Groundwater at the Crossroads:
Emerging Contaminants and the Biochar Black Box

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Denmark's Groundwater Challenge: A Perfect Storm Brewing

100%

GW Dependence

Denmark relies almost exclusively on groundwater for drinking water, with minimal treatment compared to other European nations

400+

Chemicals Detected

Single waterworks screening revealed over 400 different chemical compounds

Natural as well as Artificial

5

Never Found Before

Five compounds detected in Danish groundwater have never been reported in groundwater anywhere in the world

Primarily qualitative, not quantitative

Many detected peaks cannot be identified

Detect unexpected contaminants

screen for emerging pollutants

understand chemical fingerprints

Key Challenge

- Current monitoring focuses mainly on known and regulated substances like nitrates and known pesticides/degradation products, while possibly hundreds of unregulated emerging contaminants which may be risky slip through undetected.
- QA/QC and Monitoring cost
- And **it is not all the chemicals that are toxic/risky,** so prioritization is a must

PFAS - The Forever Chemical Crisis Accelerating in Danish Aquifers

1960
Before 1960
Unmeasurable
No detectable TFA levels in Danish groundwater

1980
1960-1980
0.06 ppb
Average TFA concentration

2000
1980-2000
0.24 ppb
4x increase from previous period

2020
2000-2020s
0.6 ppb
Exceeds EU safety limit of 0.5 ppb
Denmark – 0.9 ppb

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OCCURRENCE, FATE, AND TRANSPORT OF AQUATIC AND TERRESTRIAL CONTAMINANTS | September 4, 2024

A 60-Year Increase in the Ultrashort-Chain PFAS Trifluoroacetate and Its Suitability as a Tracer for Groundwater Age

Christian N. Albers*, and Jürgen Sültenfuss

Diffus grundvandsforurening med trifluoreddikesyre (TFA)

Report | Danmarks og Grønlands Geologiske Undersøgelse Rapport 2024/4

Christian Nyrop Albers
Department of Geochemistry, GEUS

A rare case!

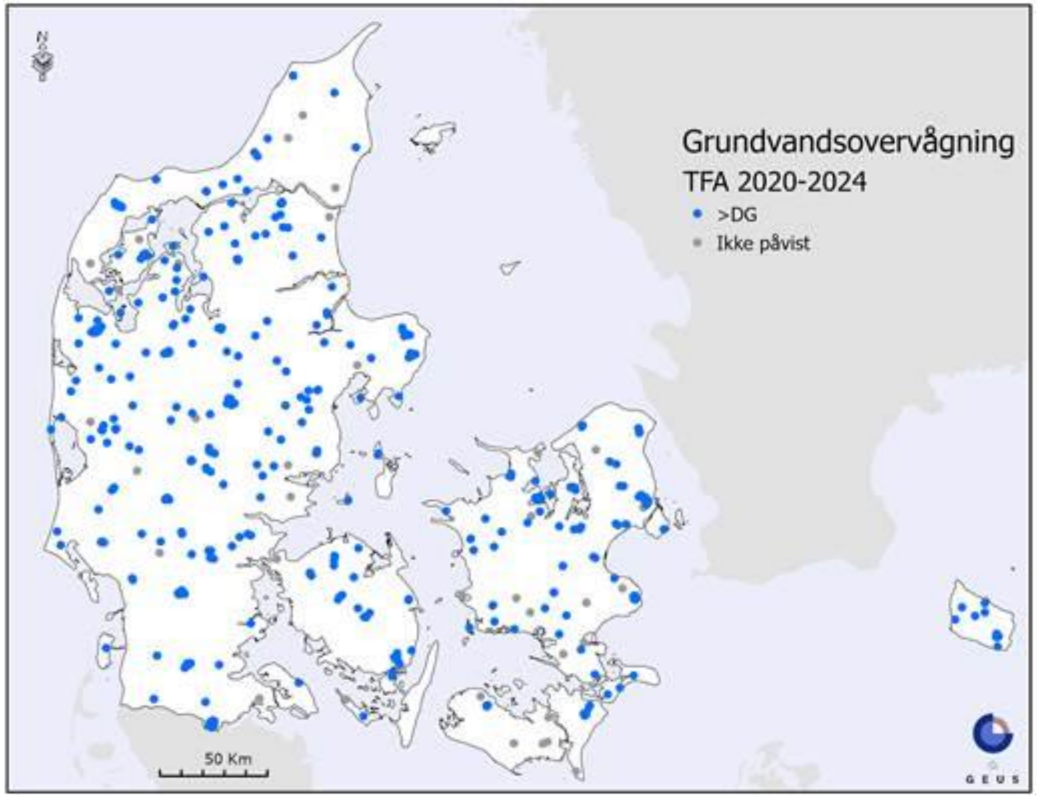
⚠ Ronneby Case Study: World's Worst PFAS Contamination

2,450×
Above Safety Threshold (highest ever in municipal drinking water)

