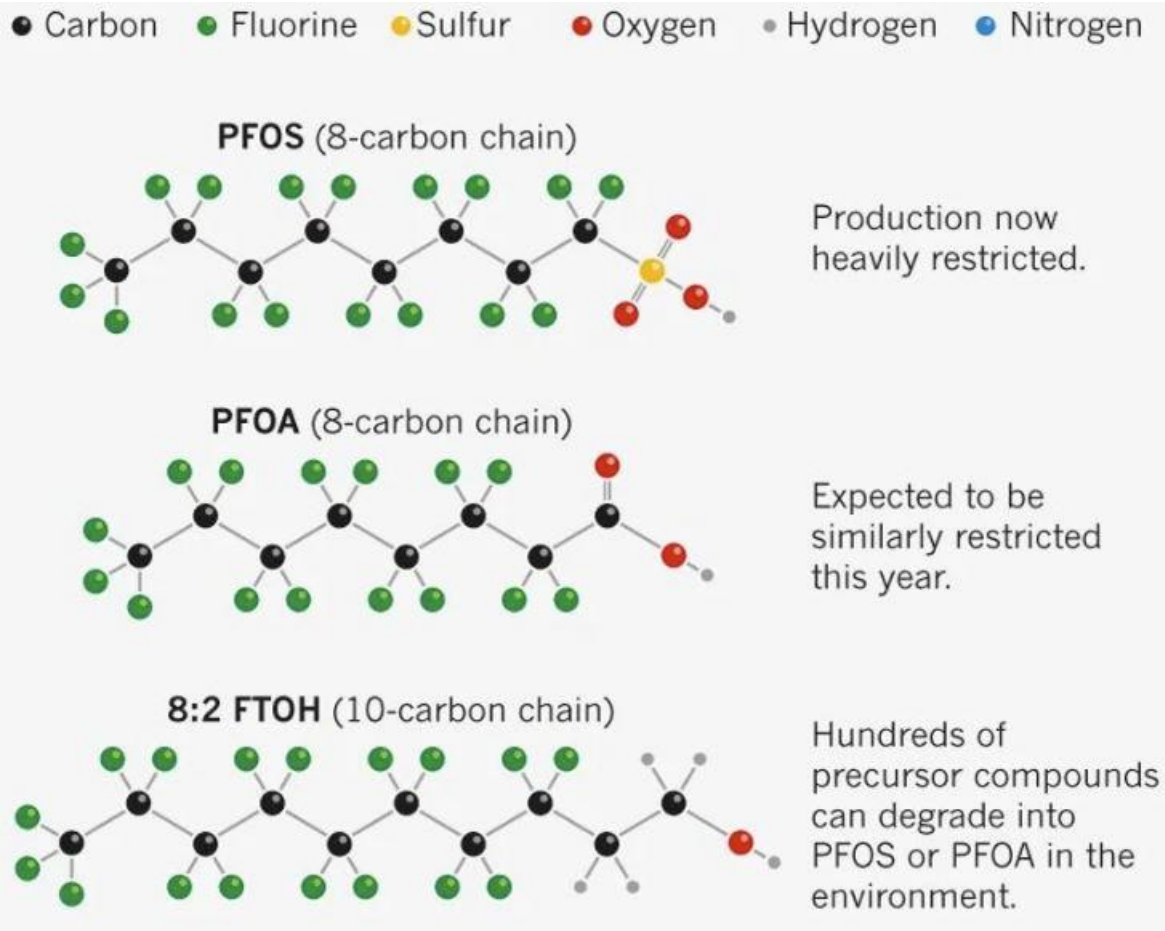
PFAS Biotransformation Pathways: A Species Comparison Study

Richard C. Kolanczyk [1,*], Megan R. Saley [2], Jose A. Serrano [1], Sara M. Daley [2] and Mark A. Tapper [1]

