TURNOVER

Waste less, make more

The Business Case for Carbon Utilization

Turnover Labs | September 2026

CONTENTS

SECTION ONE

Chemistry is critical, so why has it been dying?

The past five years have been a perfect storm for the chemicals Industry. First, COVID broke supply chains, then tariffs reshuffled them. Russia's pipeline cutoff following the invasion of Ukraine took Europe's cheap gas off the table, sending costs even higher. Weak domestic demand in China turned into export availability, and cheap chemical products quickly flooded global markets.

The result has been structural overcapacity across the industry, compressed margins, and more than 120 plant closures and mothballings since 2022.[1] If you don't work in chemicals, these shifts are easy to miss, but consumers are already paying for it through the price of the plastic in a jug of milk, the paint on a car, and the fuel in the cargo ship carrying an online order.

If you are informed about global manufacturing, however, you will have noticed the industry's unprecedented instability. A January 2026 European Chemical Industry Council (CEFIC) report found that European plant closures have surged sixfold since 2022, reaching 37 million tonnes of capacity, roughly 9% of European production, and costing over 100,000 jobs (20,000 direct, with another 89,000 indirect jobs at risk).[2] Announced annual investment capacity fell from 2.7 million tonnes in 2022 to 0.3 million tonnes in 2025, a shift, in CEFIC's words, from broad investment across electrification, hydrogen feedstocks and circular plastics to barely one pilot initiative.[2] CEFIC Director General Marco Mensink put it plainly: “It's no longer a question of being five minutes before or after twelve. The sector is under severe stress and breaking.”[2]

The disappearance of upstream production capacity is not only relocating historically relevant manufacturing hubs in Europe and threatening its labor markets, it is introducing a new geopolitical balance of power. In 2004 Europe accounted for 27% of global chemical sales; by 2024 that had fallen to 13%, while China's share rose from 10% to 46%.[3] Global commercial growth consulting firm Simon-Kucher found that roughly three-quarters of energy-intensive companies in Germany are shifting investment abroad rather than expanding centralized domestic capacity,[4] and Deloitte's 2026 analysis describes this trend as a “hollowing out of the middle.”[1]

This level of instability will not stay siloed upstream in the value chain for long, with impact already trickling downstream. When Italy's largest chemical manufacturer Versalis shut its cracker in Sicily, the polyethylene unit at nearby Ragusa lost its main lifeline feedstock source.[5] Another polypropylene plant ran by LyondellBasell also felt the shock from Versalis' exit and had to grapple with closing down in the near-term, or buying more expensive feedstocks that jeopardize the plant's competitiveness.[5]

Industry analysts read these events as indicators of a structural reset rather than a cyclical correction: a permanent reorganization of how and where chemicals get made. Chemicals sit underneath nearly everything physical in the modern economy, which is why a reset in this industry ripples outward into every other one.

How policy has exacerbated volatility

As decarbonization mandates mature from best practices to enforceable legislation (such as the EU's Emissions Trading System (ETS)), responsibility for emissions is increasingly pushed upstream onto whichever manufacturer sits closest to the raw material. Carbon policy is not inherently unfair to the upstream players, but it becomes unfair when the accounting boundaries do not match how a plant actually runs.

Emissions disclosure is one area where policy clashes with operational reality. The chemical industry is highly integrated, with production units, utility systems, CHP plants and heat networks. These are often reported under different ETS installations, or facilities, despite operating as one industrial system. Emissions disclosures are not always recorded under the same permit, so any honest assessment of carbon-cost exposure needs a boundary that captures both the production units and the utilities feeding them.[6] CEFIC analyzed how this can quickly break down; 29.3% of verified emissions went uncovered by the free allocation of emission permits between 2013 and 2024.[6] It should be noted that ETS is now shifting to new mechanisms, like CBAM, which more strictly track emissions from imported goods.

Another area straining the chemical industry's ability to decarbonize is necessitating action over a short time period, which then requires massive and long-term capital investment. Under the EU's methodology for renewable and recycled carbon fuels, industrial CO_2 qualifies only if it comes from an ETS Annex I activity, is priced upstream under an effective carbon-pricing system, and is incorporated into the fuel before a fixed cutoff date.[7] That cutoff exposes a basic problem with the system: the chemistry may endure, but the rules do not. For Turnover's utilization process that uses CO_2 from industrial sources, the avoided carbon value stops counting for fuel production in 2041, and in 2036 when it comes from electricity generation.[8]

In practical terms, that means a company can build equipment to capture CO_2 and turn it into fuel, but the regulatory value assigned to that CO_2 can disappear while the equipment is still being paid for. The technology does not suddenly stop working when the deadline arrives, and investors cannot suddenly make a project pencil because they wish it to.

The industry association FuelsEurope has asked for at least five more years of counting recycled CO_2 under the favorable pricing scheme, arguing that the current sunset makes it impossible to amortize investment in shared CO_2 capture and transport infrastructure.[9] This is not a plea for weaker climate ambition, it is simple arithmetic. Chemical infrastructure is built and financed over decades. If the regulatory value of the carbon disappears before the infrastructure has paid for itself, the investment case disappears with it. No amount of technological promise can make a project bankable when the price is designed to expire before the check comes due.

CEFIC warned that the EU's decarbonization policy “risks cutting industry, not emissions.”[10] Unfortunately, this has proven true. Between 1990 and 2022 the European chemical industry cut emissions by more than 60% while increasing production by more than 43%.[10] Yet investment dropped 86% in the past year alone.[10] CEFIC President Markus Kamieth, who is also BASF's chief executive, said it directly: “Every missed opportunity makes it harder to reverse the downswing, and increases the risk that investment, production and innovation leave Europe for good.”[11] After a year of negotiations, earlier this month in September 2026, the EU finally moved to deliver its most direct financial relief mechanism yet, handing heavy industries, primarily chemical and metal producers, an additional 121 million free CO2 permits from 2026 through 2030. Reuters noted this move effectively shields chemical plants from €8.25 billion ($9.52 billion) in carbon costs to help them survive intense foreign competition.[12]

Policy with the right design, however, can spark innovation as well as incentive. Canada's federal Output-Based Pricing System sets an emissions-intensity benchmark per unit of production, derived from the national production-weighted average for that product. A facility under its limit earns surplus credits it can bank or sell; a facility over it pays only on the excess.[13] Because the benchmark is per tonne of product, a manufacturer that cuts purchased energy generates a tradeable asset rather than simply avoiding a penalty. Here we pay the upstream producer for improving rather than charging it for existing.

