



DOES MAGNETIC SCALE TREATMENT WORK?

The scientific background — from limescale chemistry to Coey's design criterion



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IN BRIEF

Many people find that hard water causes limescale problems throughout the home, yet many are also sceptical of the solutions available for removing them – water softeners add sodium to the drinking water, and magnetic water treatment is met with scepticism. Does it work at all, or is it a modern form of quackery?

This whitepaper takes that scepticism seriously. It reviews where limescale comes from, which solutions exist and – as its main subject – the now-substantial peer-reviewed research into whether and how a magnetic field can change the way limescale precipitates. Finally, it explains why LAGUR's patented HOME and PRO are technically optimised against physicist J.M.D. Coey's mathematical criterion for when such treatment actually works.

SUMMARY

Limescale in drinking water is not a health problem but a physical and economic one: it forms a hard coating on heating surfaces and shortens the lifetime of appliances. For decades, magnetic water treatment was dismissed because no one could explain how a magnetic field could leave a lasting effect on limescale. The breakthrough came when it was shown that limescale precipitates via long-lived pre-nucleation clusters (PNCs/DOLLOPs) – and that these very clusters give a magnetic field a physical point of attack. Coey (2012) formulated a concrete design criterion showing that the effect depends on the treatment unit's length and the gradient of the magnetic field. LAGUR HOME and PRO are engineered to meet this criterion, and four independent external analyses commissioned by LAGUR (GEUS, the Danish Technological Institute, Rambøll and FORCE Technology) point consistently to a transformation of the limescale crystal structure from hard calcite towards soft aragonite – without removing the water's healthy minerals. FORCE Technology's XRD quantification of the phases is preliminary and still ongoing.

This whitepaper refers exclusively to peer-reviewed literature and named analysis reports. All sources are cited throughout and listed together at the end.



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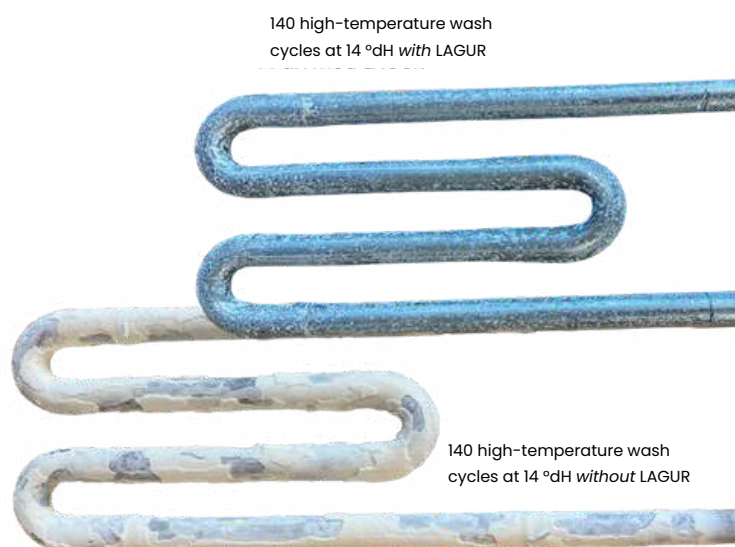
01 LIMESCALE PROBLEMS: WHY HARD WATER IS AN ISSUE

Hardness in drinking water is caused primarily by dissolved calcium and magnesium ions, where calcium carbonate (CaCO_3) is the dominant source in calcareous groundwater aquifers (WHO, 2011). In Denmark, where most drinking water is drawn from limestone and chalk aquifers, the water typically has a total hardness of 15–30 °dH, which is classified as "hard" to "very hard" (Hansen et al., 2011).

The problem is not one of health — there is no documented health risk from drinking hard water. The problem is technical and economic. When limescale precipitates on heating surfaces, it markedly reduces heat transfer: a deposit of just 1 mm CaCO_3 can increase the energy consumption of a hot-water tank by 7–10% (Müller-Steinhagen et al., 2011). Added to this are increased pressure loss in pipe systems, a shortened lifetime for household appliances and higher consumption of soap and cleaning agents (MacAdam & Parsons, 2004; Gabrielli et al., 2006). Several European studies have estimated that the total costs of hard water over a 10-year period exceed the cost of a scale-treatment system (van der Bruggen et al., 2009).

The reason conventional limescale is so difficult to remove lies in how it forms. When limescale precipitates directly onto a heating surface, dense, oriented deposits form with needle-shaped or rhombohedral crystals that anchor mechanically in the micropores of the surface (Andritsos & Karabelas, 2003). This epitaxial growth is why limescale deposits are hard, dense and typically require acid to be removed.

Figure 1. Heating elements from two identical washing machines after ~190 hours of boil-wash cycles at 14–15 °dH. Top (blue): with LAGUR. Bottom (white): without LAGUR. Source: Danish Technological Institute (TI LAGUR Test, 2020).





02 HOW DOES LIMESCALE GET INTO THE WATER?

Limescale dissolves through CO₂-driven weathering. Rainwater is slightly acidic (pH ~5.6) because atmospheric CO₂ dissolves and forms carbonic acid (Stumm & Morgan, 1996). When this CO₂-enriched water percolates through soil layers, where the CO₂ partial pressure can be 10–100 times higher than in the atmosphere, the dissolution of calcareous rock is accelerated – the classic carbonate weathering described by Plummer & Busenberg (1982). This weathering of carbonate rock is at the same time a central part of the Earth's long-term carbon cycle (Berner, 2003).

In groundwater, "limescale" exists as separate ions – not as a solid. Inorganic carbon occurs in three forms whose distribution is governed by pH. At typical groundwater pH (6.8–7.8), bicarbonate (HCO₃⁻) dominates, while carbonate (CO₃²⁻) is present in low concentrations. Calcium occurs as the free cation Ca²⁺ (Parkhurst & Appelo, 2013). Limescale is thus present as Ca²⁺, HCO₃⁻ and a little CO₃²⁻ – not as solid CaCO₃.