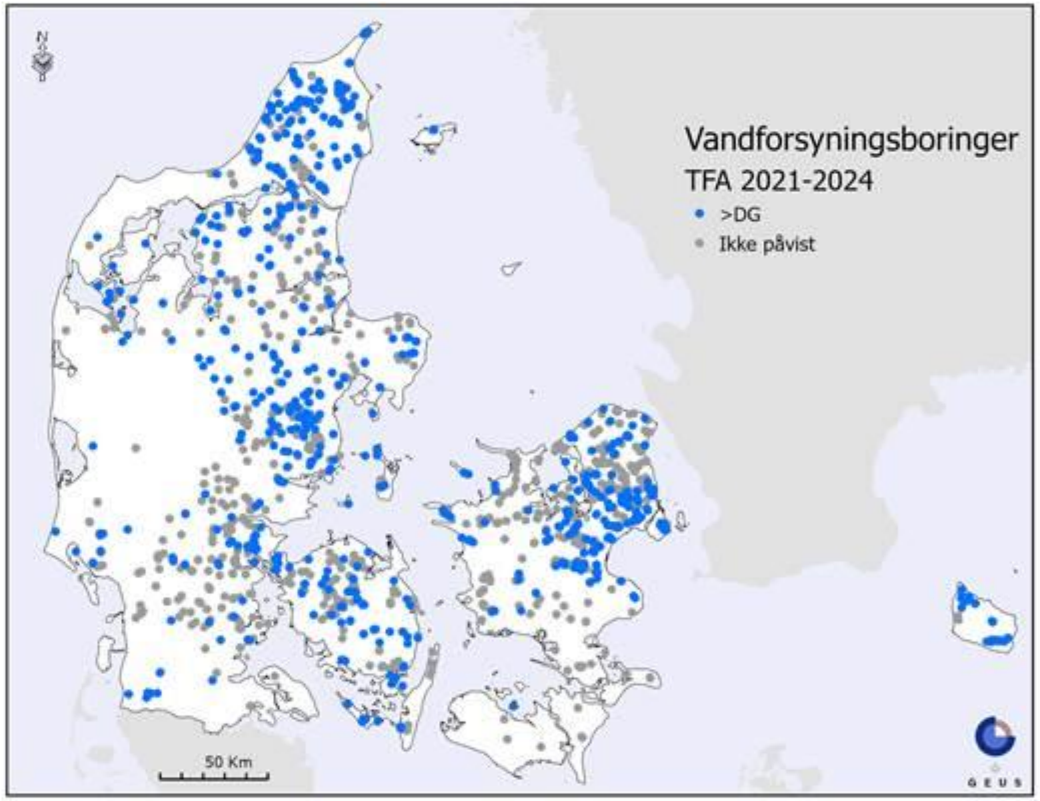
37×
Higher PFAS in children's blood vs. non-contaminated areas

31
PFAS pesticides banned in Denmark (2025)

Groundwater monitoring wells



Water supply wells



Blue: “TFA detected”
Grey: “TFA below detection limit”

Grundvandsovervågning
Status og udvikling 1989 – 2024

GEUS 2025

www.grundvandsovervaagning.dk

Pharmaceuticals and Personal Care Products - The Invisible Invasion

Caffeine	14,000+ ng/L
Diclofenac (painkiller)	1.4M ng/L
DEET (insect repellent)	Ubiquitous

Prioritization is a must based on the toxicity & mobility

Persistent, mobile and toxic (PMT) and very persistent and very mobile (vPvM) substances pose an equivalent level of concern to persistent, bioaccumulative and toxic (PBT) and very persistent and very bioaccumulative (vPvB) substances under REACH

Sarah E. Hale, Hans Peter H. Arp, Ivo Schliebner & Michael Neumann

Environmental Sciences Europe **32**, Article number: 155 (2020) | Cite this article

Contamination Pathways

Wastewater treatment plant effluent (compounds not removed)
Hospital discharges and pharmaceutical factories
Landfill leachate and agricultural runoff
Veterinary antibiotics in manure from livestock

Antibiotic Resistance Genes (ARGs)

Missing!

- **More than 85 individual ARGs detected globally in groundwater** conferring resistance to 13 antibiotic classes
- **Denmark**: ARG contamination linked to sludge spreading on agricultural fields
- **EEA Priority (2025)**: Europe-wide monitoring for antimicrobial resistance in water needed

Industrial Chemicals to Tap Water

Benzothiazoles

Rubber & Tyre Products

Primary Sources

Car tyres, artificial turf pitches, rubber products

Pathways to Groundwater

Road runoff, leaching from sports facilities, stormwater infiltration

Toxicity Profile

High toxicity in cell tests; never found before in Danish groundwater

⚠ **Unknown long-term health effects**

TDCPP

Flame Retardants

Primary Sources

Furniture, building materials, electronics, textiles

Pathways to Groundwater

Leaching from landfills, building demolition, product degradation

Health Effects

Endocrine disruptor, reproductive toxin, carcinogenic potential

⚠ **Acknowledged health hazard**

Melamine

Plasticizers & Detergents

Primary Sources

Hard plastics, cleaning detergents, industrial products

Pathways to Groundwater

Wastewater discharge, landfill leachate, household waste

Health Effects

Kidney and bladder damage, endocrine disruption

⚠ **Organ toxin**

Real-World Scenario

High-Risk Locations: Waterworks near major highways, industrial zones, or sports complexes with artificial turf should monitor for benzothiazole compounds and flame retardants. These sources create persistent contamination plumes that can reach aquifers through road runoff and stormwater infiltration.

