

DUNA

SERIES-HYBRID / FULL BY-WIRE / RALLY-RAID CLASS

A desert race motorcycle, re-engineered as software.

An engineering feasibility read for a Baja 1000 / SCORE-class rally-raid machine with an engine-as-generator powertrain and an electric-driven wheel.

~157 kg

DRY MASS, ESTIMATED

+13%

VS KTM 450 RALLY,
QUANTIFIED

~\$0.75 M

ONE RUNNING PROTOTYPE

18–24 mo

TO SHAKEN-DOWN PROOF

What this document is, and how to read it.

This is a feasibility read, not a brochure. Its job is to answer one question honestly: **can this machine be prototyped for real?** The architecture, the mass, the thermal load, the energy math, the cost and the timeline are here so a mechanical engineer and an investor can sit in the same room and both find the work sound.

Every load-bearing figure carries its confidence. The discipline is the credibility.

VERIFIED Read on the maker’s own datasheet or page. A real, buyable part with a cited spec.

ESTIMATE An engineering estimate with its assumption stated inline. Traceable, defensible, not invented.

TARGET A design target we are engineering toward, not yet a measured result.

THE NUMBER TO WATCH, NAMED FIRST

Range, fuel and generator sizing all scale off one estimate: a **~20 kW stage-average power demand**. We surface it here on page one, not buried in an appendix, and we carry a Phase-0 telemetry plan to close it before any hardware is frozen. See §12.

CONTENTS

01	Concept & positioning	03
02	The reference bar	04
03	Architecture & the energy path	05
04	Why series — the case against the alternatives	07
05	Component selection & the load-bearing BOM	08
06	Mass budget — the honest +13%	10
07	Energy & range — showing the work	12
08	Thermal strategy	13
09	Controls & by-wire	14
10	Risk register	15
11	Cost stack — one running prototype	17
12	Timeline to prototype & long-lead items	18
13	The open assumption & validation plan	19
14	What survives diligence	20

ONE LINE, BEFORE ANYTHING ELSE

Series hybrid turns every hard mechanical problem — traction, torque delivery, engine efficiency, thermal management — into a software problem. A software-defined powertrain in a category that has never had one.

One engine that never touches the wheel.

A small engine runs at one fixed, most-efficient RPM as a *generator only*. It feeds an inverter and a small buffer battery; those drive an electric traction motor at the rear wheel. There is no mechanical link between the engine and the ground.

THE MACHINE, IN ONE LINE

A Baja / Dakar-class rally-raid race motorcycle with a series-hybrid powertrain and full by-wire control. Range is set by fuel-tank size, not by battery charging.



The machine · Exposed Core, stealth graphite · Baja golden hour — canonical form

THE THESIS

Every hard problem in a rally powertrain — traction, torque delivery, engine efficiency, thermal load — becomes a **software problem** once the wheel is driven by an inverter the controller commands directly. This is a software-defined powertrain in a category, rally-raid, that has never had one.

THE PROVING GROUND

The near-term target is **US desert racing — the Baja 1000 and SCORE International**: fewer rules constraints, wide-open innovation, and a real proving ground a prototype can enter sooner. Dakar is the aspirational ceiling, not the first homologation gate.

THE DESIGN DNA

Ducati-grade silhouette, finish and detail obsession over genuine desert race engineering. The bones are Dakar — long travel, rally geometry, serviceable in a bivouac. The skin is superbike. *Ducati DNA is skin; the bones are Dakar.*

The bar we must respect, then the honest question.

Rally-raid, not a street superbike. The machine is measured against the class it wants to race in: ~140 kg, ~35 L of fuel, hours at load, long travel, serviceable in the field. Our hybrid will be heavier. The honest question is *how much*, and whether the offsetting advantages justify it.

REFERENCE MACHINES — THE PERFORMANCE BAR VERIFIED

SPEC	KTM 450 RALLY REPLICA (MY26/27)	HONDA CRF450 RALLY
Engine	449 cc single, 4-stroke, liquid-cooled	449 cc single, liquid-cooled
Peak power	~63 hp / ~47 kW	~55–60 hp class
Dry weight	139 kg	~140 kg class
Race-ready weight	~138 kg / 304 lb	~140 kg wet
Fuel capacity	34.5–35 L	34.7–35 L
Fuel layout	3-tank (2×9 L front + 16 L rear)	front + rear tanks
Suspension	WP XACT PRO 48 mm, long-travel	Showa, ~300+ mm travel

Sources — ktm.com 2026/2027 450 Rally Replica model page (35 L, three-tank); motorcycles.news (139 kg dry, 63 hp, 35 L); Cycle News 2027 spec (304 lb race-ready, 9.11 gal); advpulse / methodracewheels (CRF450 Rally 34.7–35 L). Read directly.

~140 kg

THE CLASS MASS THE MACHINE IS JUDGED AGAINST

~35 L

FUEL A 450 RALLY BIKE CARRIES, IN THREE TANKS

~47 kW

KTM PEAK POWER — THE NUMBER OUR E-DRIVE MUST CLEAR

THE HONEST FRAME

We do not claim to beat the KTM on the scale. We quantify the penalty, show why it is smaller than a layperson expects, and argue the offset — a lower centre of gravity from centralised mass. See §06.

WHAT “THE CLASS” ACTUALLY DEMANDS

Hours at load, not laps. A rally special runs for five to six hours in heat, over dunes and rock, refuelled at points spaced along the route. The machine has to make power continuously and be serviceable in a bivouac overnight — a different bar from a motocross sprint or a road superbike.

WHERE THE KTM CARRIES ITS MASS

The 35 L sits in three tanks — two 9 L up front, one 16 L at the rear — because the fuel has to feed a top-end engine. That places ~22 kg of fuel high and spread as the tanks drain. It is the reference the offset argument turns on: our mass can sit lower and more central.