The chemical formula for the dissolution of limescale looks like this:



The water "balances on the edge". Danish groundwater is typically close to saturation or slightly supersaturated with respect to calcite (Appelo & Postma, 2005; Hansen et al., 2011). This means that even small disturbances – a rise in temperature, a pressure drop or CO₂ degassing – drive the system towards precipitation. This marginal stability explains why limescale deposits arise spontaneously from even modest changes in the state of the water.

Heating triggers the reverse reaction. When hard water is heated, the equilibrium shifts: the solubility of CO₂ falls with temperature (Henry's law) and it degasses, and – unlike most salts – the solubility of calcite also falls with temperature. This retrograde solubility (Plummer & Busenberg, 1982; Morse et al., 2007) is precisely the mechanism that forms the white deposit in kettles, shower heads, heating elements and washing machines (MacAdam & Parsons, 2004; Muryanto et al., 2014). Pressure drop at tap outlets and evaporation act in the same way.

When hard water dries out or is heated, the reaction therefore runs in reverse – CO₂ is released, and CaCO₃ precipitates as a solid:





Three crystal forms — one soft, one hard. CaCO_3 precipitates in three anhydrous polymorphs: calcite, aragonite and vaterite (Elfil & Roques, 2001; Morse et al., 2007). Calcite is the thermodynamically stable form, with a rhombohedral crystal structure (Markgraf & Reeder, 1985) and dominates in slow precipitation on heating surfaces — it is what produces the hard, tightly bound crust. Aragonite is favoured at higher temperatures ($>60\text{ }^{\circ}\text{C}$) (Chen et al., 2006) and forms softer, less adhesive deposits. This distinction — hard calcite versus soft aragonite — is the key to understanding what magnetic treatment sets out to do.



03 SOLUTIONS FOR SCALE PROBLEMS: REMOVE OR TRANSFORM

Solutions for limescale fall into two fundamentally different families that are often confused:

A. Methods that REMOVE calcium (and minerals) from the water

- Ion exchange / softening: Ca^{2+} and Mg^{2+} are exchanged for sodium (Na^+) over a resin. Effective against limescale, but it adds sodium, requires salt and regeneration, and produces saline wastewater (Gabrielli et al., 2006).
- Reverse osmosis (RO) / nanofiltration: The water is forced through a membrane that retains ions. Removes limescale effectively, but it demineralises the water, wastes some as reject water and requires energy and maintenance (van der Bruggen et al., 2009).
- Template-assisted crystallisation (TAC/NAC): Limescale binds to seed sites on a granulate and is removed as microgranules. Chemical-free, but the consumable medium must be replaced (Fox et al., 2014).

B. Methods that TRANSFORM the limescale without removing it

Physical water treatment — including magnetic and electromagnetic treatment, as used by LAGUR — does not remove calcium. Instead, it changes the way the limescale precipitates, so that it forms a soft, non-adhering coating rather than a hard crust. The chemical composition of the water is unchanged. Summarising review literature describes this category as non-invasive: it neither alters the composition of the water nor produces chemical waste (Martínez Moya & Boluda Botella, 2021; Fox et al., 2014).

Table 1 Comparison of limescale solutions

Method	Principle	Removes minerals?	Chemistry / waste?	Type
Ion exchange (softening)	$\text{Ca}^{2+}/\text{Mg}^{2+}$ exchanged for Na^+	Yes	Salt + wastewater	Removes
Reverse osmosis	Membrane filtration	Yes (all)	Wastewater	Removes
Nanofiltration	Partial membrane filtration	Partly	Wastewater	Removes
TAC / template	Limescale binds to granulate	Partly	Consumable medium	Removes
LAGUR (magnetic)	Transforms calcite → aragonite	No	None	Transforms

Sources: Gabrielli et al. (2006); van der Bruggen et al. (2009); Fox et al. (2014); Martínez Moya & Boluda Botella (2021).



04 THE ADVANTAGE OF NOT REMOVING THE MINERALS

Transforming the limescale rather than removing it has an important consequence: the water's natural content of calcium and magnesium is preserved. This is an advantage for several reasons.

- Calcium and magnesium are nutrients. In a dedicated expert report, WHO reviewed the possible health significance of calcium and magnesium in drinking water, including the water's contribution to total daily intake and the epidemiological links between water hardness/magnesium and cardiovascular disease (WHO, 2009). Drinking water may thus make a supplementary – if minor – contribution to the intake of these minerals.
- Demineralised and very soft water is more aggressive. Water with a low mineral content is more corrosive to pipes and installations, which is exactly part of WHO's assessment of the technical and economic aspects of softening and demineralisation (WHO, 2009; van der Bruggen et al., 2009).
- No sodium load. Ion-exchange softening replaces calcium with sodium and thereby raises the water's sodium content – relevant for people on a sodium-restricted diet (Gabrielli et al., 2006). Magnetic treatment adds nothing.
- No chemicals, no waste. Membrane and ion-exchange methods produce waste or regeneration water. Physical treatment does not (Martínez Moya & Boluda Botella, 2021).



05 CAN MAGNETISM CHANGE HOW LIMESCALE PRECIPITATES?

This section is the whitepaper's core.

The question is simple to ask and hard to answer: can a magnetic field — without adding anything — change the way limescale precipitates, and thereby remove the problems caused by limescale in water? The answer has moved from "probably not" to "yes, under the right conditions" as the fundamental research into how limescale forms in the first place has matured. The evidence is reviewed below.

