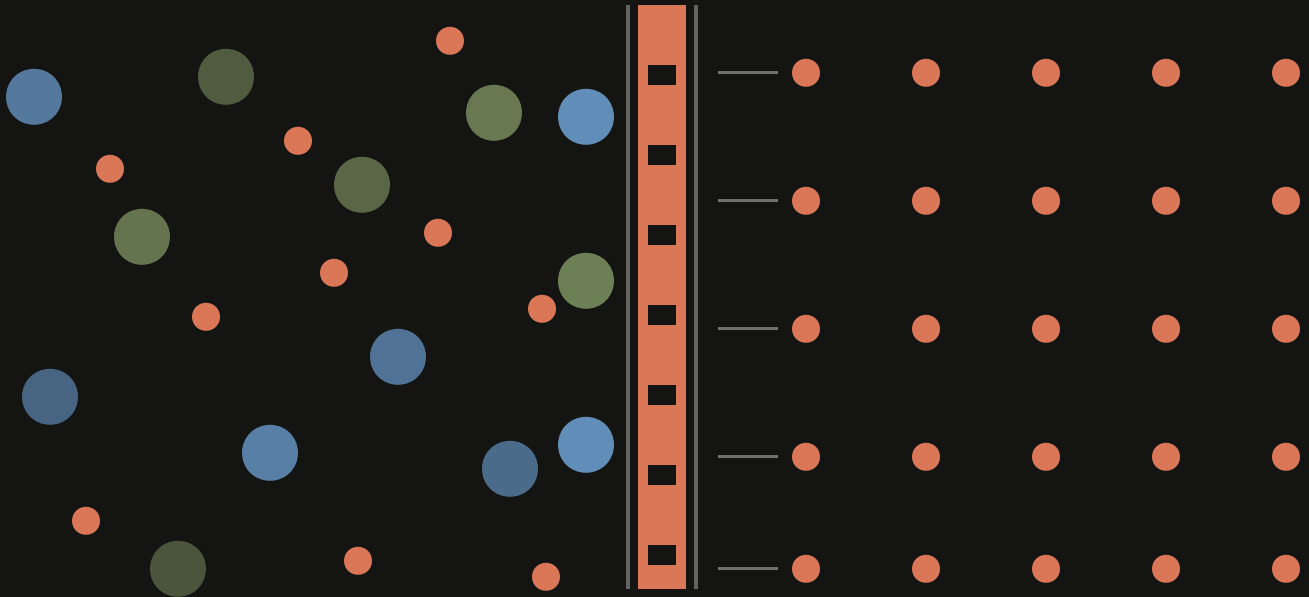




COVER STORY · ADVANCED MATERIALS

Chemistry Just Got Its *Transistor* Moment

A film that is more than nine-tenths crystal sponge just pulled propylene out of propane at a selectivity near 100 — and came off an industrial roll-to-roll coating line. The headline is an 80% cut in purification cost. The story underneath is that separation stopped being a building.

- Why one-eighth of the world's energy is spent un-mixing things · p.3
- The Contrarian: this does not save energy — it changes the currency · p.6
- Signals: a quantum computer that tunes itself mid-performance · p.7

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DISPATCH

Everything in the room you are sitting in was, at some point, *un-mixed*.

Nature is a mixer. Entropy shuffles atoms together at no charge and will not shuffle them apart for any price. So every manufactured thing — the fuel, the polymer, the drug, the electronic-grade silane — is defined less by what was added to it than by what was successfully removed. Purity is a debt paid to the second law, and somebody pays it every single time.

For a century the payment method has barely changed: boil the mixture, and catch the pieces as they come off at different temperatures. Distillation works, which is precisely why nobody interrogates it. It is also the largest industrial process that almost no one outside chemical engineering can name, and it consumes, together with its thermal cousins, between 10 and 15 percent of the world's annual energy.

This week a paper in *Nature* reported a membrane that performs one of the hardest of those separations without

boiling anything — and, more to the point, reported making it on a roll. The lens we would offer for reading it is this: **watch the form factor, not the efficiency**. Efficiency gains get absorbed by the system that receives them. Form-factor changes rearrange the system itself. The transistor did not defeat the vacuum tube on power draw alone. It won because of what became buildable once the part got small.

