ECONOMIC ANALYSIS

2000 T Inland Cargo Electric Barge NW-5

Diesel vs Battery Swap

A 28-Year Total Cost of Ownership and Public-Value Assessment

Prepared for: Policy and Programme Stakeholders — Inland Water Transport Decarbonisation
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Contents

1. Executive Summary

This report evaluates two propulsion configurations for a 2000-tonne inland cargo barge operating on a 320 km route in Indian waterways under a long-term cargo contract at 100% utilisation: a conventional diesel power train and a battery-swap configuration using LFP (Lithium Iron Phosphate) chemistry supplemented by a 20 kW solar plant. Both vessels share an identical hull, displacement, cargo capacity, and crew complement; only the energy system differs. The analysis is conducted over a 28-year operating horizon and applies a 5% real discount rate to all monetary flows.

Battery Swap delivers a present-value Total Cost of Ownership (TCO) of approximately ₹101 Cr against ₹259 Cr for diesel — a 61% reduction. Net Present Value (NPV) is ₹497 Cr versus ₹338 Cr on a full profit-and-loss basis at ₹2/t-km cargo rate, a ₹159 Cr advantage. Both configurations recover capital in approximately two years. The TCO saving of ₹159 Cr is independent of cargo rate — it holds at every rate tested. The case for battery swap is unambiguous on every measured financial dimension.

Metric	Diesel	Battery Swap	Advantage
TCO (PV, Cr INR)	₹259 Cr	₹101 Cr	**₹159 Cr lower**
NPV (Cr INR)	₹338 Cr	₹497 Cr	**₹159 Cr higher**
Simple Payback (yrs)	3	3	Equal recovery

Beyond direct financial returns, Battery Swap delivers substantial public-value externalities: avoided diesel consumption of approximately 767,000 litres per vessel per year (21.5 million litres over the asset life), corresponding to roughly 2,025 tonnes of avoided CO_2 per year (56,700 tonnes lifetime); reduction in diesel import dependence equivalent to approximately ₹215 Cr per vessel at today's flat price (₹448 Cr nominal with escalation); and creation of domestic value in battery, motor, and solar manufacturing.

Recommendation

Treat battery-swap propulsion as the default configuration for new-build 2000 T inland cargo barges operating under long-term cargo contracts. Direct policy support toward

(i) battery-swap shore infrastructure at major river ports,
(ii) (ii) viability-gap funding for the ₹11.3 Cr CAPEX premium during early deployment — recovered in 2 years — and
(iii) (iii) standardisation of battery pack form factors to enable inter-operator swap interoperability.

2. Policy Context and Strategic Rationale

Inland water transport accounts for less than 1% of India’s freight when measured in tonne-kilometres — the most meaningful metric for logistics — against a global benchmark of 6–9% in peer economies (IWAI / World Bank). The government’s own Maritime India Vision 2030 targets raising this share to 5% by 2030, acknowledging how severely underutilised the network remains. The structural advantages of inland shipping are clear: a single 2000 T barge displaces approximately 100 truck-trips per voyage, with lower per-tonne-km energy intensity and infrastructure wear.

Decarbonising the existing and planned IWT fleet is a triple-objective policy problem: it must simultaneously (a) improve unit economics so that inland shipping is commercially competitive with road and rail freight, (b) reduce greenhouse-gas emissions in line with India's 2070 net-zero pathway, and (c) reduce diesel-import exposure given that India imports more than 85% of its crude oil requirements. The battery-swap electric barge with onboard solar augmentation assessed in this report addresses all three objectives simultaneously.

3. Project Overview

3.1 Vessel and Route Parameters

The reference vessel is a 2000-tonne inland cargo barge (85 m × 12 m × 3.5 m draft) operating under a long-term cargo contract at 100% utilisation on a 320 km route with three intermediate swap stops, completing four trips per one-way voyage.

Parameter	Value
Vessel size (L×B×D×T)	85 m × 12 m × 3.5 m × 2.5 m
Displacement (t)	2,650
Cargo capacity (t)	2,000
Max / Cruise speed (knots)	8 / 7
Voyage distance (km)	320
Trips per one-way voyage	4
Intermediate swap stops	3 (Points B, C, D)
Operating days / year	350
Voyages per year	175
Total cargo per year (t)	3,50,000
Cargo rate (₹/t-km, base case)	₹2.00 (escalating at 5%/yr)
Crew complement	3 per shift × 2 shifts

Trip Schedule — Battery Pack Assignment by Barge and Stop

The table below shows the complete round-trip voyage for all six barges. Trips 1–4 cover the outbound leg (A → E); Trips 5–8 cover the return (E → A). At each intermediate stop (B, C, D) the spent pack is swapped in ~30 minutes; at terminal stops (A and E) the barge undergoes cargo operations while shore packs are charged. Each coloured cell shows the LFP battery pack (B1–B9) riding on that barge for that leg.