05.01 WHY WAS MAGNETIC WATER TREATMENT MET WITH SCEPTICISM?

For decades, a plausible mechanism was lacking. Classical nucleation theory assumes that (limescale) crystals form spontaneously from free ions, and that such a nucleus lives for only microseconds — far too short to "remember" a magnetic influence that may have occurred minutes or hours earlier (Coey, 2012). In addition, the effect of magnetic treatment of water was hard to reproduce in many early experiments, because it depends on flow velocity, magnetic-field gradient and field strength (Vaskina et al., 2020; Martínez Moya & Boluda Botella, 2021). Without a mechanism and with fluctuating results, the scepticism was justified.

05.02 NON-CLASSICAL NUCLEATION AND PRE-NUCLEATION CLUSTERS

The scientific breakthrough came when it was shown that limescale in fact follows a non-classical nucleation pathway, that is, a non-classical crystal formation. Even in undersaturated solutions there are stable, pre-nucleation clusters (PNCs) — nanometre-sized, dynamic ion aggregates that can make up as much as about 50% of the dissolved calcium in the water (Gebauer, Völkel & Cölfen, 2008; Pouget et al., 2009). Molecular-dynamics simulations showed that these clusters are flexible, liquid-like ionic polymers — so-called DOLLOPs (Dynamically Ordered Liquid-like Oxyanion Polymers) — chains, rings and branches of alternating Ca^{2+} and CO_3^{2-} held together by purely ionic interactions (Demichelis, Raiteri, Gale, Quigley & Gebauer, 2011). Crucial for what follows: a DOLLOPs radius can be changed by a factor of two at an energy cost less than the thermal energy $k_B T$ — in other words, it is easy to deform (Demichelis et al., 2011).



The existence of PNCs has since been confirmed experimentally by several independent methods – including synchrotron-based X-ray scattering (SAXS), which finds the clusters even in solutions undersaturated with respect to all known limescale phases (Avaro, Moon, Schulz & Rose, 2023), and DNP-enhanced NMR spectroscopy, which has captured the short-lived pre-nucleation species directly (Balodis et al., 2024). The clusters have even been measured as real nanoparticles in ordinary drinking water (Zarei et al., 2024). Recent work from Coey's own group has moreover examined the stability of the pre-nucleation clusters and their interaction with nanobubbles during ultrasonic treatment of hard water (Fitzgerald et al., 2024).

Limescale crystal formation therefore proceeds in steps – not directly from free ions:
 $\text{Ca}^{2+} + \text{CO}_3^{2-} \rightarrow \text{PNCs} / \text{DOLLOPs (1–3 nm)} \rightarrow \text{aggregates} \rightarrow \text{amorphous CaCO}_3 (\text{ACC}) \rightarrow \text{crystalline limescale}$

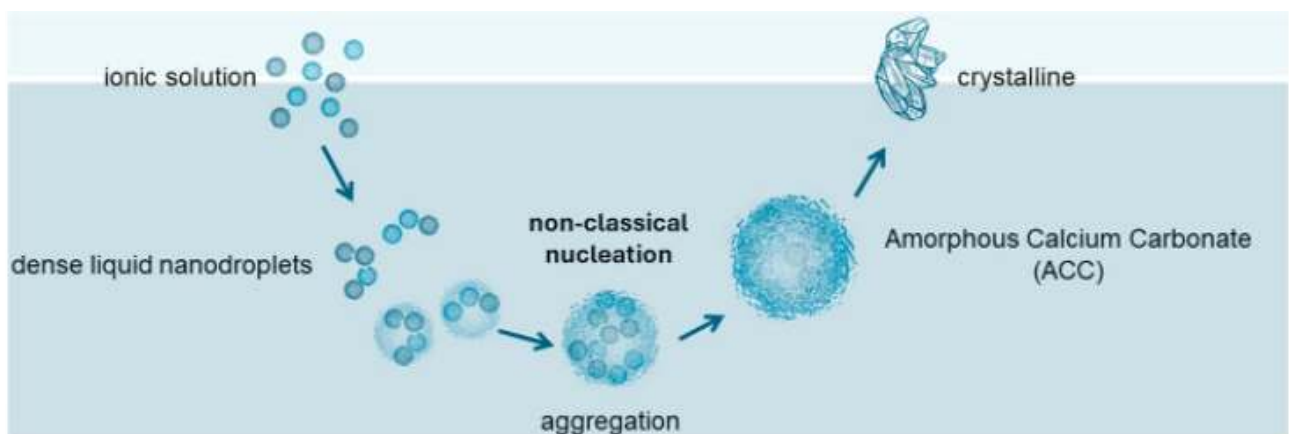


Figure 2. The non-classical nucleation pathway: from ions via liquid-like nanodroplets and amorphous calcium carbonate to crystalline limescale. Source: LAGUR, after Gebauer & Cölfen (2011).

The point is that the PNCs are neither solid crystals nor free ions, but dynamic nanoscale clusters. It is precisely the geometry of the cluster – and the distribution of protons on its surface – that determines whether it later nucleates, or precipitates, as hard calcite or as soft aragonite. And a long-lived, deformable cluster is something a magnetic field has time to influence.

IN EVERYDAY TERMS

Imagine people in small conversation groups. The strongly alternating field acts like repeated gusts of wind: it disturbs the groups, and when they gather again they do so in a slightly different constellation. The charge (the people) is the same — but the organisation has changed. In the same way, LAGUR does not change the chemistry of the water, but rearranges the positions of the ions within the clusters, and thereby the crystal structure they later develop into.

05.03 COEY'S MECHANISM — AND A CONCRETE DESIGN CRITERION

The physicist J.M.D. Coey (Trinity College Dublin) supplied the missing mechanism in 2012. He pointed out that direct forces from the field on free ions are far too weak to explain anything. The effect must therefore act on a slow, long-lived intermediate: the pre-nucleation clusters (Coey, 2012). Two physical mechanisms are at play:

- The Lorentz force deforms charged clusters. The force on a charged particle in a magnetic field is $F = q(E + v \times B)$. On the polar PNC aggregates it acts as a mechanical stress — and because DOLLOPs are liquid-like and easily deformable, even moderate forces can rearrange the ions' relative positions (Coey, 2012; Demichelis et al., 2011).