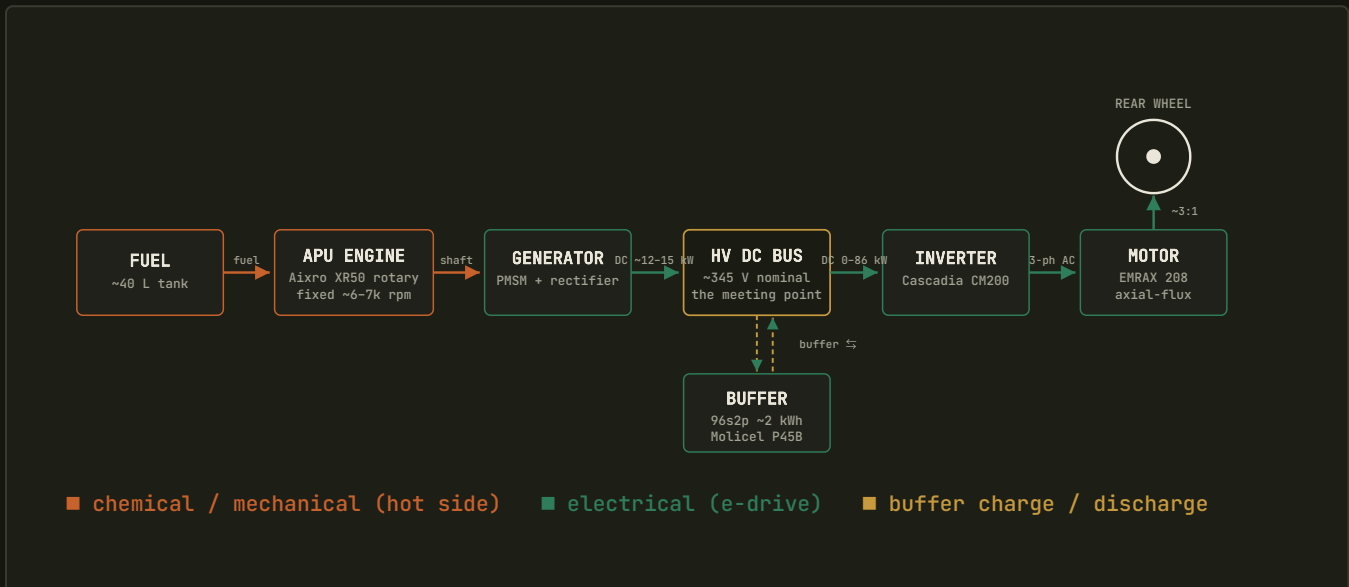
WHY NOT A STREET SUPERBIKE BAR

The bones are Dakar: ~300 mm of travel, 21”/18” wheels, rally geometry, a nav tower. The Ducati DNA is the skin — silhouette, finish, detail. Measured against a rally-raid machine, not a Panigale, the engineering targets are the right ones.

Fuel in one end, torque out the other.

The defining fact of a series hybrid: the engine and the wheel are electrically coupled, never mechanically. That single decision is the source of every advantage and every penalty in this document.

THE ENERGY PATH — FUEL TO REAR WHEEL



Fuel → APU engine → generator → rectifier → DC bus ↔ buffer battery → inverter → traction motor → single reduction → rear wheel. No mechanical connection between engine and wheel. The rider's throttle commands wheel torque, not engine speed.

READ IT LEFT TO RIGHT

Chemical energy enters as fuel and leaves the hot side as a steady electrical flow. From the DC bus on, everything is electrons the controller can meter to the millisecond. The hand-off from combustion to software happens once, at the rectifier, and never reverses.

THE BUS IS THE WHOLE TRICK

One node — the ~345 V DC bus — is where the smooth genset flow and the spiky wheel demand meet. The battery bridges the gap in both directions. Because they never touch mechanically, the engine is free to ignore the wheel entirely and just hold its most efficient point.

ONE REDUCTION, NO GEARBOX

The motor's flat torque curve drives the wheel through a single fixed ~3:1 reduction. There is no clutch, no gear stack, no shift — the six speeds a 450 single needs are replaced by a torque map. Fewer moving parts in the dirtiest environment a machine can race in.

The battery is a shock absorber between two mismatched flows.

The generator delivers a **smooth, steady ~12–15 kW**. The wheel demands a **spiky 0–86 kW** — idle to dune-climb burst. The buffer stands between them so the engine never has to chase a transient. It just holds its efficient point.

1 The APU runs at ONE fixed, efficient point

A single RPM/load target where brake-specific fuel consumption is lowest. It does not rev with the throttle. This is why a series hybrid is efficient in a stop-start, spiky duty cycle like rally.

2 Surplus charges, deficit discharges

When wheel demand is below genset output, the surplus charges the battery. When it is above, the battery supplies the difference — up to ~31 kW extra, stacking on top of the generator.

3 Regen is free where it exists

On a closed throttle or brake, the motor becomes a generator and feeds kinetic energy back to the buffer. Modest in deep sand; real and free on hardpack and downhill.

4 SOC is held mid-band

The VCU targets ~40–65% state of charge so the buffer always has room to *accept* regen and headroom to *supply* bursts. This is why the pack is a buffer, not a range store.

WHY THE BUFFER IS SMALL ON PURPOSE

Its only three jobs: absorb generator output, supply peak power above generator output for short bursts, and accept regen. It runs a shallow 60–65% SOC window — ~2.0 kWh usable from a ~3.1 kWh gross pack.

A buffer, not an EV pack. That single decision keeps mass off the machine.

~12–15 kW

STEADY GENSET OUTPUT

TARGET

0–86 kW

WHEEL DEMAND RANGE

~31 kW

EXTRA THE BATTERY
CAN SUPPLY

EST

40–65%

SOC OPERATING
WINDOW

PACKAGING THE ENGINEERING DEMANDS

- Battery low and central — ~20×30×15 cm block at the CG
- Traction motor at the swingarm pivot, sprung, chain to the wheel
- APU low, ahead of or below the battery; exhaust routed away from rider and electronics
- Fuel ~40 L, more centralised than the KTM's three-tank spread
- Twin front radiators for ram air; nav tower high and forward
- Long-travel suspension, 21"/18" rally wheels — the geometry is Dakar

The genset never has to chase transients. It holds its efficient point while the buffer does the fast work — **that is the whole efficiency argument for series hybrid in this duty cycle.**

Two flows, one bus. The smooth one comes from the engine; the fast one comes from the battery. The rider feels only the wheel torque the controller decides to deliver.

Four ways to build it. Only one fits the brief.

The architecture was not chosen for novelty. Each alternative fails this specific brief — a halo desert race machine whose range is a fuel question, whose traction is a software question, and whose engine should never leave its efficient point.

