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DECARB SERIES · JULY 2026

AUTOMOTIVE DECARBONIZATION

The paint shop, fleet electrification, and the economics of a pathway that moves with prices.

A CLIMATE DECODE WHITE PAPER

Part of the Climate Decode industrial decarbonization series

A vehicle assembly plant burns comparatively little fuel — no smelting, calcining, or reforming — yet its on-site Scope 1 and Scope 2 emissions run about 0.6 tCO_2 per vehicle, roughly 92,000 tCO_2e a year for a 150,000-unit plant. The paint shop accounts for about 80% of the plant's natural gas and roughly half of the combined Scope 1 and 2 total. Unlike the steel and battery emissions embedded in the cars it builds, this is the footprint the operator controls. This paper sets out where those emissions sit, how to abate them in the right order, and how two measures — an electric forklift fleet earning clean-fuel credits, and an industrial heat pump on the paint line — behave as energy, carbon, and credit prices move.

Purpose of this paper

Climate Decode builds dynamic marginal-abatement-cost (MACC) models for hard-to-abate sectors. This note distils our automotive-assembly model: a 150,000-vehicle/year plant, twenty decarbonization levers, and a physically consistent netting engine that sequences them against a client's target and budget. We use it to make three points. First, the paint shop is the carbon core of vehicle assembly and should anchor any credible plan. Second, sequencing matters as much as selection — demand-reducers first, because they shrink and cheapen everything that follows. Third, the economics are not fixed. Every lever's cost per tonne is a live function of the electricity-to-gas spread, the carbon price, and available funding and grants, and the model recomputes the whole pathway as those move.

SECTION 01

State of the Industry

01

The world builds on the order of ninety million vehicles a year, with more than half of that output in Asia and roughly a third in China alone. For a manufacturer's own operations, the relevant boundary is the assembly plant — the stamping, body, paint, and final-assembly halls it controls — not the upstream steel, aluminum, and battery cells that dominate a car's cradle-to-gate total but sit in Scope 3.

Within that boundary, Scope 1 (direct combustion) is dominated by surface coating and painting — the gas fired to cure and condition paint. Scope 2 (purchased electricity) powers the robots, welders, compressors, and ventilation. A typical assembly plant runs 0.5–0.7 tCO_2e per vehicle on a Scope 1+2 basis; our reference plant sits at ~0.6 t/vehicle, ~92,000 tCO_2e a year. That is small against the car's life cycle, but it is the slice the plant manager can move, and, increasingly, the slice that compliance schemes and customer supply chain targets require.

SECTION 02

Where the Emissions Sit — Model Data

02

The figures in this section come from the Climate Decode model, sized to a representative North American assembly plant that burns industry-average amounts of natural gas and electricity for its output. Of the ~594,000 GJ of natural gas it consumes, roughly 80% runs the paint shop — the low-temperature pre-treatment baths, the spray-booth make-up air, and above all the curing ovens. Electricity spreads more evenly across compressed air, HVAC, lighting, body-shop welding and robotics.

TABLE 1

Assembly-plant energy by process (Climate Decode model, 150k-vehicle reference plant). The paint shop is ~80% of on-site gas — the Scope-1 hotspot.

Process area	Gas (GJ/yr)	Electricity (MWh/yr)	Share of plant gas
Paint — curing ovens	207,900	12,600	35%
Paint — pre-treatment / E-coat	130,680	21,000	22%
Paint — spray booths	106,920	29,400	18%
Paint — VOC / RTO abatement	29,700	6,300	5%
HVAC	59,400	23,100	10%
Body, stamping, assembly, handling	59,400	65,100	10%
Compressed air + lighting	0	52,500	0%
Plant total	594,000	210,000	100%

The paint shop, therefore anchors the plan. Decarbonizing the plant means decarbonizing paint; welding efficiency, compressed-air optimization, and lighting are secondary in tonnes but, in the right sequence, valuable.

SECTION 03

Solution Families and the Order That Matters

03

Our model carries twenty levers grouped into three waves. Wave 1 is no-regret efficiency and process change — LED lighting, variable-speed drives, compressed-air optimization, an energy-management system, HVAC controls, waste-heat recovery, and paint-process innovations such as three-wet coating and low-bake chemistries. Wave 2 is on-site electrification — heat pumps and electric ovens for paint heat, and fleet electrification. Wave 3 is supply-side greening — on-site solar, a renewable-power contract, and renewable gas or hydrogen for the residual.