FACT BOX Where the force $F = q(E + v \times B)$ can be read term by term:

- F : the force on the cluster (in newtons) — it is what presses and rearranges the cluster.
- q : the cluster's electric charge (in coulombs) — the sum of the charges of the Ca^{2+} and carbonate-/bicarbonate-ion charges; the greater the charge, the greater the force.
- E : the electric field (volts per metre); the term qE acts on the charge, whether or not the cluster is moving.
- v : the velocity of the cluster (the water) through the field (metres per second).
- B : the magnetic field — the magnetic flux density (in tesla).
- $v \times B$: the cross product of velocity and field; it is perpendicular to both. This term requires motion (it is zero when $v = 0$) and couples the flow to the magnetic field — it is the magnetic part of the Lorentz force, $q(v \times B)$.



- The magnetic-field gradient manipulates proton spin. The most important, long-lasting effect arises because the clusters are polar: bicarbonate (HCO_3^-) gathers on one side and Ca^{2+} on the other. For the cluster to grow, a proton must be displaced, and briefly a proton-dimer. The protons' spin precesses at the Larmor frequency $f_p B$ ($f_p = 42.6 \text{ MHz/T}$), and in an inhomogeneous field the singlet and triplet states dephase, which increases the probability that Ca^{2+} is incorporated. The result is an altered ionic structure that survives for hours – the famous memory effect (Coey, 2012).

IN EVERYDAY TERMS

The cluster grows by taking up calcium, but first a hydrogen nucleus (a proton) must be pushed aside – and for a brief moment two protons meet. Each proton is like a little spinning top that wobbles around in the magnetic field; the stronger the field, the faster it wobbles (this is the Larmor frequency).

The crucial point: in an uneven (inhomogeneous) field – a gradient – the two protons wobble at slightly different rates and drift out of sync, like two metronomes set almost, but not quite, identically. Being out of sync tips the proton pair between two states, and one of them makes it easier for calcium to attach to the cluster.

So the field does not change the chemistry of the water – it only fine-tunes how the cluster builds itself up (towards soft aragonite rather than hard calcite). And because the clusters are long-lived, the effect persists for hours after the water has left the magnet – this is the memory effect. A perfectly uniform field would make the protons wobble in time, so nothing would happen: it is precisely the non-uniformity – the gradient – that drives the effect.

The crucial part – Coey's design criterion. Coey derived a concrete condition for when a magnetic treatment unit can work at all:

$$C = 2 \cdot (L/v) \cdot f_p \cdot a \cdot \nabla B \geq 1$$



where L is the active length of the unit, v is the velocity of the water, f_p is the proton's Larmor frequency (a fixed constant), a is the proton separation (a fixed constant of ~ 0.25 nm), and ∇B is the gradient of the magnetic field (Coey, 2012). The criterion says something counter-intuitive but important: the effect scales with the unit's length and the magnetic field's gradient – and inversely with the velocity – not with the raw strength of the field. A weak magnet with a strong gradient and sufficient length can meet the criterion, whereas a powerful but short and uniform magnet cannot. For a 5 cm unit at 0.1 m/s, the criterion requires a field gradient on the order of 100 T/m (Coey, 2012).

The very fact that the theory points to gradient and length rather than field strength explains why earlier, simple clip-on magnets often failed – and why a unit must be deliberately designed to the criterion in order to work.

FACT BOX Why gradient and flow beat field strength

A stronger field is not necessarily better. Coey's criterion depends on the strength of the field's gradient (∇B) and the unit's length – not on the raw strength of the field (B).

Flow is necessary. The magnetic force on a charged cluster, $F = q(v \times B)$, is proportional to the velocity v – if the water stands still, the force is zero. At the same time, the cluster must be carried through the field gradient to build up the spin phase shift that drives the effect; this is why the residence time L/v enters Coey's criterion. Lower velocity gives longer exposure – and thereby a greater effect (Coey, 2012; Kožić et al., 2010).

A field that is too strong can weaken the effect. The mechanism is a coherent spin effect (related to the radical-pair mechanism), not a brute force effect. A very strong field can split the spin states so much (Zeeman-splitting) that the singlet-triplet-mixing on which the effect rests is decoupled and stops (Vaskina et al., 2020; Paulitsch-Fuchs et al., 2021). This is why even very weak fields with steep gradients work: Sammer et al. (2016) and Paulitsch-Fuchs et al. (2021) achieved a measurable effect with fields of just ~ 6 gauss (0.6 mT), because the gradient was strong ($C = 1.8\text{--}8.1$).

Design implication: The goal is an optimal, not a maximal, field – a strong gradient over sufficient length at the right velocity. This is precisely why LAGUR uses an elongated coil with high gradients and an alternating frequency field rather than a single powerful, static magnet – and why simple clip-on magnets often fail.



05.04 THE EXPERIMENTAL EVIDENCE

With a plausible mechanism in place, the empirical question remains: does a magnetic field actually change how limescale precipitates in experiments? A number of peer-reviewed studies say yes – with measurable figures.