ARCHITECTURE	WHY NOT — OR WHY CHOSEN — FOR THIS BRIEF	VERDICT
Direct-drive ICE KTM / Honda	The bar, not the innovation. No torque-vectoring-by-wire freedom; the engine is always off its efficient point in transients.	Reference
Pure EV	Range is a battery-mass problem: a stage-covering pack would be ~100+ kWh (~450 kg of cells) — impossible on a rally bike. Charging in the desert is impossible. <i>This is the wall the client is right to avoid.</i>	Rejected
Parallel hybrid	Needs a mechanical path from engine to wheel <i>and</i> an electric one — a clutch/gearbox plus the electric drive. Heaviest and most complex. Loses the “engine at one efficient point” benefit.	Rejected
Series hybrid chosen	Engine decoupled → always efficient. Range = tank size (linear, refuelable). Traction control nearly free. Packaging freedom — the engine can sit anywhere. Penalty: carries both an engine and a full e-drive — the mass hit in §06.	Chosen

THE INVESTABLE FRAMING

Series hybrid turns every hard mechanical problem — traction, torque delivery, engine efficiency, thermal management — into a software problem. It is a *software-defined powertrain in a category, rally-raid, that has never had one.*

THE THREE STRUCTURAL WINS THAT FOLLOW

- **Range scales linearly with the tank**
Want 500 km? Add ~12 L (~9 kg), not 40 kWh of battery (~180 kg). Refuels in the time it takes to pour fuel. No charging problem.
- **Traction control is nearly free**
The VCU commands motor torque directly through the inverter at millisecond resolution. No engine to fight — ~100× faster than butterfly/ignition control.
- **Thermal load decouples from speed**
The engine’s heat is no longer tied to vehicle speed. The VCU can crawl on battery to shed heat, then restart the APU — a trick only series hybrid has.

THE PENALTY, SAID IN THE SAME BREATH

Series hybrid is chosen with its cost on the table: it carries both an engine and a full electric drive, and that duplication is the ~+13% mass penalty quantified in §06. The case is not that series hybrid is free — it is that its penalty is smaller than a layperson expects and buys advantages a direct-drive machine structurally cannot have.

Every advantage on this page traces to one decision: **the engine and the wheel are coupled by electrons, not by gears.**

The load-bearing BOM.

Every part is real, named, buyable today.

This is the credibility spine. Each powertrain component is a real product with a spec read from the maker's own page. The innovation is the integration, not the invention of any one part.

Traction motor
VERIFIED

EMRAX 208 • axial-flux PMSM

Peak power	86 kW (few s, hot)
Continuous power	56 kW (S1)
Peak torque	150 Nm
Max speed	6,000 rpm
Weight	9.4–10.3 kg
Diameter × length	208 × 85 mm
Efficiency	92–98%

Far exceeds the 47 kW KTM baseline. Run well below peak continuously (cruise ~15–25 kW), so thermal headroom is large; peak is there for dune climbs. Pancake form packages low and central. Single fixed ~3:1 reduction, no gearbox — the flat torque curve removes the need for the KTM's six speeds. Source: EMRAX 208 datasheet + tech table v4.5.

Inverter
VERIFIED

Cascadia Motion CM200

Peak power (electrical)	225 kW
Continuous current	300 Arms
Weight	6.75 kg
Voltage	400/800 V platforms
Environmental	IP6K9K / IP67
Rated temp	–40...+80°C

Deliberately over-rated for one 86 kW motor — that is margin and reliability. The lightest proven motorsport-grade unit in class; a Sevcon Gen4 (100 kW peak) is heavier at 10.9 kg despite lower power. Wash-rated and heavy-vehicle-qualified — exactly the desert-duty case. Source: cascadiamotion.com CM200 + current-la.com spec.

Buffer battery
CELL VERIFIED

MoLicel INR-21700-P45B cells

Cell capacity	4.5 Ah / 16.2 Wh
Continuous discharge	45 A (10C)
Energy density	231 Wh/kg
Cell mass	70 g
Pack topology	96s2p, 192 cells
Usable energy	~2.0 kWh

A buffer, not an EV pack. High voltage (~345 V nominal) for motor/inverter efficiency drives cell count up; a shallow 60–65% window keeps it small. Delivers ~31 kW continuous on its own, stacking on the genset. Source: P45B datasheet via imrbatteries, aboutenergy, cellsaviors. Pack figures estimated, +45% overhead.

Generator engine (APU)
VERIFIED

Aixro XR50 rotary • prototype engine

Power	33 kW @ 8,750 rpm
Torque	>35 Nm from 4,500
Displacement	294 cc single-rotor
Dry weight	17 kg
Fuel	gasoline + 2% oil
Cooling	charge-cooled rotor

Chosen for minimal vibration (critical in sand for electronics and rider fatigue), high power-to-weight, and a happy fixed-RPM duty cycle. Run at a low, efficient point as a genset — not at its 33 kW peak. We size for ~12–15 kW electrical. Source: woelfle-engineering.com Aixro XR50 (maker page).

TWO ENGINES, ONE HONEST DECISION

PROTOTYPE ENGINE — BUYABLE NOW VERIFIED

Aixro XR50 rotary. A real, purchasable engine today. This is what the prototype runs on. The XR50 spins a second compact PMSM as a generator, rectified through a small controller. For mass we allocate a generator machine + rectifier ~10 kg EST.
APU electrical output target: **~12–15 kW continuous** at the DC bus — well under the XR50's 33 kW ceiling. Quiet, cool, fuel-efficient. TARGET

PRODUCTION-INTENT ENGINE — THE FUTURE PATH
VERIFIED, PRE-PRODUCTION

LiquidPiston XTS-210. Inverted-rotary, multi-fuel (jet fuel / diesel / gasoline / propane). ~18.6 kW core; a 10 kW genset target “~75% lighter than fielded AMMPS.” Multi-fuel is a real rally logistics advantage.
Status: US Army development contract; integrated engine testing began 2024; **not yet purchasable.** Named as a production-intent upgrade only. The architecture is engine-agnostic — swapping the APU later is a bolt-in, not a redesign.

Prototype on the engine you can buy; name the future engine as the path. That is what keeps the feasibility honest.

BY-WIRE CONTROL HARDWARE

SYSTEM	APPROACH	RISK
Throttle-by-wire	Dual-redundant Hall grip sensors → VCU. Shipped on every premium bike today.	Mature / low
Brake-by-wire	Prototype: hydraulic front (fail-safe) + by-wire blended regen on the rear.	Managed
VCU	Automotive-grade rugged controller. Runs torque map, slip control, genset set-point, thermal, regen blend.	The real work
Sensors	Wheel-speed F+R, 6-axis IMU, throttle ×2, brake pressure, pack V/I/T, motor & coolant temps, fuel level. All commodity automotive.	Low

THE BRAKE-BY-WIRE POSITION, STATED PLAINLY

The prototype does **not** run full dry brake-by-wire. A conventional hydraulic front brake keeps a mechanical fallback on the primary stopping brake — the responsible choice for a solo, high-speed, off-road machine. Full per-corner electric actuation (the Brembo Sensify pattern, a verified production technology) is named as **production intent**, once fail-operational redundancy is validated. A diligence engineer will check this; we say it first.



