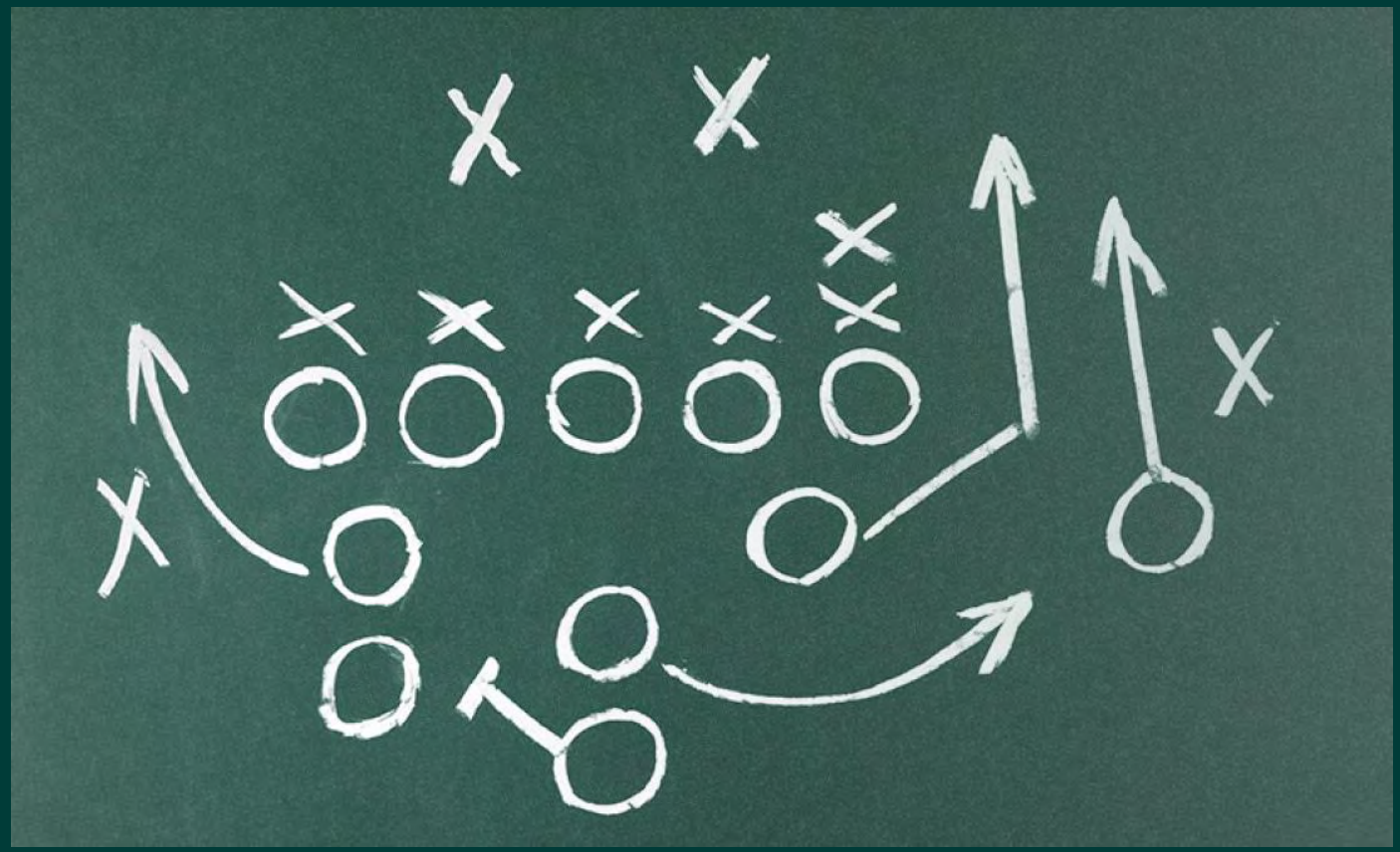
Willows at Work:

A Phytotechnology Playbook for *in situ* Management of Leachate ***and*** Emerging Contaminants.

Liability Reduction Through Volume Management and Contaminant Retention with the EVAPLANT system



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A circular economy from nature-based solutions

Tree plantation development on industrialized sites for accelerated reclamation

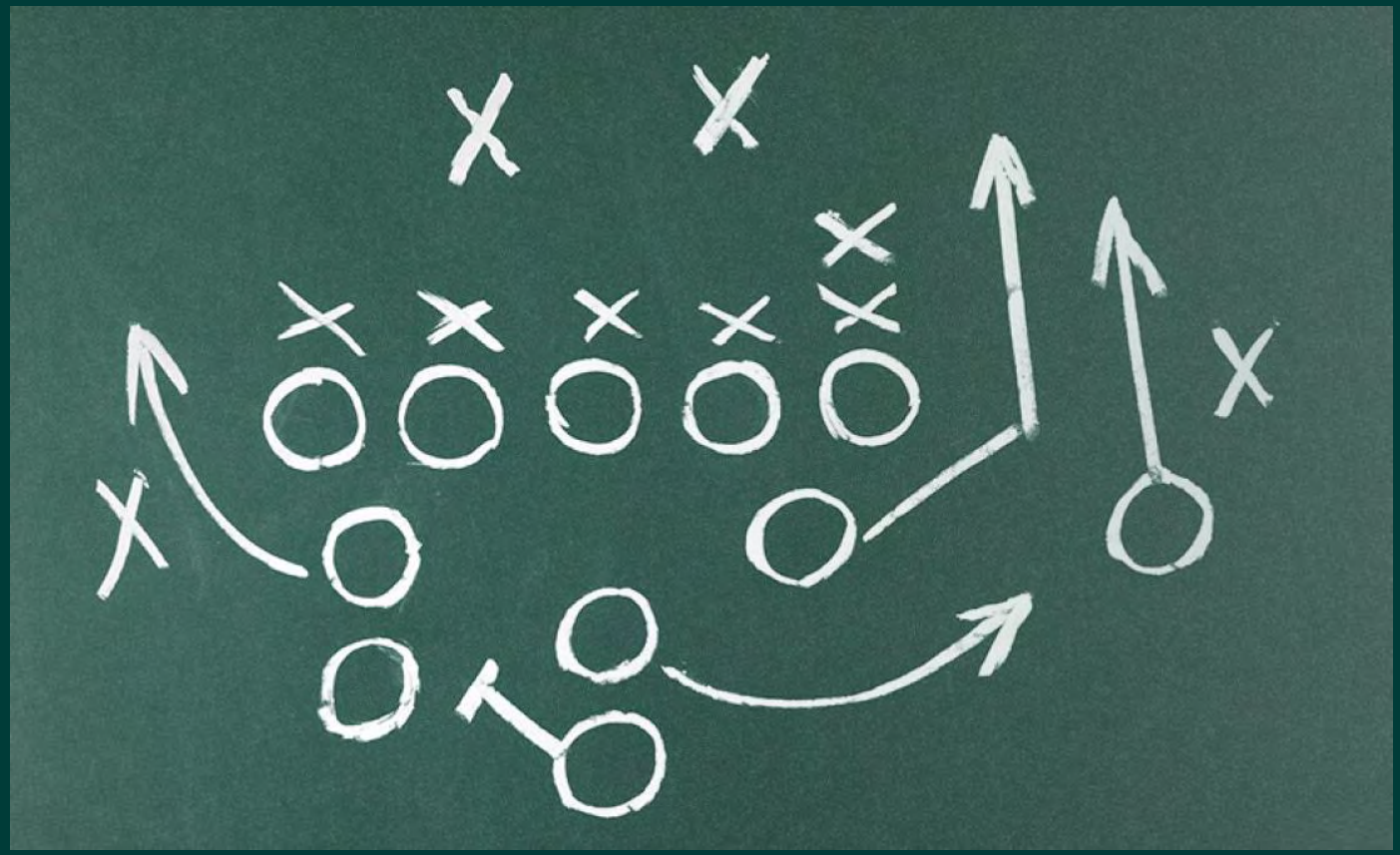
Wastewater treatment and volume reduction