- Coey & Cass (2000): in blinded experiments the proportion of aragonite rose from 7% (untreated) to 54% (treated), and the effect (memory) lasted for over 200 hours (as cited in Fox et al., 2014; Martínez Moya & Boluda Botella, 2021).
- Ben Latifa et al. (2023): with a static field of 0.70 T, the time before precipitation rose from 51 to 86 minutes; the inhibition efficiency increased with exposure time from 24% to 60% (homogeneous) and up to 88% (heterogeneous), and the field promoted aragonite. Memory effect lasted up to 24 hours.
- Lipuš & Dobersek (2007): in a 3-week parallel operating test with permanent magnets (0.6–0.8 T, flow 1.25 m/s), the limescale deposit on a heating coil became 2.5× thinner, the crystal needles ~4× thinner and the sediment ~70% less – all identified as aragonite – corresponding to about 50% better heat transfer.
- Kožić et al. (2010): confirmed a 2.5× thinner deposit, and that particles in treated water were 10–20 nm versus 50–180 nm in untreated. Importantly: dynamic (flowing) treatment at ≥ 0.05 T beat static treatment at 0.3 T, and a residence time of ≥ 0.1 s is required – fully in line with Coey's L/v and gradient logic.
- Vaskina et al. (2020): a theoretical review explaining why flow is necessary, why an inhomogeneous field (gradient) plus a Lorentz force is required, and why a field that is too strong can reduce the effect – precisely the reason a weak field with a strong gradient can be optimal.
- Sammer et al. (2016) and Paulitsch-Fuchs et al. (2021): the most direct confirmation of Coey. With very weak magnets (field ~6 gauss, i.e. 0.6 mT) but strong gradients (170–770 G/m), the authors calculated Coey's criterion to be $C = 1.8\text{--}8.1$ (i.e. ≥ 1) – and measured an increase of up to 25% in the number of nm-sized clusters, as well as a persistent, statistically significant effect in 15 of 16 and 8 of 10 experiments respectively.



- A near-zero-strength field with a large gradient works, exactly as the theory predicts.
- Martínez Moya & Boluda Botella (2021): an overarching review of the field reports typical reductions in hardness and fouling of 15–45% across field strengths from 0.007 to 1 T — but at the same time honestly stresses that the effect depends on temperature, pH, CO₂, field strength and flow.

05.05 AN INDEPENDENT ENGINEERING REALITY CHECK

For balance, the most important critical source is an independent American evaluation: Fox, Wiest, Thomure & Lee (2014) tested salt-free anti-scale devices under the German DVGW-W512 protocol for the WaterReuse Research Foundation and the U.S. Bureau of Reclamation. Here, electromagnetic treatment gave a real but moderate reduction in limescale of about 50% and — importantly in practice — a soft coating that could easily be brushed off, as well as the lowest 10-year life-cycle costs of all the alternatives tested. But the report also found that, in moderately hard water, the treatment did not convert the majority of the calcite to aragonite (over 90% remained calcite) — the soft coating was due to a changed crystal orientation, not a full phase transformation. The conclusion is sober: the effect is real and economically attractive, but its magnitude and character depend on the water and the anti-scale device.

05.06 DANISH EVIDENCE ON LAGUR SPECIFICALLY

The international literature shows that magnetic treatment changes limescale precipitation. Four independent external analyses commissioned by LAGUR were carried out directly on the LAGUR products and point consistently in the same direction: a changed crystal morphology and a transformation towards soft aragonite.



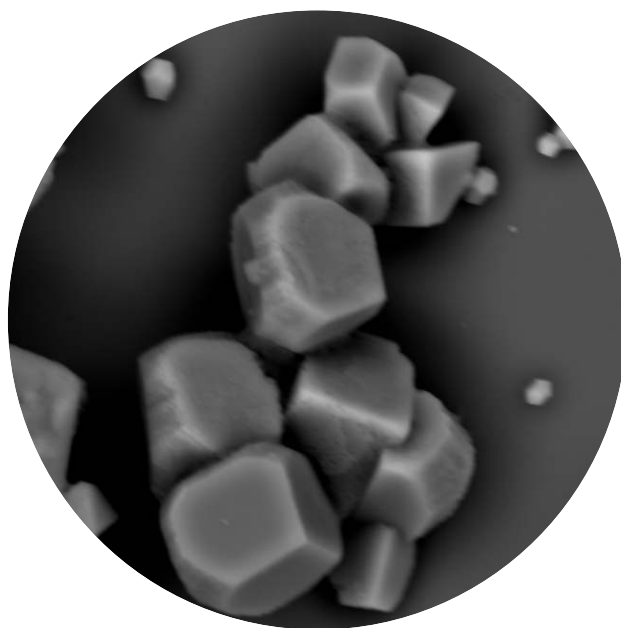
GEUS — ELECTRON MICROSCOPY OF THE LIMESCALE STRUCTURE

In collaboration with the Geological Survey of Denmark and Greenland (GEUS), LAGUR compared limescale from untreated water with limescale treated with 8 different LAGUR products under an electron microscope at over 100,000× magnification. Nothing was added to the water.

The result showed a clear difference in crystal structure. The test also showed a direct relationship between the strength of the magnetic influence and the degree of transformation (GEUS SEM test report, April 2026). SEM documents differences in the morphology of the crystals and in the softness of the coating — not the phase composition itself; the quantitative phase determination (aragonite vs. calcite) rests on FORCE Technology's X-ray diffraction (the section below).



Untreated limescale: needle-shaped, intergrown dendrites that adhere to surfaces.



LAGUR-treated limescale: separate, rounded/cubic crystals that give a loose, soft coating.

Figure 3. GEUS SEM analysis (>100,000×) of limescale from untreated water (left) and LAGUR-treated water (right).
Source: GEUS SEM images, April 2026.



DANISH TECHNOLOGICAL INSTITUTE — OPERATING TEST ON TWO WASHING MACHINES

The Danish Technological Institute ran two identical Siemens washing machines side by side — one with and one without LAGUR — over about 190 hours of boil-wash cycles at a water hardness of ~15 °dH (140–147 cycles in total, corresponding to ~28–29 weeks of household laundry). The heating element with LAGUR had markedly less residual limescale, confirmed visually and by microscopy at three measurement points. A scrape test showed that the limescale on the untreated element adhered 1.2–2.1 times more firmly (Danish Technological Institute, 2020; cf. the figure in Section 1).