Left-side profile • battery low and central, no gearbox bulge, no top-end engine



Exposed core • buffer pack in the trellis, axial-flux motor, twin rads

Every kilogram, on the table.

Built up from verified component masses (motor, inverter, cells, engine) plus estimated structure and ancillaries, then re-added — the honest sum of the line items below, not a headline.

SYSTEM	ITEM	MASS (KG)	BASIS
TRACTION			
	EMRAX 208 motor	10.0	VER
	Cascadia CM200 inverter	6.8	VER
	Final drive (chain, sprockets, single reduction)	4.0	EST
ENERGY STORE			
	Buffer pack (96s2p, ~2.0 kWh usable)	19.5	EST cells ver.
APU (GENSET)			
	Aixro XR50 rotary engine	17.0	VER
	Generator PMSM + rectifier	10.0	EST
	APU exhaust + intake + starter	4.0	EST
FUEL			
	Fuel tanks (empty, multi-cell, ~40 L)	6.0	EST
	Fuel — 30 L @ 0.74 kg/L	22.2	EST
COOLING			
	Radiators x2, pumps, coolant, lines	9.0	EST
CHASSIS & SUSPENSION			
	Frame (carrying HV + centralised mass)	12.0	EST
	Swingarm	4.5	EST
	Forks (WP XACT PRO class)	7.0	EST
	Rear shock + linkage	4.0	EST
WHEELS, TYRES, BRAKES			
	Wheels, tyres (21"/18" rally)	14.0	EST
	Brakes (hydraulic front + by-wire rear + regen)	7.0	EST
BODYWORK & ELECTRICS			
	Shrouds, seat, subframe, nav tower, skid plate	11.0	EST
	VCU, sensors, DC-DC, 12 V, contactors, LV harness	6.0	EST
	HV cabling, connectors, busbars	3.5	EST
	Bars, controls, footpegs, roadbook/nav	3.0	EST
	TOTAL (with 30 L fuel)	~180	179.5 summed
	TOTAL (dry, no fuel)	~157	157.3 summed

~157 kg

DRY MASS, RE-ADDED FROM THE LINE ITEMS

+18 kg

OVER KTM 450 RALLY (139 KG DRY)

+13 %

THE HONEST PENALTY — QUANTIFIED, NOT HIDDEN

A CORRECTION WE KEPT IN THE RECORD

An earlier draft carried ~181 kg dry / +30% from an arithmetic error in the total. The re-added sum is ~157 kg dry / +13%. The truth is *better* than the first draft — which is exactly why the arithmetic has to be right.

READ THE VERDICT OPPOSITE

Where the extra weight lives, why the net penalty is smaller than a layperson expects, and the mass-placement offset that turns +13% into a handling argument. See page 11.

The +13% is one story: you carry two powertrains.

Series hybrid duplicates by definition — a full APU *and* a full electric drive. That duplication is the entire penalty. The rest of the machine is shared with the KTM and comparable.

WHERE THE ~71 KG OF POWERTRAIN LIVES

APU — engine + generator + ancillaries

~31 kg

Electric drive — motor + inverter + final drive + pack

~40 kg

KTM 450 — single engine + gearbox + exhaust

~35–40 kg

The duplication penalty is ~31–36 kg of powertrain. The reason the net penalty is only ~+18 kg dry is that our electric drive is remarkably light — the EMRAX 208 at 10 kg, the CM200 at 6.8 kg — and the buffer is a buffer (19.5 kg), not an EV pack.

THE OFFSET — WHERE THE MASS SITS

The heaviest single item, the battery at 19.5 kg, sits **low and central**, and the APU can sit low too. The KTM carries 22 kg of fuel high and spread across three tanks (two up front, one at the rear).

We package a smaller, more centralised fuel load plus a low battery, lowering the **centre of gravity and polar moment** — which is what actually governs dune handling.

A +13% machine that also handles better than the KTM — because its mass is low and central, not high and spread — is a **strong, defensible race argument.**

But the handling claim must be *proven* — modelled in multibody simulation, then ridden — not asserted. It is carried as risk **R1** with a commitment to prove it, not a promise that it is already true.

THE LIGHTEST PARTS ARE THE ELECTRIC ONES

The motor and inverter together weigh ~16.8 kg — less than half the mass of the KTM's engine, gearbox and exhaust. If the electric drive were as heavy as a typical EV powertrain, this machine would be undeliverable. It is buildable precisely because axial-flux and motorsport inverters are this light.

THE TRIM LEVERS WE HOLD

A 1.5 kWh buffer instead of 2.0 kWh saves ~5 kg at the cost of burst duration; a composite frame trims the 12 kg frame estimate; a smaller validated tank cuts fuel-system mass. None is assumed in the ~157 kg figure — they are headroom, not the baseline.

WHY WE PUBLISH THE PENALTY

A feasibility read that hides its heaviest liability is not a feasibility read. The +13% is the first thing a rally engineer will estimate for a series hybrid; putting the real, re-added number in front of them — and the offset argument beside it — is how the document earns the rest of its claims.

Range is a fuel-tank question. Here is the whole calculation.

A series hybrid is not magically more efficient on fuel, and we say so. What is structurally true: range scales linearly with tank size and refuels in the time it takes to pour fuel. The math is shown in full so a diligence engineer can trace it.

THE WORKED DERIVATION — A 400 KM SPECIAL

EST, MATH SHOWN

Stage-average power demand	20 kW
Stage distance ÷ moving avg (400 km ÷ 70 km/h)	= 5.7 h
Energy at the wheel (20 kW × 5.7 h)	= 114 kWh

FUEL → WHEEL CHAIN EFFICIENCY

Engine (APU) brake thermal, fixed point	33%
Generator (PMSM)	× 93%
Rectifier + buffer + inverter + motor	× 88%
Overall fuel → wheel	≈ 27%

Fuel energy needed (114 ÷ 0.27)	= 422 kWh
Gasoline energy density	8.9 kWh/L VER

FUEL VOLUME (422 ÷ 8.9) ≈ 47 L

KTM carries 35 L and its engine is direct-drive at ~33% too, so this is the right order of magnitude. Working spec: design tank ~40 L for a ~340 km special reserve, matching rally refuel-point spacing; the architecture accepts a larger tank at only linear mass cost.