Europe is highlighted so prominently in this review because it is where trends impacting the entire industry have collided most dramatically. It offers examples of challenge, and triumph, a canary in the coal mine of deploying aggressive decarbonization policy in an age of supply chain disruption. It would be easy to read the challenges of the ETS rollout as bad policymaking, but rather it serves as evidence that change is genuinely hard.

Carbon accounting frameworks are being retooled while the science underneath them keeps moving: how end-of-life emissions should be treated, how to weigh gases with very different atmospheric lifetimes, where a boundary should sit when a plant and its utility supplier are legally separate but physically inseparable. Anyone who has built a company from scratch will recognise the shape of it. You build, you learn something that invalidates the plan, you rewrite the plan. The difference is that when a startup does it, it is called iteration, and when a regulator does it, it is called uncertainty.

The chemical industry did not orchestrate the disruption it has endured, but now it has to decide how it adapts. If the industrial and accounting systems are changing at the same time, the question becomes: how can old models be updated in a way that is both environmentally and economically secure?

SECTION TWO

Waste-to-Value in chemicals: a look back

Feedstock is the generic term for the carbon-rich building blocks behind everything from the spandex in gym clothes to the paint on a car to the fuel powering a cargo ship. It comes primarily from centralized fossil deposits, shipped across the world and processed through systems whose underlying assumptions have remained the same for more than a century. Innovations in chemistry and catalysts have scaled and improved this manufacturing, but the basic architecture is unchanged. That framework was optimized to extract maximum value from cheap oil and gas. It has not adapted to trade economics, electrification, carbon policy, or supply-chain security.

A significant share of imported virgin feedstock never reaches a finished product. U.S. EPA data covering 1990 to 2016 indicates that of the potential carbon entering the manufacture of non-fuel petrochemical products, roughly a third was released during production rather than retained in the product itself.[14]

In a world where carbon is increasingly taxed, supply chains are regularly disrupted, and imports are tariffed, wasting that much carbon stops making economic sense. If that carbon were gold, no one would keep using a pan that let that much of it fall back into the river. The natural conclusion is to find a way to reuse that carbon so it stays within the system rather than being released.

But this idea is not new. The chemical industry has converted a waste stream into a profit center before, and the precedent is instructive. The Claus process, now the global standard for recovering sulfur from oil and gas processing, turned an emissions liability into the dominant source of world sulfur supply.

Every single ton of elemental sulfur produced in the United States today is recovered as a byproduct—at petroleum refineries, natural-gas-processing plants, and coking plants. The consequence is that the mined sulfur industry no longer exists. Most of that recovered sulfur goes on to become sulfuric acid, which accounts for roughly 90% of all US sulfur consumption and runs through fertilizer and industrial supply chains worldwide.[15]

That infrastructure did not appear because producers wanted a new product line. It appeared because environmental regulation forced it to. Production of native sulfur declined worldwide in the 1970s as rules tightened on sulfur dioxide, a harmful airborne toxin, and recovery grew faster than sulfur demand did.[16] Sour gas processing in Alberta made Canada a major recovered-sulfur supplier, pulling domination away on sulphur supply from Texas, and modeling a winning strategy for using a regulated waste stream as a monetizable new supply chain.

For producers who mined sulfur rather than recovering it from other processes being regulated, the consequences were deadly. US Frasch production peaked in 1974, when hot-water mining produced eight million tons of sulfur: about three-quarters of all US elemental sulfur production. The remaining quarter came from byproduct recovery.[17] By 2000 the US Frasch industry had shuttered its last mine, driven out by low prices caused by weakened phosphate demand, rising competition from low-cost recovered sulfur, escalating production costs and technical problems.[16] Peak to zero in a single generation.

Something structurally similar is happening now for carbon, and the most revealing example is not a plant that closed but a plant that was never built. In January 2026, Vioneo, backed by A.P. Moller Holding, abandoned plans for a €1.5bn fossil-free plastics plant in Antwerp, choosing China for its first commercial-scale facility instead and citing access to green methanol and a faster route to market.[18] The company's own explanation is more damning: after a year of engineering work and market research, Vioneo concluded there was no prospect of enough green methanol being produced in Europe in the near term, and that customers balked at the price they would have to pay if the plant were built in Antwerp.[19] Vioneo still believes European plastics have a future. It just could not get the carbon.

That is the sulfur story running in reverse. A company that wanted to build the recovery infrastructure could not, because the feedstock it depended on was not available at the scale or price the project needed.

Plant closures tell the other half of the story. ExxonMobil's Gravenchon complex in Normandy lost more than $530 million between 2018 and its closure with the company citing the cracker's configuration, its small size relative to newer units, high European operating costs and higher energy prices. 677 jobs went with it.[20] This raises a question worth asking: if a plant in a region with abundant low-carbon power and available industrial CO2 still could not make the economics work, was the problem the electricity price, or was it that nobody had designed a system optimized for those operating conditions?

SECTION THREE

De-mystifying Industrial Decarbonization

The transition toward a lower-carbon chemical industry has largely followed two parallel approaches: capture or prevent the emissions from existing processes, and build new plants around non-fossil or geographically advantaged feedstocks. Both have run into the same wall.