Stop	Trip	Barge 1	Barge 2	Barge 3	Barge 4	Barge 5	Barge 6	Event
Point A	1	B1	B2	B4	B6	B9	B3	Start — depart A (staggered every 4 hrs)
Point B		B1	B2	B4	B6	B9	B3	Swap start
Point B	2	B3	B5	B8	B2	B6	B9	Swap end — depart B
Point C		B3	B5	B8	B2	B6	B9	Swap start
Point C	3	B7	B1	B5	B8	B2	B4	Swap end — depart C
Point D		B7	B1	B5	B8	B2	B4	Swap start
Point D	4	B4	B7	B1	B3	B5	B6	Swap end — depart D
Point E		B4	B7	B1	B3	B5	B6	Cargo discharge / pack charging (~21.7 hrs)
Point E	5	B7	B8	B1	B3	B6	B9	Return voyage departs E
Point D		B7	B8	B1	B3	B6	B9	Swap start
Point D	6	B9	B2	B5	B8	B3	B6	Swap end — depart D
Point C		B9	B2	B5	B8	B3	B6	Swap start
Point C	7	B4	B7	B2	B5	B8	B1	Swap end — depart C
Point B		B4	B7	B2	B5	B8	B1	Swap start
Point B	8	B1	B4	B7	B9	B2	B3	Swap end — depart B
Point A		B1	B4	B7	B9	B2	B3	Cargo loading / pack charging at A

Note: Barges depart Point A staggered every 4 hours. Packs B1–B9 are the 9 LFP units shared across the 6-barge fleet at a 1.5:1 ratio. Yellow rows = terminal stops (cargo + charging). Blue rows = intermediate swap stops.

3.2 The Battery-Swap Configuration

The battery-swap design replaces the diesel engines, gearbox, and fuel-oil system with two electric motors, an Energy Storage System (ESS), and a fleet of swappable battery packs based on Lithium Iron Phosphate (LFP) chemistry. LFP is selected for its proven reliability in marine and heavy-duty applications, strong safety profile (thermal stability), competitive cost at scale, and rated cycle life of approximately 3,500 cycles at 80% depth-of-discharge — sufficient for approximately 7 years of high-utilisation operation before replacement.

The swap mechanic eliminates idle charging time: at each of three intermediate stops, a discharged pack is exchanged for a fully charged one in approximately 30 minutes. The 21.7-hour terminal stay at the destination is for cargo discharge and loading — this window is also used to charge the packs at shore stations. LFP chemistry supports standard charge rates without significant degradation over its rated cycle life. A fleet of six barges shares nine battery packs (1.5:1 ratio), with surplus packs charging at shoreside stations while barges remain in service.

Shore Charging Infrastructure — Sizing and Sequential Logic

Each swap station requires a single ~465 kW DC charger per station — not multiple simultaneous units. This follows directly from the pack size and charge time: each 2,210 kWh LFP pack, charged to 80% DoD (1,768 kWh usable), requires approximately 465 kW over 4 hours at a C-rate of 0.21C, well within LFP's comfortable continuous operating range of 0.5C.

A detailed trace of all 9 pack movements across the 94-hour fleet rotation window confirms that packs charge strictly sequentially at every station — there is never more than one pack charging at the same time at any given station. At intermediate stops (B, C, D), one pack completes its 4-hour charge cycle exactly 30 minutes before the next barge arrives for its swap. That 30-minute window is the swap operation itself. The sequencing is tight but self-consistent: the swap time acts as the scheduling buffer between consecutive charge cycles.

The infrastructure implication is significant: one ~500 kW charger per station is sufficient for the entire fleet operation. This keeps the shore-side capital cost manageable — estimated at approximately ₹1.5–2.5 Cr per station installed (charger unit, transformer, switchgear, marine-grade cabling, grid connection, and civil works), or ₹6–10 Cr for all four swap stations (A, B, C, D) on the route. The corollary is that any charging delay beyond 4 hours at an intermediate station directly delays the next arriving barge — charger reliability and grid uptime are therefore critical operational dependencies.

A 20 kW solar plant integrated with the shoreside charging infrastructure displaces approximately 25,500 kWh annually, improving the project's carbon profile and providing a partial hedge against grid-tariff escalation.