Ramial Chipped Wood Mulch for Reclamation

Noise barrier and wood product manufacturing

Part 1:

Phytotechnology 101



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Phytoremediation 101: Evolution of a Science

800 BC to 500 AD

Recognition that certain plants thrived in polluted environments

Cleansing properties of wetlands and marshes

1860s

Plant nutrition through hydroponic solutions (Julius von Sachs, 1868)

1930s – 1940s

Discovery of hyperaccumulator species for metals (*Alyssum, Thlaspi*)

1960's-1980's

Sustainable cleanup methods exploration

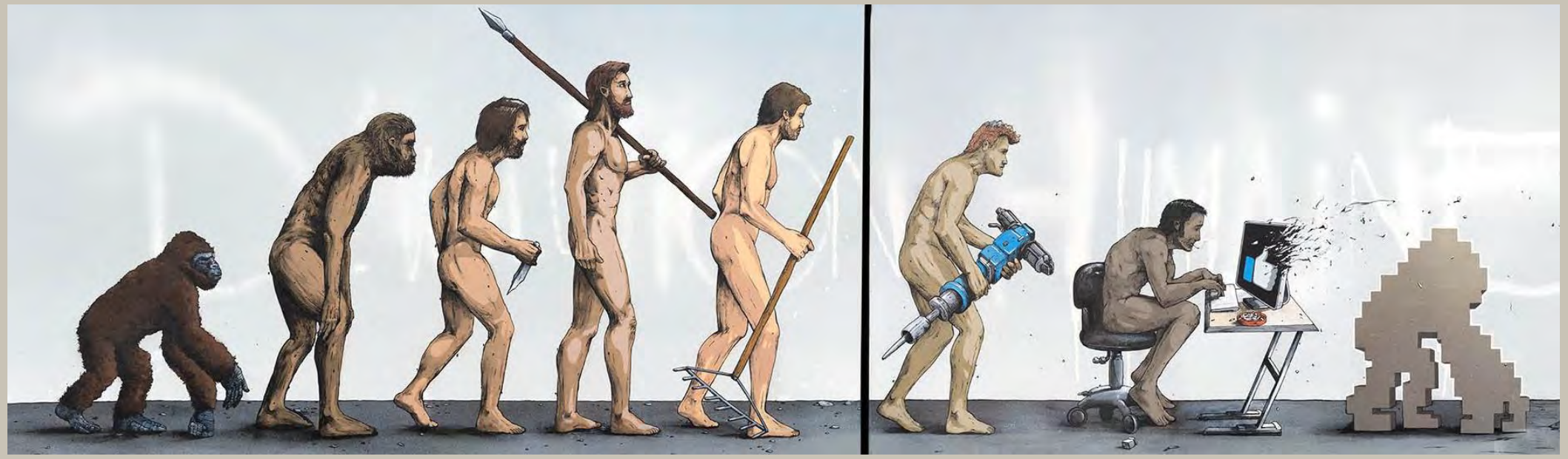
Minimata, Japan (mercury poisoning)

Love Canal (halogenated organics, dioxins, chlorobenzenes)

1990s

Formalized science of phytoremediation (R.L. Chaney, I. Raskin)

Phytoextraction
Phytodegradation
Phytostabilization
Rhizofiltration



A Rose By Any Other Name – Phytoremediatic Types

- Constructed Wetlands
- Floating Wetlands
- Hydroponic
- Phytoreactors
- Soil/Land Based Systems

A Short Phytotechnology History of Willows

1970s

Willows used as a vegetation filter for wastewater and sludges (Aronsson and Perttu *eds.*, 1994)

1980s

Willows for phytoremediation/phytoextraction

1990s

Biomass technology trials in Canada

2000s

Willow leachate management

- Sweden (Aronsson, Dahlin, & Dimitriou, 2010)

