# The Oasys Sail

A wind-driven, kilometer-scale mesh for atmospheric $CO_2$ removal and water recovery.

## Concept

The Oasys Sail is a large-area, sheet-form sorbent system that captures both carbon dioxide and water from ambient air with near-zero external electricity. A sorbent mesh — on the order of 10 $km^2$ (e.g., 5 × 2 km) — is flown on tethered aerostats at 500–1,500 m altitude in a high-wind coastal or offshore region. Wind delivers air through the porous mesh; captured atmospheric water drives a moisture-swing regeneration cycle that releases concentrated $CO_2$ and simultaneously rinses the sorbent surface, making the system self-cleaning. Surplus water — roughly 70–80% of what is harvested — is exported as a clean liquid product alongside the concentrated $CO_2$ stream.

## Why the geometry matters: the physics baseline

Thermodynamics is permissive: the minimum work to separate $CO_2$ from air at 420 ppm is ~19.3 kJ/mol, and daily solar insolation on 1 $m^2$ exceeds that floor by orders of magnitude. The binding constraint for any passive sheet is instead **mass transfer** — the rate at which still air delivers dilute molecules to a surface. For a flat sheet under natural convection ($k \sim 10^{-3}$ m/s), the ceiling is roughly 65 g $CO_2/m^2$/day and 0.6 L $H_2O/m^2$/day, and real systems achieve 5–20% of that. At that rate, even a 10,000 $m^2$ ground installation captures only ~240 t $CO_2$/yr — not climate-relevant. Three design reframings remove this wall without violating any conservation law:

**1 — Water as the cycle driver.** Moisture-swing sorbents (Lackner-class anion-exchange resins) bind $CO_2$ when dry and release it when wet, at near-zero thermal cost — but they consume 5–10 mol $H_2O$ per mol $CO_2$, which self-defeats in arid air. A sail that also harvests atmospheric water closes this loop. At 10 m/s wind and 50% RH, captured water exceeds the swing requirement by 4–7× (roughly 10× at 70% RH in the marine boundary layer), so the chemistry becomes ideally matched rather than self-defeating, and the same wet pulse provides the self-cleaning rinse.

**2 — Wind plus mesh, not still air plus flat sheet.** Mounting the sail perpendicular to a 5–20 m/s wind replaces natural convection with forced through-flow. A porous mesh presents every fiber as a fresh leading edge, so air passes *through* the sorbent rather than past it. The limit becomes throughput — how much $CO_2$ the wind carries to the sail — multiplied by the capture efficiency, the fraction the mesh grabs before the air leaves. An engineered, layered mesh can realistically reach a $CO_2$ capture efficiency of 0.3–0.5.

**3 — Kilometer scale.** A 10 $km^2$ installation is three orders of magnitude larger than the flat-sheet reference case. Combined, the three reframings raise achievable $CO_2$ capture by roughly four orders of magnitude over the still-air baseline and move the bottleneck from sorption science to structural and aerospace engineering.

## Projected performance (single 10 $km^2$ installation)

| Scenario | $CO_2$ capture | Context |
|---|---|---|
| 5 m/s wind, 10% capture eff. (conservative) | ~119 kt/yr | ~3× Climeworks Mammoth (~36 kt/yr) |
| 10 m/s wind, 30% capture eff. (realistic) | ~712 kt/yr | ~20× Mammoth |
| 15 m/s wind, 50% capture eff. (engineered) | ~1.78 Mt/yr | ~50× Mammoth |

On the water side, the same installation at 70% RH yields roughly 15–61 GL/yr of surplus clean water — at the upper end, municipal-scale supply for millions of people. A fleet of ~560 sails at the engineered rate would meet the ~1 Gt/yr IPCC-aligned target for direct air capture, on a total deployed area of ~5,600 $km^2$ (about 0.06% of the Sahara).

## Step 1 findings: the sorbent shortlist (August 2026)

Step 1 of the roadmap asked for 3–5 published sorbents that could plausibly sustain 20–30 cycles/day toward $10^5$+ cycles. The literature dive returned five candidate families. The kinetics half of that question now looks passable on paper; the endurance half narrows to a single defined experiment.

| Candidate family | Key published numbers | Read |
|---|---|---|
| Quaternary-ammonium (QA) anion-exchange resins — the Lackner baseline | ~1–3.4 mmol/g working capacity; direct moisture-swing cycle tests reported only to ~6–15 cycles; a related study shows 150 room-temperature regeneration cycles with no measurable degradation; industrial strong-base resins serve 3–8 years in wet duty | The only fully passive chemistry, and the incumbent. Bead kinetics are too slow as supplied — requires thin-film or fiber formatting to reach the cycle rate. |
| Porosity-engineered QA polymers (mesoporous quaternized resin) | Adsorption half-time about 2.9 min at ambient conditions — the fastest moisture-swing kinetics reported; ~15 stable cycles demonstrated | Kinetically ready for 20–30 cycles/day today. Cycle life is the entire remaining gap. |
| COF-999 (amine-functionalized covalent organic framework) | 2.05 mmol/g at 400 ppm and 50% RH; half-time 18.8 min; regenerates at 60 °C; more than 100 open-air cycles with full capacity retention | Best endurance demonstration in the set. Covalently anchored polyamines resist the oxidation that kills grafted amines; needs a ~60 °C solar-thermal swing rather than pure moisture swing. |
| COF-1000 | 2.19 mmol/g at 75% RH; half-time 6.8 min — humidity improves both uptake and speed; 50 outdoor-air cycles run in three days (~17 cycles/day sustained), 22.1 mmol/g/day | The strongest de-risking datapoint available: the closest published demonstration of the cycle rate the Sail actually requires. |
| Rapid-cycle amine monolith processes (Global Thermostat-class) | 900 s adsorption plus under 90 s steam desorption per monolith; a benchmark primary-amine resin lost 31.2% capacity over 180 realistic air/vacuum cycles | Validates the rate at process level rather than material level. The degradation result argues against primary-amine chemistry and in favour of QA or COF families. |

