PROTECTION

Biofouling Prevention on Submerged Surfaces Without Biocides

How marine organisms prevent colonisation at the surface level

5	3	3–5	5
convergent strategies	principle clusters	TRL range	featured strategies

PROBLEM FRAMING

Biofouling costs the marine industry billions annually in fuel penalties and maintenance. Chemical biocides are increasingly restricted. Biological antifouling strategies use surface energy, micro-texture, and chemical signals — not toxicity — to prevent settlement.

Application domains: transportation, materials, water_management

Principle cluster: superhydrophobicity, surface microstructure, hydrophobicity

Physics & Mechanism

Underlying physics

[DRAFT] Biofouling proceeds in sequential stages: dissolved organic conditioning film (minutes), bacterial biofilm (hours), microfouling (days), macrofouling (weeks). Effective prevention must interrupt early-stage adsorption. Superhydrophobic surfaces reduce protein adsorption by minimising contact area at the solid-liquid interface — a consequence of Cassie-Baxter wetting states where air pockets prevent continuous liquid contact. Lotus-effect microstructures (10–100 µm pillars, 100–500 nm secondary roughness) can achieve >160° contact angles. However, fouling resistance also depends on surface energy hysteresis: surfaces with low roll-off angles (low contact angle hysteresis) shed organisms before adhesion strengthens. The shark skin analogue — denticles with 50–200 µm spacing — prevents larval settlement through a combination of surface curvature (difficult for setae to grip) and flow-induced micro-turbulence near the surface (disrupting chemoreceptor-mediated settlement cues). [END DRAFT]

Biological Strategies

Protect From Excess Liquids Lotus leaf · TRL 3/9 · 136 genera

Carbon nanostructures create superhydrophobic surfaces by mimicking the hierarchical roughness found in nature — similar to how lotus leaves repel water. These structures include carbon nanotubes, nanofibers, nanospheres, nanodiamonds, and graphene, which can be combined with metals, ceramics, or polymers to form composite coatings. The nano-scale texture traps air pockets between microscopic peak…

Design principle: Engineer multi-scale roughness into protective coatings by layering nanoscale features — using carbon-based materials as the foundation — to trap air and create low-adhesion surfaces for liquids. This

Protect From Excess Liquids Lotus leaf · TRL 3/9 · 136 genera

The lotus leaf achieves exceptional water repellency through a hierarchical nanostructured surface composed of microscale papillae and nanoscale epicuticular wax crystals. The leaf's epidermis is covered with waxy protrusions that create a two-tier topography: larger pillar-like structures at the micrometer scale are studded with smaller crystalline wax features at the nanometer scale. When water …

Design principle: To replicate lotus leaf water repellency, engineer a two-tier hierarchical surface topology using microfabrication and nanofabrication techniques. First, create primary structures (pillars or ridges)

Protect From Excess Liquids Lotus leaf; Desert beetle; Spider web · TRL 5/9 · 136 genera

The lotus leaf manages water through a hierarchical surface architecture composed of papillae and epicuticular wax crystals that create microscale and nanoscale structures. These structures establish regions of extreme water repellency (superhydrophobic zones) interspersed with more wettable pathways. When water contacts the leaf surface, it beads and rolls away from hydrophobic peaks while being …

Design principle: Engineer hierarchical surface textures combining superhydrophobic and hydrophilic regions to achieve simultaneous moisture collection and self-cleaning function. Pattern micro and nanostructures—such

Protect From Excess Liquids Salvinia fern · TRL 3/9 · 136 genera

Salvinia species floats on water by engineering a specialized leaf surface architecture that traps and retains a stable air layer when submerged. The plant's microstructured surface—composed of hair-like papillae arranged in specific patterns—creates air pockets that resist water penetration. When the leaf is pushed underwater, water molecules cannot breach the hydrophobic surface, leaving behind …

Design principle: Design submerged or wet-exposed surfaces with hierarchical microstructures that trap and stabilize air layers. The principle: create hydrophobic features at multiple length scales—larger pillars or pa

Protect From Excess Liquids Lotus leaf, Shark skin, Pitcher plant, Insect cuticle · 136 genera

Multiple biological organisms exhibit extreme wetting behaviors through specialized hierarchical surface structures. The lotus leaf develops microscopic papillae combined with waxy epicuticular cells that create superhydrophobic surfaces, causing water droplets to bead and roll away while self-cleaning. Shark skin possesses nanoscale riblet textures in its dermal tissue that reduce drag and repel …

Design principle: Develop hierarchical surface textures by combining multiple length scales of roughness, mimicking biological templates that integrate micro and nanostructures. Select materials or apply coatings with

Combination Intelligence

Strategies that address different aspects of the same problem and are not redundant when combined.

Protect From Excess Liquids + Protect From Excess Liquids

Shared principles: hydrophobicity, superhydrophobicity, surface microstructure

These strategies share 3 underlying principles including hydrophobicity and superhydrophobicity and surface microstructure. They may not be alternatives — combining them could address different scale regimes of the same problem simultaneously.

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EXPLORE THE INTERACTIVE VERSION

This report is a static synthesis. The interactive version includes live strategy cards, the Design Brief generator, Combination Intelligence engine, and filtering by TRL, scale, and principle.

`https://atlasofnature.org/challenge/biofouling-prevention`

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