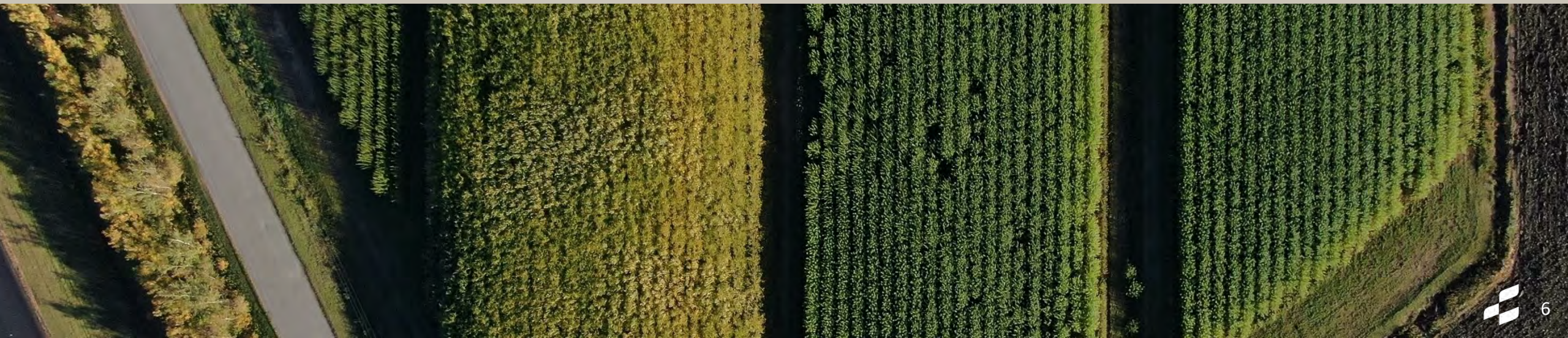
- 2010s Canada – (Ramea, Montreal Polytechnic *et. al*)

2008

2020s

Industrial and Mining Effluents (Ramo)

Circular Economy Establishment through Phytostabilization and Rhizofiltration

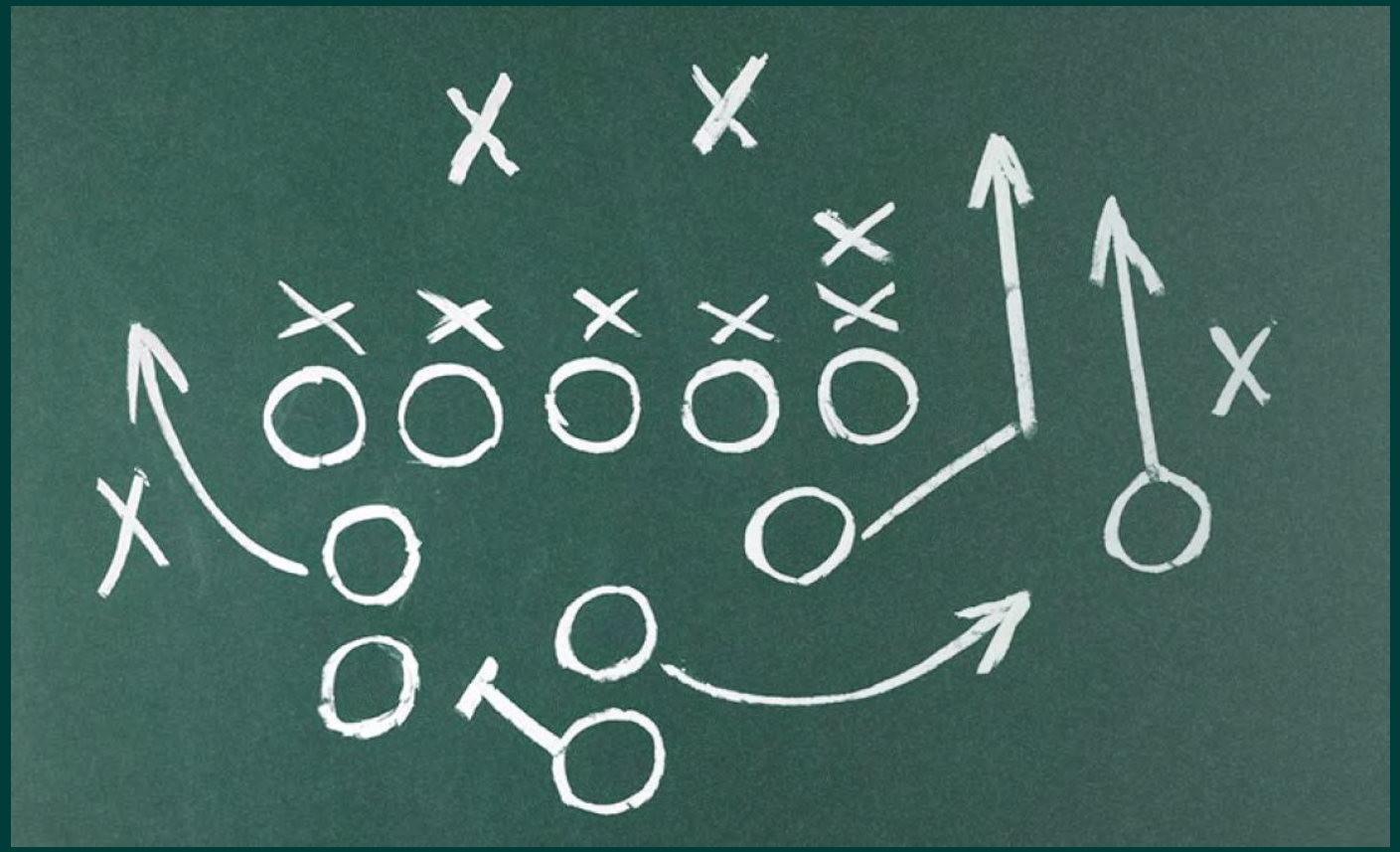


Part 2:

Why Bother?

or

An analysis of human decisionmaking.



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What is in Leachate Anyway?

- Matrix of Constituents / Decision Matrix
  - Regulated vs Unregulated
  - Managed vs Unmanaged
  - Treated vs Untreated
- Unregulated, Unmanaged and Untreatable (U^3)

To act or not to act on U^3 – that is the question

- Regulation-Based Approach: Minimizes the Cost of Action
- Evidence-Based Approach: Reduces the Cost of Action
- Precautionary Approach: Reduces the Cost of Inaction

Open Access Review

Overview of Per- and Polyfluoroalkyl Substances (PFAS), Their Applications, Sources, and Potential Impacts on Human Health

by Zunaira Habib [1,*], Minkyung Song [2], Sadaf Ikram [3,4] and Zahra Zahra [5,*]

[1] Institute of Environmental Sciences and Engineering, School of Civil & Environmental Engineering, National University of Sciences and Technology, Islamabad 44000, Pakistan
[2] Plamica Labs, Batten Hall, 125 Western Ave., Allston, MA 02163, USA
[3] Department of Chemistry, Quaid-i-Azam University, Islamabad 44000, Pakistan
[4] Chemistry Department, Rawalpindi Women University, Rawalpindi 46300, Pakistan
[5] Department of Civil & Environmental Engineering, University of California-Irvine, Irvine, CA 92697, USA
[*] Authors to whom correspondence should be addressed.

