Inland Waterway Electrification
Economics White Paper 2026

From Policy Driver to Commercial Return
– The Business Case for Lithium Battery Adoption

Contents

Europe's inland waterways are at a crossroads.

With 41,000 kilometers of navigable rivers and canals spanning 25 member states, the EU's inland waterway transport (IWT) network carries approximately 150 billion tonne-kilometers of freight annually. Yet this highly efficient mode of transport accounts for only 5-6% of total EU land freight—a share that has declined in recent years despite growing demand for sustainable logistics.

The tide is turning.

The EU's ambitious climate goals, codified in the European Green Deal and the NAIADES III action plan, have set clear targets: increase inland waterway freight by 25% by 2030 and 50% by 2050, while transitioning to zero-emission vessels. The Alternative Fuels Infrastructure Regulation (AFIR) mandates that core inland ports provide shore-side electricity (OPS) by January 2025, with comprehensive ports following by 2030.

This white paper, based on research from the European Environment Agency (EEA), ReNEW project, and DINA initiative, provides a comprehensive analysis of the economics of inland waterway electrification. Key findings include:

Policy momentum:

41,000km of waterways, 25 EU countries face historic transition with mandatory shore power deadlines

Decarbonization targets:

25% freight increase by 2030, 50% by 2050, zero-emission vessels by 2050

Emission reduction:

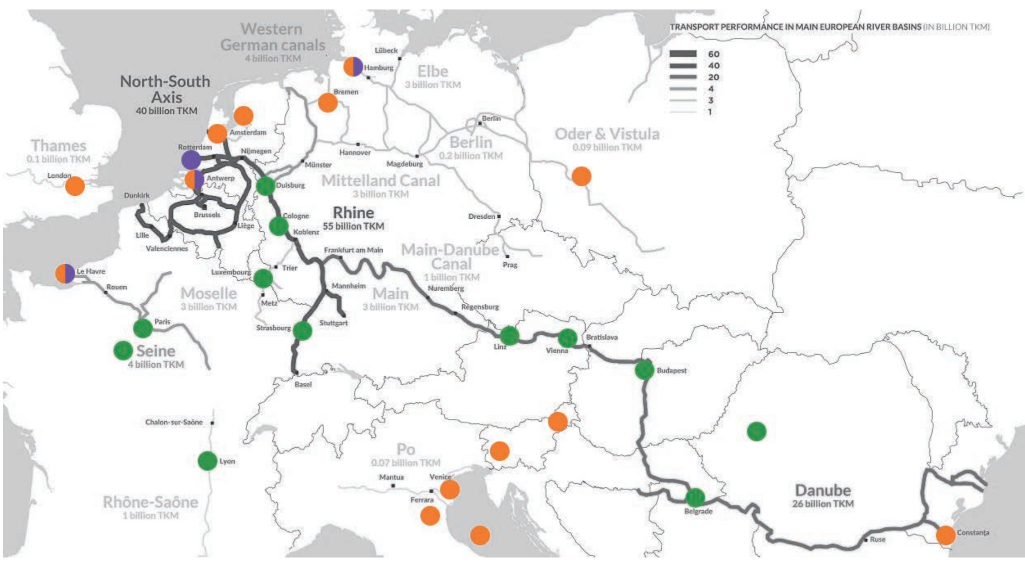
Electrification can cut emissions by over 60%

Technology readiness:

DNV-certified lithium battery systems with cell-level thermal runaway protection, IP67 rating, and flexible scalability are available today

Economic returns:

Hybrid systems can provide 35-70% of propulsion energy from batteries, reducing operational costs by 45% with payback periods as short as 3.5 years



Europe's Inland Waterways & TEN-T Core Ports

AFIR Onshore Power Supply (OPS) Mandatory Deadlines

- Core inland ports (OPS mandatory by 1 Jan 2025)
- Core maritime ports (OPS mandatory by 31 Dec 2029)
- Mixed ports (both deadlines apply)

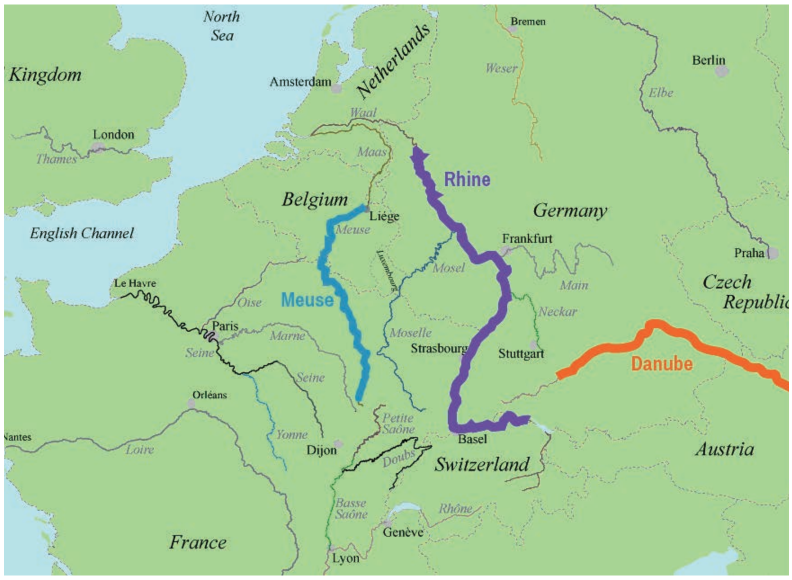
Based on EU AFIR Regulation and TEN-T Network

Whether you are a shipowner, shipyard, system integrator, or policymaker, this white paper provides a complete roadmap for inland waterway electrification—from policy drivers to technical solutions to commercial returns.