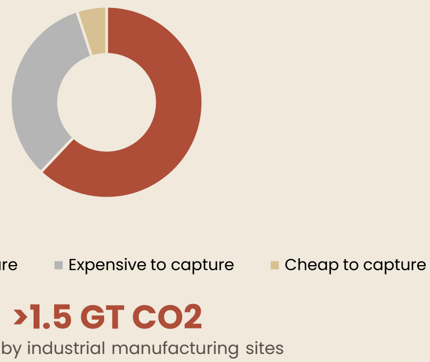

FIGURE 1 Industrial manufacturing emissions, segmented by the cost of capturing them. Source: P. Gabrielli, Net-zero emissions chemical industry in a world of limited resources, 2024.

The first response has been to capture the carbon and put it underground. Chevron's Gorgon project in Western Australia, the largest CCS project in the world, was approved on condition that it captures 80% of the CO2 removed from its reservoir on a five-year rolling average. IEEFA's analysis found it captured 33%, 34% and 30% in successive years, never reaching the target in any year since operations began.[21] Petra Nova was suspended after four years, Kemper never started, and Boundary Dam and the Illinois Industrial project have each underperformed by roughly half. Shell's Quest, by contrast, has performed close to capacity.[22]

The fair reading is not that carbon capture doesn't work though. As one analyst inside the sector put it - while conceding each of those failures, the difficulty reflects the hard work of deploying first-generation commercial infrastructure in a capital-intensive sector with inadequate incentives, rather than a technology itself does not function.[23] That is the more useful conclusion, because it points at the actual constraint: every one of these projects required finding a sequestration site, building transport to reach it, and committing capital at a scale that makes a single execution failure existential. The compounding risk is not in the technology. It is in the build.

CCS is the appropriate solution in many situations, wherever there are cheap, stable, storage locations near emissions sources, for instance. After all, when a body is poisoned one must first purge the toxins out of the system before doing anything else. However, once purged, that body will need to consume energy to get up and go again.

The second response from industry has been to build new plants around non-fossil feedstocks, and two constraints have proven stubborn. The first is cost: a 2026 techno-economic assessment modelling renewable methanol across Germany, Sweden and Portugal found bio-methanol approaching cost parity with conventional methanol around 2030, while e-methanol remains substantially more expensive, with imports competitive only after 2040.[24] The second is scale: global e-methanol production sits under half a million tonnes a year despite industry estimates of roughly 8 million tonnes needed by 2030 to meet regulation and existing vessel orders. That's a sixteen-fold increase requiring tens of billions in investment.[25]

Biological feedstocks face a different physical ceiling. Europe's waste oils and fats are already contested, with road transport, marine fuel and the chemical industry competing for the same finite pool,[26] and that competition is tightening across fuel and food supply chains at once.[27] The ICCT finds EU blending targets through 2035 can be met from low-GHG waste and residue biomass without touching feedstocks that would affect food markets, but that later targets of up to 35% bio-SAF will be considerably harder.[28] Biomass is a bridge with a known length. Electricity on the other hand has no such end; the IEA's Electricity 2026 outlook forecasts global demand growing 3.6% a year through 2030, at least two and a half times faster than overall energy demand, with renewables and nuclear together supplying about half of global generation by the end of the decade.[29] A carbon mitigation pathway that scales with electricity scales with the fastest-growing energy system on the planet. A carbon pathway that scales with agricultural residues scales with how much land there is.

Together, these two approaches require building greenfield capacity for low-carbon processes while simultaneously building a separate capture, transport and storage system for the emissions of existing infrastructure. That is capital and time intensive, and it replicates the bulky, centralized characteristics of the incumbent fossil model it is meant to augment. Even Europe's flagship new build makes the case. INEOS' Project ONE in Antwerp, a €4bn ethane cracker producing about 1.45 million tonnes of ethylene a year, is the first new cracker built in Europe in roughly thirty years. Its answer to the feedstock problem? Import ethane from the United States.[18] That a €4bn European plant whose solution to a European feedstock disadvantage is a transatlantic shipping route demonstrates just how narrow options have become under the centralized model.

Large projects need large, concentrated sources of material, large infrastructure commitments, and sites capable of justifying the investment. Storage needs access to sufficiently large sequestration opportunities. New production needs sufficiently large sources of non-fossil or captured carbon. Both require substantial new infrastructure before a useful product exists.

The Case for Utilization

Following the model from sulfur, carbon utilization suggests another path to profitably and scalably move the industry under their own constraints. The most accessible source of carbon is the emissions the industrial facilities already generate. The same emissions a facility is being penalized for can instead be repurposed, letting it reduce carbon leaving its operations while reducing the amount of new fossil-sourced carbon entering the global system.

While utilization seems conceptually elegant, in practice it has faced three barriers to adoption:

1. **Technical:** most carbon-transformation processes require significant separation and reaction energy, raising the cost of the input above the market value of the output molecule.
2. **Regulatory:** utilization of CO2, particularly when the carbon originated from fossil feedstocks, has not received the same policy treatment or incentives as permanent storage.
3. **Systemic:** the chemical industry has spent more than a century optimizing around scale. Small additions of carbon-utilization capacity to existing plants do not naturally fit the centralized mega-plant model, even where they may be economically prudent.

These hurdles are not insignificant, but with the right approach, they are surmountable. Turnover is betting on an industrial system that treats emitted carbon as reusable feedstock, distributes production and carbon accountability more effectively, integrates with existing infrastructure, and can be deployed incrementally rather than through enormous first-of-a-kind bets. To understand what would have to change for utilization to become a serious industrial contender, each of those three barriers has to be considered.

Our system consists of 3 key steps

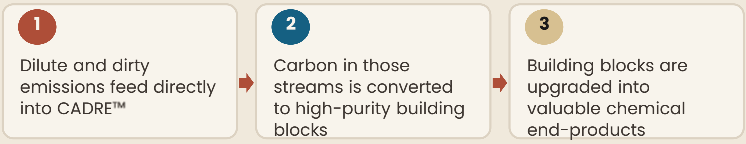

FIGURE 2 Turnover's drop-in process. Dilute, contaminated emissions are fed directly into the reactor and upgraded using established downstream processes.