THE EFFICIENCY GAIN THAT IS REAL

The APU runs at ONE efficient point (~33%) for the whole stage. The KTM's engine spends most of the stage *off* its sweet spot — part-throttle, transient — where real efficiency drops to 20–25%.

Apples-to-apples, the steady-state genset can beat a direct-drive single's real-world stage average by ~15–25% — a claim to validate, not a guarantee.

THE HEADLINE THAT IS TRUE

Want 500 km? Add ~12 L (~9 kg), not 40 kWh of battery (~180 kg). No charging problem, no range anxiety, no battery-mass explosion. **That is the series-hybrid structural advantage, and it is real.**

SILENT RANGE — THE STEALTH STORY, HONESTLY

~6 min

AT FULL RALLY PACE
(20 KW)

~24 min

AT LOW-SPEED
CRAWL (~5 KW)

Stealth is a **tactical low-speed capability** — starts, bivouac, technical sections, sensitive terrain — not a touring EV range. The buffer is a buffer. We frame it as minutes, not hours.

READING THE 47 L HONESTLY

The ~47 L a full 400 km special needs at these assumptions is *more* than the KTM's 35 L, because a series hybrid is not magically more efficient on raw fuel — and we say so rather than hide it behind a headline. The working ~40 L tank is sized to a ~340 km reserve that matches real rally refuel-point spacing; a longer special is a bigger tank, at ~0.74 kg per litre, and nothing else. The whole derivation on this page is shown so the number can be pushed on, not taken on trust.

**Fuel is the constraint
— and a fuel constraint
is a tank, not a wall.**

Two heat loops, sized for hours at load at 45°C.

Saudi and Baja desert ambient. Two independent loops, both sized for continuous rating in heat. The dominant heat source is the engine — and decoupling its heat from vehicle speed is a controls advantage only series hybrid has.

LOOP 1 — POWERTRAIN (MOTOR + INVERTER)

EMRAX 208 combined-cooled needs ~6–8 L/min coolant at ≤50°C inlet; CM200 needs ~12 L/min at ≤80°C. At 20 kW average and 95% efficiency the motor and inverter reject only **~1.5–2 kW of heat** at cruise — modest.

A peak dune-climb (86 kW, ~90% eff) rejects ~8 kW in bursts; the radiator is sized for the *burst + soak*, not the average.

LOOP 2 — APU (ROTARY ENGINE)

The XR50 at ~15 kW electrical output / ~33% efficiency burns ~45 kW of fuel, rejecting **~30 kW as heat** (exhaust + coolant). This is the dominant heat source and drives radiator size.

Rotaries run hot exhaust; routing it away from rider and electronics is a packaging constraint the form must honour.

~32 kW

TOTAL CONTINUOUS HEAT REJECTION **EST**

~30 kW

FROM THE APU ALONE — THE DRIVER OF RADIATOR SIZE

2

INDEPENDENT LOOPS — KTM TWIN-RAD IDIOM, UPSIZED

80 °C

P45B CELL CUTOFF — MARGIN AT DESERT AMBIENT

BATTERY THERMAL

At a 31 kW burst across 7 mΩ cells the pack self-heats modestly. A cold-plate tied to the powertrain loop holds cells in the 20–45°C window. Desert ambient means *cooling*, not heating, is the concern — and the P45B's 80°C cutoff gives margin.

THE REAL RISK — LOW-SPEED SOAK

The danger is soak at low speed: no ram air, high ambient, APU still running. The radiator sizing above targets exactly this case, not the cruise average.

THE SERIES-HYBRID THERMAL TRICK

The VCU can command APU-off + battery-only crawl to shed heat, then restart.

The engine's thermal load is decoupled from vehicle speed — a direct-drive bike cannot do this without stalling. It is a controls advantage, not just a cooling system. Bench-test the APU loop at ambient before the bike ever runs (see §12, Phase 1).

THE HEAT BUDGET IN ONE SENTENCE

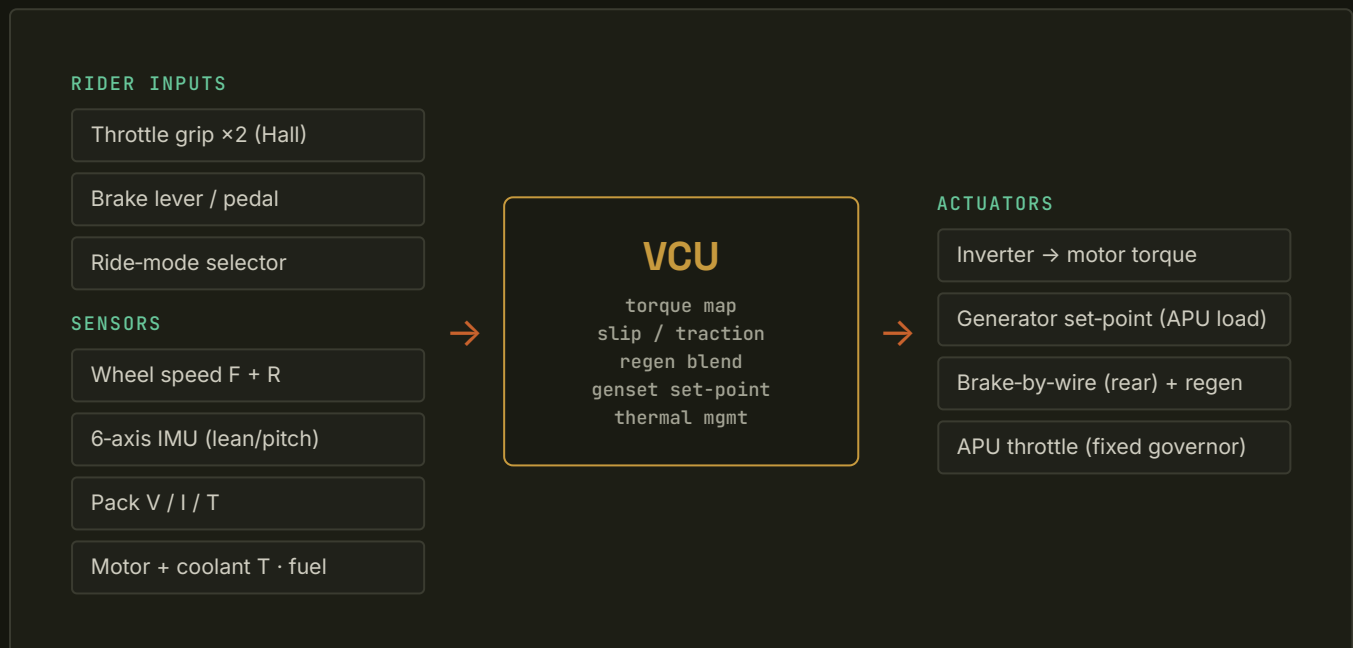
At cruise, the electric drive is nearly cold (~1.5–2 kW rejected) and the radiators exist almost entirely for the engine and for burst/soak events. Sizing the cooling system to the worst case — a hot dune climb followed by a low-speed soak — is what earns the two upsized loops, and it is a number that gets measured on the bench in Phase 1 before it is ever trusted on the machine.