2.1

The Scale of Europe's Inland Waterways

Europe's inland waterway network is one of the world's most extensive and strategically important transportation systems.



41,000 km
Total waterway length

25
Member states

150 bn tkm
Annual freight volume

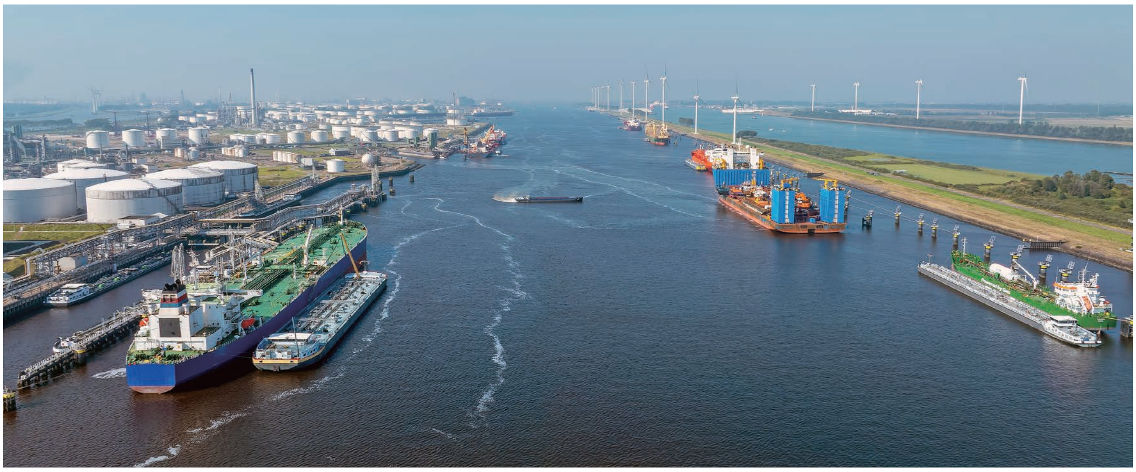
44,000
Workforce

~6%
Share of EU inland freight

Source: NAIADES III / EEA

2.2 NAIADES III: The EU's Strategic Action Plan

In June 2021, the European Commission tabled the NAIADES III action plan—a 35-point strategy to boost the role of inland waterway transport in Europe's mobility and logistics systems.



Core objectives:

1. Shift more cargo from road to Europe's rivers and canals
2. Facilitate the transition to zero-emission barges by 2050
3. Align with the European Green Deal and Sustainable and Smart Mobility Strategy

Commissioner for Transport, Adina Vălean, stated:

"As one of the most CO_2-efficient transport modes available, inland waterways have the potential to play a central role in decarbonising our transport systems. Yet today, our canals and rivers carry just 6% of EU freight. With an inland waterway network of 41,000km spanning 25 Member States, there is scope to do a lot more."

Key targets:

2021

NAIADES III action plan launched

2030

2030 Targets

+25% inland freight
+25% short sea shipping

2050

2050 Targets

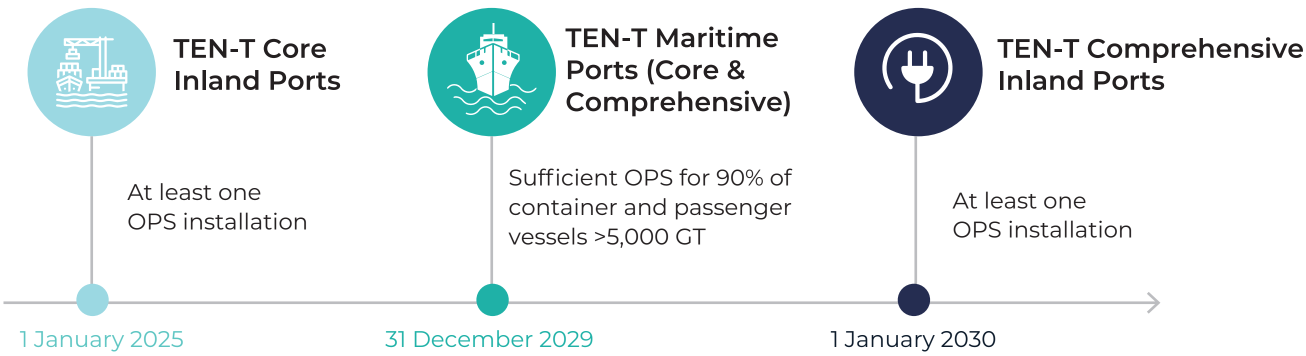
+50% inland freight
+50% short sea shipping
Zero-emission vessels

2.3

AFIR: Mandatory Shore Power Deadlines

The Alternative Fuels Infrastructure Regulation (AFIR) sets legally binding deadlines for shore-side electricity (OPS) installation at European ports.

AFIR MANDATORY DEADLINES FOR SHORE POWER (OPS)



Additional requirements:

- **Member states must provide adequate grid capacity**
- **FuelEU Maritime regulation: From 1 January 2030, ships must use installed OPS systems**
- **Alternative zero-emission technologies must achieve equivalent emissions reductions**

2.4 Key Research Findings: EEA, ReNEW & DINA

European Environment Agency (EEA) research:

- Hybrid systems can provide 35-70% of propulsion energy from batteries
- Inland waterways are one of the most carbon-efficient freight modes
- Waterway transport remains crucial for EU decarbonization

ReNEW Project (Resilient and sustainable digital twin for smarter, greener IWT):

- Electric autonomous vessels (e.g., RoRo ships) could lower OPEX by 45%
- Payback periods as short as 3.5 years
- Emission reductions exceeding 60%

DINA Initiative (Digital Inland Navigation Area):

