

The background of the slide is a photograph of a wastewater treatment plant. In the foreground, there are large, circular aeration tanks with visible water surface and some steam or mist rising from them. In the background, there are industrial structures, including tall chimneys and metal frameworks, silhouetted against a dramatic sky with orange and yellow clouds from a low sun. The overall scene is industrial and atmospheric.

ART CARBON[®] in Quaternary Wastewater Treatment

Why our technology differs from established practice in Germany and Switzerland — energy demand, regeneration, and removal of pharmaceuticals, drugs and hormones

A technically rigorous, business-readable comparison for water utilities, WWTP operators, municipalities and investors.

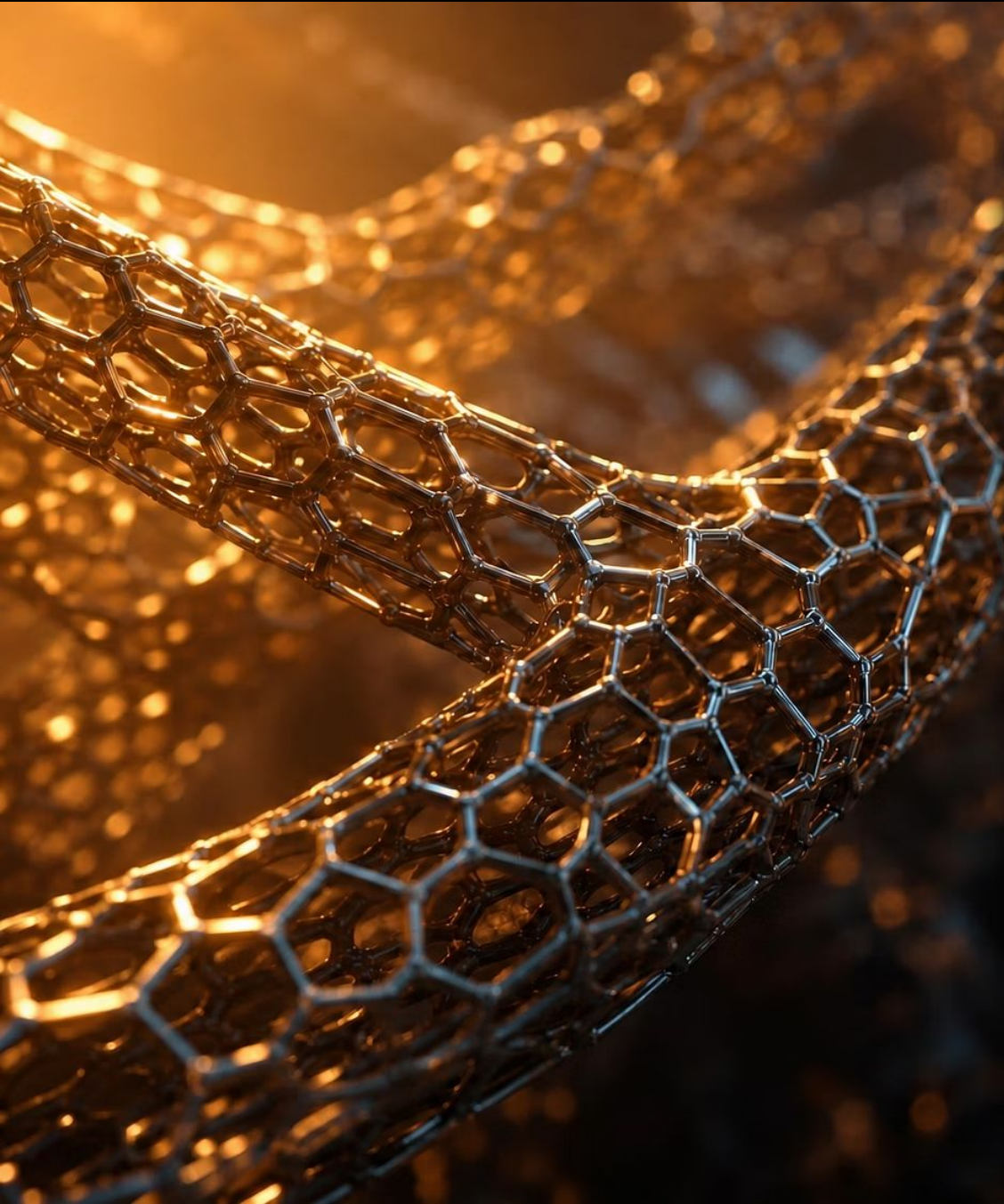
DANIEL-LM s.r.o. — Aqua TECH North Bohemia Division · Vinořské nám, 34 – Vinoř, Czech Republic · info@aquananotech.eu · www.aquananotech.eu · September 2026

An aerial photograph of a wastewater treatment plant at sunset. The plant features several large circular clarifiers, numerous storage tanks, and various industrial buildings. A bridge is visible in the background over a body of water. The scene is bathed in the warm, golden light of the setting sun.