There is a version of this issue that led with the quantum computer on page seven, and we nearly made it. But separations sit underneath everything else, including the semiconductors that quantum processor is built from, whose feedstock gases are purified to parts per billion by thermal methods. When the substrate moves, it is worth noticing before the applications do.

The Un-Mixing Problem

For a hundred years, purity has meant heat. A membrane that is more than ninety percent crystal, cast on an industrial coating line, suggests it does not have to.

BY THE EDITORS OF INFLECTION · REPORTING ON NATURE 655, 23 JULY 2026

Stand at the base of a propylene-propane splitter and look up; you will not see the top. These columns carry more than 150 theoretical plates and recirculate their own contents ten to fifteen times before a single molecule leaves as saleable product. They are that large for one reason: propylene and propane are both three carbons long, differ by a single double bond, and boil roughly five degrees Celsius apart. To separate them by temperature you must boil and re-condense the same material over and over until a five-degree difference compounds into a purity spec. The column is not a machine so much as a monument to a very small number.

The hardest easy problem

In 2016, David Sholl and Ryan Lively used a comment in *Nature* to name the seven chemical separations most worth changing. Third on the list was alkenes from alkanes — precisely this problem — and their reasoning was volumetric. Annual production of alkenes exceeds 200 million tonnes, and essentially all of it passes through cryogenic distillation. They noted that hybrid schemes pairing membranes with columns could cut the energy by a factor of two or three, then immediately named the obstacle: doing so might demand up to one million square metres of membrane at a single chemical plant.

That is the shape of the whole field. The physics has never been in doubt. The manufacturing has.

Why membranes kept losing

Metal-organic frameworks ought to have settled this a decade ago. A MOF is a crystalline lattice of metal nodes joined by organic struts, and the lattice leaves behind windows whose diameter you set by choosing the strut. Tune the window to sit between two molecules and you have, in principle, a perfect sieve — one that sorts by

shape rather than by boiling point, and therefore needs no heat at all.

In practice, pure MOF films crack, delaminate and refuse to be made over large areas. The industrial workaround has been the mixed-matrix membrane: MOF crystals suspended in a polymer that supplies the toughness. But polymer is not sieve. It dilutes the very thing you are paying for, and past a modest loading the crystals flocculate into clumps, the film turns brittle, and defects open. Defects are unforgiving here. Gas, like water, takes the path of least resistance, so a single pinhole does not degrade selectivity — it short-circuits it.

The field has therefore lived inside a trade for twenty years: load enough MOF to matter, or little enough to process. Nobody had managed both, at scale, in the same film.

Be exact about what “enough” means. Polymer-grade propylene is a specification — conventionally 99.5 percent or better — because the downstream reactor treats propane as inert ballast that displaces product. A membrane that gets most of the way there is not a partial victory. It is a unit you still have to follow with a column.

Flattening the Crystal

Make the crystal behave like a polymer

The team's move is not a new material. It is a surface trick. They describe a “merged-phase” approach that fuses MOF and polymer into a single pseudo-continuous phase, so the MOF particles present polymer-like surfaces to one another. That single change lets the slurry form what the authors call rheologically controlled flocculated networks *even at extreme solid concentrations*.

Read plainly: the crystals stop behaving like sand in syrup and start behaving like dough. Dough can be cast. The product is what they name a quasi-pure membrane — more than 90 percent MOF by volume, with separation performance approaching that of a pure MOF film, made using what the paper calls industry-reliable solution processing.

The numbers that matter

On propylene/propane, the membrane delivers a propylene permeability of about 160 barrer at a *mixed-gas* selectivity of about 100. The emphasis belongs on mixed-gas. Ideal selectivities, measured by running two pure gases separately, flatter a membrane the way a benchmark flatters a chip; a real blend is where films go to die. About 100, on a blend, is enough to make polymer-grade propylene. The accompanying techno-economic analysis puts the purification cost at 80 percent below distillation.