- Supports transition through digital infrastructure improvement
- Enhances interoperability across the sector
- Enables smarter, more efficient operations

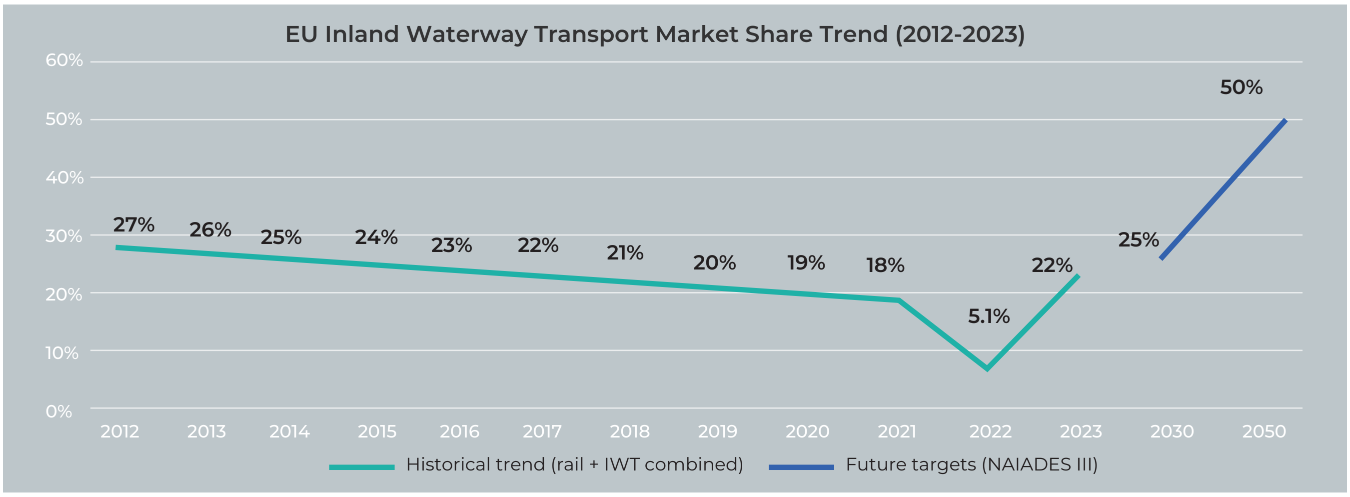
2.5 Challenges and Opportunities

Challenges:

- IWT share of EU inland freight declined to 5.1% in 2022
- Significant infrastructure investment required
- High upfront vessel conversion costs
- Climate-related water level fluctuations affecting reliability

Opportunities:

- Massive growth potential from current 5-6% market share
- EU funding programs covering 30-40% of conversion costs
- Integration into multimodal transport chains
- Green last-mile logistics in urban areas



Sources: European Environment Agency (EEA), NAIADES III Action Plan, Eurostat

3.1 Conventional Diesel-Electric System

Components:
- PM Propulsion Motor
- DC-HUB
- Diesel Generator
- Transformer
- MSB

Operation:

Diesel generator provides all power through PCS control to propulsion motor.

Best for:

Ocean-going vessels, unlimited range requirements

3.2 Shaft Generator Diesel-Electric System

Components:
- PM Propulsion Motor
- Main Engine
- DC-HUB
- Battery
- Diesel Generator
- Transformer
- MSB

Operation:

Optimizes fuel consumption, supports PTO/PTI/PTH operating modes. Significant fuel savings, especially in acceleration and high-power scenarios.

Best for:

Vessels with variable operating profiles

3.3 Hybrid Propulsion System

Components:

- PM Propulsion Motor
- DC-HUB
- Battery
- Diesel Generator
- Transformer
- MSB

Operation:

Diesel generator provides all power through PCS control to propulsion motor.

Best for:

Ocean-going vessels, unlimited range requirements

3.4 All-Electric Propulsion System

Components:

- PM Propulsion Motor
- DC-HUB
- Battery
- Transformer
- MSB

Operation:

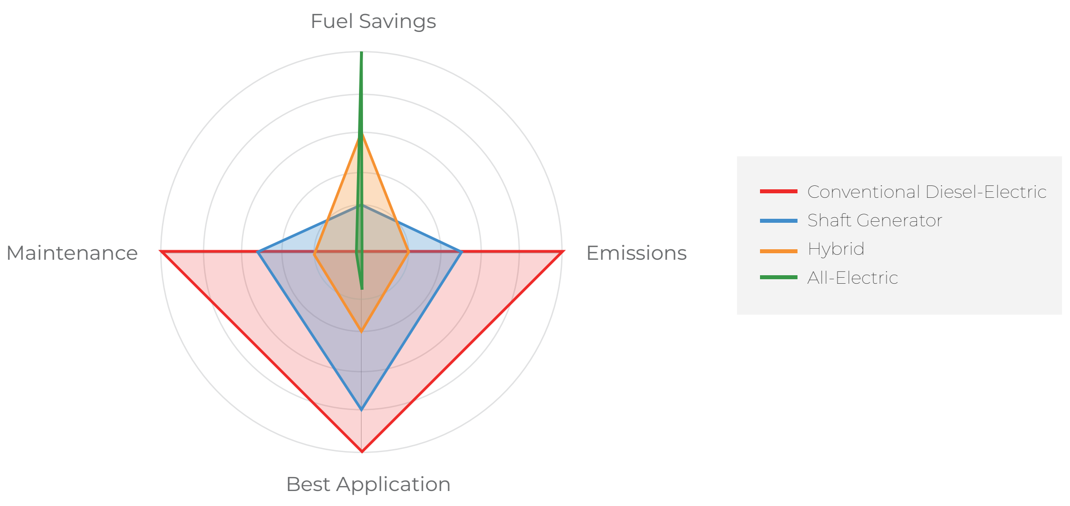
Pure battery power for propulsion. Zero emissions, zero noise, minimal maintenance. The "king of environmental protection." Main limitation: range.