1. Introduction and Legislative Context

The revised EU Directive 2024/3019 on urban wastewater treatment introduces a requirement for a quaternary treatment stage targeting micropollutant removal (pharmaceuticals, pesticides, hormonally active substances, PFAS) at large wastewater treatment plants. Pressure is rising on the drinking-water side too — a new limit for total PFAS has applied in the Czech Republic since 12 January 2026.

The established European response — mainly in Germany and Switzerland — is a combination of ozonation and biologically active carbon (BAC/GAC), or dosing of powdered activated carbon (PAC). This document compares that established route with the Czech carbon-nanotube (CNT) technology ART CARBON®.



2. Why the ART CARBON[®] Principle Is Different

2.1 Two capture mechanisms

Classic granular activated carbon (GAC) captures contaminants by diffusion into its internal pores — it works like a sponge. ART CARBON[®] operates on a completely different principle: an adsorbent based on carbon nanotubes with a very large external surface area. Contaminants are not captured by diffusion into the material — they bind instantly to the outer surface of the nanotubes. The mechanism resembles a flytrap more than a sponge.

2.2 Chemical oxidation vs. physical capture of the whole molecule

Ozonation does not break down pharmaceutical molecules directly into CO₂ and water — ozone chemically splits them into smaller fragments. ART CARBON[®], by contrast, captures the molecule in its original form directly on the nanotube surface. No new, unknown transformation products are formed.

2.3 Number of Process Steps and Contact Time

In German and Swiss practice, BAC is always embedded in a chain with three additional steps: ozonation upstream of BAC, mechanical post-filtration/ultrafiltration downstream of BAC, and strong terminal disinfection. The result is four interdependent process steps, where failure of any one affects the whole chain.

ART CARBON® needs only ceramic ultrafiltration ahead of the adsorption step itself — two steps instead of four. While indicative BAC contact time is 5–10 minutes (plus 10–20 minutes of ozonation), ART CARBON® achieves high capture in seconds to a few minutes.

✓ **LAB-VERIFIED** — Independent tests by the Technical University of Liberec (TUL)

Step / parameter	Traditional BAC chain	ART CARBON® chain
 Number of process steps	4	2
 Indicative contact time	5–10 min (+10–20 min ozonation)	Seconds to a few minutes
 Terminal disinfection	Yes (strong)	Yes (strong)
 Step interdependency	4 interdependent	2 interdependent





3. Energy Demand

3.1 Where energy is consumed in ozonation

At Weißenburg, ozonation accounted for 52% of the total electricity consumption of the new polishing stage. Specific consumption: 0.04–0.17 kWh/m³ of treated water. Roughly 80–90% of the electricity supplied converts to waste heat, removed by water cooling.

3.2 ART CARBON® energy balance

A complete ART CARBON® line requires no oxidant-generation step at all. Ceramic ultrafiltration approx. 0.10 kWh/m³ + pumping approx. 0.50 kWh/m³ = approx. 0.60 kWh/m³ total for complete micropollutant separation.

3.3 Behaviour in demanding seasonal conditions

With ozonation + BAC, bacterial metabolism slows in winter — roughly 2× longer contact time is needed. ART CARBON®: zero temperature effect — capture is purely physical. Sterile behaviour — TUL 2023 confirmed zero colonies even after 14 days of stagnation.

4. Regeneration — Economic and Ecological Aspects

4.1 GAC/BAC — thermal reactivation

Exhausted activated carbon must be mechanically excavated, trucked to a reactivation furnace and fired at 700–900 °C. This process irreversibly loses 5–15% of the carbon's mass per cycle.