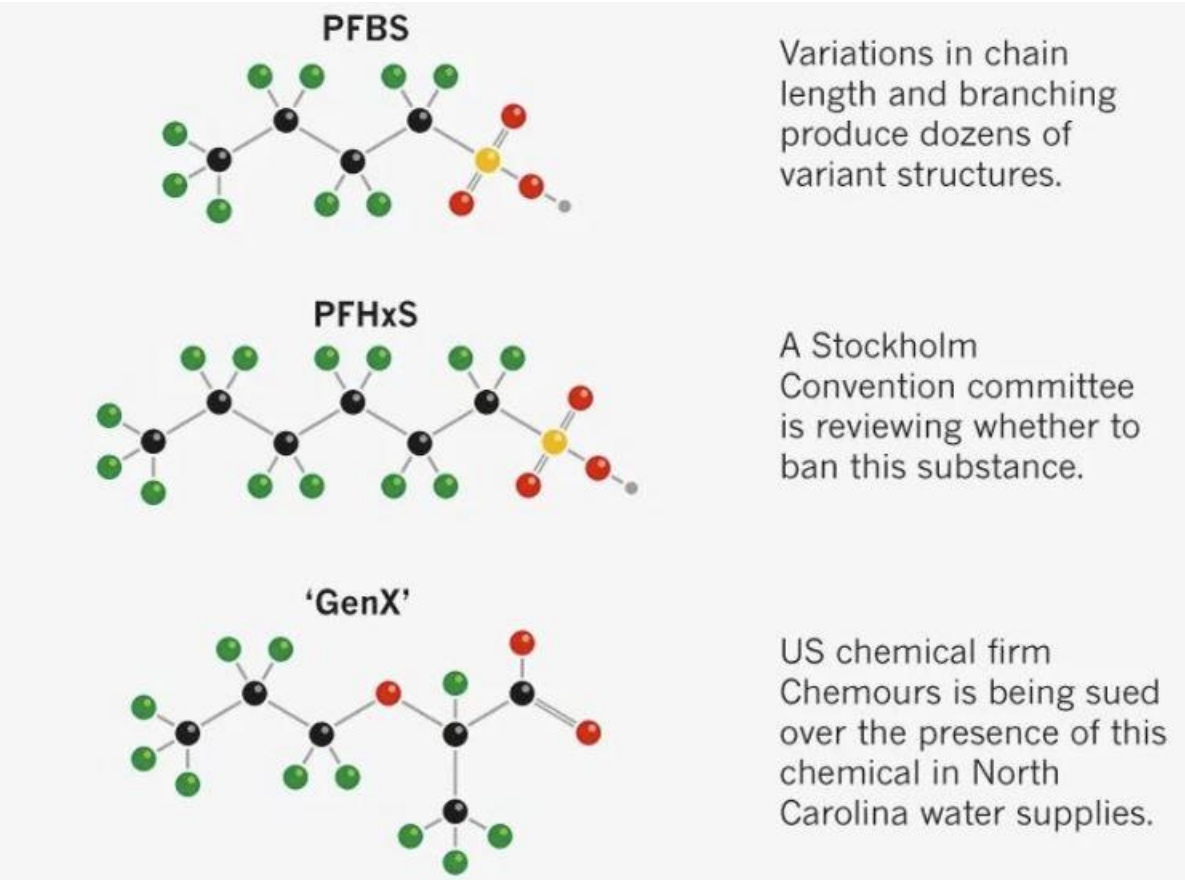
[1] Great Lakes Toxicology and Ecology Division, Center for Computational Toxicology and Exposure, Office of Research and Development, US Environmental Protection Agency, 6201 Congdon Blvd., Duluth, MN 55804, USA
[2] Oak Ridge Institute for Science and Education, Great Lakes Toxicology and Ecology Division, 6201 Congdon Blvd., Duluth, MN 55804, USA
* Correspondence: kolanczyk.rick@epa.gov; Tel.: +1-218-529-5152; Fax: +1-218-529-

MDPI

‘Old PFAS’



‘New Gen PFAS’



Scientific American, Feb. 19, 2019. *The Fluorine Detectives*.