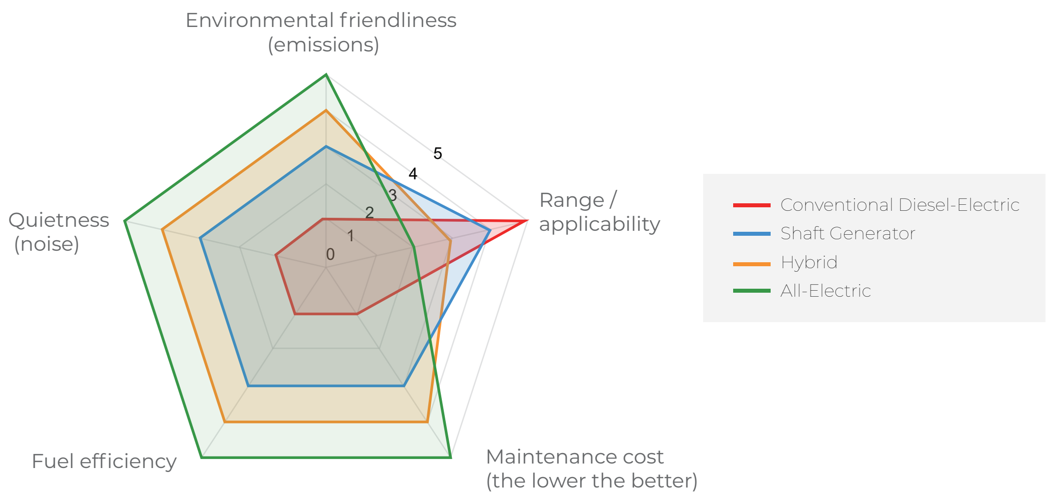
Best for:

Ferries with fixed routes, sightseeing boats, short-distance operations

3.5 Technology Comparison Summary

System	Emissions	Noise	Fuel Savings	Maintenance	Best Application
Conventional Diesel-Electric	4High	High	Baseline	High	Ocean-going
Shaft Generator	Medium	Medium	10-20%	Medium	Variable profiles
Hybrid	Low	Low	30-50%	Low	Ferries, tugs
All-Electric	Zero	Zero	100%	Minimal	Fixed routes, short distance





4.1 Operational Cost Comparison: Diesel *vs.* Electric

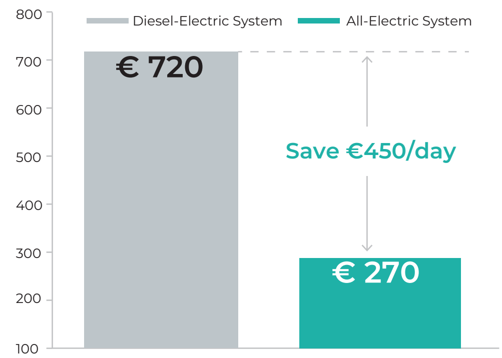
Parameter	Diesel-Electric	All-Electric
Vessel power (propulsion + hotel load)	450 kW	450 kW
Daily operating hours	4 hours	4 hours
Daily energy consumption	360 liters diesel	1,800 kWh electricity
Fuel/electricity price	€2.00/L	€0.15/kWh
Daily energy cost	€720	€270
Daily savings	—	€450
Annual savings (300 days)	—	€135,000

Based on a representative tourist vessel case study

Note: Estimates are for reference only and subject to local market conditions.

- **Diesel-electric efficiency: 1** kWh = **0.24L** diesel → **1,800** kWh = **432L** diesel equivalent → adjusted to **360L** considering real operating efficiency
- **Diesel price: ~€2.00/L** (current Europe market)
- **Electricity price: ~€0.15**/kWh (average industrial rate in Europe)
- Based on a **450**kW tourist vessel, **4** hours daily operation, **300** days/year

Note: Estimates are for reference only and subject to local market conditions.



*Based on 450kW tourist vessel, 4h daily operation, 300 days/year.
Diesel: 360L/day @ €2.00/L, Electricity: 1,800kWh/day @ €0.15/kWh.*

4.2 Initial Investment Comparison

System Component	Diesel-Electric	Diesel-Electric	Difference
Generator (450 kW)	€29,500	—	-€29,500
Battery system (1,800 kWh @ €290/kWh)	—	€522,000	+€522,000
Initial investment difference	—	—	+€492,500

Note: Estimates are for reference only and subject to local market conditions.

4.3 Maintenance Cost Comparison

Maintenance Item	Diesel-Electric (Annual)	All-Electric (Annual)
Engine overhaul	€20,000	€0
Lubricants and filters	€15,500	€0
Cooling system	€8,000	€0
Exhaust system	€5,000	€0
Battery maintenance	—	€0
Total annual maintenance	€48,500	€0

Note: Estimates are for reference only and subject to local market conditions.