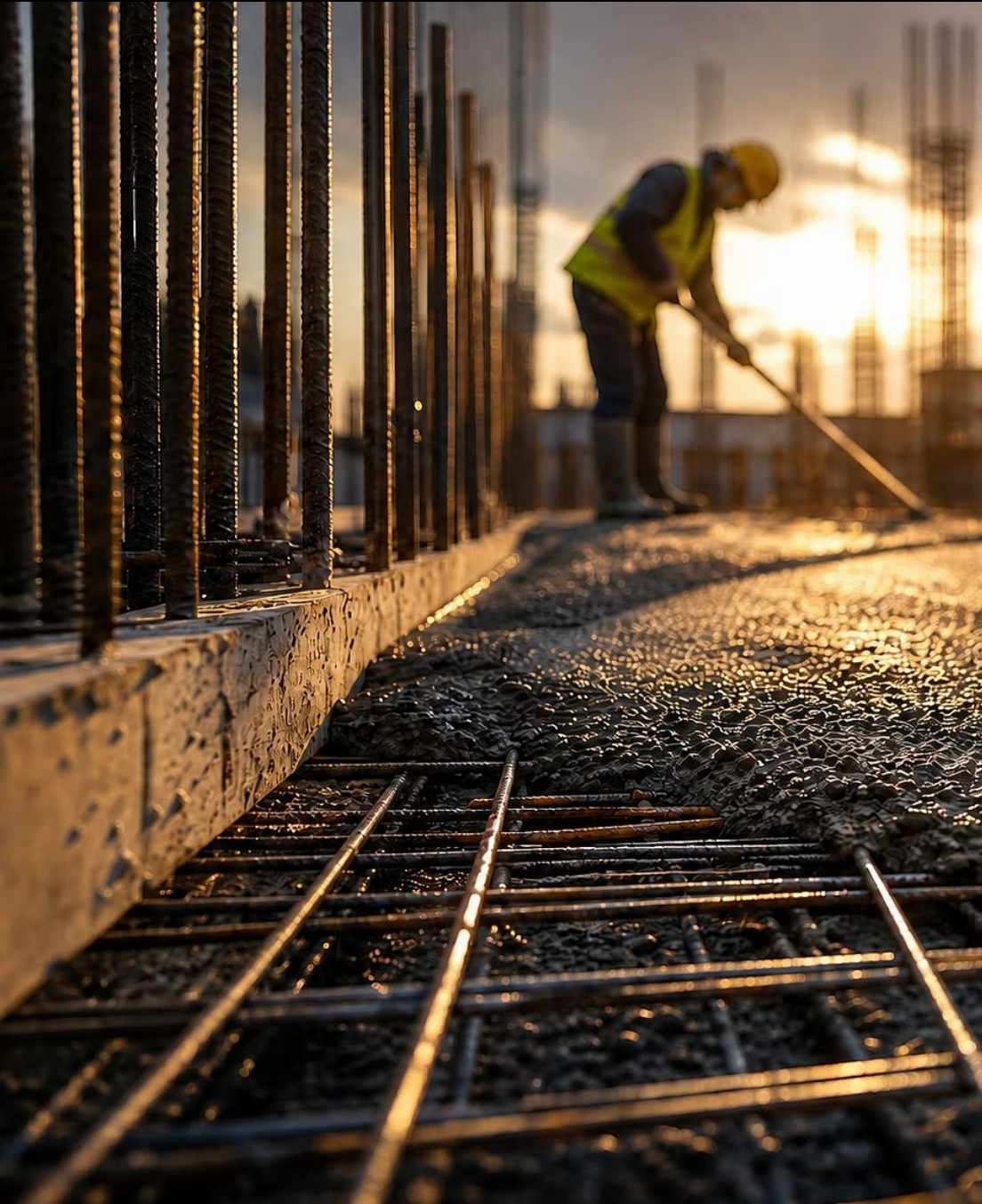
4.2 ART CARBON® — cold, in-situ

Regeneration takes place directly in the column, without removing the adsorbent. The bed is flushed with a dilute (approx. 5%) food-grade ethanol solution at 20–40 °C for approx. 30 minutes. Reverse osmosis separates the regenerate — approx. 90% of the volume returns as recycled ethanol, the remaining approx. 10% forms a concentrated liquid concentrate for thermal disposal (approx. 0.02 l/m³).

4.3 Service life and cyclability

✓ FIELD-VERIFIED — up to 32 full regeneration cycles without loss of sorption performance; total adsorbent service life is 2 years of continuous operation.





4.4 End of Material Life — Circularity

Spent nanotubes are regenerated once more and then added to a plasticizer as a functional additive, which is further applied in high-strength concretes and mortars, where it improves mechanical properties (especially compressive strength) and allows a reduction in cement consumption — one of the largest industrial sources of CO₂. This closes the material cycle: the spent adsorbent does not end up as waste for disposal, but as a raw-material input for a downstream industry.