Not a membrane — a method

Three benchmark MOFs were run through the process: ZIF-67, CALF-20 and CuBDC. Between them they covered propylene/propane, ethylene/ethane, carbon capture and hydrogen purification. That breadth is the actual claim. This is not “we found the magic material.” It is “we found a way to print the ones you already have.”

CALF-20 deserves a pause. It is the framework already working inside commercial carbon-capture units, chosen there precisely because it tolerates water — the property that has killed most MOFs in flue gas. Putting it through the same casting route says the method is not tuned to one chemistry's quirks.

What the propane actually does

Molecular dynamics gives the mechanism a pleasing bluntness. Propylene crosses the ZIF-67 apertures readily. Propane does not merely move slower — it is immobilised at the interface and rarely crosses at all. The film does not race the two molecules. It admits one and parks the other at the door.

“The crystals stop behaving like sand in syrup and start behaving like dough. That is the entire trick — and it is why this is a manufacturing paper wearing a chemistry paper's clothes.”

The tell is the coating line

Buried near the end is the sentence that should move a technologist more than any permeability figure. Continuous roll-to-roll fabrication of quasi-pure, (110)-oriented ZIF-67 membranes was achieved at an industrial plant — on an automated casting machine at Shenzhen Senior Technology Material, a company whose day job is functional membranes.

Not a spin-coater in a glovebox. Not a coupon. A web moving through rollers at a firm that already knows how to sell film by the square kilometre. Every previous generation of MOF membrane died in the gap between those two facilities.

What would falsify it

The number to watch next is not permeability. It is defect density across width. A film that is selective on a five-centimetre coupon and a film that is selective across a metre-wide web are different achievements, and only the second one is a product. Nobody has yet published how selectivity varies along the length of a produced roll — mean and tail, not best sample. Until that distribution exists, the roll-to-roll run is a proof of concept for the casting step rather than for the thing being cast.

From Bench to Line

Where it lands first

Not where you would guess. The first market is almost never the biggest one; it is the one with the least sunk steel. New-build propane-dehydrogenation capacity in Asia has no depreciated column to defend, and a debottlenecking retrofit — bolting a membrane onto the front of an existing splitter to strip 30 to 50 percent of the duty and buy throughput without new towers — is an easier cheque to sign than a replacement.

The adjacent doors matter too. CALF-20 is already the working material in commercial carbon-capture sorbents; a version you can print rather than pack changes the cost curve for point-source capture. Hydrogen purification, whether from cracked ammonia or a blended pipeline, is a membrane-shaped problem that has been waiting for a membrane worth buying.

The honest timeline

A roll coming off a line is roughly technology-readiness level six, not nine. No one has yet run one of these films on a live refinery stream — with its water, sulfur, heavy oligomers and catalyst fines — for eight thousand continuous hours. Until someone does, the 80 percent is a spreadsheet output. A very good one, but a spreadsheet.

The buyer's question

For anyone allocating capital rather than lab time, the frame is not “is this better than distillation” but “what does it do to optionality.” A column commits you to one location, one steam system and one nameplate capacity for thirty years. A membrane skid commits you to a replacement schedule. Those are different risk instruments, and where feedstock economics move faster than plants can be rebuilt, the shorter one carries a premium no efficiency figure captures.

FIELD NOTES

How a molecular sieve works, in three steps

1

Build the gate

A MOF is metal nodes joined by organic struts. The lattice leaves windows, and the strut you choose sets their diameter. ZIF-67's window sits right at the width of a propylene molecule.

2

Make it the only door

Cast the crystals so densely — above 90 percent by volume — that no molecule can go around them. Every route through the film now runs through a window.

3

Let shape sort

Propylene slips through. Propane jams at the entrance and parks there. No heat, no phase change — only geometry and a pressure difference across the film.

GLOSSARY

MOF (metal-organic framework)

A crystalline solid of metal ions linked by organic molecules, honeycombed with pores of a designed size. A sponge with a spec sheet.

Barrer

The unit of membrane permeability — gas moved per unit area, time and pressure. 160 barrer is fast for a film this selective.

Mixed-gas selectivity

The separation factor measured on a real blend rather than on two pure gases run separately. Always lower, always more honest.