Problem I: Tackling the technoeconomics

Today's utilization technologies are constrained by fundamental technical economics. The major criticism of CO2 utilization is that transforming CO2 into usable feedstocks takes more energy than the resulting product is worth. That energy cost consists of two parts: preprocessing the input carbon dioxide, and performing the reduction reactions that turns that carbon into useful chemicals.

Real industrial exhaust contains plenty of CO2, but these streams are still dilute, contaminated, and variable. This is in contrast to what current utilization systems require, which is comparatively pure, uncontaminated, invariant CO2. Corrosive pollutants found in industrial exhaust can permanently contaminate a reactor, and non-reactive dilutants accumulate and impair performance. While pure sources of CO2 do exist in industry, they make up under 2% of emissions from large stationary sources, and they sit geographically isolated from industrial hubs.[30]

At Turnover, our goal is to cut the preprocessing of input streams by developing our technology on industrial CO2 streams first. By emphasizing impurity tolerance in the reactor, our team has widened the range of emissions that can serve directly as feedstock.

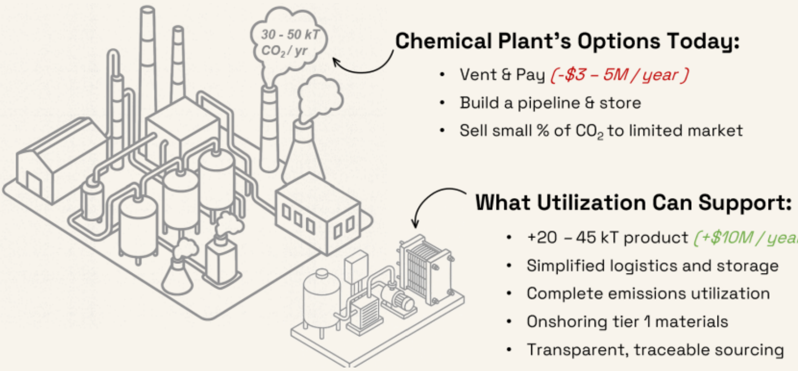

FIGURE 3 Turnover helps plants turn their liability into resilience. Figures in diagram are illustrative and not to scale..

This is the approach that Turnover believes is the most scalable, and why we build technology specifically for this use. Rather than seeking the cheapest molecules and shipping them globally from a fixed greenfield mega-plant, we target locations where the price of industrial electricity relative to delivered imported natural gas lets our process compete on cost without needing subsidies to close the gap. The feedstock for our process is already on site, coming out of the stack.

In laboratory trials, we have demonstrated sustained continuous stable operation for more than 1,000 hours, including on contaminant-rich streams with CO2 concentrations as low as 10%. Tested against an unpurified industrial waste-gas sample containing sulfur oxides, oxygen and more than ten organic compounds, the system showed less than a 5% reduction in performance and returned fully to baseline once a pure CO2 feed resumed.[31] At current performance, the process is compatible with a substantial share of the emissions chemical manufacturing already produces: the dilute, contaminated streams conventional utilization systems cannot accept without an expensive purification step in front of them.

The second criticism of carbon utilization is that an impractical amount of energy goes into breaking CO2's chemical bonds to make the molecule reactive again. That is true. You *must* spend energy to make CO2 useful. But energy is always spent making molecules; in conventional thermocatalytic production it is simply drawn from what is already stored inside fossil feedstocks like crude oil, coal and natural gas rather than supplied externally. Industrial processes today are not built to be energy efficient. They are built to be cost efficient. When energy from oil and gas are cheaper than electricity, then that is where operations will optimize.

Electrified processes like Turnovers allow manufacturers to decouple their feedstock and processing emissions burden, and place more bets on the global transformation to cheap, clean power. This decoupling gives manufacturers - especially those in import-dominant regions - greater control and flexibility over their energy stack.

Of the products CO2 can be converted into, carbon monoxide requires the least energy: one oxygen atom removed through a simple two-electron transfer.[32] In the chemical sector CO is already a platform molecule rather than an end product. Methanol synthesis, Fischer-Tropsch fuel synthesis, acetic acid production, steelmaking are all mature, commercial scale processes that consume high purity CO today. This critical molecule is currently generated onsite by transforming fossil feedstocks such as coal, petcoke and natural gas through thermocatalytic reforming, partial oxidation, gasification and byproduct recovery.

This is the low hanging fruit available to the chemicals industry today, and it is why CO is Turnover's first target product to manufacture from emissions. Rather than replacing engrained processes, downstream infrastructure serving multi-billion-dollar chemical markets can stay in place while the upstream carbon source is transitioned.

For identical hardware at an identical site, Turnover's system can avoid an estimated 23,400 tons of CO2 annually on natural-gas grid electricity, or roughly 60,000 tons on solar.[33] That is more than double the avoided emissions, with no change to the core process or technology for the manufacturer, just a pivot to a grid that is already greening up.

Problem II: Who foots the carbon bill?

Current policy tends to ensure the carbon bill is footed by the emitter. But emissions in any highly integrated process industry don't fall onto one player, they are divided across three categories:

> **Scope 1** covers direct emissions from a company's own operations.

> **Scope 2** covers emissions embedded in purchased process energy such as electricity, steam or heat.

> **Scope 3** covers everything else: emissions generated by suppliers upstream and customers downstream.

For most manufacturers, Scope 3 exceeds the other two combined, and for the average chemical producer, upstream and downstream Scope 3 attributes account for roughly three-quarters of their total emissions.[34] However, the majority of carbon policy today is only billing the chemicals sector for its Scope 1 emissions. It's like a dinner guest who only ordered a salad, having to split the bill equally with their friends who got the lobster and steak.

So why is this imbalance happening? Well, emissions tracking started with a pledge in the Kyoto protocol in 1997, then creating a system for projections in the GHG protocol in 2001.[35] Participation in these protocols were all voluntary, and therefore the system of projections for Scope 1, 2, and 3 emissions did not need to be designed with the rigor of an accounting system. However, as corporations began taking ownership of their responsibility to the climate, this system became the de facto accounting method. Now that governments are embracing involuntary carbon regulation, this loose legacy system needs to be re-evaluated, and a new system that is comparable, verifiable, and traceable must take its place.