Industrial Chemicals: The Potent Threat of Transformation Products

Bisphenol-A (BPA)

Source: Plastics (polycarbonate), epoxy resins in pipe linings, food cans

Type: Endocrine-disrupting chemical

Health Risk: Reproductive health effects, developmental impacts

EU Status (2025): Designated as a priority hazardous substance under the revised Water Framework Directive

Implication for Engineers

BPA designation signals move towards stricter control and potential source-control measures. Review pipe materials and treatment effectiveness.

6PPD-quinone

Source: Transformation product of 6PPD antioxidant in vehicle tires

Pathway: Road runoff and stormwater infiltration

Toxicity: Highly toxic; linked to acute toxicity in aquatic organisms

EU Status (2025): Included on EU Watch List due to high toxicity

Critical Action

Water works near major highways and high-traffic areas must prioritize monitoring for 6PPD-quinone as a real-time, highly toxic threat from urban runoff.

ARTICLE | June 16, 2025

Occurrence and Distribution of 1,3-Diphenylguanidine, Benzotriazole, Benzothiazole, *N*-(1,3-Dimethylbutyl)-*N*′-phenyl-p-phenylenediamine, and Their Derivatives in Surface Water, Drinking Water, Stormwater Runoff, and Rainwater from New York State, USA

Zhong-Min Li, HuiHo Jeong, and Kurunthachalam Kannan*

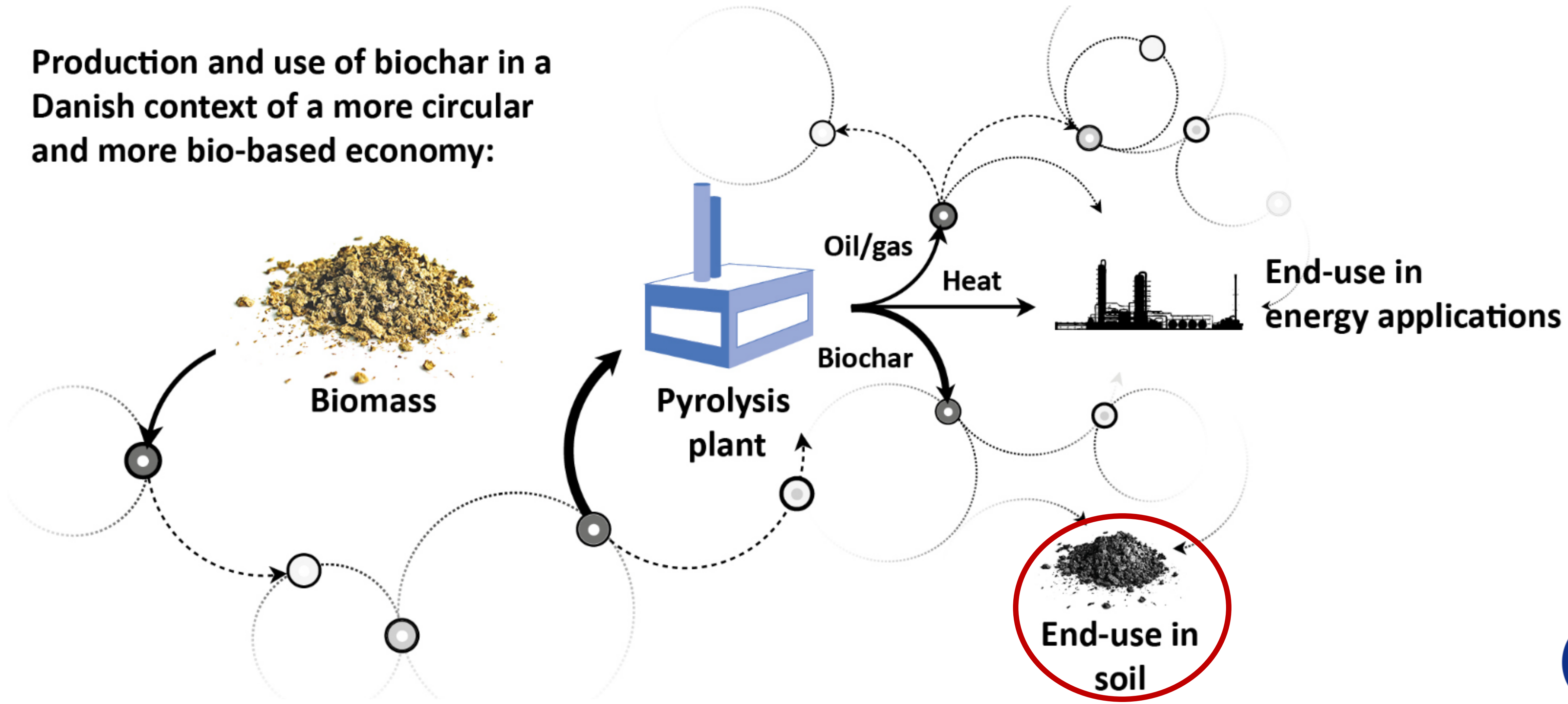
Melamine – A PMT/vPvM substance as a generic indicator for anthropogenic activity and urbanisation? An explorative study on melamine in the water cycle and soil

WHAT IS BIOCHAR?