4.4 Total Cost of Ownership and Payback Period

Annual operating savings (fuel + maintenance):

Fuel savings: €89,700

Maintenance savings: €48,500

Total annual savings: €138,200

Payback period calculation:

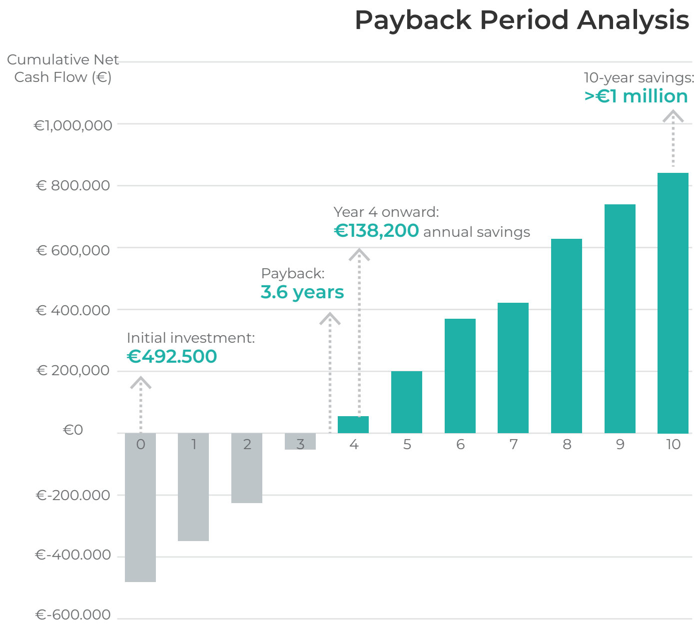
Payback period = Initial investment difference ÷ Annual savings

€492,500 ÷ €138,200= 3.6 years

Long-term value:

Year 4 onward: €138,200 annual net savings

10-year cumulative savings: Over €1 million

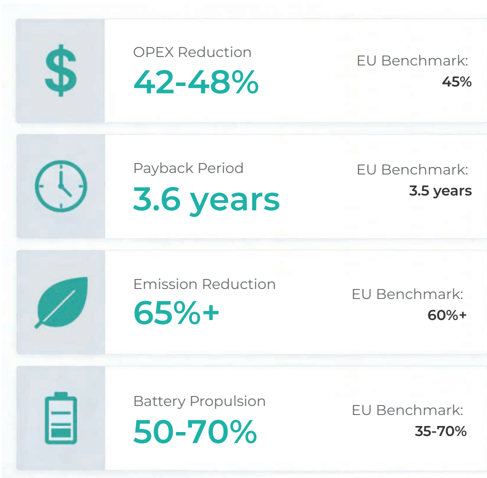


4.5 EU Research Validation

These calculations align with findings from EU-funded research:

Metric	ReNEW/DINA Research	ROYPOW Case
OPEX reduction	45%	42-48%
Payback period	3.5 years	3.6 years
Emission reduction	60%+	65%+
Battery propulsion share	35-70%	50-70%

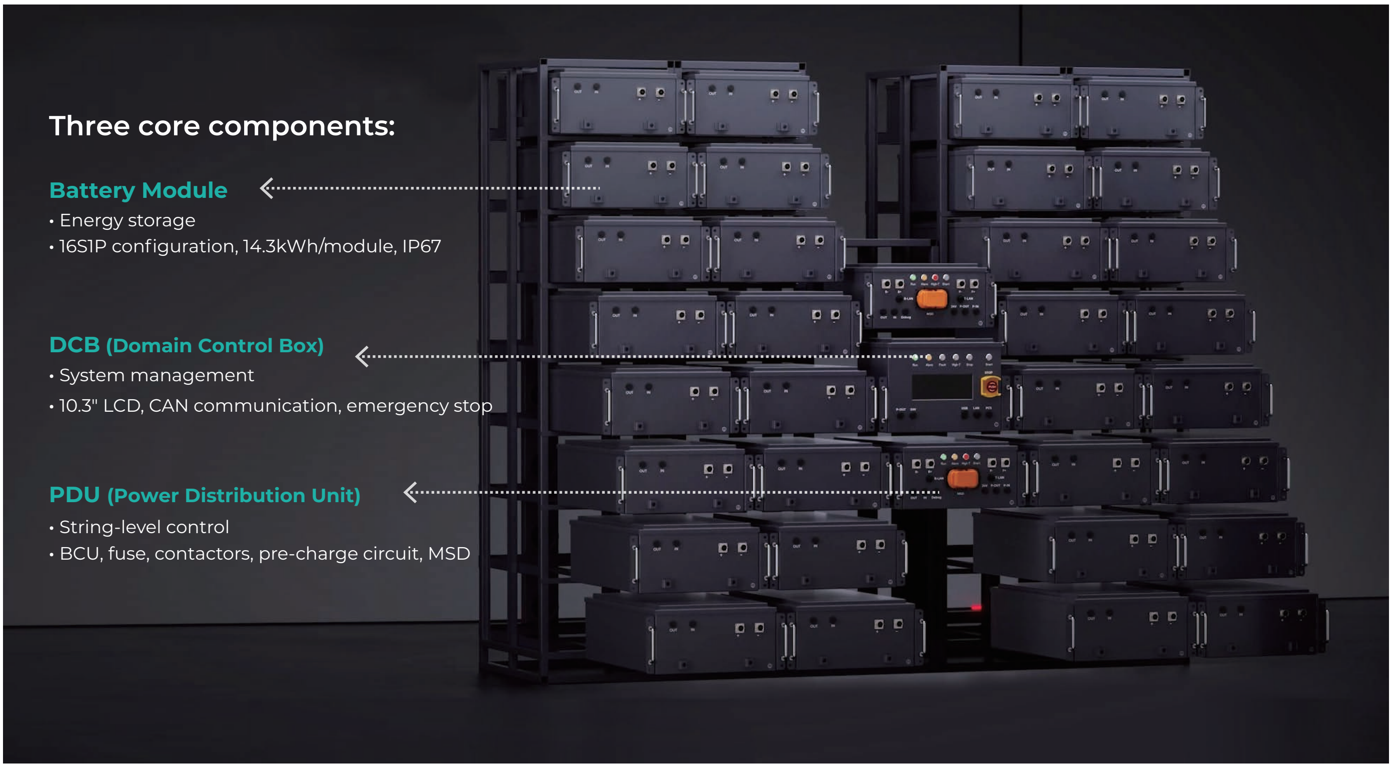
Key insight: Electrification is not just environmentally responsible—it's economically compelling. With EU subsidies covering 30-40% of conversion costs, payback periods can be even shorter.