Plenty of industry professionals are already on the task. Case studies from the nonprofit E-ledgers Institute, which develops methods for tracking emissions product-by-product across supply chains, show how far the gap runs. In a pilot with BMW Group covering a customizable component of its iX line, the obstacle was not the accounting method. Many of BMW's own suppliers lacked the capacity to calculate their embedded emissions at all.[36] Scope 3 accounting is therefore not primarily a data-quality problem but, in many places, a data-existence problem.

Part of the challenge is open debate amongst scientists and policy makers on the “fair” lifecycle analysis of different sources of carbon. Under the EU's framework, CO2 captured by direct air capture, biogenic CO2 meeting RED II criteria, CO2 from compliant RFNBOs and recycled carbon fuels, and geological CO2 are all eligible as fuel feedstock without an end date. However, ETS industrial CO2 from power production is eligible only until 2036, and from other industrial production until 2041.[8] Carbon from an industrial stack has an expiration date. Carbon from a tree does not.

This LCA debate doesn't have to stall clarity on policy if the “carbon issue” is reframed as an industrial growth opportunity. The United States reached the same conclusion recently. Before 2025, Section 45Q paid $85 per tonne for point-source CO2 placed in secure geological storage, but only $60 for CO2 utilized.[37]

The One Big Beautiful Bill Act introduced parity: CO2 converted into valuable products now qualifies for the same credit value as CO2 permanently sequestered.[38] This shift came under an administration with no enthusiasm for climate policy and outright hostility toward climate scientists. Their reasoning was purely economic; carbon treated as a commodity rather than a liability supports projects that create domestic jobs and strengthens industrial infrastructure.[39] Utilization gained support not because it was reframed as a climate measure but because it was recognized as good business. That is a more durable foundation than it sounds. Policies that depend on sustained climate ambition are vulnerable to public sentiment. Policies that are sustained by economic sense, survive every election cycle.

When climate policy is not designed to honor fundamental economics, the result is that all of the penalty lands at the beginning of the chain, and the geographies trying hardest to do the right thing are the ones punished on the global market. This outcome is expensive and unfair, and it is not tied to science. It is an artifact of a well-intentioned but outdated “IOU” carbon accounting framework.

As a society we have made do with the tools available, but tools are always evolving. The E-ledgers Institute has since published several case studies of partnering with industrial clients to launch their e-ledger and e-asset solution. Where data exists, commercial outcomes change. Pilots with Tata Steel and Heidelberg Materials applied product-level emissions accounting to a commodity steel product and to cement clinker, in each case creating grounds to differentiate on emissions rather than price alone.[40] Implementing tools like that could distribute ownership of carbon across the value chain and prioritize end-impact over accounting ease, giving manufacturers and downstream buyers real agency over feedstock selection while letting carbon responsibility and incentives move with the material itself.

However, it takes trust to adopt a new tool when the stakes are high. E-ledgers Institute was able to gain such visibility and access to supply chain data that would normally be a trade secret precisely because they are a non-profit. Their tool was framed as a learning exercise (covered by NDA), as opposed to a commercial liability. This is part of the challenge felt throughout the chemical value chain: getting help can sometimes feel like exposing your vulnerabilities.

Companies have addressed this challenge by using mass balance and book and claim. In the former, the low-carbon and fossil streams are mixed, but the final product has a proportional allocation of low-carbon credits. In the latter, the environmental attribute is separated from the physical product entirely and traded as a certificate. The logic is the same one that underpins renewable electricity: you cannot direct particular electrons from a wind farm to a particular socket, so the generator books a quantity of green power into the grid, and a customer elsewhere claims a corresponding amount.[41]

Chemical manufacturers are already fluent in this. Mass balance is effectively what a multi-year, multi-billion-dollar plant does when it commits to a feedstock source: the physical supply is contracted, verified and allocated, and everyone in the chain knows which molecules went where. The industry did not adopt mass balance because of sustainability reporting. It adopted it because that is how large integrated plants have always had to account for what they buy.

Book and claim exists because the physical version does not reach far enough. SAF costs two to five times conventional jet fuel and production is extremely limited, so a corporate buyer who never purchases jet fuel directly has no physical route to procure it at all.[41] The certificate is the only mechanism that connects that buyer's money to that molecule.

Book and claim was broadly recognised as the only viable mechanism for scaling voluntary demand, yet major suppliers including Neste and Shell initially resisted it, preferring mass balance for its physical traceability, which they viewed as more defensible under GHG Protocol and SBTi guidelines.[42] Early corporate buyers including Microsoft and Boston Consulting Group provided the market's initial commercial traction, but each supplier operated its own product definition and audit protocol.[42] The tension between pragmatic scale and traceable integrity has defined that market for years.

That tension is exactly the one running through Scope 3 in chemicals, and it is why on-site conversion is interesting beyond the tonnes of carbon it handles. A system installed at the emissions source produces primary, physically verifiable data about a specific stream at a specific facility; mass balance evidence, generated as a byproduct of operating.

For example, Turnover's carbon utilization system installed onsite gives each participant of a materials value chain visibility into, and a lever over, the portion of carbon accounting that is genuinely theirs:

At the manufacturing facility, CO_2 that would otherwise have gone up the stack is consumed on-site instead, reducing their **Scope 1**.

At the electrolyzer, durability, pretreatment requirements and the electricity source reduce the **Scope 2** of processors committed to electrification.

Downstream, a low-carbon material input can reduce the buyer's **Scope 3** where supplier-specific data (now easily provided through Turnover's system) demonstrates a lower cradle-to-gate footprint than the fossil product it replaces.

By mapping a partner's actual energy inputs, existing power purchase agreements and renewable certificates, and incentivizing them to connect us with their existing value chain partners, Turnover's team can optimize for deployments across partners and regions that make rigorous carbon accounting cheaper, and more secure to satisfy.