RAMBØLL — FIELD STUDY IN AN ENTIRE SUPPLY NETWORK

Rambøll investigated LAGUR installed at Grauballe Waterworks by comparing water samples from four consumers before and after the installation. After installation, the limescale was transformed from hard calcite deposits into soft, finely reshaped aragonite deposits at all four consumers — greatest at those who originally had the most limescale precipitation. A follow-up showed that the effect could still be measured at least 8 days after sampling and up to 6 km from the waterworks (Rambøll, Grauballe Waterworks, February 2026). The persistent effect over distance is consistent with the documented memory effect in the literature.

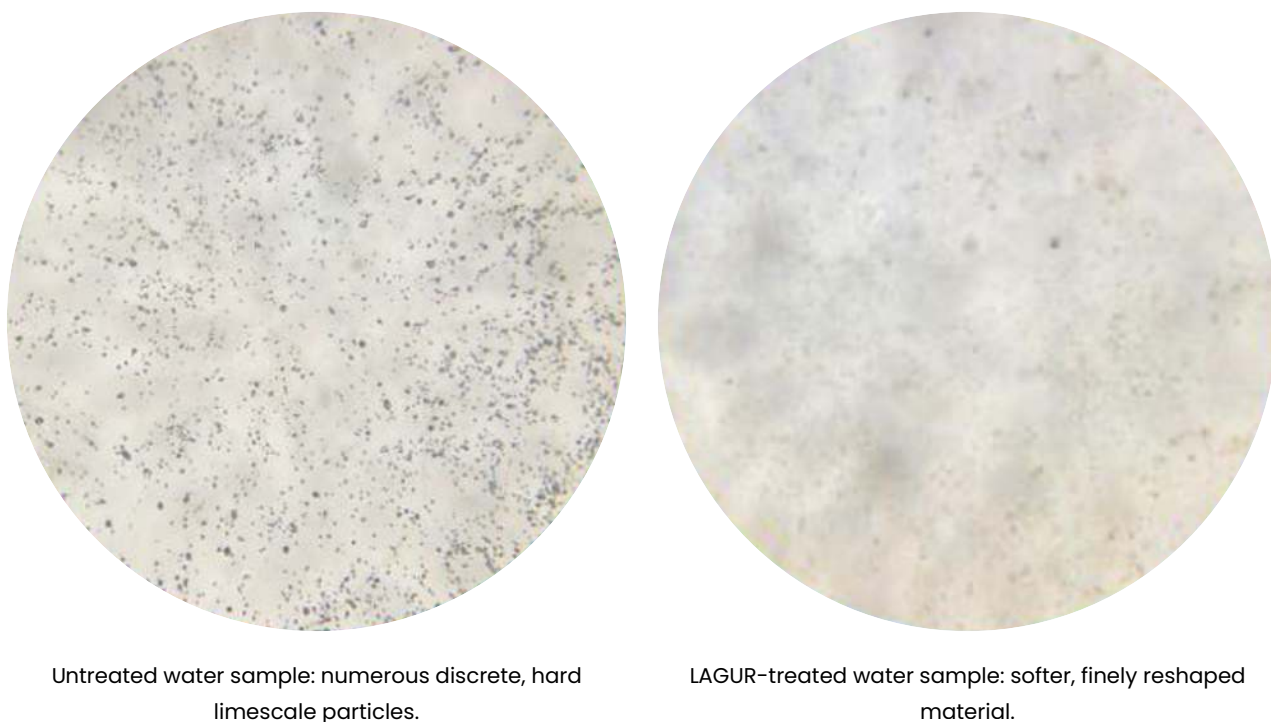


Figure 4. Evaporated water samples from consumers at Grauballe Waterworks, before and after LAGUR. Source: Rambøll, February 2026.



FORCE TECHNOLOGY — SYNCHROTRON X-RAY DIFFRACTION

FORCE Technology analysed limescale samples from three different LAGUR products as well as raw water using transmission X-ray diffraction at 35 keV. All four samples could be described as a combination of aragonite and calcite/Mg-bearing calcite. The most calcite and the most amorphous material were found in the raw water (FORCE Technology, synchrotron XRD, July 2026). This is a preliminary assessment — a more thorough analysis is needed to establish the precise phase concentrations — but it confirms the phase transformation towards aragonite on an independent, quantitative basis.