3.1 Sequence to cut the cost of the next move

The order changes the capital bill. Wave 1 measures pay for themselves and cut demand, so the Wave 2 electrification that follows is sized to a smaller load — fewer kilowatts of heat pump, fewer megawatt-hours of new electricity, less capital. In the opposite order, the electrification is sized to the full load that the efficiency measures would otherwise have removed, which means larger equipment and more capital for the same abatement. Our Roadmap engine deploys wave-by-wave, cheapest cost-per-tonne first, and stops when the client's target is met or the capital budget is exhausted.

3.2 Net the overlaps — do not sum them

Levers share energy pools. Electric ovens, waste-heat recovery, three-wet paint, and low-bake chemistries all target the same curing-oven gas; a dry scrubber and a desiccant both cut the same booth-air electricity. Summing each lever's stand-alone abatement double-counts — in our reference case by roughly 7%. The model instead deploys levers through shared pools and caps each at the physical energy available, so the headline reflects what the plant can actually achieve rather than an inflated sum of overlapping claims.

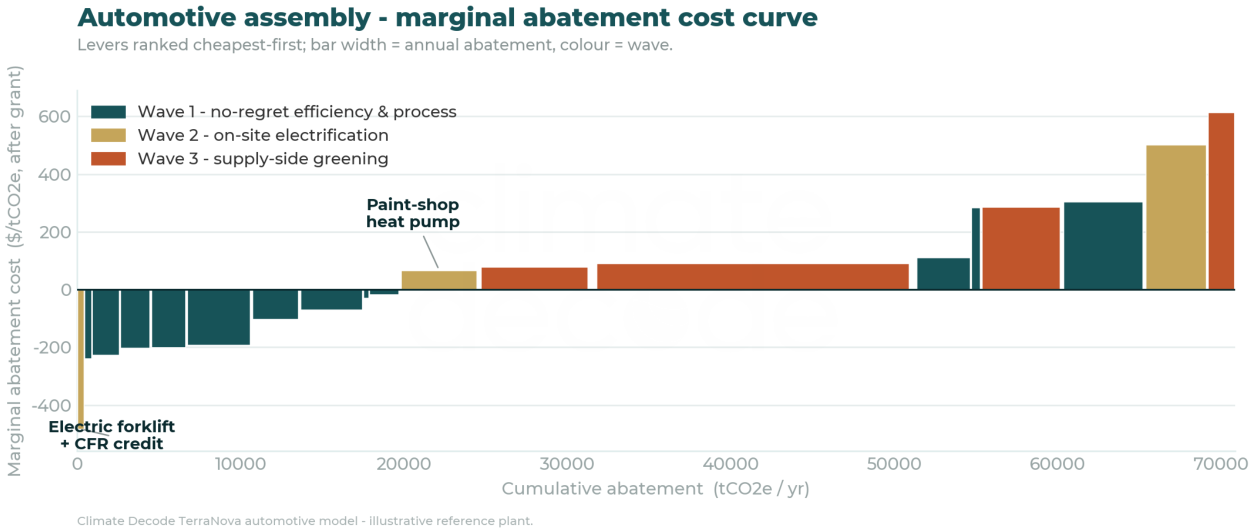


Figure 1. Marginal abatement cost curve for the reference plant, after grant, colored by wave. Everything left of the zero line pays for itself — the no-regret first wave, plus the CFR-credited forklift. The two case studies sit at opposite ends of the curve; the forklift deep in the money, the paint-shop heat pump at a modest $66/t that a carbon price pushes below zero.

SECTION 04

Carbon Markets and Clean-Fuel Standards

04

Three policy instruments move automotive-assembly projects, and any of them can decide whether a project clears. Carbon pricing (compliance schemes, output-based systems) rewards Scope-1 reductions and can flip a paint-shop electrification from cost to saving. Investment tax credits and grants lower the capital hurdle on renewables and electrification. Clean-fuel standards — Canada's Clean Fuel Regulations (CFR), California's LCFS — pay credits for displacing high-carbon transport fuel with low-carbon electricity, and are the least-used of the three in this sector.