4. Methodology and Assumptions

4.1 Analytical Framework

The financial assessment follows a standard discounted-cash-flow (DCF) methodology applied to two parallel cost streams over a 28-year operating horizon. Total Cost of Ownership is calculated as the present value of capital expenditure plus all operating expenses, net of residual asset value, discounted at a 5% real rate. Net Present Value is the present value of net revenue over the same horizon. IRR is computed on the unlevered cash-flow stream.

Revenue is held identical between the two configurations — both barges carry the same cargo on the same route at the same rate. This isolates the propulsion-system economics; any premium that battery-swap operators may secure through green-shipping rates is treated conservatively as zero.

4.2 Key Input Assumptions

Assumption	Base-Case Value
Cargo rate	₹2.00/tonne-km, escalating at 5%/yr
Diesel price	₹100/litre, escalating at 5%/yr
Grid electricity tariff	₹7/kWh, escalating at 5%/yr
Discount rate (real)	5.0% per annum
Battery replacement cycle	Years 7, 14, 21 at ₹15,000/kWh
Battery DoD (LFP)	80%
Solar plant size	20 kW, 3.5 kWh/kW daily yield
Operating days per year	350
Scrap value (residual)	25% of hull cost (₹3 Cr PV, same for both)
Analysis horizon	28 years

5. Financial Analysis

5.1 Capital Expenditure

Upfront capital expenditure for the diesel configuration totals ₹18 Cr, comprising ₹12 Cr for the vessel hull and ₹6 Cr for the diesel power train and fuel-oil system. The battery-swap configuration carries a total CAPEX of ₹29.26 Cr: the same ₹12 Cr hull, ₹4 Cr for the electric power train and ESS housing, ₹8.84 Cr for the onboard 4,420 kWh battery pack, and ₹4.42 Cr for surplus swap-stock batteries.

Component (Cr INR)	Diesel	Battery Swap
Vessel hull (excl. power system)	₹12 Cr	₹12 Cr
Diesel power train + FO system	₹6 Cr	—
Electric power train + ESS	—	₹4 Cr
Onboard battery pack (4,420 kWh)	—	₹8.84 Cr
Swap-stock batteries (surplus packs)	—	₹4.42 Cr
TOTAL CAPEX	**₹18 Cr**	**₹29.26 Cr**

The ₹11.3 Cr CAPEX premium is the principal economic obstacle to deployment. As demonstrated in Section 5.4, this premium is recovered within three years, but the working-capital strain during construction is a real barrier for operators with limited balance-sheet capacity — a key rationale for targeted viability-gap support.

5.2 Operating Expenditure

Over the 28-year horizon, present-value OPEX is ₹244 Cr for the diesel configuration and ₹74 Cr for battery swap. The dominant driver is energy cost: diesel consumes approximately ₹205 Cr of fuel in PV terms, against ₹34 Cr in grid and solar electricity for battery swap. This ₹171 Cr swing results from three compounding effects:

- Energy-conversion efficiency — electric drivetrains operate at ~90% well-to-shaft efficiency vs 35–40% for diesel.
- Input fuel-cost differential — grid electricity at ₹7/kWh is roughly one-quarter the per-energy-unit cost of diesel at ₹100/L.
- Solar augmentation — the 20 kW plant displaces grid energy at zero marginal cost during daylight hours.

Component (Cr INR, PV)	Diesel	Battery Swap	Net Savings
Energy cost	₹204.5 Cr	₹33.6 Cr	**₹170.9 Cr**
Maintenance	₹20.5 Cr	₹3.4 Cr	**₹17.1 Cr**
Crew cost	₹8.8 Cr	₹8.8 Cr	—
Insurance & statutory (2% CAPEX)	₹9.6 Cr	₹12.2 Cr	−₹2.6 Cr
Battery replacement (Yrs 7, 14, 21)	—	₹16.2 Cr	−₹16.2 Cr
Scrap value (recovery)	₹3.0 Cr	₹3.0 Cr	—
NET TCO (PV)	**₹259 Cr**	**₹101 Cr**	**₹159 Cr**

5.3 Cumulative TCO Trajectory

The diesel curve rises steeply due to compounding 5% annual fuel-price inflation. By Year 28, undiscounted cumulative diesel TCO reaches ₹551 Cr. The battery-swap curve rises slowly and almost linearly, with visible step-jumps at Years 7, 14, and 21 (battery replacements). By Year 28, undiscounted cumulative TCO reaches only ₹180 Cr — 33% of the diesel total. The two curves cross in Year 3.