Pollutants **2024**, *4*(1), 136-152; **https://doi.org/10.3390/pollutants4010009**

ESSAY

Risk Assessment

Global Challenges

www.global-challenges.com

Microplastics in the Environment: Much Ado about Nothing? A Debate

Thomas Backhaus and Martin Wagner**

RESEARCH ARTICLE ATMOSPHERIC SCIENCE

Constraining global transport of perfluoroalkyl acids on sea spray aerosol using field measurements

BO SHA, JANA H. JOHANSSON, MATTHEW E. SALTER, SARA M. BLICHNER, AND IAN T. COUSINS Authors Info & Affiliations

SCIENCE ADVANCES • 5 Apr 2024 • Vol 10, Issue 14 • DOI: 10.1126/sciadv.adl1026

Impact of Microplastics on Human Health: Risks, Diseases, and Affected Body Systems

by Ghulam Abbas [1], Usama Ahmed [2] and Muhammad Arsalan Ahmad [3,*]

[1] Guangdong Key Laboratory for Biomedical Measurements and Ultrasound Imaging, School of Biomedical Engineering, Shenzhen University Medical School, Shenzhen 518060, China
[2] Department of Medicine, School of Biomedical Engineering, Shenzhen University Medical School, Shenzhen 518060, China
[3] Shenzhen Key Laboratory of Marine Bioresource and Eco-Environmental Science, College of Life Sciences and Oceanography, Shenzhen University, Shenzhen 518060, China
[*] Author to whom correspondence should be addressed.

Microplastics **2025**, *4*(2), 23; **https://doi.org/10.3390/microplastics4020023**

Brief Communication | Open access | Published: 03 February 2025

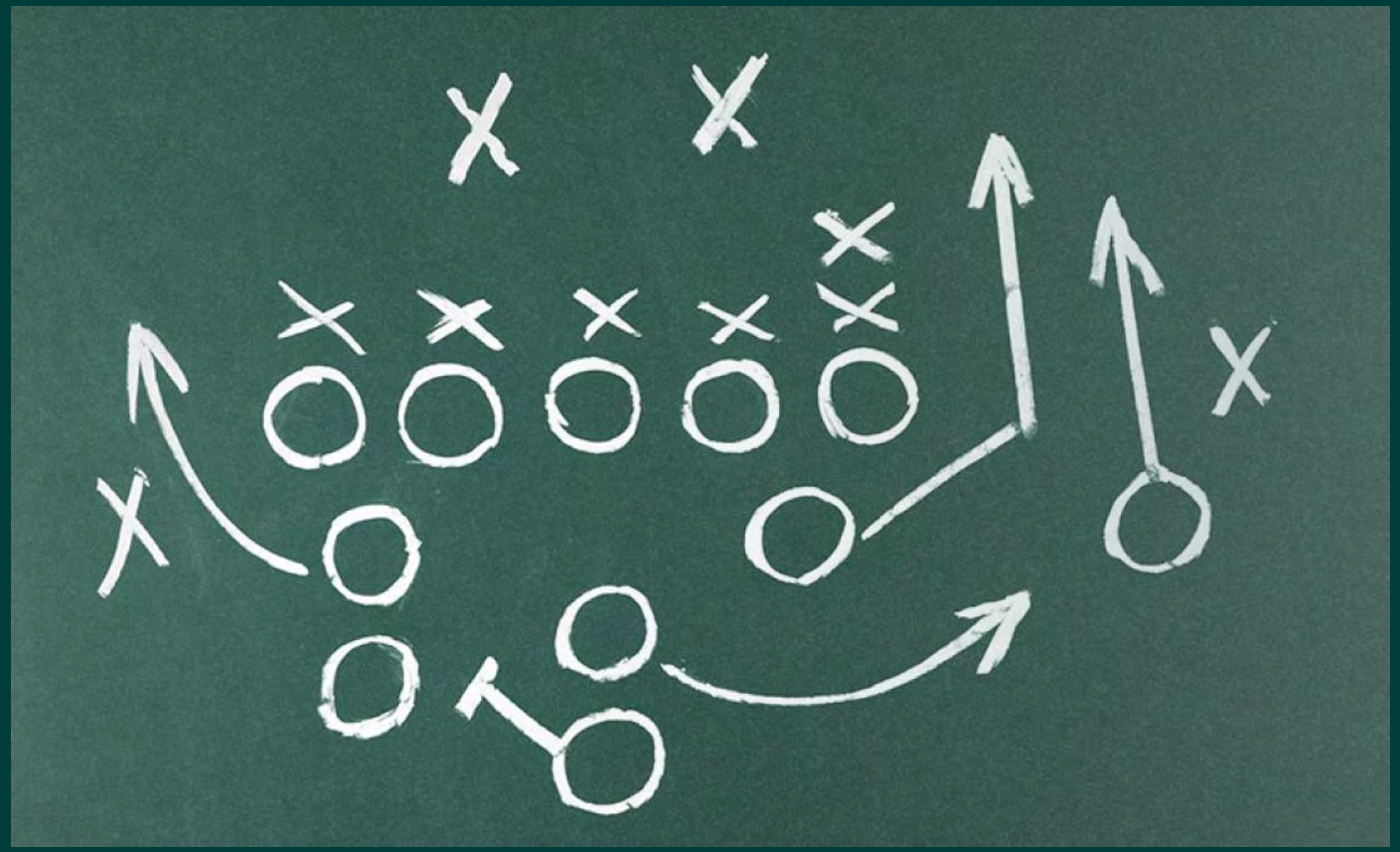
Bioaccumulation of microplastics in decedent human brains

Alexander J. Nihart, Marcus A. Garcia, Eliane El Hayek, Rui Liu, Marian Olewine, Josiah D. Kingston, Eliseo F. Castillo, Rama R. Gullapalli, Tamara Howard, Barry Bleske, Justin Scott, Jorge Gonzalez-Estrella, Jessica M. Gross, Michael Spilde, Natalie L. Adolphi, Daniel F. Gallego, Heather S. Jarrell, Gabrielle Dvorscak, Maria E. Zuluaga-Ruiz, Andrew B. West & Matthew J. Campen