Clean-fuel credits attach revenue to measures whose direct tonnes are small. A plant does not have to abate much CO_2 to earn them; it has to switch a diesel duty to grid (or, better, renewable) electricity. That reframes the business case for on-site fleet electrification.

SECTION 05

Two Solutions in Focus

05

We picked these two on purpose. They sit at opposite ends of the abatement curve and run on different economics, so together they show the full range of how the model behaves. The electric forklift fleet abates almost nothing on its own, yet a clean-fuel standard turns it into the most cash-positive project on the sheet — the clearest case of policy, rather than tonnes, driving the decision. The paint-shop heat pump is the opposite kind of project — a large, capital-heavy electrification of the plant's core heat load, whose economics turn on the electricity-to-gas spread, the carbon price, and one technology choice. One is a credit-revenue play, the other an energy-and-carbon play, and between them they touch every price the model re-ranks against.

5.1 Electric forklift fleet + clean-fuel-standard credits

Every assembly plant runs a fleet of diesel forklifts and tractors for internal logistics. Replacing them with battery-electric units is well-understood and low-risk — TRL 9, done on the normal fleet-renewal cycle. In our reference plant, the switch displaces ~8,000 GJ of diesel and adds ~600 MWh of electricity, for a direct net abatement of just ~430 tCO_2/year, because the grid electricity carries its own Scope-2 emissions. On a tonnes-ranked plan, it barely registers, which is why plants routinely overlook it.

A clean-fuel standard changes the arithmetic. Programs like Canada's CFR and California's LCFS credit an electric drivetrain for the diesel energy it displaces. The fleet earns credits equal to (diesel reference carbon-intensity × EER − grid carbon-intensity) × the electricity delivered, which at the current CFR credit price of ~$400/$tCO_2e$ is about $229,000 a year against a $1.6M incremental capital cost. That is a payback under three years and a marginal abatement cost near −$480/tonne, because the ~430 physical tonnes become ~570 creditable tonnes once the efficiency uplift is counted. A measure that abates almost nothing directly becomes the most cash-positive project on the sheet.

5.2 Paint-shop heat: the industrial heat pump (and why not an electric boiler)

The second solution is the larger prize. It goes to the core of the plant's Scope-1 emissions — the low-temperature heat for pre-treatment and E-coat conditioning (~45–80 °C), the duty an industrial heat pump serves best. In our model, a heat pump on the pre-treatment load displaces ~127,000 GJ of gas while adding only ~8,300 MWh of electricity, because a coefficient of performance of 3.6 moves 3.6 units of heat per unit of electricity. It abates ~4,840 tCO_2/year — more than ten times the forklift — at a capital cost of ~$6.0M, a marginal cost of about $66/tonne before carbon pricing that a compliance carbon price turns to roughly −$30/tonne.

An electric boiler on the same duty removes exactly the same on-site gas, so its Scope-1 saving is identical to the heat pump's — about 7,100 tCO_2/year of combustion emissions eliminated. The difference is entirely on the Scope-2 side. At a coefficient of performance near one, the boiler needs ~3.8× the electricity a heat pump would, and on a grid at ~0.27 tCO_2/MWh that electricity carries about 8,600 tCO_2/year of Scope-2 emissions — more than the 7,100 tonnes of Scope-1 gas it removed, so the plant's total footprint rises by roughly 1,500 tCO_2/year. The heat pump wins because its COP of 3.6 holds the added Scope 2 to about 2,300 tCO_2, a third of the boiler's, so the same Scope-1 saving nets to a ~4,840-tonne cut instead of an increase. The design rule is to match the technology to the temperature, heat-pumping the low-temperature majority and reserving electric boilers, or hydrogen, for the small high-temperature residual. A plant that gets that distinction wrong can make a decarbonization project add emissions rather than cut them.

5.3 Side-by-side

TABLE 2

The two measures earn their return from completely different levers — one from a credit market, one from energy and carbon prices. A single model values both.