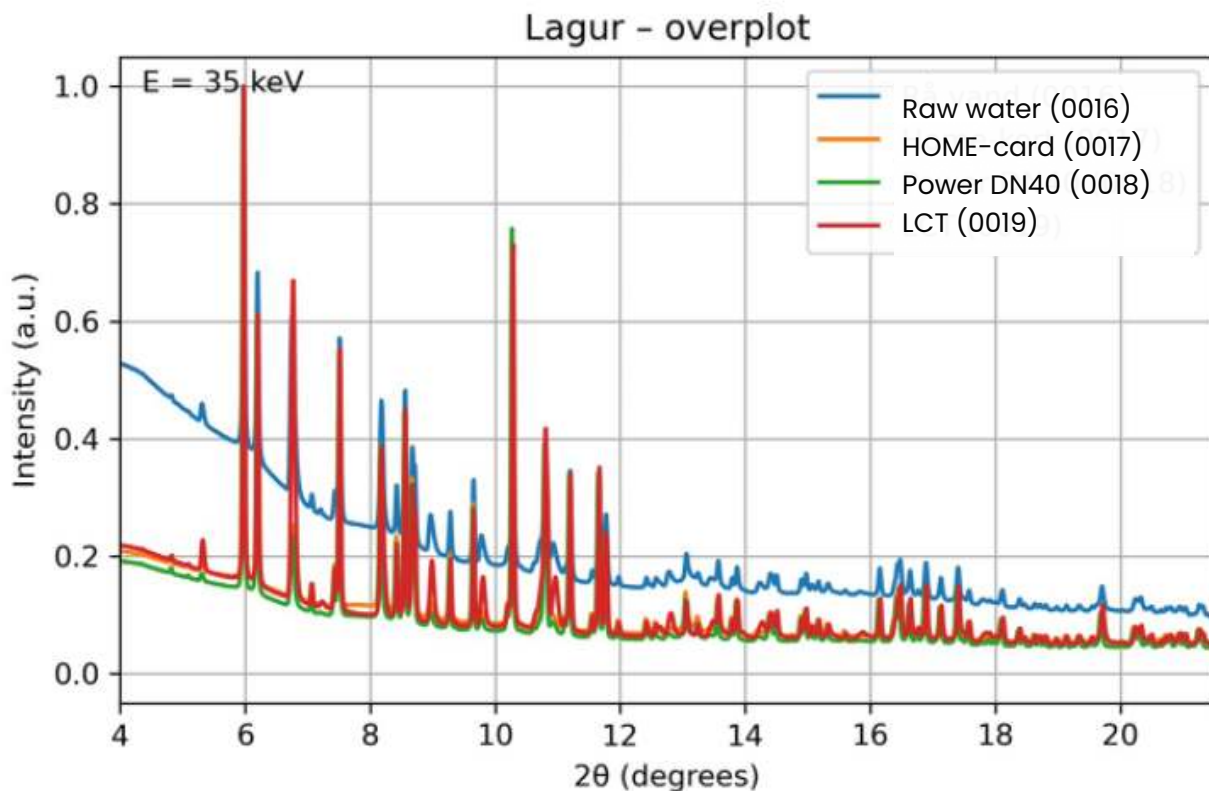


Figure 5. Synchrotron XRD spectra (35 keV) for raw water and three LAGUR-treated samples. Source: FORCE Technology, July 2026.



06 WHY LAGUR IS OPTIMISED: COEY'S FORMULA IN PRACTICE

The difference between an ineffective magnet and an effective treatment unit lies, as Section 5.3 showed, in Coey's criterion $C = 2(L/v) \cdot f_p \cdot \alpha \cdot \nabla B \geq 1$. LAGUR HOME and PRO products are deliberately engineered to precisely this criterion.

The construction. A LAGUR unit is fitted as an active part of the water supply and contains at least 1.5 kg of copper windings that generate a strong and elongated magnetic field with steep field gradients into the water stream itself. The field alternates systematically in a patented frequency range of 300–3000 Hz ("frequency-modulated magnetic"). This frequency sweep is repeated up to 20 times a second, so that every volume element of the water is exposed thousands of times during its passage. Together, the pole reversal and frequency sweep produce a strong temporal field change ($\partial B/\partial t$) — an independent contribution on top of the spatial field gradient itself (∇B), which stems from how the field falls off in the space around the windings.

06.01 HOW LAGUR AFFECTS THE FIELD: $\partial B/\partial t + v \cdot \nabla B$ — SIMPLY EXPLAINED

What drives the effect is not the field's strength, but how much the field changes as a droplet of water passes through the unit. A LAGUR droplet experiences two kinds of change at once, and the effects add up:

Total field change $dB/dt = \partial B/\partial t + (v \cdot \nabla)B$

- $v \cdot \nabla B$ — change because the droplet moves. The field is stronger at the coil than farther away (that is the gradient, ∇B). As the droplet flows through at velocity v , it experiences a change precisely because it is moving. The stronger the gradient and the faster the flow, the larger this term.
- $\partial B/\partial t$ — change because the field itself shifts in time. LAGUR reverses the poles (north/south) many times a second and simultaneously runs at 300–3000 Hz — and the control box is built so that each switch is as fast and steep as possible. This produces a large field change in time, entirely independent of how fast the water flows.