05. ROYPOW High-Voltage Marine Battery System

5.1 System Architecture

The ROYPOW marine battery system features a modular, scalable design ideal for both hybrid and all-electric vessels.



5.2 Battery Module Specifications

Component	Parameter
Cell chemistry	$LiFePO_4$ (LFP)
Configuration	16S1P
Nominal capacity	280Ah/320 Ah
Nominal energy	28.6-2437.1 kWh 32.7-2785.2 kWh
Nominal voltage	51.2V
Operating voltage range	102.4- 870.4 V
Continuous current (RMS)	0.35 C / 100 A, 5.1 kW 0.35 C / 110 A, 5.6 kW

Component	Parameter
Peak current (30s)	1C / 280A, 1C / 320 A
Weight	112kg / 117 kg
Dimensions	L800 × W465 × H247mm
Cooling	Natural Cooled
Ingress protection	IP67
Cycle life	6,000 cycles @ 80% SOH
Certifications	DNV, KR, NK, UN 38.3

5.3 System Scalability: Voltage and Capacity Matrix

The system can be configured from 2 to 17 modules in series (102V to 1000V) and up to 10 strings in parallel, achieving system capacities from 28.7kWh to over 2.8MWh.

System energy matrix (kWh):

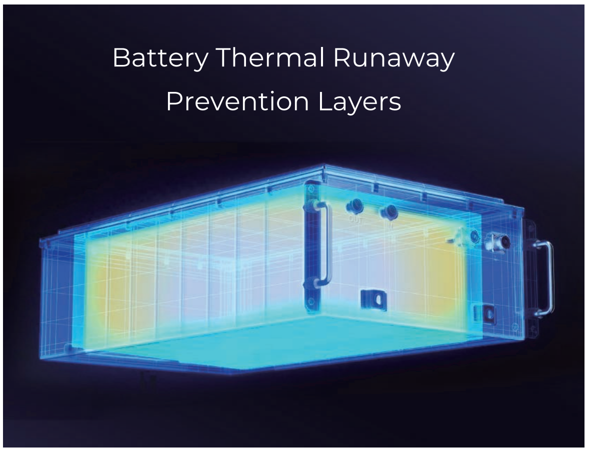
Strings	Minimum voltage	Maximum voltage	Rated voltage	1P	2P	3P	4P	5P	6P	7P	8P	9P	10P
1S	40	58.4	51.2	16.4	32.8	49.2	65.5	81.9	98.3	114.7	131.1	147.5	163.8
2S	80	116.8	102.4	32.8	65.5	98.3	131.1	163.8	196.6	229.4	262.1	294.9	327.7
3S	120	175.2	153.6	49.2	98.3	147.5	196.6	245.8	294.9	344.1	393.2	442.4	491.5
4S	160	233.6	204.8	65.5	131.1	196.6	262.1	327.7	393.2	458.8	524.3	589.8	655.4
5S	200	292	256	81.9	163.8	245.8	327.7	409.6	491.5	573.4	655.4	737.3	819.2
6S	240	350.4	307.2	98.3	196.6	294.9	393.2	491.5	589.8	688.1	786.4	884.7	983.0
7S	280	408.8	358.4	114.7	229.4	344.1	458.8	573.4	688.1	802.8	917.5	1032.2	1146.9
8S	320	467.2	409.6	131.1	262.1	393.2	524.3	655.4	786.4	917.5	1048.6	1179.6	1310.7
9S	360	525.6	460.8	147.5	294.9	442.4	589.8	737.3	884.7	1032.2	1179.6	1327.1	1474.6
10S	400	584	512	163.8	327.7	491.5	655.4	819.2	983.0	1146.9	1310.7	1474.6	1638.4
11S	440	642.4	563.2	180.2	360.4	540.7	720.9	901.1	1081.3	1261.6	1441.8	1622.0	1802.2
12S	480	700.8	614.4	196.6	393.2	589.8	786.4	983.0	1179.6	1376.3	1572.9	1769.5	1966.1
13S	520	759.2	665.6	213.0	426.0	639.0	852.0	1065.0	1278.0	1490.9	1703.9	1916.9	2129.9
14S	560	817.6	716.8	229.4	458.8	688.1	917.5	1146.9	1376.3	1605.6	1835.0	2064.4	2293.8
15S	600	876	768	245.8	491.5	737.3	983.0	1228.8	1474.6	1720.3	1966.1	2211.8	2457.6
16S	640	934.4	819.2	262.1	524.3	786.4	1048.6	1310.7	1572.9	1835.0	2097.2	2359.3	2621.4
17S	680	992.8	870.4	278.5	557.1	835.6	1114.1	1392.6	1671.2	1949.7	2228.2	2506.8	2785.3

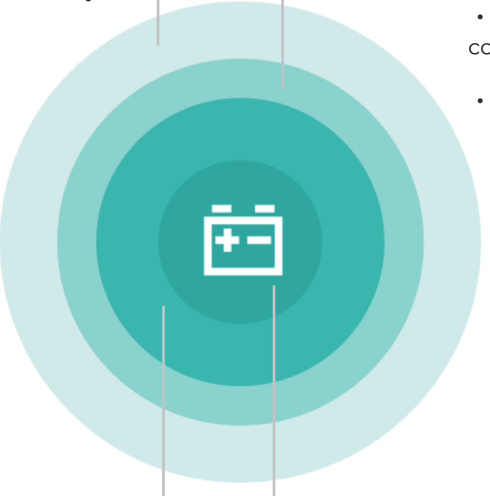
Maximum system capacity: **10 strings × 17S × 163.8kWh = 2,785.3kWh (≈2.8MWh)**

Note: Additional capacity can be achieved with higher series configuration or custom engineering. Contact ROYPOW for project-specific requirements.

