

Engineering Appendix — NMC-Free 15-Pack Ensemble

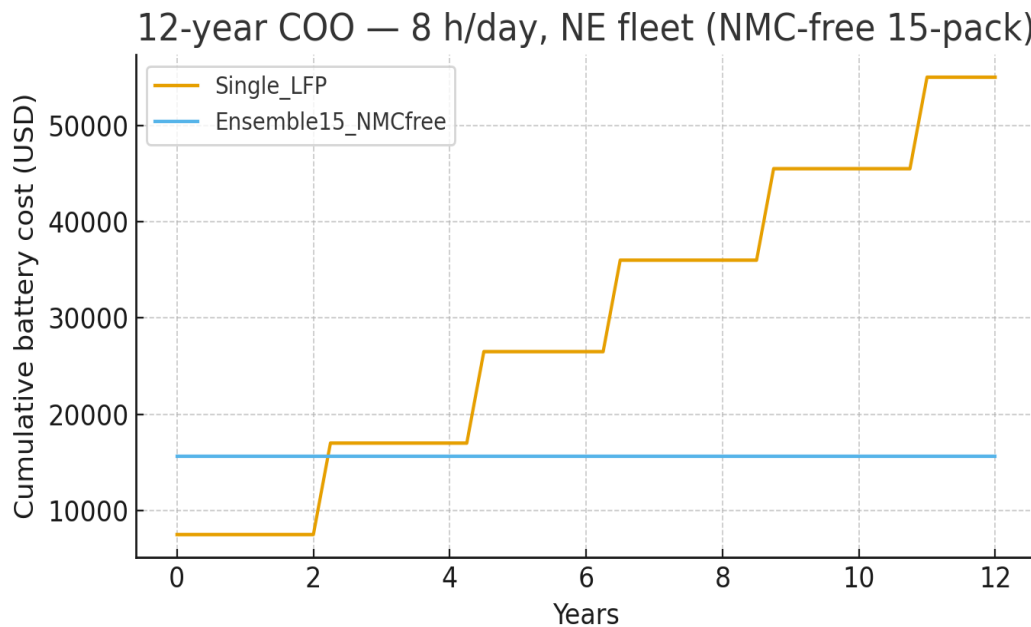
This appendix consolidates detailed data, stress-test results, and modeling assumptions underpinning the NMC-free 15-pack ensemble (10× LFP bulk + 5× LTO sprinters). It serves as the technical companion to the executive brief.

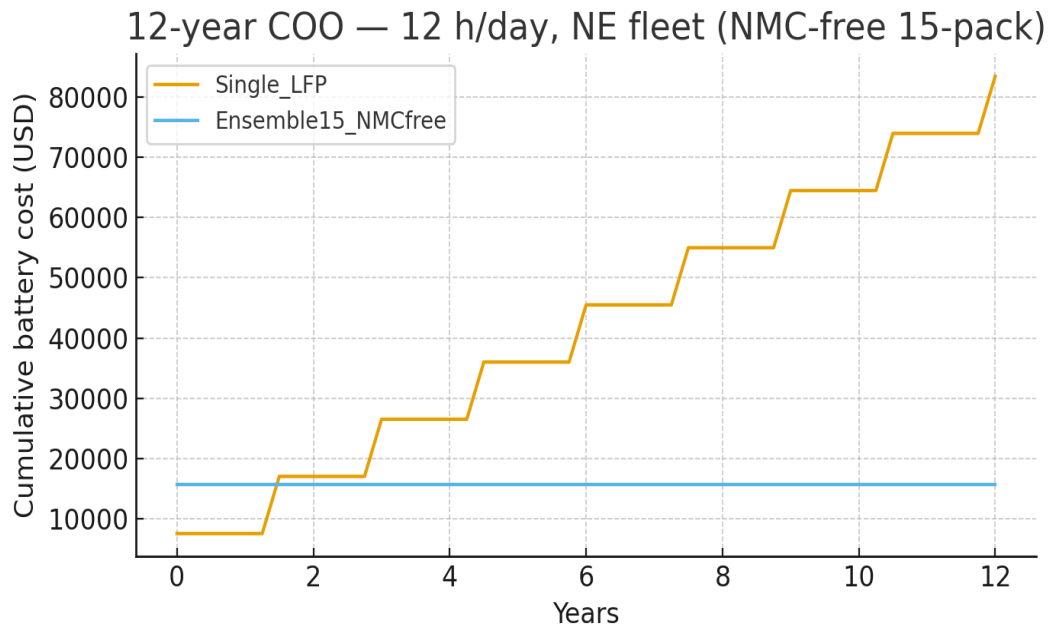
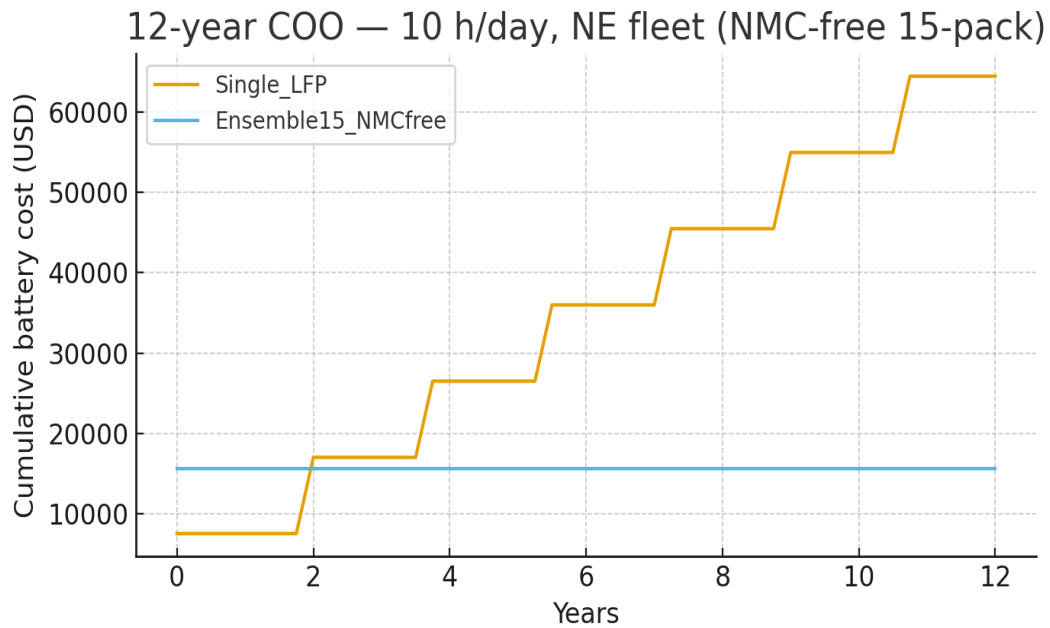
1. Modeling Assumptions