The aim of all these methods is not to remove accountability, but to make accountability reflect where carbon actually moves and where participants have the ability to change its path. In practice, that means connecting physical carbon reuse to more precise carbon accounting: source-level emissions data generated at an operating facility, usable by a customer further down the chain, in place of an industry-average estimate standing in for a figure no one measured.

Problem III: Making smaller, incremental steps

The chemical industry's current mega-plant model is under measurable strain. Large centralized facilities benefit from economies of scale but also carry execution risk that compounds when market conditions shift across long build timelines. The economics are unforgiving in a specific way: the capital is spent upfront and the margin depends on running near design capacity. Fall materially below full-scale operation and the fixed costs do not fall with you.

Japan's ethylene sector is the clearest current illustration. As prominent petrochemical researcher Chihiro Momose put it, operating rates have fallen far below the 90% level needed to secure profitability, dealing a direct blow to the sector.[43] The consequences are structural rather than cyclical: four Japanese crackers are set to close in the coming years, reducing operating units from twelve to eight and cutting national ethylene capacity by nearly 30%.[43]

Europe faces the same arithmetic from the other direction, with EU chemical capacity utilization holding around 74–75%, well below long-term averages and consistently below competing regions since 2022.[44] Analysts estimate that roughly two million tonnes a year of ethylene capacity must be permanently removed to restore European utilisation to about 90%.[45] A plant that is subscale against global competition and running below breakeven has no good options. It cannot shrink gracefully, because the economics were never designed to.

Feedstock fragility compounds it, and the most acute current example is unfolding in Asia right now. Japan imports roughly 60% of its naphtha, and about 70% of those imports come from Persian Gulf countries.[46] When disruption around the Strait of Hormuz hampered procurement in 2026, Japanese producers cut cracker output deliberately, not because demand had vanished, but to stretch the feedstock they had.

The chair of the Japan Petrochemical Industry Association, Asahi Kasei president Koshiro Kudo, said so directly: “The operating rate has been reduced in order to maintain supplies.”[47] The rate fell to a record 67.3% in April 2026,[47] against a historical norm of 95–100%.[48] The cost did not stay in the plant: Japanese polyolefin prices climbed by as much as 90% for polyethylene and nearly 80% for polypropylene, and imports rose sharply as domestic ethylene production fell by around ten percentage points.[46] That is what concentrated feedstock dependency costs when the route is interrupted, and the interruption had nothing to do with the chemistry, the plants, or the demand. It was a 100mi long shipping lane.

Large first-of-a-kind capital projects illustrate the other side of the problem. Shell's petrochemical complex in Monaca, Pennsylvania was initially estimated at roughly $6 billion; final construction cost reached $14 billion, a 130% increase over the original projection.[49] The facility then entered a difficult petrochemicals market, and public reporting as of early 2026 indicated the company was exploring a sale or partnership for the asset.[50]

The alternative to this model is to deploy small, replicable, distributed infrastructure. A technology that can be deployed incrementally does not have to concentrate the same technical, market, feedstock and customer risk into a single decision. On the earnings call disclosing the final cost, Shell's leadership drew the lesson that illustrates the approach we believe will be required going forward: “small and replicable is beautiful.”[49]

The technical literature notes that electrochemical processes lend themselves to small, modularizable plants sited directly at a customer's location, in contrast to the centralized facilities that dominate conventional processes.[51] Utilization processes that require clean CO2 have to be built large and sited where the cleanest feedstock is available. A technology that tolerates the conditions of an operating industrial site can instead be deployed small, in parallel, against whatever stream a facility already produces.

Scaling on-site field pilots

Now	2027 & 2028	2030+
TRL 4	TRL 5–6	TRL 7+
0.1–1 TPA capacity	1–10 TPA capacity	100+ TPA capacity
1,000 hr stability simulated emissions	2,000+ hr stability direct process emissions	Established pilot operating continuously
< 5.1 MWh/ton	< 4.8 MWh/ton	< 4.6 MWh/ton

FIGURE 4 Turnover's staged deployment path, from current field pilots through continuously operating commercial systems.

Removing the need for a separate capture step gives Turnover more freedom to deploy modularly than other carbon transformation technologies. Our growth strategy is therefore structured around small, consecutive field deployments rather than a single flagship site. Turnover CO2-utilization systems will be placed with partners spanning different CO2-stream qualities and different target end products rather than concentrating risk in one chemistry or one customer. Each deployment tests a different part of the proposition: a different contaminant profile, a different downstream process, a different set of operating and emissions data. Collectively they reduce dependence on any single plant, feedstock, chemistry or customer while testing whether one output can function at multiple points in the chain.

Feedstock security is the hot topic, and for good reason. Procurement is no longer a footnote in the technical annex, they are central to whether the asset has a future at all. Versalis closing precipitating its downstream neighbors' closure showed that a plant with no independent feedstock position does not decide its own fate.[5] Vioneo walking away from an attractive €1.5bn investment because the carbon it needed would not arrive in time[19] showed that investment is ready once supply strategy catches up. And Japan's crackers showed throttling output not for want of customers but for want of a shipping lane.[47]

An asset that makes its own feedstock from what it already emits is not exposed to any of those three failures in the same way. That is not a claim about emissions. It is a claim about resilience, and it is why we think distributed carbon utilization is a commercial argument before it is an environmental one.

SECTION FOUR

Final thoughts

The chemical industry is entering a new operating environment. The old balancing act of scale versus specificity is now underpinned by supply.

Turnover is betting that carbon utilization can be one practical part of that response: treating emitted carbon as feedstock, converting it into molecules industry already uses, deploying infrastructure in smaller and more flexible increments, and creating better information about where the resulting carbon benefits actually occur. The technical characteristics of our technology unlock a different deployment model, one that can help the industry grow rather than asking it to start over.