5.4 Safety Design: Multi-Level Protection

ROYPOW batteries incorporate four layers of safety protection, meeting the highest DNV standards.





Level 1: Cell Chemistry Safety

- $LiFePO_4$ chemistry—safer than any other lithium type
- Superior thermal and chemical stability

Level 2: Passive Cell-Level Thermal Runaway Isolation

- Individual cell failure does not propagate to neighbors
- Tested at 45°C ambient temperature for 3 consecutive test cycles
- Fireproof materials between modules

Level 3: Active Protection Systems

- Advanced BMS with three-level architecture
- Independent hardware overcharge protection (independent of BMS)
- Integrated fire extinguishing system in each battery
- HVIL (High-Voltage Interlock Loop) on all power connectors

Level 4: Structural Safety

- IP67 ingress protection (waterproof, corrosion-resistant)
- Integrated exhaust duct for flammable gas extraction
- Explosion-proof valves on each module
- Emergency stop (local and remote)

5.5 DNV Certification: The Gold Standard

DNV is one of the world's leading maritime classification societies, serving over 14,000 vessels and offshore structures with 21% global market share.

TYPE APPROVED PRODUCT
DNV
DNV.COM/AF

Why DNV certification matters:

1. Large vessels require "classification" to operate—like a license plate for ships
2. DNV certification is the most demanding, with the highest entry barrier
3. Passing DNV opens the door to other class societies (ABS, BV, LR, etc.)

ROYPOW's DNV advantage:

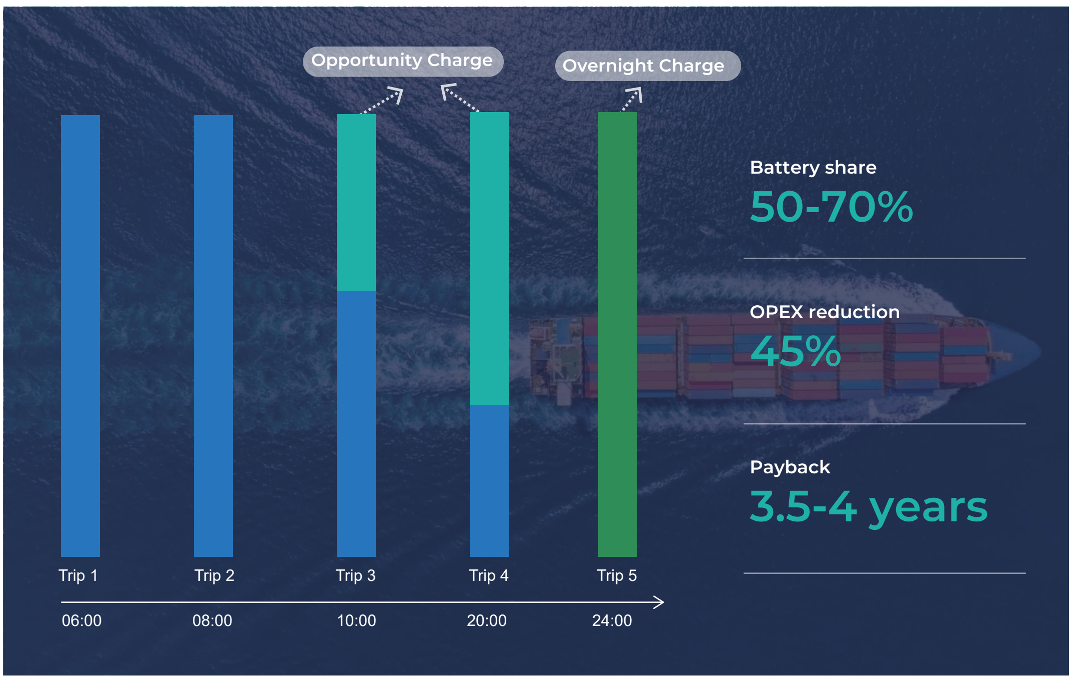
1. Successfully passed cell-to-cell thermal propagation test at 45°C ambient, 3 consecutive
2. IP67 rating exceeds industry mainstream (Others IP44/IP65)
3. 6,000-cycle lifespan at 80% SOH

6.1 Target Vessel Types

	Vessel Type	Typical Capacity	Characteristics	Recommended Solution
	**Ferry**	1.0-1.5 MWh	Short distance, high frequency, fixed routes	All-electric + fast charging (3C in development)
	**Sightseeing Boat**	200-600 kWh	Daytime operation, overnight charging	All-electric, zero noise
	**Harbor Tug**	600 kWh - 1.5 MWh	High-power pulses, frequent start/stop	Hybrid, 1C peak capability
	**Inland Cargo Vessel**	0.5-3.5 MWh	Medium-long distance, hybrid operation	Hybrid, 35-70% battery propulsion
	**Luxury Yacht**	200 kWh - 1 MWh	Silent operation, zero emissions	Custom all-electric or hybrid

Ferry Application: **Short Distance, High Frequency**

EEA Research: 50-70% of propulsion energy from batteries



Typical Ferry Profile:

- **8-12** trips per day
- **15-45** minutes per crossing
- Fixed route with return to port
- Opportunity charging during turnaround