Metric	Electric forklift + CFR	Paint-shop heat pump
Wave / role	Fleet electrification	Paint-shop electrification
Direct abatement	~430 tCO_2/yr	~4,840 tCO_2/yr
Incremental CAPEX	$1.6M	$6.0M
Key revenue / value	CFR credits ~$229k/yr	Gas saved + carbon value
Simple MAC	~ −$480/t	~ $66/t
MAC (grant + carbon)	~ −$570/t	~ −$30/t
Simple payback	~2.7 yr	~6.6 yr
What drives it	Clean-fuel credit price	Electricity/natural gas spread + carbon

SECTION 06

Why the Model Is Dynamic

06

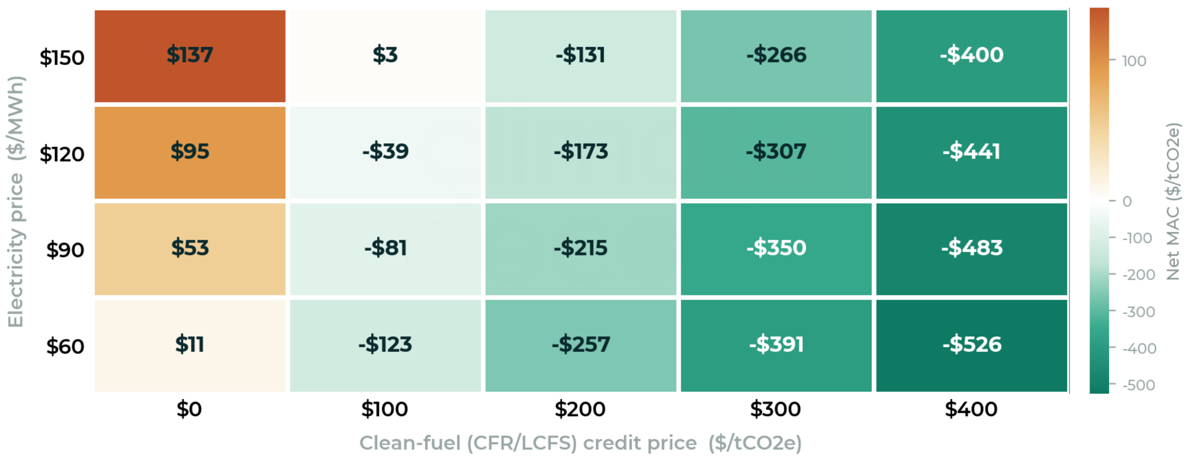
A static MACC is obsolete the day prices move. Ours recomputes every cost-per-tonne from the current electricity, gas, carbon, and credit prices and re-sequences the recommended pathway accordingly. Two slices show the range.

6.1 The forklift is a bet on the credit price

The forklift's economics depend almost entirely on the clean-fuel credit price. With no credit it is a modest cost; as the credit price rises it flips decisively net-negative.

Electric forklift - MAC vs credit price & electricity price

Green = net saving, terracotta = net cost. The credit price dominates.



Climate Decode TerraNova automotive model - illustrative.

Figure 2. Electric-forklift MAC across every combination of clean-fuel credit price (horizontal) and electricity price (vertical). Red is a net cost, green a net saving. The credit price dominates. With no credit the fleet is a modest cost; by ~$200/credit it is cash-positive at any realistic power price. Recent CFR/LCFS spot has run below $400, so the credit assumption is the sensitivity that matters most, which is why the model takes it as an editable input rather than a hard-coded number.

6.2 The heat pump is a bet on carbon and the grid

The heat pump's cost per tonne falls about a dollar for every dollar of carbon price on its Scope-1 saving, crossing into net-saving near a $60–66/tCO$_2$ carbon price — a level most compliance jurisdictions already exceed. Its abatement holds up across grid intensities, because a COP of 3.6 adds little electricity. An electric boiler behaves the opposite way; it abates only below a break-even grid intensity (~0.22 tCO$_2$/MWh) and adds emissions above it. The model draws that line automatically.