Nature Medicine **31**, 1114–1119 (2025) | Cite this article

Part 3:

EVAPLANT



EVAPLANT - Managing All Liabilities

Managed vs Unmanaged vs Unregulated

- Removal from the landfill resets the requirement to assess management.
- Evolving understanding of constituents and their effects is redefining the certainty of management

Managed: Phytoextraction, degradaation, stabilization

- Nutrients
- Trace elements
- COD/CBOD/Organics

Unmanaged: Phytostabilization and Rhizofiltration

- PFAS
- Microplastics
- PBDEs

Evaplant’s Patented Technology

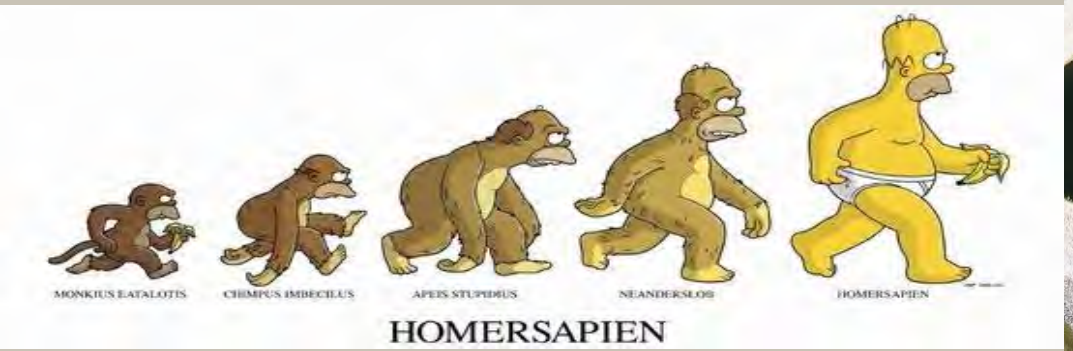
A patented technology that:

- Irrigates willows to absorb effluent → water lost to atmosphere via evapotranspiration
- Smart scheduling using weather + soil data = optimized irrigation
- No discharge: it’s volume *management*, not treatment
- 2-year harvest cycle → biomass valorized as stems or Ramial Chipped Wood (RCW)

Vive La Difference!

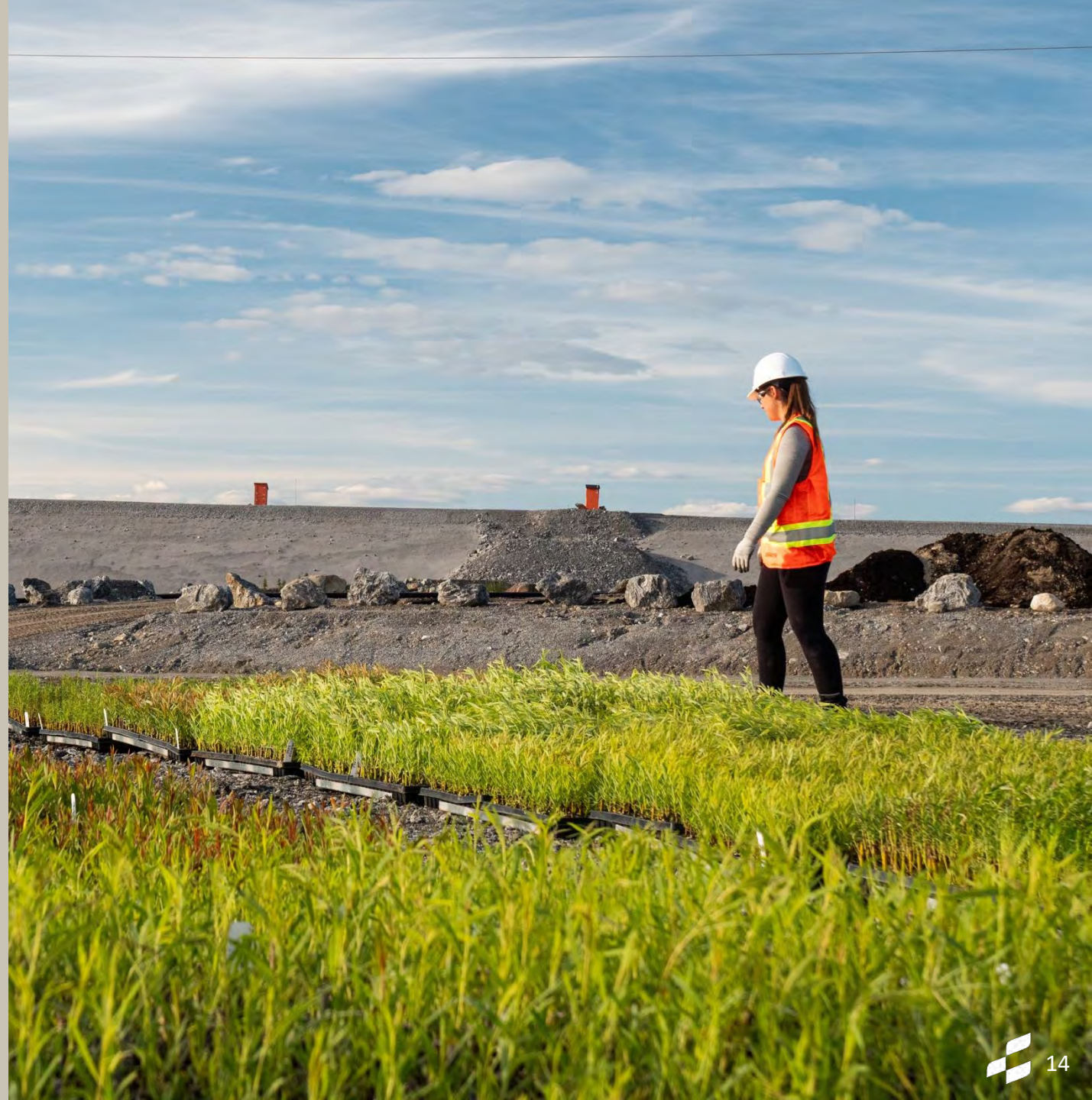
Why is Evaplant Different?