Quasi-pure membrane

This paper's coinage: above 90 percent MOF by volume, so it performs almost like pure MOF while processing like a polymer.

This Is Not an Energy Story

THE CONSENSUS READ

A large efficiency win. Eighty percent off purification cost, filed under incremental industrial decarbonisation, watched by chemical engineers and nobody else.

THE MOVE 37

The membrane's product is not purity. It is **plant architecture**.

A distillation column is not really a machine. It is a building with a boiler attached, and its economics are pure scale: the only way to make thermal separation cheap is to make the column enormous, which forces the plant around it to be enormous, thermally integrated and immovable. That is why petrochemical complexes look the way they do. Everything is co-located because the steam has to be.

A membrane skid has none of that geometry. It runs at ambient temperature. Its capacity scales with area, so ten small units cost roughly what one large unit costs — there is no scale penalty to pay, and therefore no scale advantage to defend. And it is driven by pressure, which is to say by compressors, which is to say by electricity.

Sit with that last clause, because it inverts the headline. Membranes do not abolish separation energy. They **change its currency, from heat to electrons**. Under a carbon price and a cheap clean grid, the conversion is worth more than the efficiency figure, because it turns purification into a modular electrical load that can be sited where the power is rather than where the steam is.

The right comparison is not distillation versus membrane. It is mainframe versus microprocessor: the same compu-

tation, a radically different unit economics of scale — and the second one unbundled an industry.

WHY THE CONSENSUS DISAGREES — AND WHERE IT IS RIGHT

The 80 percent is a model. Techno-economic analyses of emerging separations have a long, documented history of optimism. This one is not an invoice.

Nothing has run long. The paper reports no multi-thousand-hour operation on a real feed. ZIF-67 is a cobalt imidazolate; its hydrothermal and chemical stability against water, sulfur and catalyst fines is unproven at industrial duration.

Plasticisation waits. Hydrocarbon-selective films historically lose selectivity as the feed swells them under pressure. A selectivity of 100 measured fresh is not a selectivity of 100 twelve months in.

Scale is brutal. Sholl and Lively put the requirement at up to a million square metres of membrane at a single plant. One roll at one materials company is a demonstration, not a supply chain.

The incumbent is already paid for. A fully depreciated splitter has a marginal cost that no capex-bearing challenger beats. New capacity is where this wins first, and that is a slower clock than the number implies.

And the grid decides. Trading heat for electricity is a win only where electricity is clean and cheap. Elsewhere it is a step sideways or backwards. This technology's value is contingent on somebody else's decarbonisation.

Move 37 was not a better move than the human move. It was a move that only made sense if you were optimising a different objective. So is this one.

Three from elsewhere

What else moved this week, outside the cover story.

3.5

FOLD

QUANTUM

A quantum computer that tunes itself mid-performance

Google Quantum AI put a reinforcement-learning agent inside the error-correction loop of its Willow processor. Quantum machines are analog and they drift; today, recalibrating one means halting the computation outright. The team repurposed the error-detection events that quantum error correction already emits as a training signal, letting an agent steer thousands of control parameters while the circuit runs. Under deliberately injected drift, logical stability improved 3.5-fold. After exhaustive human expert calibration, RL fine-tuning still suppressed the logical error rate a further 20 percent. Together the stack reached fewer than one logical error per thousand surface-code cycles. In simulation, the training epochs required were independent of system size — the property that decides whether it scales.

SOURCE: SIVAK, MORVAN & KLIMOV ET AL., NATURE 655, 879–884 (2026); GOOGLE RESEARCH, 22 JUL 2026

90%

CARRIERS

MEDICINE

The mechanism linking a near-universal virus to MS

Epstein-Barr virus is carried by roughly 90 percent of the global population and has long been implicated as a leading cause of multiple sclerosis, which affects about 2.9 million people — but the mechanism stayed dark. Researchers report that T-cell activity against the virus runs about twice as high in people with MS as in controls, and that selectively depleting CD4+ T cells sharply cuts that responsiveness, identifying them as the driver. The work also explains a therapy already in use: across 60 patients, anti-CD20 treatment reduced CD4+ T-cell levels roughly 2.5-fold within six months, an effect that persisted up to a year — and those patients carried less virus in their saliva than untreated controls.