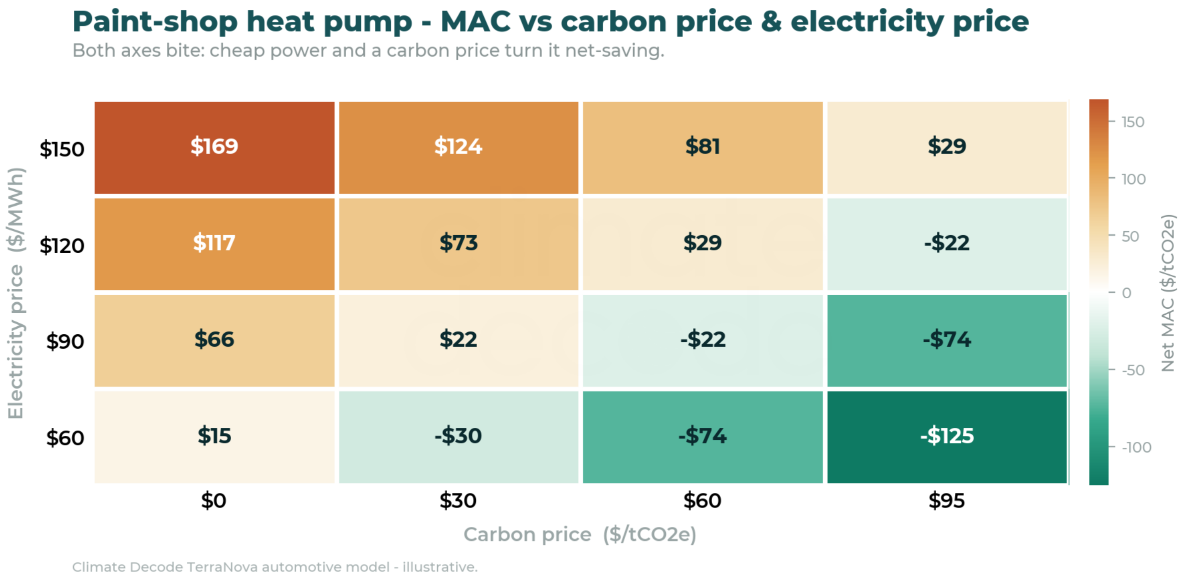


Figure 3. Paint-shop heat-pump MAC across carbon price (horizontal) and electricity price (vertical). Unlike the forklift, both axes bite. The heat pump rewards cheap electricity and a carbon price on its gas saving; at a mid electricity price it turns net-saving around \$50–60/tCO_2 (a level most compliance jurisdictions already exceed), and on cheap power it is a no-regret move even without carbon.

Because these are live inputs, the model does more than rank levers once — it answers “what is the cheapest path to the client’s target, at today’s prices, within this budget?” and updates that answer as the world changes.

SECTION 07

Challenges to Deployment

07

A project that clears on cost per tonne still has to be built into a working plant, financed against uncertain policy, and plugged into a grid that may be constrained.

The paint-shop measures carry the most integration risk. The heat pump of Section 5.2, plus the three-wet and low-bake process changes among the Wave 1 levers, all touch a line that builds a car about every minute, where an unplanned change threatens finish quality and throughput. They are cheapest and least disruptive fitted to a scheduled paint-shop rebuild or a new line, so the calendar, not only the cost per tonne, decides when they happen. Electrification adds a second constraint. Both headline solutions, and most of Wave 2, swap fuel or diesel for electricity, raising the plant’s power draw and grid connection just as many jurisdictions tighten supply. On-site solar and a renewable-power contract ease that exposure and improve the carbon math, but bring their own siting and price-premium questions.

The forklift carries a different risk. Its return rests on clean-fuel credit revenue, which depends on continued program eligibility and a credit price that has historically fluctuated significantly. Deeply cash-positive at $400, the fleet is only marginal near $100, so that assumption should be stress-tested. At the far end of the pathway, the deepest cuts still lean on renewable gas or hydrogen for the small residual of genuinely high-temperature heat, and neither is yet abundant at industrial scale, which is why the model holds them as a late, small pilot rather than a load-bearing lever.

These frictions bear on timing and financing more than on the ranking itself. Building the no-regret efficiency first, timing the paint-shop electrification to a rebuild, and treating credit revenue as upside rather than certainty are how a plant manages them — and why the model re-prices the whole pathway as policy, grid, and fuel markets move.