Turnover is currently advancing deployments with field partners across multiple industries and CO2-stream types. We invite feedback and discussion from manufacturers, operators, policymakers, and researchers alike.

Contact us for more information. hello@turnoverlabs.com

Britt Chong, Head of Growth and Operations

Marissa Beatty, Chief Executive Officer

SECTION VI

Endnotes

1 Deloitte, *The Domino Effect: Implications of Chemical Plant Closures on Supply Chains*, 2026. Analysis of more than 120 publicly announced closures and mothballings since 2022, and the source of the "hollowing out of the middle" framing. deloitte.com/us/en/insights/industry/chemicals-and-specialty-materials/reshaping-chemical-supply-chains-plant-closures.html

2 Cefic and Roland Berger, *European Chemical Closures & Investments Radar 2022–2025*, January 2026. cefic.org/news/chemical-plant-closures-surge-six-fold-in-europe-since-2022-reaching-37mt-new-report-finds/

3 "Chemical plant closures surge in Europe, investment drops," *Chemistry & Industry*, Society of Chemical Industry, January 2026, reporting Cefic data. soci.org/news/2026/1/chemical-plant-closures-surge-in-europe-investment-drops

4 Simon-Kucher, *Location Perspectives Study 2025*, as reported in "In Europe, more lights will go out at chemical plants," *Chemical & Engineering News*, June 2026. cen.acs.org/business/economy/Europe-lights-chemical-plants/104/web/2026/01

5 Natrium Capital, *European Cracking in Crisis*, October 2025. natriumcapital.com/wp-content/uploads/2025/10/European-Cracking-in-Crisis-vF8.pdf. See also Eni, "Eni sets out its transformation, decarbonization and relaunch plan for Versalis," October 2024.

6 Cefic, "Cefic perspective on EU ETS carbon-cost exposure in the chemical industry," July 2026. cefic.org/resources/cefic-perspective-on-eu-ets-carbon-cost-exposure-in-the-chemical-industry/

7 "The EU publishes methodology for calculating greenhouse gas emissions for renewable and recycled carbon fuels," Baker McKenzie / Global Compliance News, March 2023. globalcompliancenews.com

8 CO2 Value Europe, *EU Policy Context*. CO2value.eu/wp-content/uploads/2023/10/EU-Policy-Context-TB-CVE-Days-.pdf

9 FuelsEurope, *Recommendations on the Delegated Act specifying a methodology for assessing greenhouse gas emissions savings from low-carbon fuels*. fuelseurope.eu/publications

10 Cefic, "Despite positive elements, the ETS revision proposal risks cutting industry, not emissions," July 2026. cefic.org/news/ets-review/

11 Markus Kamieth, President of Cefic, quoted in "EU Emissions Trading System Revision Proposal Risks Cutting Industry," *CHEManager*, July 2026. chemanager-online.com/en/news/eu-emissions-trading-system

12 "EU countries back plan to give industries more free CO2 permits," Reuters, 16 September 2026. reuters.com/business/environment/eu-countries-back-plan-give-industries-more-free-CO2-permits-2026-09-16/

13 Government of Canada, "Carbon pricing: regulatory framework for the output-based pricing system." canada.ca/en/services/environment/weather/climatechange/climate-action/pricing-carbon-pollution/output-based-pricing-system.html. See also International Carbon Action Partnership, *Canada Federal Output-Based Pricing System* factsheet.

14 U.S. Environmental Protection Agency data, 1990–2016, as cited in "Balancing Act: Can Petrochemicals Be Both Emissions-Free and Zero-Waste?", Kleinman Center for Energy Policy, University of Pennsylvania. kleinmanenergy.upenn.edu/research/publications/balancing-act-can-petrochemicals-be-both-emissions-free-and-zero-waste/

15 U.S. Geological Survey, Mineral Commodity Summaries 2025: Sulfur, January 2025. pubs.usgs.gov/periodicals/mcs2025/mcs2025-sulfur.pdf

16 U.S. Geological Survey, *Minerals Yearbook: Sulfur*, 2000. pubs.usgs.gov/minerals

17 Joyce A. Ober, "Mineral resource of the month: sulfur," *Geotimes*, July 2003, U.S. Geological Survey. pubs.usgs.gov/publication/70044769

18 "Europe's petrochemical collapse: plants close as investment heads for China," *bne IntelliNews*, August 2026. intellinews.com/europe-s-petrochemical-collapse-plants-close-as-investment-heads-for-china-461036/

19 Vioneo corporate statement, vioneo.com; and Judy Hicks, Vice President of Corporate Affairs, Vioneo, interviewed in "The Antwerp renaissance of the plastics sector," ScienceLink. sciencelink.net/features/the-antwerp-renaissance-of-the-plastics-sector/23013.article

20 "ExxonMobil, Sabic to shutter European ethylene," *Chemical & Engineering News*, April 2024. cen.acs.org/business/petrochemicals/ExxonMobil-Sabic-shutter-European-ethylene/102/i12

21 Institute for Energy Economics and Financial Analysis, "Gorgon CCS underperformance hits new low in 2023-24," 2024. ieefa.org/resources/gorgon-ccs-underperformance-hits-new-low-2023-24

22 Institute for Energy Economics and Financial Analysis, *Fact Sheet: Carbon Capture and Storage (CCS) has a poor track record*, February 2024. ieefa.org/sites/default/files/2024-02/fact-sheet-CCS-ADR.pdf

23 Jack Andreasen, "The Biggest Failures in CCS," *Carbon Middle Management*, March 2026. carbonmiddlemanagementinc.substack.com/p/the-biggest-failures-in-ccs

24 "A comparative techno-economic assessment of renewable methanol production under FuelEU Maritime and EU ETS regime," *Energy Conversion and Management*, 2026. sciencedirect.com/science/article/pii/S0196890426003651

25 Andritz, "The rise of e-methanol." andritz.com/power-to-x-en/resources/the-rise-of-e-methanol

26 Airbus, "From Ambition to Reality: Securing Europe's Aviation Fuel Supply with Sustainable Aviation Fuel," December 2025.