Cooling is where a rally machine dies in the heat. We size for the soak, not the average.

Traction control is nearly free when torque is software.

A conventional bike's traction control fights the engine — it retards ignition, cuts fuel, closes a butterfly, all slow and lossy. Here the VCU commands motor torque directly through the inverter, at millisecond resolution, with the exact torque known.

THE BY-WIRE STACK



TRACTION / TORQUE

Slip control clamps motor torque the instant the rear wheel outruns a target slip ratio — no engine to fight, ~100× faster than butterfly/ignition. Lean-sensitive torque and per-surface launch/dune maps are trivial once torque is a software variable. Two-motor torque vectoring is a roadmap option, not in prototype scope.

BRAKE-BY-WIRE — HONEST

Prototype: hydraulic front (fail-safe) + by-wire blended regen on the rear. A mechanical fallback on the primary stopping brake — the responsible choice for a solo, high-speed machine. **Production intent:** full per-corner electric on the Brembo Sensify pattern, once fail-operational redundancy is validated.

FUNCTIONAL-SAFETY POSTURE

HV interlock on all HV connectors; contactor + pyro-fuse for crash/fault disconnect; redundant throttle and brake channels; VCU watchdog. We do **not** claim ISO 26262 certification for a prototype — we claim a safety-conscious architecture *designed toward* it. Honest.

WHY THE CONTROLS LINE IS THE REAL WORK — AND THE REAL VALUE

Every advantage the machine claims — traction, torque delivery, thermal decoupling, regen blending, the fixed-point genset — lives in the VCU's code, not in a casting. That is why the controls software is the biggest line in the cost stack (§11) and the critical path in the timeline (§12). It is also why the machine is a platform: the same hardware gains capability with a software release, the way a software-defined car does. The moat is the maps, not the metal.

The moat is the maps, not the metal.

Nine risks. None hand-waved. Each with an honest mitigation.

Rated by severity (impact if it bites) × likelihood (how probable). Nothing here is a physics wall — series hybrids, high-power axial motors, high-rate buffers and rugged inverters all exist and are proven in other vehicles. The innovation is integration, not invention.

RISK	SEVERITY	LIKELIHOOD	RESIDUAL
R1 Weight (+~13% vs KTM) ~157 kg dry (~180 kg wet) vs 139 kg. In deep sand and on jumps, mass hurts. Mitigation: package all major mass low and central to cut CG and polar moment; a heavier bike with a lower CG can out-handle a lighter one with mass high and spread. Model in multibody sim, then validate on a rider. Trim via composite frame, lighter 1.5 kWh buffer option. We claim to beat the KTM on handling, not the scale — and commit to proving it.	 HIGH	 HIGH • CERTAIN	 MED
R2 Thermal — hours at load in 45°C APU rejects ~30 kW heat; low-speed soak with no ram air is the danger. Mitigation: two independent, upsized cooling loops; the VCU can command APU-off + battery crawl to shed heat (a series-hybrid-only trick). Rally-grade fans. Bench-test the APU loop at ambient before the bike runs.	 HIGH	 MED	 MED
R3 Controls software maturity Torque/slip/regen/thermal maps and fail-safe logic are new code on a new machine; bugs are performance <i>and</i> safety issues. Mitigation: start on a proven VCU platform; develop maps on a dyno + rolling rig before open-desert running; extensive hardware-in-loop sim; conservative default torque limits; watchdog + limp modes. The single biggest schedule and cost driver — treated as such.	 HIGH	 HIGH	 MED
R4 The 20 kW stage-average assumption is wrong All range/fuel/APU-sizing math scales off it. If real average is 30 kW, fuel demand and APU size grow. Mitigation: validate early — data-log a real 450 rally bike at Baja/desert pace <i>before</i> freezing APU and tank size. Design APU + tank with margin (XR50 has headroom to 33 kW; tank scales linearly). The #1 number to close. See §13.	 HIGH	 MED	 MED
R5 Reliability in sand & vibration Rally destroys machines: dust ingress, vibration-cracked brackets, connector failures, seal wear. HV electronics add failure modes — a wet or dusty HV connector is a safety issue, not just a DNF. Mitigation: IP6K9K-rated inverter; sealed HV connectors, conformal-coated boards, vibration-isolated mounts; the rotary APU chosen partly for low vibration. Redundant sensing. Bivouac-serviceable modular design. Test to failure on a shaker + dust chamber.	 HIGH	 HIGH	 MED-HIGH

RISK	SEVERITY	LIKELIHOOD	RESIDUAL
R6 Homologation / eligibility FIM/ASO rally-raid classes were written for ICE; a series hybrid must fit a category. The door is open: ASO's Dakar Future / Mission 1000 program explicitly welcomes hybrid and alternative-propulsion machines (~100 km/day, ~1000 km total, judged on reliability/efficiency). FIM already publishes Equivalence-of-Technologies / Balance-of-Performance rules for electric vs ICE elsewhere. Enter via Mission 1000 first; pursue full-class eligibility as rules mature. We name the real path; we do not claim a class that does not exist yet.	●●● MED	●●● MED	●●● MED
R7 The production-intent APU is pre-production The multi-fuel story depends on the LiquidPiston engine, not yet buyable. Mitigation: prototype on the Aixro XR50 — a real, purchasable engine — today. LiquidPiston named only as a production-intent path with its status stated. The architecture is engine-agnostic; swapping the APU later is a bolt-in, not a redesign.	●●● MED	●●● MED	●●● LOW
R8 Cost & capital intensity A halo prototype is expensive; a running bike is only the first of many program costs. Mitigation: phase the spend — a running proof-of-concept is achievable for the \$11 budget; full race development is a separate, larger raise. Be honest with investors about what the first number buys.	●●● MED	●●● HIGH	●●● MED
R9 HV safety for a solo rider in a crash Rally means big offs; a compromised HV pack is a fire/shock risk. Mitigation: crash-rated pack enclosure, pyro-fuse disconnect on impact (IMU-triggered), HV interlock, insulation monitoring, cell-level fusing. Standard EV-motorsport practice — FIA/FIM electric safety regs exist and we design to them from day one.	●●● HIGH	●●● MED	●●● MED