Biochar is a stable carbonaceous material produced by heating organic waste (like crop waste, wood waste, livestock and poultry manure, etc.) in an oxygen-free environment through pyrolysis technology. Biochar looks similar to charcoal, but it has higher carbon stability.

Biochar in Denmark – Reduce C Footprint

Production and use of biochar in a Danish context of a more circular and more bio-based economy:



Thomsen 2022, Introduction to Production and Use of Biochar: working towards a more circular and bio-based Danish economy

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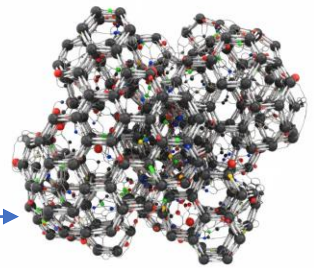
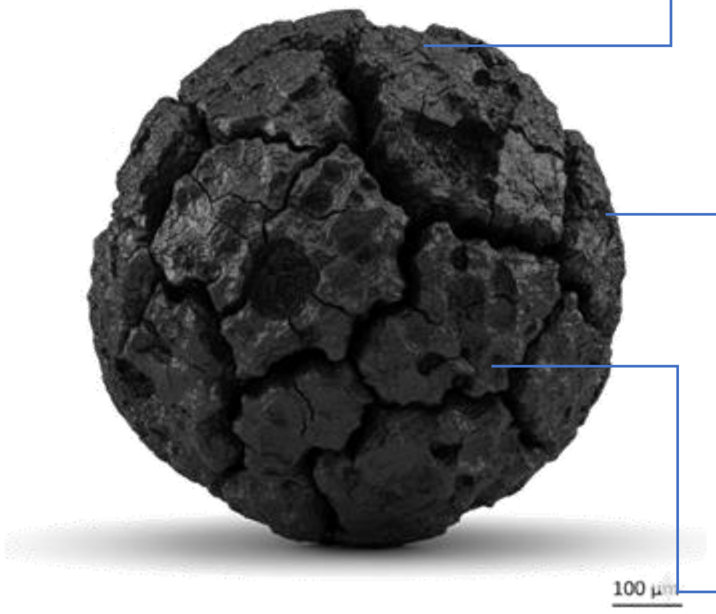
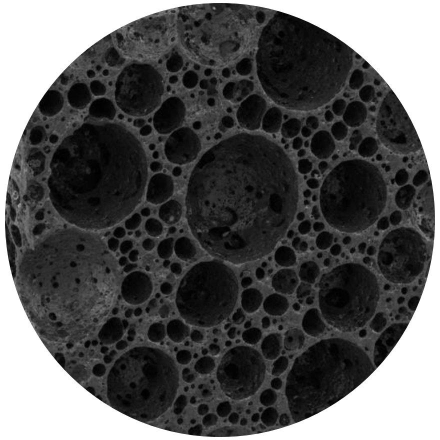
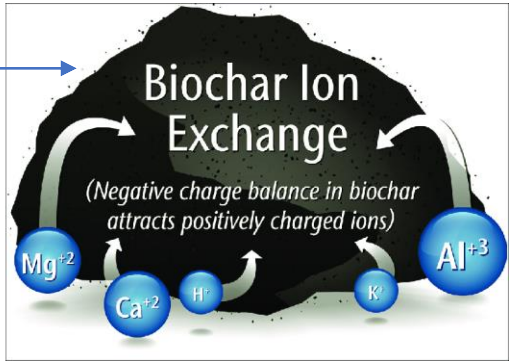
Biochar Properties Favorable for Long-Term Carbon Storage









Chemical Stability
- Highly aromatic polycyclic carbon structure
- Resists microbial decomposition (recalcitrant)
- Long half-life (100s to 1000s of years) due to fused ring systems

Physical Structure
- High porosity & surface area
- Micro & macro-pores protect C from microbes
- A dense rigid structure provides durability

Surface Chemistry
- Negative surface charge
- High cation exchange capacity
- Forms stable-organic-complexes in soil