4.5 Operating Economics (OPEX)

Direct production costs of the technology (energy, chemicals, regeneration, recycling, concentrate disposal, CNT replacement) are approximately CZK 3.00/m³ of treated wastewater.

⚠ TECHNICAL ASSUMPTION — *Technical calculation based on an internal reference document; not a multi-year audited OPEX operating balance.*

5. Removal of Pharmaceuticals, Drugs and Hormones

5.1 How efficiency is assessed in Germany and Switzerland German and Swiss practice assesses the quaternary stage using a set of indicator substances (e.g. diclofenac, carbamazepine, metoprolol, citalopram, clarithromycin, benzotriazole, candesartan, irbesartan, and others) – the statutory target is an average reduction of at least 80% across the monitored substances. Ozone splits reactive substances very well (diclofenac, carbamazepine above 95%), while less reactive substances (benzotriazole, metoprolol, candesartan, irbesartan) rely on further polishing by the downstream activated carbon (a further 70–95%).

⚠ EXTERNAL SOURCE – TO VERIFY: German/Swiss methodologies (DWA, KomS-BW) and full-scale data from Weißenburg – external sources, recommended to verify against the primary publication.

5.2 Weaker points of ozonation

- **Antibiotics:** clarithromycin is among the most problematic substances for ozonation lines – at Weißenburg combined efficiency (ozone + BAC/sand filter) averages only 64–65%. Ozone also chemically converts clarithromycin into the metabolite clarithromycin N-oxide, which only the final filter can capture. Sand and BAC filters downstream of ozonation are also reported to carry a risk of releasing antibiotic-resistant bacteria and resistance genes.
- **Hormones:** estrogens react quickly with ozone, but an imperfect dose can generate partially oxidised intermediates that retain estrogenic activity – special bioassays (e.g. the YES assay) are therefore recommended to confirm an actual decrease in hormonal activity, not merely the disappearance of the parent compound.

5. Removal of Pharmaceuticals, Drugs and Hormones

5.3 ART CARBON® capture kinetics (independent TUL tests)

- Naproxen (analgesic) — 30 s — ART CARBON® >91% · GAC/BAC 0%
- Carbamazepine (psychoactive drug) — 2 min — ART CARBON® 93% · GAC/BAC 8%
- Metoprolol (beta-blocker) — 5 min — ART CARBON® 97% · GAC/BAC 9%
- Simazine (pesticide) — 5 min — ART CARBON® 96% · GAC/BAC 1%

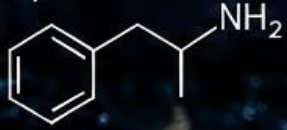
5.4 Breadth of removal in real wastewater

In a pilot verification on real wastewater from the Prague Císařský ostrov WWTP, 37 active pharmaceutical ingredients were identified. At a contact time of approx. 8 seconds, 35 of the 37 pharmaceuticals were removed below the detection limit.

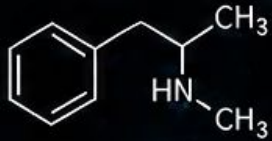
✓ FIELD-VERIFIED — Pilot verification, Prague Císařský ostrov WWTP.



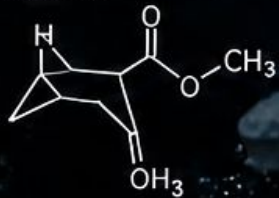
Amphetamine



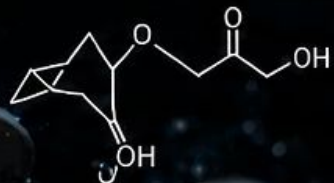
Methamphetamine



Cocaine



Benzoylecgonine



PHARMACEUTICALS

DRUGS

METABOLITES

CLEANER WATER
SAFER TOMORROW

5.5 Illegal Drugs and Their Metabolites

For illegal drugs and their metabolites (e.g. amphetamines, methamphetamine, cocaine/benzoylecgonine) we do not have separately measured data. Chemically these are small polar-to-aromatic organic molecules comparable to the tested pharmaceuticals, so similar adsorption behaviour can be expected — but this remains an unsubstantiated technical assumption, not a verified result, and targeted testing is required before making any efficacy claim for specific drugs of abuse.