- **How we irrigate**
  - Large droplet emitters
  - Precision irrigation
- **What we irrigate**
  - Dense Willow Plantation
- **Biomass Utility**
  - Useful in the landfill
  - Useful as a product
  - Soil amendment in the plantation
- **Viewshed Management**

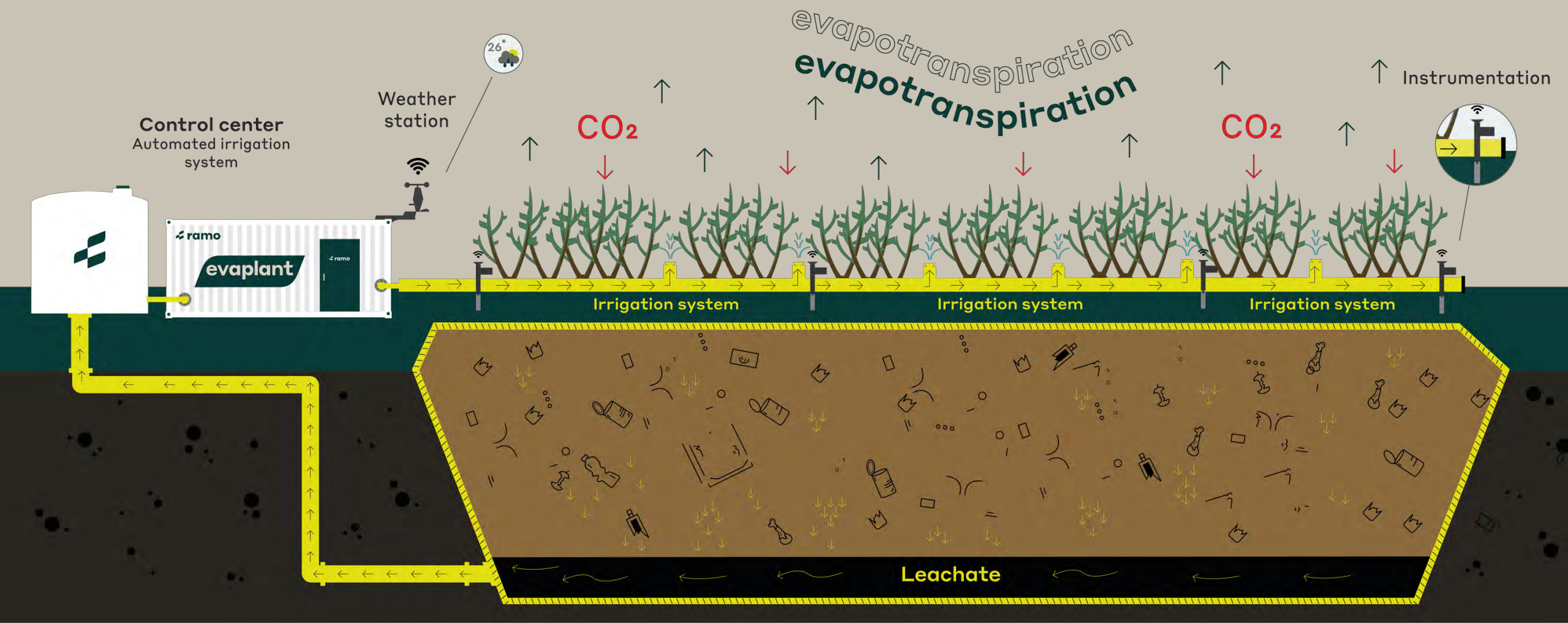


Why willows?

- **Up to 1,500 mm/season** uptake = serious water reduction
- **20–25 t/ha/yr** biomass → low-cost output
- Biomass = **usable** or **landfillable** → both help ESG
- **Coppices**: regrows fast, no replanting
- **Tough species**: thrives in tough water, not hyperaccumulating
- **Shallow rooting:** rooting depth to 30cm, does not normally penetrate landfill cap



Evaplant’s Patented System



PFAS Retention (preliminary)

- Soils
- Plant Biomass
- Not known to directly volatilize PFAS

Microplastics Retention (future)

- Soils
- Plant Biomass
- Not volatilized

Process binds the constituent in biomass or in soils on site.

Allows for a considered pathway of management.