HOW LAGUR AFFECTS THE FIELD: TWO CONTRIBUTIONS AT ONCE

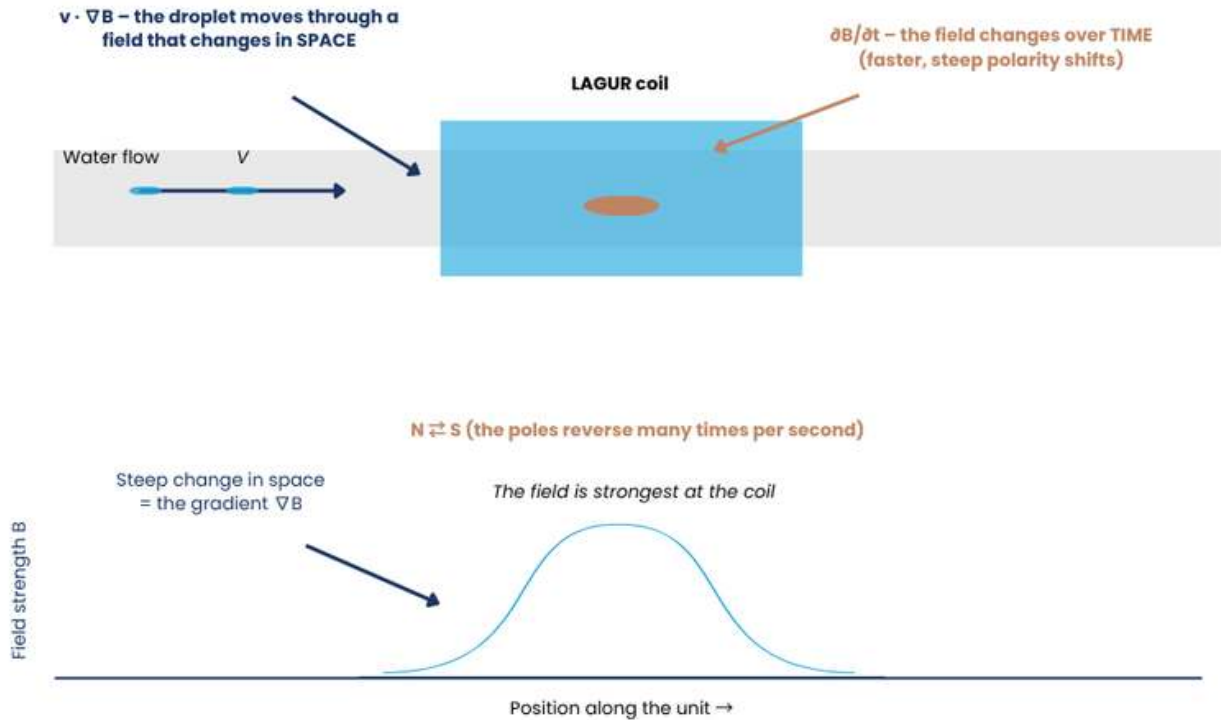


Figure 6. The two contributions: the droplet moves through the spatial gradient ($v \cdot \nabla B$), while the coil simultaneously switches the field in time ($\partial B / \partial t$).

Why this matters. The two terms complement each other. At high flow, the motion ($v \cdot \nabla B$) contributes most. At low flow, $v \cdot \nabla B$ becomes small, and then it is the fast switching ($\partial B / \partial t$) that carries the effect. Because LAGUR actively maximises $\partial B / \partial t$, the product also works when the water flows slowly.

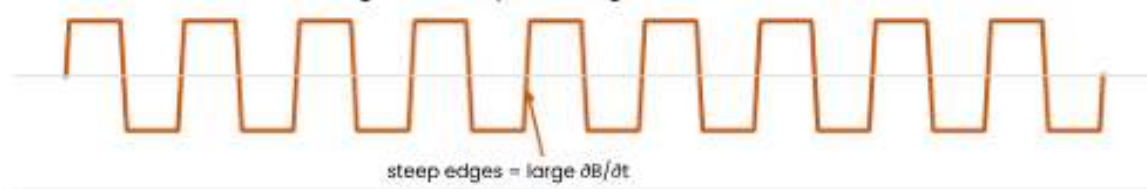


THE FIELD EXPERIENCED BY A WATER DROPLET DURING PASSAGE

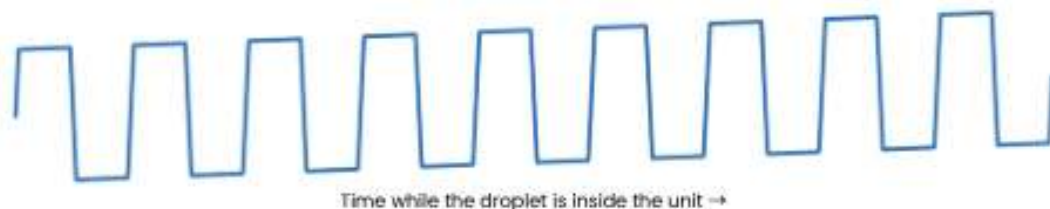
Contribution from movement: $v \cdot \nabla B$ (slow change)



Contribution from switching: $\partial B / \partial t$ (rapid change over time)



What the droplet experiences OVERALL: $\partial B / \partial t + v \cdot \nabla B$



At low flow, the slow slope ($v \cdot \nabla B$) is almost flat — so the rapid, steep changes ($\partial B / \partial t$) carry the effect.

Figure 7. The field a droplet experiences along the way: a slow change from the motion ($v \cdot \nabla B$) plus fast, steep switches from the switching ($\partial B / \partial t$), added together. At low flow it is the steep switches that dominate.

In Coey's original criterion, only the motion-borne term is included (derived for a static magnet). LAGUR adds the temporal term with its alternating field.

Table 2 LAGUR's design mapped to Coey's criterion

Parameter in C	What the criterion requires	LAGUR's design answer
L (length)	A long active section increases C	Elongated coil, substantial active length
∇B (gradient)	A strong field gradient is the load-bearing factor	≥ 1.5 kg copper coil gives high field gradients
v (velocity)	Lower velocity gives longer exposure – and thereby a greater effect (higher C)	Dimensioned for a long residence time (L/v) in the intended flow range
$\partial B/\partial t$ (temporal switching)	A time-varying field gives extra exposures – LAGUR's addition beyond Coey's static criterion; carries the effect at low flow	300–3000 Hz frequency sweep + pole reversal up to $20\times/s$ = many exposures per pass

The consequence. By accelerating the formation of clusters and microparticles in the water stream itself, a larger share of the precipitation occurs in the water phase (homogeneous nucleation) rather than on pipe and heating surfaces (heterogeneous nucleation). Depending on the water, the result can arise via two routes, which may occur separately or together: a partial phase transformation towards soft aragonite, and/or – as Fox et al. (2014) found in moderately hard water, where over 90% remained calcite – a changed crystal orientation, in which the limescale remains predominantly calcite but acquires a random orientation and variable size. Both routes form a soft, loose coating that can easily be wiped or brushed off – instead of a hard calcite crust. This is exactly what GEUS, Rambøll and FORCE document on LAGUR samples, and what the Danish Technological Institute's scrape test quantifies in practice.

Scalability. The same physics applies from a single household (HOME), through larger installations (PRO), to an entire waterworks: Rambøll's field study showed that the effect from a single unit at Grauballe Waterworks could be measured at consumers up to 6 km away. LAGUR thus transforms the limescale where the water is used – without removing the minerals that make the water healthy to drink.



07 CONCLUSION

Magnetic scale treatment is no longer a mechanism without an explanation. The discovery of pre-nucleation clusters gave the field a physical foundation, Coey's criterion turned it into engineering science, and a growing peer-reviewed literature — together with LAGUR's Danish analyses — documents that a correctly designed field changes the limescale crystal structure from hard calcite towards soft aragonite.

LAGUR's patented HOME and PRO are built to meet precisely that criterion — and reduce limescale problems without adding chemicals and without removing the water's healthy minerals.



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