5.4 NPV, IRR, and Payback

At a 5% real discount rate over 28 years, NPV is ₹338 Cr for diesel against ₹497 Cr for battery swap on a full profit-and-loss basis at ₹2/t-km cargo rate — a ₹159 Cr advantage. Battery swap wins on absolute NPV value despite higher CAPEX, because OPEX savings of ₹159 Cr in present-value terms more than compensate over the full horizon. Note: IRR comparisons are not presented here as the metric is sensitive to the NPV definition used; TCO and NPV provide the more robust basis for comparison.

Payback for both configurations is approximately two years at ₹2/t-km cargo rate. Year-1 net cash flow for battery swap (₹19.7 Cr) exceeds that of diesel (₹13.2 Cr) because the energy-cost saving more than offsets the incremental capital cost of the higher-spec power train.

6. Sensitivity and Risk Analysis

6.1 Diesel Price Sensitivity

The sensitivity grid spans ₹80 to ₹140 per litre against a base case of ₹100. At the 2000-tonne vessel scale and 100% utilisation, diesel NPV remains positive across the entire tested grid. However, every ₹10/L of diesel-price escalation reduces diesel NPV by roughly ₹41 Cr at the base discount rate (NPV presented on full P&L basis including revenue at ₹2/t-km) — a meaningful exposure that battery swap avoids entirely.

Table 6.1 Diesel NPV (Cr INR) — diesel price × discount rate

₹/L ↓ / Rate →	5%	7%	9%	11%	13%
₹80/L	228	171	131	103	82
₹100/L (base)	**187**	139	107	83	66
₹120/L	146	108	82	63	49
₹140/L	105	77	57	43	32

Table 6.2 Battery Swap NPV (Cr INR) — discount rate only

Discount Rate	5%	7%	9%	11%	13%
Battery Swap NPV (Cr)	**497**	374	288	227	183

6.2 Cargo-Rate Sensitivity

Because revenue is identical for both configurations, the cargo-rate assumption affects absolute NPV but not the gap between them. The NPV differential between battery swap and diesel is approximately ₹158 Cr at every cargo rate tested. The NPV gap of ₹159 Cr holds constant across every cargo rate tested — the advantage is purely from OPEX, not revenue. At the IWT cost benchmark of ₹1.06/t-km, diesel NPV is ₹57 Cr and battery swap NPV is ₹216 Cr — the ₹159 Cr gap is unchanged.

Table 6.3 NPV sensitivity to cargo rate

Cargo Rate (₹/t-km)	Diesel NPV (Cr)	Swap NPV (Cr)	Benchmark
₹1.06	58	216	IWT cost benchmark (IWAI)
₹1.41	163	321	Rail benchmark
₹2.00 (base)	**187**	**348**	Base case
₹2.58	512	670	Road benchmark

6.3 Material Risks

- Battery cost trajectory: Model assumes ₹15,000/kWh for LFP replacement packs (Yrs 7, 14, 21), a 25% reduction from ₹20,000/kWh original install cost, reflecting expected learning-curve cost decline. LFP prices have been declining consistently; the model is robust to a 50% overrun while maintaining positive NPV.
- Swap infrastructure availability: The 30-minute swap presupposes a fully operational shore station. Without it, the configuration is non-functional. Highest-leverage area for public investment.
- Grid reliability and tariff stability: Battery swap shifts exposure from diesel-price volatility to grid-tariff risk. Solar augmentation provides a partial hedge.
- Solar yield variability: The 20 kW plant contributes modestly (~25,500 kWh/yr); the project is resilient to substantial under-performance on this input.

On a probability-weighted basis, none of these risks individually overturn the central finding.

7. Externalities and Public-Value Assessment

7.1 Greenhouse-Gas Emissions

The reference diesel barge consumes approximately 767,000 litres of diesel per year and emits approximately 2,025 tonnes of CO_2 annually, accumulating to approximately 56,700 tonnes over the 28-year asset life. At the current Indian grid emissions factor (0.71 kg CO_2/kWh), battery-swap tank-to-wake emissions are approximately 1,639 tonnes per year — a 19% reduction. As the grid decarbonises to a plausible 2035 factor of 0.35 kg/kWh, lifetime emissions fall to approximately 22,600 tonnes — a 60% reduction against the diesel baseline.

At a social cost of carbon of approximately ₹4,200 per tonne, the net emission reduction over 28 years has an unmonetised public value of approximately ₹4.5 Cr at today's grid mix and approximately ₹14 Cr under the 2035 grid scenario per barge.

7.2 Fuel-Import Substitution

The reference barge consumes approximately 767,000 litres of diesel annually, equivalent to approximately 21.5 million litres displaced over the 28-year horizon. At ₹100 per litre, this corresponds to roughly ₹215 Cr at today's flat price of ₹100/L — or approximately ₹448 Cr in nominal terms when the model's 5% annual fuel-price escalation is applied — of avoided diesel-import value per barge. This is a real sovereign-balance-sheet benefit entirely unpriced in the operator's P&L.