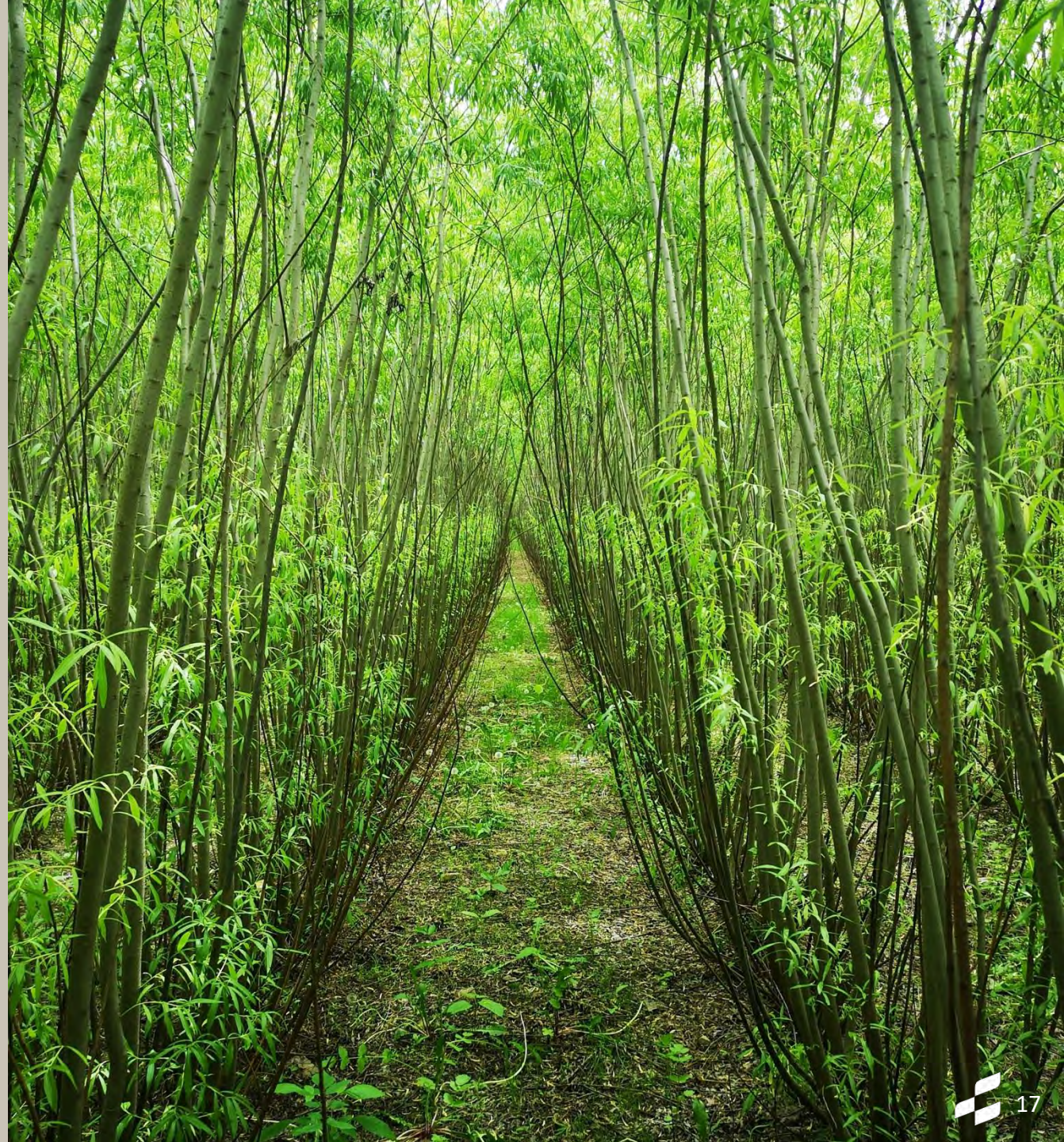
PFAS sampling in Evaplant Systems

- Collaborative research
- Sampled leachate, soil, and plant tissues (roots, stems, leaves)
- Multiple replicates across different willow varieties
- Analysis of 77 PFAS compounds

Early determination of Evaplant PFAS Capture characterization

Université de Montréal

Institut de recherche en biologie végétale



Leachate characterisation

# de C	Composé	Unités	Date d'échantillonnage		
			2023-05-25	2023-07-12	2023-09-13
-	Σ 77 PFAS	ng/L	1550	1433	817
6	PFHxA		611	507	293
5	PFPeA		343	368	213
8	PFOA[1]		213	91	52
4	PFBS[1]		82	121	53
7	PFHpA		77	84	44
6	PFHxS[1]		64	66	48
5	5:3 FTCA		27	42	16
6	6:2FTS		39	28	9
8	PFOS[1]		32	20	17
4	4:3 FTCA		-	19	15
9	PFNA[1]		17	19	8
6	6:2 FTAB		12	17	15
4	PFBA		-	7,7	3,6
6	HFPO-DA[1]		-	5,4	-

[1]Regulated in drinking water by USEPA

Evaplant Soil Characterization

# of C	Coumpound	Concentration		
		Initial Soil 2023	Final Soil 2023	Initial soil 2024
		(ng/g)	(ng/g)	(ng/g)
-	ΣPFAS	1,07 - 1,41	1,44 - 2,26	2,5 - 12,1
6	PFHxA[2]	0,056	0,069 - 0,097	-
8	PFOA[12]	0,026 - 0,044	0,0406 - 0,0406	-
4	PFBS[1]	0,117 - 0,177	0,0727 - 0,0793	0,2 - 0,3
4	PFBA	0,127 - 0,235	0,0927 - 0,107	1,8 - 11,3
10	PFDA[2]	0,266 - 0,446	0,115 - 0,119	-
5	PFPeS	0,0214 - 0,0214	-	-
7	PFHpS	-	0,085 - 0,088	-
3	PFPrS	-	0,124 - 0,131	-
0	PFECHS	-	0,134 - 0,134	-
0	PFOSAmS	0,0455 - 0,0731	-	-
0	FOSAA	0,0286 - 0,0327	-	-
8	8:2FTS[2]	-	0,144 - 0,144	-
0	8_8-PFPi	0,026 - 0,026	-	-
11	PFUnA	-	0,0921 - 0,0987	-
10	PFDS	0,0471 - 0,0471	-	-
10	10_2-FTUCA	-	-	-
2	PFEtS	-	0,127 - 0,132	-
9	PFNS	-	-	-
0	MeFOSA	-	-	-

Evaplant Biomass Characterization

# de C	Composé	LOD	Concentration dans la biomasse (ng/g)					
			Variété 1			Variété 2		
			Bois	Feuilles	Racines	Bois	Feuilles	Racines
-	Somme 77 PFAS	-	3,3 - 3,4	17 - 49	7,3 - 8,5	3,3 - 4,8	28 - 95	6,1 - 7,4
6	PFHxA	0,250	-	-	-	-	3,2	-
5	PFPeA	0,458	-	6,1 - 18	1,4 - 1,7	-	6,3 - 22	1,8
8	MeFOSAA	0,030	0,43	0,04 - 0,06	0,09 - 0,2	0,12	0,25 - 0,3	1 - 1,3
8	PFOA	0,250	-	-	1,2 - 1,3	1,3	-	1,3
4	PFBS	0,100	-	1,7 - 3,7	1,1 - 1,2	-	3 - 3,8	1,1 - 1,2
6	PFHxS	0,080	-	0,6	0,56 - 0,58	-	0,59 - 0,65	0,52 - 0,56
8	PFOS	0,070	-	-	0,61 - 0,73	-	-	0,64 - 0,86
6	6:2 FTAB	0,250	0,42 - 2,6	2,5	-	1,9	-	-
4	PFBA	0,100	-	23	-	-	5,2 - 37	-
1	PFPrA	0,145	-	5,2	-	-	15	-
4	FBSA	0,160	-	-	0,77 - 0,83	-	-	0,75 - 0,81
5	5:3 FtB	0,160	0,56	1 - 1,9	-	-	11 - 12	-
3	PFPrS	0,100	-	1,2	1,2	-	1,1	1
8	8:2 FTS	0,100	0,24	-	0,23 - 0,24	0,23	-	0,21 - 0,27
8	FOSA	0,100	-	-	0,89 - 0,92	-	-	-
10	10:2 FTS	0,100	1,5	-	-	1,5 - 1,6	-	-