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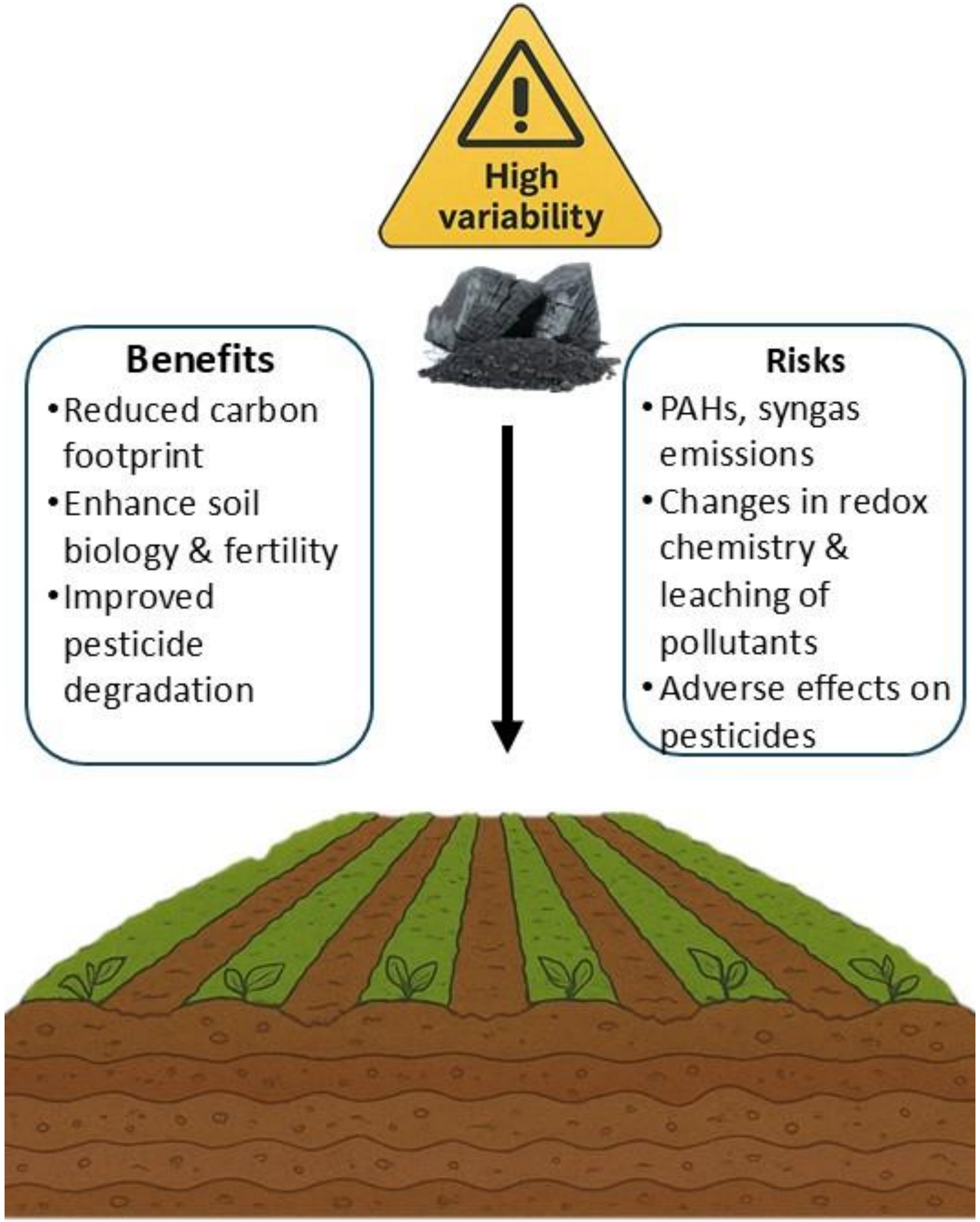
Is biochar a silver bullet?