THE HONEST TOP-LINE FOR INVESTORS

The three risks that actually decide this program are **R1 (weight)**, **R3 (controls software)**, and **R4 (the power assumption)**. Weight is certain and managed by packaging; controls is the real work and the real cost; the power number is closeable with two weeks of telemetry. Nothing here is a physics wall. **The innovation is the integration into a rally motorcycle, not the invention of any one part.**

3

PROGRAM-DECIDING RISKS, ALL NAMED & RETIRED ON THE TIMELINE

HOW TO READ RESIDUAL RISK

Residual is the risk that *remains after* the mitigation is in place — not the raw risk. Most rows fall from High to Medium once the plan runs; R7 (the pre-production engine) falls to Low because the prototype simply uses a different, buyable engine. R5 stays Med-high — sand is honest about what it does to machines.

EACH RISK BUYS A PHASE

The register is not a disclaimer — it is the plan. R4 is retired in Phase 0, R2 and the bulk of R3 on the bench in Phase 1, R1 in Phase 2's multibody sim, and R5 and R9 in Phase 3's durability and crash-safety testing. The timeline (§12) is the risk register in motion.

WHAT WE DELIBERATELY DID NOT DO

We did not rate any risk Low on likelihood to flatter the picture, did not omit HV safety because it is uncomfortable, and did not claim a homologation class that does not exist. A register a diligence engineer trusts is one that names the risk they were about to raise themselves.

~\$0.75M buys one running, shaken-down prototype.

Budgetary ranges from component list prices (verified where cited) plus fabrication, integration and labour. A prototype is dominated by *engineering labour*, not parts. These are estimates for planning, not quotes.

HARDWARE / BOM (ONE PROTOTYPE) EST

EMRAX 208 motor	\$8–12k
Cascadia CM200 inverter	\$6–9k
Buffer pack (192× P45B + BMS + enclosure)	\$6–10k
Aixro XR50 + generator PMSM + rectifier	\$12–18k
Fuel system, tanks (custom)	\$3–5k
Cooling (2 loops, radiators, pumps)	\$3–5k
Chassis + swingarm (one-off fabrication)	\$10–20k
Suspension (WP/Öhlins rally-class)	\$6–10k
Wheels, tyres, brakes	\$5–8k
Bodywork (hand-laid composite, Ducati-grade finish)	\$8–15k
VCU, sensors, wiring, HV cabling, contactors	\$6–10k
Hardware subtotal	~\$85–130k

ENGINEERING & PROGRAM (ONE BIKE RUNNING) EST

Systems/controls engineering (VCU code, maps, HIL)	\$150–300k
Mechanical design & packaging (CAD, sim, CG)	\$80–150k
Fabrication labour & assembly	\$50–100k
Dyno + rig + dust/shaker testing	\$40–80k
Telemetry validation (R4: log a real rally bike)	\$15–30k
Contingency (~20%)	\$80–150k
Engineering / program subtotal	~\$415–810k

TOTAL — ONE RUNNING, SHAKEN-DOWN PROTOTYPE

~\$0.75M (\$0.5–0.95M)

One machine that runs, self-powers, and completes controlled test running. **A single-bike, prove-the-architecture number.**

WHAT THIS NUMBER DOES NOT INCLUDE

A race-season budget, a second or spare bike, a team, or homologation testing. Those are the *next* raise and are labelled as such (R8). This buys the prototype; the race program is the next, larger, de-risked raise.

SANITY CHECK AGAINST THE INDUSTRY

A factory Dakar bike program runs into the **tens of millions per season**. A single innovative prototype at ~\$0.75M is credible and modest against that — a seed-stage number to prove the thesis, exactly what a venture investor funds.

WHERE THE MONEY GOES — LABOUR, NOT PARTS

Hardware ~15%	Engineering & program ~65%	Contingency ~20%
---------------	----------------------------	------------------

Proportions of the ~\$0.75M midpoint. A prototype's cost is people solving the integration problem — overwhelmingly the controls software (R3) and the mechanical packaging — not the price of the components. The parts, the credibility spine of \$05, are the smallest line on the page.

THE RAISE THIS NUMBER IS

A seed round to build one machine and prove the architecture runs, self-powers and survives a representative stage. It is deliberately *not* the race-program raise — that comes next, larger, and de-risked by exactly the data this prototype produces. An investor funding this line knows precisely what it buys and what it does not.

Prove the power system on a bench before it ever moves.

~18–24 months to a shaken-down running prototype, phased so risk retires in the right order. The hardest, most novel subsystem is proven in the cheapest, safest place first.

Phase 0 Architecture freeze & validation

M0–3

Close R4: data-log a real 450 rally bike at desert pace → freeze the 20 kW average, APU output, tank size. Freeze BOM, voltage architecture, pack topology. Order long-lead items. **Deliverable:** frozen spec, sourced BOM, sim started.

Phase 1 Powertrain bench — “the bike on a table”

M3–9

Build the APU genset on a bench; tune to its efficient point; measure real BSFC and output (retires R2 + R4 cheaply). Build the buffer pack, commission BMS. Integrate inverter + EMRAX 208 on a dyno. Stand up the VCU on hardware-in-loop (retires the bulk of R3 before anything is dangerous). **Deliverable:** a complete powertrain running on a bench.

Phase 2 Rolling chassis & integration

M6–15

Mechanical design → CAD → multibody CG/handling sim (retires R1 on paper). Fabricate chassis, swingarm; mount the bench-proven powertrain. Cooling loops installed and bench-tested at ambient. First rolling, self-powered running on a closed pad. **Deliverable:** the machine moves under its own power.