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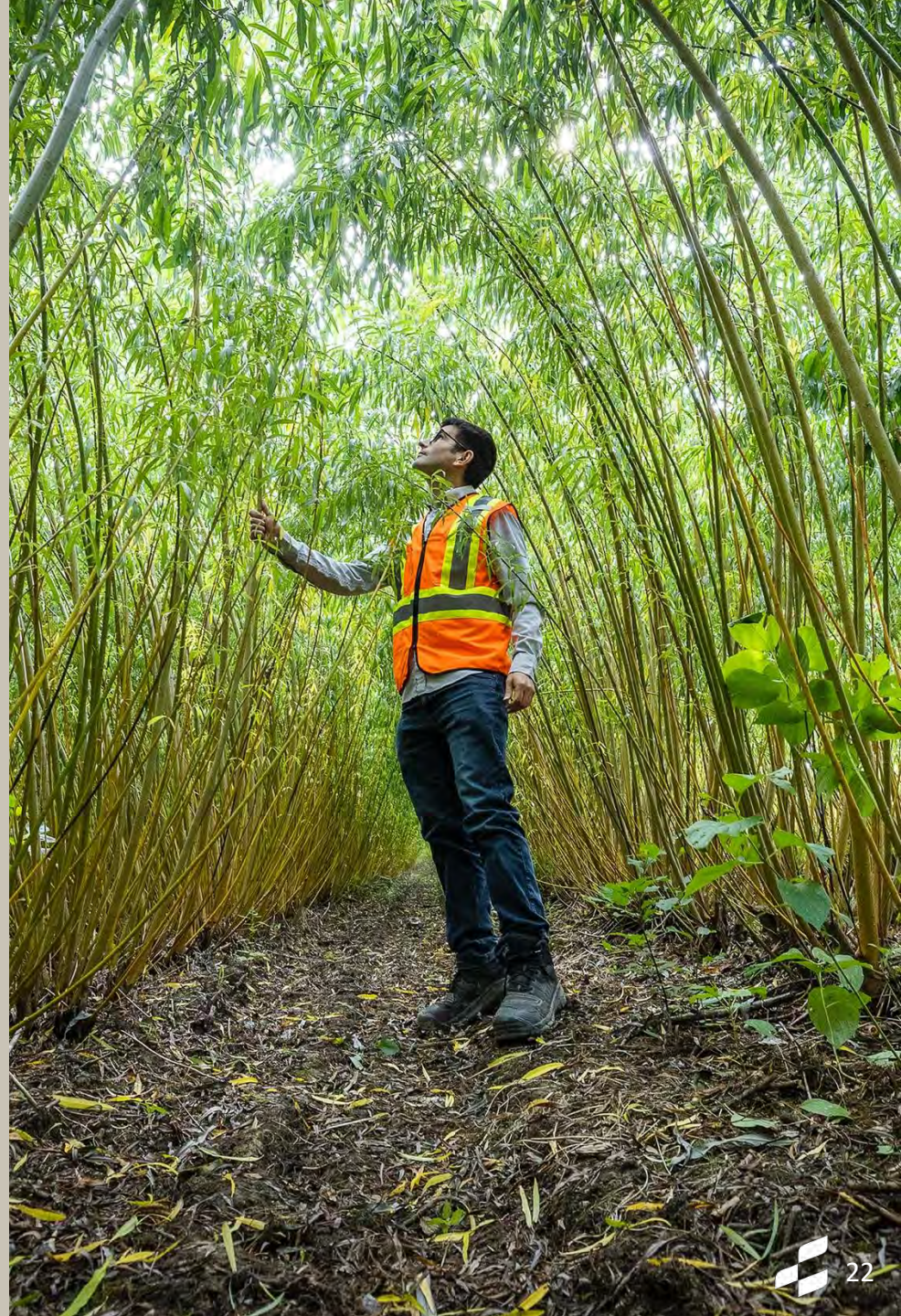
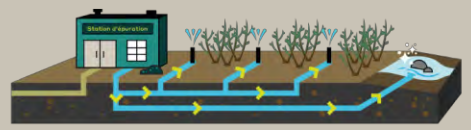
Compound	Concentration in the leaves per variety (ng/g)						
	61	64	Di	In	Pb	Sv	Tu
ΣPFAS	32 770	47 003	53 103	23 827	43 449	23 279	34 307
PFBA	18 159	30 405	32 320	14 947	27 919	12 625	21 275
PFBS	1 744	1 829	2 149	1 143	1 749	2 196	1 526
PFPeA	8 956	10 309	13 271	5 567	10 288	5 837	7 900
PFHxA	1 576	1 963	3 201	662	1 581	841	1 793
Gen-X	660	843	558	530	514	516	538
PFOA	559	553	577	274	499	351	371
PFHxS	638	708	643	474	525	650	556
PFNA	331	266	253	132	270	148	255
PFOS	147	129	130	98	104	115	93

Trial Summary

- Fluctuation in PFAS concentration in leachate during the season
- PFAS capture is dependent on molecular weight and structure, and may be partitioned to:
  - Soils
  - Roots and Bark
  - Leaves
  - Little accumulation in wood
- Bioaccumulation in all willow parts : roots, above-ground woody biomass and leaves
- Variation in bioaccumulation capacity between varieties
- Some PFAS appear to be preferentially bioaccumulated, with capture rates of up to 100% for some compounds
- Woody biomass remains lower than other parts, remaining viable for engineered product use.



Management Pathway



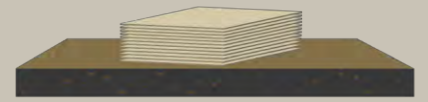
Recycling leachate on willow plantation

Chipped wood harvesting

Chipped wood

Soil amendment on site

(Ramial chipped wood)



Chipped board / sound board

Incineration / Pyrolysis / Gasification

Stems harvesting

Stems

Noise barriers / fences

Control center

Willows after two years of growth

Overview

Client

Location

LET Sainte-Sophie

Tons of co2 eq captured annually

432 tonnes/yr

m3 reduced annually

3000-5000 m^3/ha

Plantation area

10 hectares

Expanded to 10 ha from 1.2 ha in 2024

Summary

- Manages effluent through evapotranspiration – a nature-based solution
- Generates biomass, harvested and reused as mulch or other by-products
- Biomass and soils bind PFAS contaminants, simplifying management
- 7 systems active in Quebec (landfills and mines)
- Western Canada sites expected to match or exceed performance
- Lower lifecycle cost: less water to treat, plus RCW as a valuable output
- Turns a water liability into an asset

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