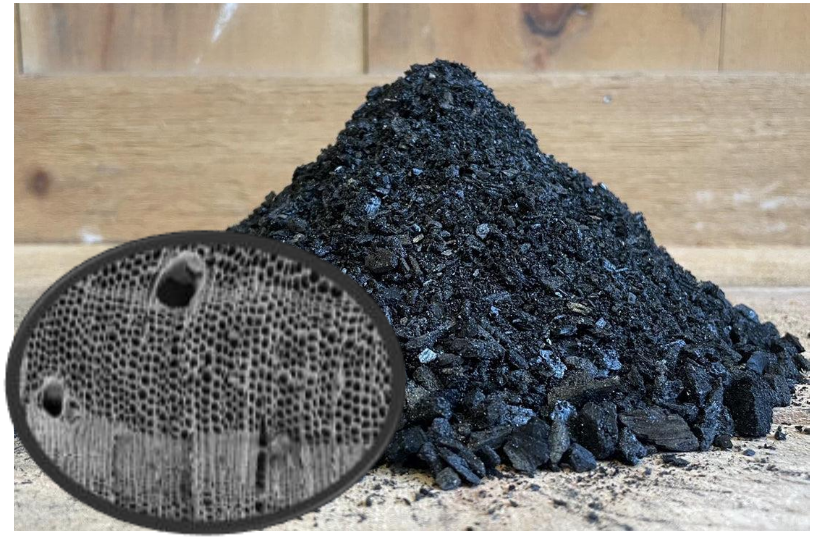
Focus in Geochemistry - GEUS

Biochar for Removal of Emerging and Forever Chemicals

pesticide residue, antibiotics
highly mobile chemicals

Composite Fertilizer from Manure and Biochar

reduce manure application
and improve soil health



Engineered Sewage Sludge Biochar

recover P

Fundamental Mechanisms of Biochar on Pesticide Residue

when applied in soil

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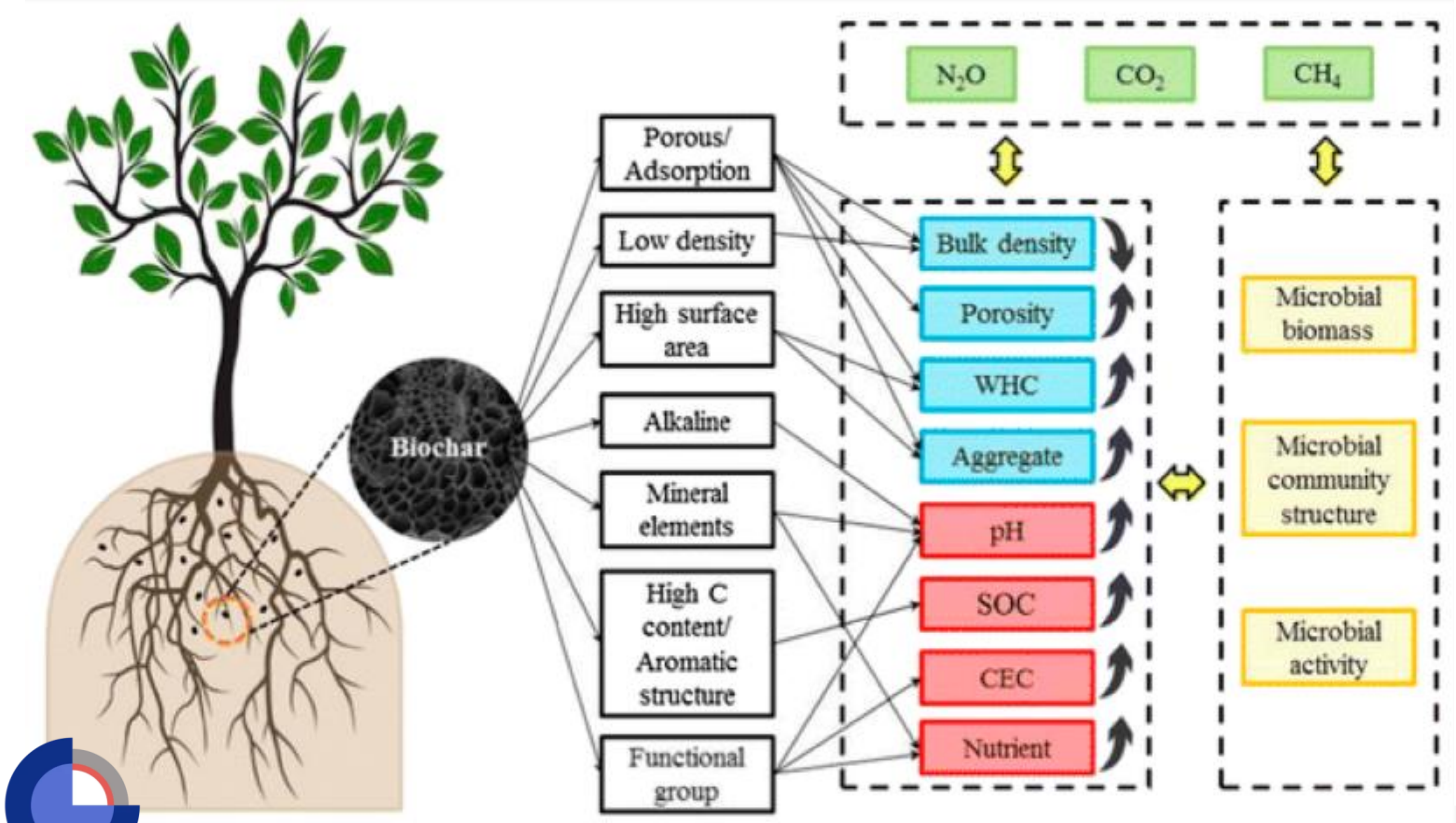
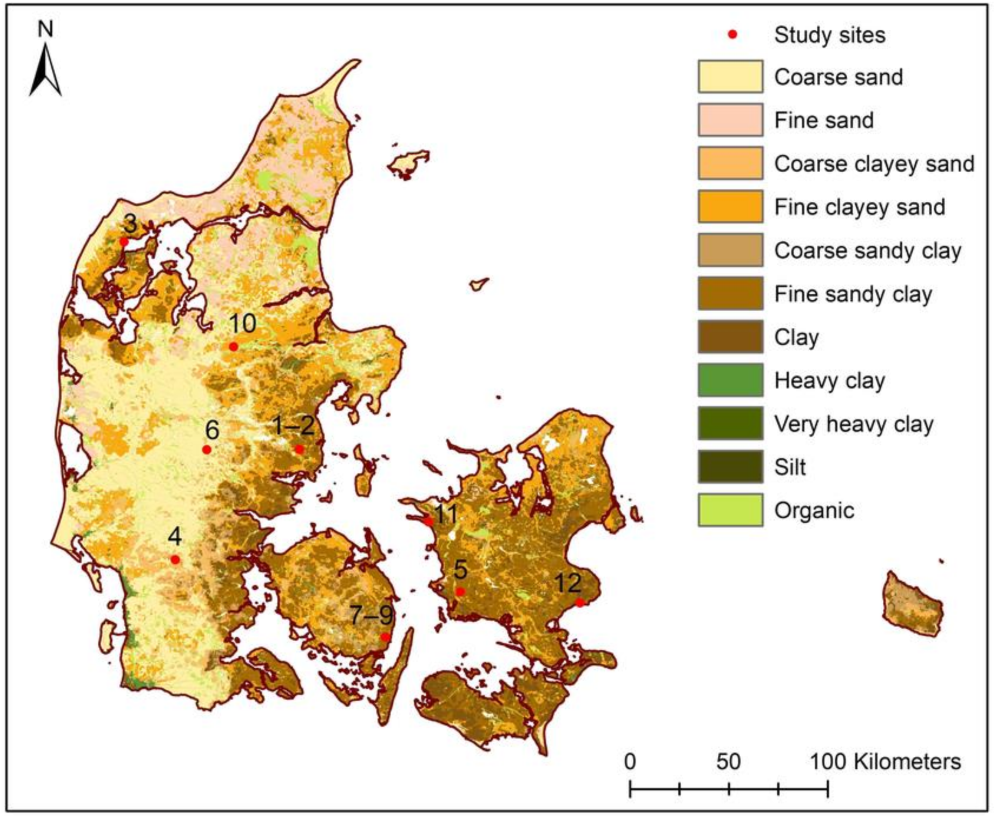
BC application changes soil conditions