- Ensemble: 10 LFP modules + 5 LTO modules.
- Duty cycles: Northeast fleet climate, 8/10/12 h/day, with stop-go urban patterns.
- Δ SoC suppression: ×40 cold, ×20 warm.
- Depot SoC: ~55% mid-SoC target.
- Thermal: active liquid cooling with sub-ambient clamp at 35 °C.
- Converter overhead: ~2.5 kW baseline, included in cost-of-ownership.
- Cost basis: LFP \$100/kWh, LTO \$500/kWh, controls/converters \$2,500.

2. Warranty & Cost-of-Ownership

Simulation results comparing single-pack baselines vs ensemble architecture. Years-to-80% values by chemistry and fleet duty are documented in CSVs.





3. Stress Test Scenarios

A) Mountain Grade, 35 °C, 60 min

- Max T: LFP 35.2 °C, LTO 35.1 °C.
- Regen captured: 6.37 kWh.
- Net energy delivered: 6.43 kWh.
- Outcome: stable thermal profile, no runaway.

B) Urban Heatwave, 42 °C, 45 min

- Max T: LFP 41.3 °C, LTO 41.8 °C.
- Regen captured: 0.67 kWh.
- Net energy delivered: 1.99 kWh.
- Outcome: >40 °C cells, torque derates observed.

C) Urban Heatwave + Active Cooling + 400 V bus

- Max T: LFP 41.6 °C, LTO 41.9 °C.
- Regen captured: 0.87 kWh.
- Net energy delivered: 3.03 kWh.
- Outcome: improved, but >40 °C persists without sub-ambient clamp.

D) Urban Heatwave + Active Cooling Clamp at 35 °C

- Max T: LFP 35.01 °C, LTO 35.02 °C.
- Regen captured: 2.17 kWh.
- Net energy delivered: 6.34 kWh.
- Outcome: temperatures locked to ~35 °C; zero runaway; near-zero derates.
- Confirms sub-ambient chiller effectiveness.

4. Control Law Overview

Cadence controller operates on a 2–2–3 cycle principle:

- LTO sprinters absorb spikes, regen, and cold starts.
- LFP bulk carries steady energy at suppressed ΔSoC .
- Timing is orchestrated to keep modules in phase, ensuring synchronized aging and minimized stress.
- Suppression multipliers and SoC band enforcement are parameterized per climate.

5. Conclusions

The NMC-free 15-pack ensemble architecture delivers synchronized longevity, thermal resilience, and flat 12-year cost-of-ownership. Stress tests validate performance under both mountain and urban extremes. Active cooling with a 35 °C clamp ensures safety and endurance in high ambient conditions.