7.3 Domestic Manufacturing and Employment

A diesel barge's lifecycle expenditure flows predominantly to imported petroleum products. A battery-swap barge's lifecycle expenditure flows to domestic battery cells (PLI for Advanced Chemistry Cells), domestic motors and power electronics, and domestic solar installations. Substituting battery swap for diesel redirects approximately ₹215 Cr (flat price) to ₹448 Cr (escalated nominal) per barge of lifecycle fuel-equivalent expenditure from imports to domestic value creation, plus the additional ₹11 Cr CAPEX uplift that flows to domestic manufacturing.

7.4 Air-Quality Co-Benefits

Diesel-engine exhaust contributes PM2.5, NOx, and SOx to local air sheds, with documented public-health consequences in port towns and along populated waterways. Battery-swap configurations eliminate these emissions at the point of use.

8. Implementation and Policy Recommendations

The financial case for battery-swap propulsion is settled. The question for policymakers is how to accelerate deployment given the enabling-condition constraints identified in Section 6. We propose five concrete interventions, ranked by leverage.

8.1 Build Swap and Charging Infrastructure at Designated National Waterways

The single highest-leverage intervention is publicly-funded swap-and-charge infrastructure at the major terminals of National Waterway 1 (Ganga), NW-2 (Brahmaputra), and NW-3 (West Coast Canal). Without this infrastructure, no operator can deploy the configuration. Capital cost is estimated at ₹15–25 Cr per major terminal.

8.2 Provide Viability-Gap Funding for Early-Deployment CAPEX Premium

The ₹11.3 Cr CAPEX premium is, on present-value grounds, an excellent investment. But it is a real working-capital burden for smaller operators. A targeted viability-gap fund covering 30–40% of the premium for the first 20–50 deployments would catalyse an operational evidence base, after which commercial financing should be able to support deployment without subsidy.

8.3 Standardise Battery-Pack Form Factors

For battery swap to deliver network-level economies of scale, multiple operators must be able to exchange packs interchangeably. The Bureau of Indian Standards, working with IWAI and an industry consortium, should publish a mandatory technical standard for IWT battery packs covering form factors, voltage, communications protocols, and mechanical interfaces.

8.4 Co-Locate Solar with Charging Infrastructure

Shoreside charging stations are natural candidates for co-located solar plants. A 200–500 kW solar installation at each major swap terminal would meaningfully offset grid demand during daylight charging cycles and reduce embodied-carbon intensity.

8.5 Treat Inland Battery-Electric Shipping as a PLI-Eligible Sector

The domestic manufacturing footprint of a battery-swap deployment aligns closely with existing PLI priorities. Explicitly designating inland battery-electric shipping as a PLI-eligible end-use sector would allow operators and manufacturers to coordinate procurement across linked support schemes.

9. Conclusion

Inland water transport sits at a productive intersection of three national policy priorities: modal-share rebalancing in freight transport, decarbonisation of hard-to-abate sectors, and reduction of crude-oil import dependence. The 2000-tonne battery-swap barge assessed in this report advances all three objectives simultaneously, and does so while delivering a stronger return profile than the diesel incumbent on every measured financial dimension.

The 28-year present-value Total Cost of Ownership is ₹101 Cr for battery swap against ₹259 Cr for diesel — a 61% reduction. NPV at 5% discount rate is ₹497 Cr against ₹338 Cr on a full P&L basis — a ₹159 Cr absolute advantage. Both configurations recover capital in two years. The ₹159 Cr TCO saving is invariant to cargo rate — it holds across every sensitivity tested. These results are robust across the range of diesel-price, discount-rate, and battery-cost assumptions tested.

The principal barriers to deployment are not technical and not financial in the long run. They are coordination problems: the absence of swap infrastructure at major terminals, the working-capital burden of the upfront CAPEX premium for smaller operators, and the lack of standardised battery-pack form factors. Each is addressable with modest, well-defined public-sector commitment.

We recommend that policymakers treat battery-swap propulsion as the default configuration for new-build IWT vessels in the 2000-tonne class, and that public capital be directed in the first instance toward swap-and-charge infrastructure at National Waterway terminals, a viability-gap fund for the first 20–50 deployments, and a mandatory technical standard for IWT battery packs. With these enabling conditions in place, the configuration will scale on commercial terms, and inland water transport will move from marginal contributor to a meaningful, low-carbon, foreign-exchange-positive component of India's national freight system.