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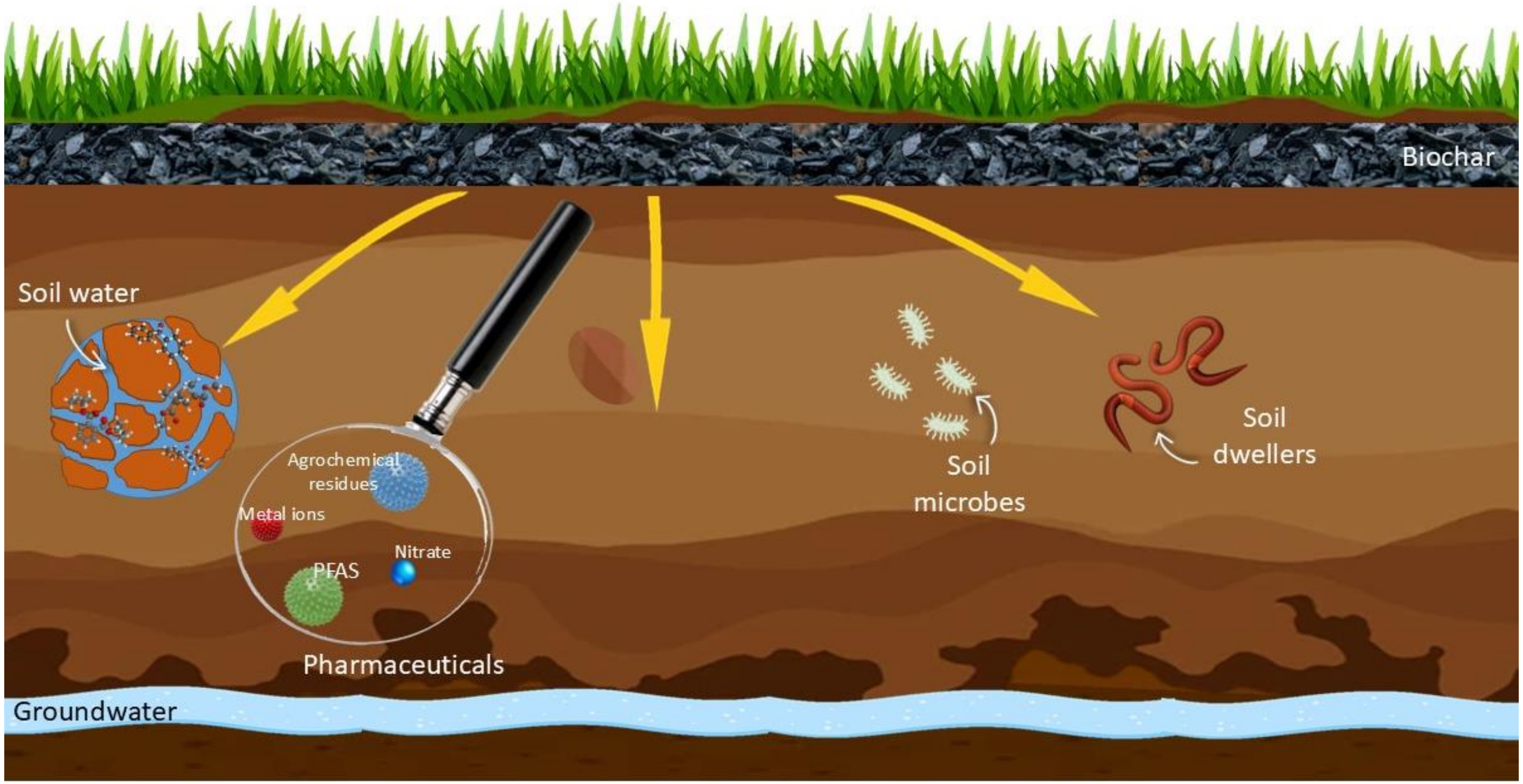
Bhat et al., 2022

Project 1

BioReCo

Biochar, Redox, and Contaminant fate in CO_2 sequestration

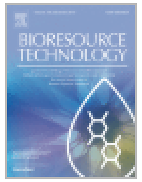
Will focus mainly on the retention/release mechanisms of contaminants with the application of BC into different Danish soils