**Two cautions carry forward.** First, direct endurance measurement ends near $10^2$ cycles across every family surveyed; published claims of hundreds of thousands of cycles are extrapolations from stability arguments, not measurements. The $10^5$ requirement remains roughly three orders of magnitude beyond demonstrated evidence. Second, a 2026 meteorology-driven screening study finds relative humidity is the dominant performance driver and that sustained high humidity can suppress the $CO_2$ swing entirely. That cuts against naive marine-boundary-layer siting: the Sail needs a genuinely dry half-cycle — from diurnal RH variation, engineered dry-side airflow, or the COF-class ~60 °C thermal swing as fallback — and this becomes an explicit constraint on the Step 2 water-loop mass balance.

**Step 1 verdict.** The kinetics half of gate (a) is passable on paper: three families now show half-times between roughly 3 and 19 minutes, comfortably inside a 65-minute cycle. The endurance half is not answered, but it is no longer open-ended — it is a defined experiment. An accelerated wet/dry protocol on a ~10-minute bench cycle reaches $10^4$ cycles in about ten weeks, run head-to-head on a formatted QA resin, an engineered porous QA polymer, and a COF-999/1000-class framework.

## Engineering bottlenecks

With mass transfer solved by geometry, three new constraints govern feasibility. **Sorbent cycle life and kinetics:** at 10 m/s and 30% capture efficiency, a 100 g/m$^2$ sorbent loading must complete a wet/dry cycle roughly every 65 minutes (~22 cycles/day) — about $10^5$ cycles over a ten-year life, roughly three orders of magnitude beyond the best published demonstrations (~$10^2$ cycles). Raising loading to 1 kg/m$^2$ relaxes this to ~2 cycles/day but multiplies sail mass, drag, and lift-gas demand. **Structure and drag:** a 10 km$^2$ mesh in 10 m/s wind loads its tethers with ~300 MN sustained (roughly 8× a Saturn V first stage); distributed across ~10,000 attachment points this is ~30 kN per tether — within the working load of 8 mm UHMWPE cable — but ground anchoring is a serious civil-engineering project, and angling the sail to the wind (kite-style) may cut drag by an order of magnitude. **Lift gas:** a ~3,000 t payload needs ~3.0 million m$^3$ of helium — nearly 2% of annual world production per installation — making hydrogen, with segmented envelopes and modern inerting practice, the only realistic gas at fleet scale. Aviation integration (a 10 km$^2$ no-fly object), lightning protection, and a storm furl-and-recover mode are unavoidable operational requirements; the furl mechanism is likely the largest schedule risk.

## The feasibility claim

The sail concept appears physically possible at Mt-$CO_2$/yr scale per installation, conditional on three gates, each at the edge of — but not beyond — current science and engineering:

| Gate | Requirement | Status |
|---|---|---|
| (a) Sorbent endurance | Sorbent survives ~$10^5$ wet/dry cycles without capacity loss | Narrowed by Step 1. More than 100 open-air cycles demonstrated (COF-999) and ~17 cycles/day sustained (COF-1000), but $10^5$ is still ~3 orders beyond measured evidence — now a defined accelerated-cycling experiment rather than an open question |
| (b) Capture efficiency | Mesh geometry achieves at least 0.3 at ~10 m/s wind | Supported by filter-engineering analogy; no published model for this regime — CFD required |
| (c) Aerostat structure | Hydrogen-lifted km-scale envelope with distributed tethering and storm recovery | Component practice exists at ~100 m scale; km scale is unproven |

None of these gates is a known dead end. The novelty of the system is the closed water loop wrapped around known moisture-swing chemistry in a wind-delivered mesh geometry — the contribution is the system, not a new molecule.

## Materials and computational approach

The baseline chemistry is the quaternary-ammonium moisture-swing resin family — the only sorbent class demonstrated to regenerate passively in ambient humid air — with amine-functionalized COFs (COF-999 and COF-1000 class, regenerating at ~60 °C within passive solar reach) as the leading alternative. A 2026-era computational materials pipeline (CoRE MOF / hMOF / CURATED-COF screening, ML pre-ranking, three-component GCMC with humidity, MLFF stability checks, and generative augmentation via MOFDiff-class models) is applied to co-optimize working capacity, wet-pulse kinetics, and cycle endurance — with kinetics now a co-equal design target rather than an afterthought.

## Roadmap

**Step 1 — Sorbent kinetics literature dive: initial pass complete (August 2026).** Five candidate families identified, above. Remaining work is to design and run the accelerated wet/dry cycling protocol targeting $10^4$ cycles across the three shortlisted chemistries. **Step 2 — System feasibility study (4–6 weeks):** mesh-fiber CFD with sorbent boundary conditions, the drag-versus-efficiency Pareto frontier, tether load distribution, and a full water-loop mass balance — now including the humidity swing-suppression constraint identified in Step 1 — producing go/no-go engineering numbers for a single installation. **Later phases:** aerostat structural and lift-gas engineering, lifecycle carbon accounting, $CO_2$ off-take (tether piping vs. at-altitude compression), cost-per-tonne analysis, and aviation/regulatory engagement. If the endurance experiment finds no viable sorbent, the concept reverts to a ground-based mesh installation in a high-wind region — a lower-yield but still substantially wind-advantaged configuration.

## Step 1 sources


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