27 "Europe's green fuel squeeze: SAF mandates, rising feedstock costs and a protein market feeling the pinch," Fastmarkets, May 2026. fastmarkets.com/insights/europes-green-fuel-squeeze-saf-mandates-rising-feedstock-costs-and-a-protein-market-feeling-the-pinch/

28 International Council on Clean Transportation, *Availability of biomass feedstocks in the European Union to meet the 2035 ReFuelEU Aviation SAF target*. theicct.org/publication/low-risk-biomass-feedstocks-eu-refueleu-aug24/

29 International Energy Agency, *Electricity 2026: Analysis and Forecast to 2030*, February 2026.

30 Intergovernmental Panel on Climate Change, *Special Report on Carbon Dioxide Capture and Storage*, Chapter 2: Sources of CO2, 2005. High-concentration, high-partial-pressure sources such as ammonia and hydrogen production and gas processing operations contribute a relatively low share, under 2%, of emissions from large stationary sources. ipcc.ch/site/assets/uploads/2018/03/srccs_chapter2-1.pdf

31 Turnover Labs internal laboratory testing, single-cell scale, 2026. Not independently verified. Full test conditions available on request.

32 "CO2 electrochemical reduction: A state-of-the-art review with economic and environmental analyses," *Chemical Engineering Research and Design*, 2024. sciencedirect.com/science/article/pii/S0263876224004064

33 Turnover Labs internal technoeconomic modeling, 2026, for a mid-scale deployment compared against incumbent steam-methane-reforming-based CO synthesis. Project-level avoided-emissions estimate.

34 Deloitte, "Reducing Scope 3 Emissions in the Chemical Industry." Upstream and downstream Scope 3 emissions average 50.3% and 25.8% of total emissions for chemical producers respectively. deloitte.com/us/en/insights/industry/oil-and-gas/reducing-scope-3-emissions-in-chemical-industry.html

35 Greenhouse Gas Protocol, "History of GHG Protocol." The Kyoto Protocol was adopted in 1997; WRI and WBCSD launched the GHG Protocol initiative in 1998; the first edition of the Corporate Standard, introducing the Scope 1/2/3 framework, was published in 2001. ghgprotocol.org/about-us

36 E-ledgers Institute BMW Group case study, as described in "How BMW Started Auditing Emissions Across Its Supply Chain," *Harvard Business Review*, February 2025. hbr.org/2025/02/how-bmw-started-auditing-emissions-across-its-supply-chain

37 Payne Institute for Public Policy, Colorado School of Mines, "Keeping Up with Carbon: Key Changes for 45Q Tax Credits Under the One Big Beautiful Bill Act." payneinstitute.mines.edu

38 Global CCS Institute, "U.S. Preserves and Increases 45Q Credit in One Big Beautiful Bill Act," 2025. globalccsinstitute.com/u-s-preserves-and-increases-45q-credit-in-one-big-beautiful-bill-act/

39 Beveridge & Diamond, "Congress Eyes Sweeping Changes to Carbon and Biomass Incentives: 45Q Tax Credit Reforms, New Biochar Program, and Forest Residues Carbon Credit Introduced." bdlaw.com/publications

40 E-ledgers Institute case studies, Tata Steel and Heidelberg Materials. e-ledgers.institute/case-studies/. See also "Getting a Clearer View of Your Company's Carbon Footprint," *Harvard Business Review*, April 2023.

41 RMI, "Clean Energy 101: Book and Claim." rmi.org/clean-energy-101-book-and-claim/

42 Stillwater Associates, "SAF Accounting, SAF Registries, and the 'Truth' of the Market," April 2026. stillwaterassociates.com/saf-accounting-saf-registries-and-the-truth-of-the-market/

43 Chihiro Momose, petrochemical industry researcher, quoted in "Deluge of petrochemicals from China swamps other Asian countries," *Chemical & Engineering News*, January 2026. cen.acs.org/business/petrochemicals/Deluge-petrochemicals-China-swamps-Asian/104/web/2026/01

44 Marco Mensink, Director General of Cefic, interviewed in "Europe's chemical industry in crisis," *PROCESS Worldwide*. process-worldwide.com

45 "European overview of steam crackers and solvent-related upstreams," Chemicals United, January 2026. chemicalsunited.com/industry-reactions/european-overview-of-steam-crackers-and-solventrelated-upstreams

46 "New Middle East disruption threatens Asia's chemical makers," *Chemical & Engineering News*, September 2026. cen.acs.org/business/economy/new-middle-east-disruption-threatens-chemical-makers/104/web/2026/09

47 Japan Petrochemical Industry Association data, and Koshiro Kudo, JPCA chairman and president of Asahi Kasei, quoted in "Ethylene plant operating rate hits record low in Japan," *The Japan Times*, May 2026. japantimes.co.jp/business/2026/05/22/ethylene-plant-operating-rate-low/

48 S&P Global Commodity Insights, reporting Japan Petrochemical Industry Association data, February 2026. spglobal.com/energy/en/news-research/latest-news/chemicals/

49 Abhishek Sinha, Tom Sanzillo and Suzanne Mattei, "Shell acknowledges $14 billion price tag for petrochemical plant, more than double street estimates," Institute for Energy Economics and Financial Analysis, February 2024. Also the source of the "small and replicable is beautiful" quotation from Shell's earnings call. ieefa.org/resources/shell-acknowledges-14-billion-price-tag-petrochemical-plant-more-double-street-estimates

50 "Desperately Seeking an Exit," Ohio River Valley Institute, February 2026. ohiorivervalleyinstitute.org/shell-desperately-seeking-an-exit/

51 "Review: Electrochemical CO2 Reduction for CO Production: Comparison of Low- and High-Temperature Electrolysis Technologies," *Journal of the Electrochemical Society*, 2020. iopscience.iop.org/article/10.1149/1945-7111/ab7099

Notes

Notes

Notes

T U R N O V E R

Waste less, make more

hello@turnoverlabs.com