Phase 3 Shakedown & desert testing

M15–24

Dust chamber + shaker durability (retires R5). Progressive open-terrain testing: pad → gravel → sand → representative stage. Map refinement, thermal validation at real ambient, HV crash-safety validation (R9). **Deliverable:** a shaken-down prototype that completes a representative stage, plus a data package for the next raise and Mission 1000 entry (R6).

M0 M6 M12 M18 M24

LONG-LEAD ITEMS — ORDER IN PHASE 0

ITEM	LEAD	WHY
Aixro XR50 + custom generator integration	4–6 mo	specialist low-volume engine; bespoke winding/coupling
EMRAX 208 motor	2–4 mo	built-to-order axial-flux
Cascadia CM200 inverter	2–3 mo	motorsport lead times
Custom battery pack (cells + BMS)	3–5 mo	cell sourcing + BMS + safety testing
WP/Öhlins rally-spec suspension	2–4 mo	low-volume race components
Custom chassis tooling/fixtures	2–3 mo	one-off fabrication

THE CRITICAL PATH

The APU generator integration and the controls software (R3). Everything else parallelises around them. This is why Phase 1 — “the bike on a table” — comes before the bike is a bike: you prove the hardest, most novel subsystem in the cheapest, safest place first.

THE SEQUENCING LOGIC, STATED ONCE

Nothing dangerous happens until it has happened safely first. The genset is proven on a bench before it is in a frame; the control maps are proven in hardware-in-loop simulation before they command a real wheel; the machine crawls a closed pad before it sees open sand. Each phase's deliverable is the evidence the next phase's spend is justified — and the phases overlap only where the risk allows it. A milestone here is a risk retired, not a date hit.

A milestone is a risk retired, not a date hit.

One number we validate first — and we say so before you ask.

Range, fuel and generator sizing all scale off a single estimate: a ~20 kW stage-average power demand. It is an honest engineering estimate (15–25 kW from off-road racing literature), and it is the number a diligence engineer will push on. We surface it as a strength owned early, not an ambush.

RISK R4 — THE LOAD-BEARING ESTIMATE

~20 kW

Stage-average electrical demand at the wheel. Everything in the energy section (\$07) scales off it. If real average is 30 kW, fuel demand and APU size grow — so we close it before any hardware is frozen.

WHY IT DOES NOT SINK THE THESIS EITHER WAY

The XR50 has headroom to 33 kW, and the tank scales linearly. A higher real average means a larger tank and a higher genset set-point — both are dials, not redesigns. The architecture absorbs the answer.

This is the difference between an estimate that is *closeable* and one that is *fatal*. R4 is closeable in about two weeks of telemetry.

THE PHASE-0 VALIDATION PLAN

- 1 Instrument a real 450 rally bike**
GPS + a power estimate (or a direct measurement rig) on a proven KTM/Honda 450 rally machine at Baja/desert pace — the exact duty cycle the machine will race.
- 2 Data-log a representative stage**
Capture the real distribution of tractive power over mixed terrain — not a lab number, the actual histogram of what a stage demands, moment to moment.
- 3 Freeze the three numbers**
The validated stage average sets the genset output target, the tank size, and the buffer window. Only then does the BOM freeze and long-lead ordering begin.

COST & TIMING, ALREADY IN THE PLAN

Telemetry validation is budgeted at **\$15–30k** (\$11) and sits in **Phase 0, months 0–3** (\$12) — the first work funded, before a single powertrain part is ordered. The one number the whole document leans on is the first thing we close.

A feasibility read is only as credible as its treatment of the number it is least sure of. We named ours on page one, quantified its impact, and funded its validation first.

IF THE REAL NUMBER IS LOWER

Say 15 kW. Fuel demand and tank size shrink; the genset runs at an even lower, quieter set-point; the mass penalty narrows further. The thesis strengthens. The 20 kW working figure is chosen mid-range on purpose — not optimistically.

IF THE REAL NUMBER IS HIGHER

Say 30 kW. The tank grows (linear mass), the genset set-point rises toward the XR50's 33 kW headroom, and the buffer window is retuned. All three are dials the architecture already exposes — no component is re-selected, no redesign is triggered.

WHY THIS IS THE RIGHT WAY TO BE WRONG

Every credible engineering program carries one or two numbers it will measure before it commits. The failure mode is not *having* such a number — it is hiding it, or building expensive hardware around it before it is measured. We do neither.

The claim register. Every line, stress-tested.

The document ends where it began: on the discipline that is its credibility. Here is what a mechanical engineer and a venture investor can both check — and what each holds up to.

- ✓ **Every powertrain component is a real, named, spec'd part** you can quote today — motor, inverter, cells, engine — except the LiquidPiston, named as production-intent with the Aixro XR50 as the prototype engine.
- ✓ **The mass penalty is stated, quantified (~+18 kg dry / +13% vs KTM), and explained** — not hidden. The offset (low, central mass → lower CG) is argued and committed to proof, not asserted.
- ✓ **Range math shows fuel is the constraint** and does not over-claim efficiency — the ~15–25% real-world stage gain is framed as a claim to validate, and the full derivation is shown.
- ✓ **Stealth/silent range is framed honestly** as a tactical low-speed capability — minutes, not hours. The buffer is a buffer.
- ✓ **Brake-by-wire is prototype-honest** — hydraulic front + by-wire rear, with full per-corner electric named only as the production path.
- ▲ **The one load-bearing assumption (20 kW stage average) is flagged for telemetry validation** — the number a diligence engineer will push on, surfaced first and funded first.

THE PROVENANCE DISCIPLINE IN ONE SENTENCE

Every hard component spec is read from the maker's own page and cited; every derived number — mass total, range, cost, timeline — is an engineering estimate built from those verified specs with its assumption stated. **Nothing load-bearing is invented.**

NO PHYSICS WALL

Series hybrids, high-power axial motors, high-rate buffers and rugged inverters are all proven in other vehicles. The risk is integration into a rally motorcycle, not the invention of any one part.

A REAL REGULATORY ON-RAMP

Dakar Future / Mission 1000 explicitly welcomes hybrid propulsion. Enter there first — a proving ground, not a class we invented — then pursue full eligibility as the rules mature.

PHASED CAPITAL

~\$0.75M and ~18–24 months buys one running, shaken-down prototype — prove the thesis. The race program is the next, larger, de-risked raise. Said plainly.

THE WHOLE CASE, IN ONE LINE

A software-defined powertrain in a category that has never had one — built from parts that already exist, for a number a seed investor funds, on a plan that retires its own risks in order.

Single source of numbers throughout.
Verified • Estimated • Target,
labelled.