SECTION 08

Take-aways

08

- The paint shop is the carbon core. ~80% of an assembly plant's on-site gas runs pre-treatment, booths, and curing ovens. A credible plan is a paint-shop plan first.
- Sequence demand-reducers first. No-regret efficiency pays back and shrinks the load electrification must cover, so sequencing it first makes the electrification smaller and cheaper.
- Match the technology to the temperature. A COP-3.6 heat pump abates low-temperature paint heat; a COP-1 electric boiler on a carbon-intensive grid can add emissions. The distinction decides whether the project cuts emissions or adds them.
- Clean-fuel standards turn small measures cash-positive. Electric forklifts abate little directly, but CFR/LCFS credit revenue flips them to a negative MAC and a sub-three-year payback.
- Net the overlaps, don't sum them. Levers share energy pools; summing them overstates abatement by ~7%. Physical netting keeps the headline honest.
- The answer moves with prices. Every MAC is a live function of the electricity/gas spread, the carbon price, and the credit price. Our model recomputes the whole pathway as they move, so the best path is always the current one.

SECTION 09

How Climate Decode TerraNova Helps

09

TerraNova is Climate Decode's agentic-AI decarbonization manager for industrial emitters. It turns the workflow in this paper — operations data, hotspots, levers, policy stack, financing — into a decision-ready output for a specific plant. It drives a fully-populated plant model that captures real energy and production data, allocates emissions to each process step, screens the decarbonization levers against the local policy and carbon-market environment, and returns a finance-grade investment plan: a ranked portfolio, a sequenced deployment schedule, NPV, IRR and payback at lever and portfolio level, a year-by-year compliance position, and the revenue stack — clean-fuel credits included — behind each project.

The Excel model behind this paper is the calculation substrate, not the product the operator works with. The point of TerraNova is to lift decarbonization from a months-long bespoke consulting exercise into a quarterly-refreshable, board-ready output — one source of truth that finance, sustainability, and operations can all act on.

9.1 What TerraNova does

- Builds the inventory. Ingests the plant's gas, electricity, diesel, and vehicle output at whatever frequency the company reports, and returns a complete Scope-1 and Scope-2 inventory aligned with the GHG Protocol and the relevant compliance boundary (federal OBPS, EU and UK ETS, U.S. GHGRP).
- Finds the hotspots. Allocates plant totals across the process areas that drive them — paint shop, body, stamping, HVAC, compressed air — surfacing the gas and electricity concentrations shown in Section 2.
- Screens the decarbonization levers. Tests twenty-plus decarbonization levers against the plant's actual energy mix and local policy stack — carbon price, OBPS benchmark, Clean Fuel Regulations credits, investment tax credits, grants — scoring each on abatement, capital and operating cost, grant capture, TRL, and marginal abatement cost with and without policy.

- Sequences the portfolio. Proposes the least-cost pathway to the client's target and budget, or lets the operator build a custom one by toggling levers and setting start years, and returns a wave-by-wave roadmap, an emissions trajectory, and a MACC waterfall netted for overlapping levers.
- Runs the financials. Builds a multi-year discounted cash flow with the carbon-price trajectory, energy-price forecast, abatement ramp, grant and ITC capture, and clean-fuel credit revenue on its own line, reporting NPV, IRR, discounted payback, and benefit-cost ratio at lever and portfolio level.
- Tracks compliance. Scores the plant year-by-year against tightening benchmarks, showing when the selected portfolio moves it from a deficit to a surplus position.

9.2 What it replaces

TerraNova folds four workflows that have historically lived in different teams and tools — GHG inventory, marginal-abatement-cost analysis, project-level financial modelling, and compliance tracking — into one decision system. The operator does not commission a separate study for each, reconcile inputs across reports, or rebuild the analysis when policy shifts or fresh utility data arrive. The pathway can be revisited each quarter against the latest carbon prices, credit values, and energy-price forecast, and the model stays consistent across iterations — which is what makes the output finance-grade rather than indicative.

This paper is one entry in Climate Decode's industrial decarbonization series, alongside companion studies on pulp and paper, fertilizer, and food processing. Read together, they apply the same TerraNova method across the hard-to-abate sectors.

By Koorosh Behrang · Climate Decode · July 2026 · climate-decode.com

Figures and cost-per-tonne values are drawn from the Climate Decode automotive-assembly decarbonization model (150,000-vehicle reference plant). All marginal-abatement costs are model outputs and are recomputed with input prices; they are illustrative, not investment advice.

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One entry in Climate Decode's industrial decarbonization series - automotive assembly, alongside pulp & paper, fertilizer, and food.

TerraNova turns this analysis into a board-ready decarbonization plan for a specific plant.