ELSEVIER

Bioresource Technology

Volume 246, December 2017, Pages 271-281

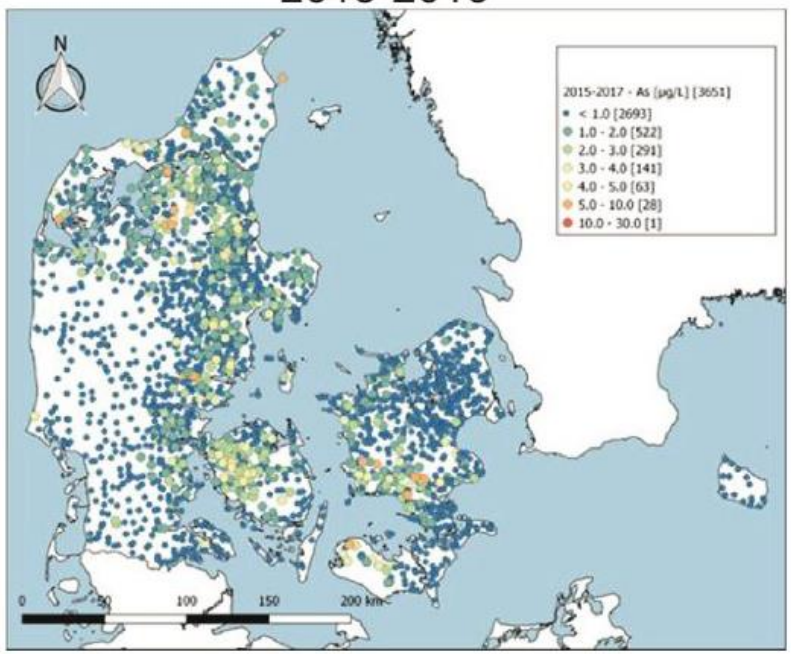


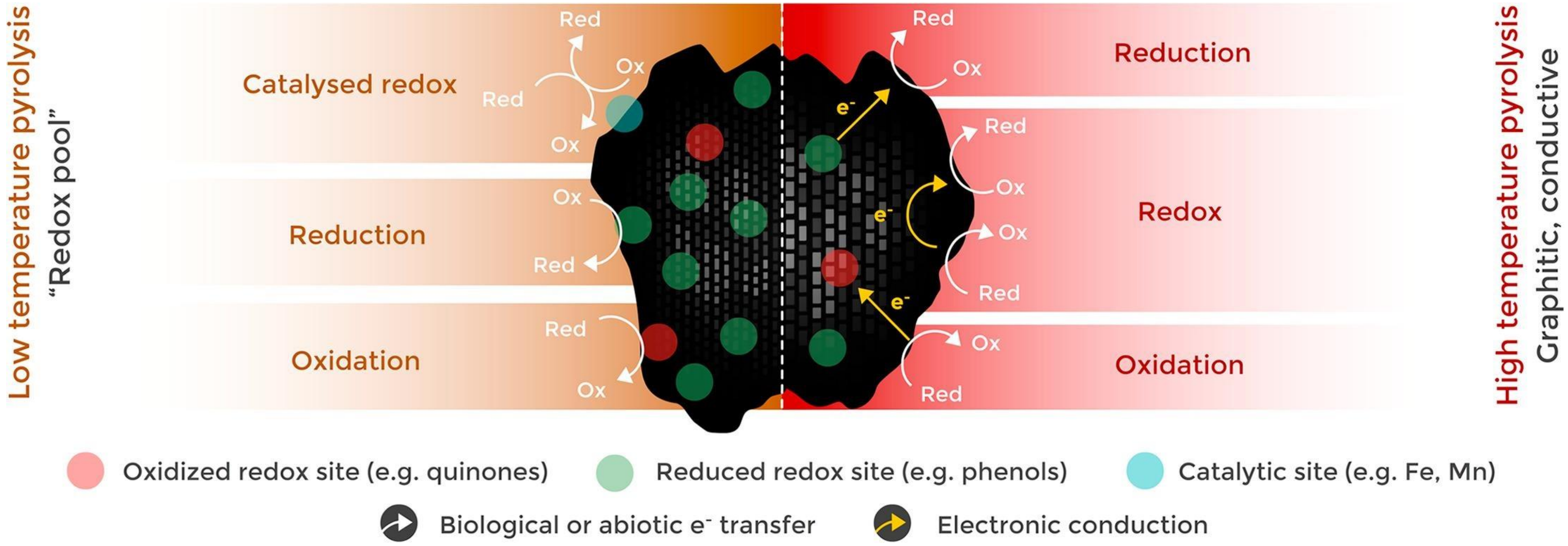
Review

Applications of biochar in redox-mediated reactions

Yong Yuan [a], Nanthi Bolan [b c], Antonin Prévoteau [d], Meththika Vithanage [e], Jayanta Kumar Biswas [f], Yong Sik Ok [g], Hailong Wang [h i]

2015-2016





Remarks

- Among many contaminants urgent attention should be given to ARGs, Transformation products from pesticides and industrial chemicals such as 6PPDQ, PMTs such as TFA, Flame retardants and DEET, however prioritization is essential with toxicity/risk and frequent and careful monitoring with strong QA/QC.
- Recharge zones to be carefully monitored, specially if there is stormwater recharge.
- Application of biochar can provide environmental benefits, but may also introduce negative effects, such as altering soil chemistry or releasing contaminants.
- In Denmark, where groundwater is the main source of drinking water, biochar used for carbon storage must not compromise groundwater quality—pollutant release due to changes in soil redox conditions is a key concern and should be looked at based on different soil and biochar types.

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Thank You

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