TECHNICAL ASSUMPTION — Not substantiated by measurement — extrapolated from chemical similarity to the tested pharmaceuticals.



Note: The figures in Table 5.3 and across Sections 5.1–5.2 come from different waters, laboratories and protocols — this is not a direct measurement on one and the same water, but an indicative comparison. Before use in a specific tender or negotiation, we recommend verifying the German/Swiss figures against the primary publication.



ČISTĚJŠÍ VODA



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6. Ionization in Ozone Generation — What ART CARBON® Avoids (1/2)

The ozone used in the German and Swiss approach is generated on-site from oxygen via a high-voltage electrical discharge (corona discharge), which ionizes oxygen molecules and splits them into reactive oxygen radicals, from which ozone is formed. This is therefore an energy-intensive ionization process, not merely "adding a chemical".

ART CARBON® does not contain this step at all — capture is purely physical adsorption on the nanotube surface, without electrical discharge, without oxidant generation, and without any chemical reaction with the target substance. The following risks and operational burdens, which arise precisely from the ionization/ozone-generation step, therefore structurally do not apply to ART CARBON®.

- **Bromate risk:** if bromide is present in the water, ozone oxidizes it to carcinogenic bromate (BrO_3^-); Germany enforces a binding limit of 10 $\mu\text{g/l}$ and a mandatory prior "ozonatability test" of the raw water.
- **Unpredictable transformation products:** ozone splits molecules into fragments and metabolites (e.g. clarithromycin into clarithromycin N-oxide), which must then be captured by the downstream biological/adsorptive stage.
- **"Ozone paradox" (chloropicrin):** if the BAC stage does not perform at 100%, undegraded split fragments can form disinfection by-products upon contact with terminal chlorine, including chloropicrin.
- **Large heat losses:** 80–90% of the electricity fed into the ozone generator is converted into waste heat, which must be removed by water cooling.



6. Ionization in Ozone Generation — What ART CARBON® Avoids (2/2)

- **Mandatory destruction of residual ozone:** residual gas from the ozonation chamber cannot be released freely — it must be destroyed energetically and catalytically, back to oxygen (the "Restozonvernichter" / residual ozone destructor).
- **Oxygen logistics:** if ozone is produced from pure oxygen, a leased cryogenic storage tank and regular deliveries of liquid O_2 are required.
- **Online monitoring requirements:** safe ozone dosing requires continuous spectrophotometric measurement of UV absorbance (SAK254/UVA254) and redox potential.
- **Resistance-release risk:** sand and BAC filters downstream of ozonation are reported to carry a risk of releasing antibiotic-resistant bacteria and resistance genes (ARB/ARG).

Note: The risks of bromate, transformation products and the ozone paradox are well addressed legislatively and technically in both Germany and Switzerland. Filtration and maintenance are managed, not disregarded, risks. They are listed here because they are a structural consequence of the underlying principle — a consequence ART CARBON® avoids entirely by choosing a different principle, not because these risks go unaddressed in foreign practice.



7. Summary Comparison

Area	Ozonation + BAC/GAC (DE/CH)	ART CARBON®
Principle	Chemical oxidation by ozone + biological breakdown on carbon	Physical adsorption of the whole molecule on the CNT surface
Number of steps	4 dependent steps (O ₃ , UF/post-filter, BAC, disinfection)	2 steps (ceramic UF + adsorption)
Contact time	Approx. 10–20 min ozonation + 5–10 min BAC	Seconds to a few minutes
Energy	0.04–0.17 kWh/m ³ for ozone alone (+ cooling, oxygen); ozone = up to 52% of stage consumption	Approx. 0.60 kWh/m ³ for complete UF + adsorption (no oxidant production)
Cold weather	Approx. 2× longer contact time needed in winter	No effect — physical kinetics independent of temperature
Heat / stagnation	Risk of biofilm and pathogen overgrowth (<i>Legionella</i>)	Sterile behaviour, no biofilm (TUL 2023)
Regeneration	Thermal reactivation 700–900 °C, 5–15% mass loss, transport	In-situ, 20–40 °C, no transport; up to 32 cycles / 2 years operation
Pharmaceuticals/hormones	Approx. 92% average (12 indicator substances); weaker for antibiotics (clarithromycin 64–65%)	35/37 APIs removed in pilot; TUL kinetics 91–97% by substance
By-products	Risk of bromates, N-oxides, ozone paradox (chloropicrin)	No oxidation intermediates — purely physical capture

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