SOURCE: BJORNEVIK, K. ET AL., SCI. TRANSL. MED. 18, EADZ6566 (2026); NATURE 655, 832–833 (2026)

12

BILLION YRS

SPACE

A comet older than the Sun, read from its isotopes

Carbon and hydrogen isotope measurements of the interstellar comet 3I/ATLAS push its formation as far back as 12 billion years — long before the Solar System existed. Its water is enriched in deuterium at $D/H = (0.98 \pm 0.06)$ percent, more than an order of magnitude above any known Solar System comet, and its carbon ratios sit outside the local range: 141–191 for carbon dioxide and 123–172 for carbon monoxide. The signature points to assembly below about 30 kelvin in a metal-poor environment — a preserved fragment of an ancient planetary system that happened to pass through ours.

SOURCE: CORDINER, ROTH & THOMAS ET AL., NATURE (2026), DOI:10.1038/S41586-026-10771-6; ESO RELEASE ESO2608

The arithmetic of *un-mixing*

10–15%

of the world's annual energy is consumed by thermally driven chemical separations.

200_{Mt}

annual global production of alkenes — the product class this separation exists to make.

80%

lower purification cost than distillation for propylene, per the new membrane's techno-economic analysis.

230_{GW}

consumed each year by atmospheric distillation of crude oil alone — about the United Kingdom's entire 2014 energy use.

~100

mixed-gas propylene/propane selectivity — measured on a real blend, not on pure gases run separately.

1M_{m²}

of membrane a single chemical plant might need for hybrid separation at scale — the distance between a demo roll and an industry.

90%+

of the film's volume is MOF crystal — the threshold that earns the name “quasi-pure.”

150+

theoretical plates in a conventional propylene–propane splitter, recirculating its own contents ten to fifteen times over.

FIGURES 1, 5, 6 & 7: SHOLL & LIVELY, NATURE 532 (2016) · FIGURES 2, 3 & 4: SONG ET AL., NATURE 655 (2026) · FULL CITATIONS, PAGE 9

The Cost of Being Pure

Three of this week's stories are the same story wearing different equipment. A membrane sorting molecules by shape. An agent sorting control error from environmental noise. A telescope sorting isotopes to date a rock older than the Sun. Sorting is the tax the universe levies on anything that wants to be specific.

What is worth carrying out of all three is *where the advance came from*. In each case it was not more force. It was a better signal to sort on. Google did not build a quieter qubit; it noticed that the error detections it was already collecting, and already discarding after decoding, were a training signal. Cordiner's team did not get a bigger telescope; they read isotope ratios that had been sitting in the light the whole time. And Song's team did not invent a better MOF — ZIF-67 has been on the shelf for years. They changed its surface so that an existing crystal could finally be cast.

That is an unglamorous pattern, and it is the operationally useful one. Before buying more energy, more compute or more aperture, check whether the signal you

need is already passing through your hands unread. Most organisations are instrumented far past the point where they actually look.

The second thing to carry is about time constants. Efficiency compounds slowly, because the system that receives an efficiency gain tends to absorb it and grow. Form factor compounds fast, because it changes what is buildable, and what is buildable changes who gets to build. A column is a hundred metres of steel that fixes a plant to a place. A film on a roll is a component. The interesting question is not whether the film is 80 percent cheaper. It is what a chemical industry looks like once purification becomes something you rack rather than something you erect.

Probably not soon, and probably not on the timeline the abstract implies. Roll-to-roll is one step; defect statistics, fouling, plasticisation and a supply chain are four more, and each has buried a promising membrane before. But the direction is legible now in a way it was not last month. Watch what gets small.

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INFLECTION.

THE WEEKLY MAGAZINE OF INNOVATION · ISSUE NO. 02

NEXT ISSUE · FRIDAY

A new deep dive, a new domain, and
the week's most consequential thing
that *looked* like nothing.

THE LENS

*“What signal is already passing through your hands,
unread?”*