ROYPOW Solution:

- **1.0-1.5** MWh battery system
- **0.35C** continuous, 1C peak
- **3C** fast charging option (in development)
- **DNV** certified

Economic Benefit:

- **50-70%** energy from batteries (EEA research)
- **45%** OPEX reduction potential
- **3.5-4** year payback

6.2

Sightseeing Boat: **Zero Emissions, Zero Noise**

Typical profile:

- 6-10 hours daily operation
- Nighttime charging
- Environmentally sensitive areas (cities, nature reserves)
- Passenger experience critical

ROYPOW solution:

- 200-600 kWh all-electric system
- IP67 protection against water ingress and external moisture
- Silent operation
- Zero emissions

Economic benefit:

- Eliminates diesel smell and noise
- Reduced operating costs
- Enhanced passenger experience

= higher ticket value

6.3

Tugboat: **High Power, High Reliability**

Typical profile:

- High-power pulses for towing
- Frequent start-stop cycles
- Critical reliability requirements
- Port emissions regulations tightening

ROYPOW solution:

- 600 kWh - 1.5 MWh hybrid system
- 1C peak capability for 30 seconds
- Cell-level safety redundancy
- DNV-certified for maximum reliability

Economic benefit:

- 30-50% fuel savings
- Zero-emission maneuvering in port
- Reduced maintenance

6.4

Inland Cargo Vessel: **Optimizing Fuel Efficiency**

Typical profile:

- Medium-long distance routes
- Variable load conditions
- Integration with multimodal transport
- Pressure to reduce emissions

ROYPOW solution:

- 0.5-3.5 MWh hybrid system
- 35-70% battery propulsion share (per EEA research)
- Flexible configuration to match vessel profile
- Compatible with shore power (OPS)

Economic benefit:

- 30-50% fuel savings
- Reduced engine maintenance
- Compliance with tightening regulations

7.1

Customer Reference: **Northern Europe Ferry Retrofit**

Project Overview

Parameter		Parameter	
Customer	**Northern European ferry operator**	Project type	**Retrofit from diesel-electric to hybrid**
Vessel type	**Passenger/car ferry**	Battery system	**ROYPOW high-voltage marine system**
Application	**Coastal route with environmental restrictions**	Installation time	**3.5 months from order to delivery**

Customer Challenge

The operator faced two converging pressures:

Regulatory: Strict emission limits in inner sea areas, with zero-emission requirements for certain zones

Economic: Government subsidies covering 30-40% of conversion costs made electrification financially attractive Initial diesel-electric system could not meet new environmental standards without major modifications.

Why ROYPOW?

The customer selected ROYPOW based on three key factors:

Factor	ROYPOW Advantage
Trust	**Existing relationship through other business units**
Technical capability	**Full in-house R&D: BMS, PCS, system integration**
Delivery speed	**3.5-4 month delivery vs. industry average of 6+ months**

Critical Customer Concerns

Concern	ROYPOW Solution
Thermal runaway safety	**Cell-level isolation, 3 consecutive DNV tests at 45°C passed**
BMS control strategy	**Three-level architecture, independent hardware protection**
Cell balancing	**Advanced BMS algorithms for long-term reliability**
After-sales support	**Local technical support, remote monitoring via 4G**

Results (Validated by Industry Research)

While specific customer data remains confidential, the project outcomes align with EU research findings:

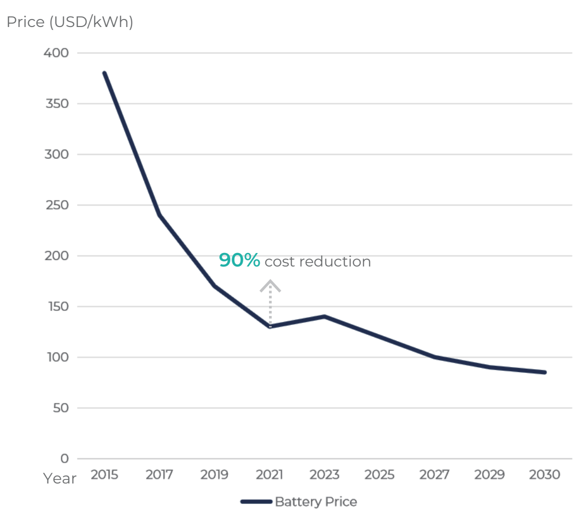
Metric	Industry Research	Project Alignment
Battery propulsion share	**35-70% (EEA)**	**Confirmed**
OPEX reduction	**45% (ReNEW)**	**Achieved**
Emission reduction	**60%+**	**Achieved**
Payback period	**3.5 years**	**On track**

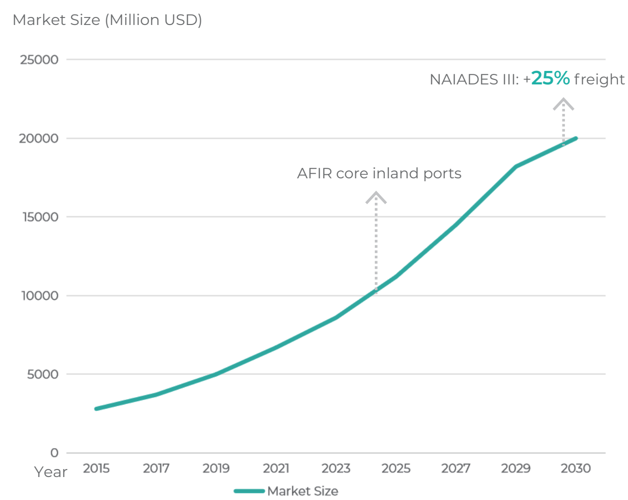
Customer feedback:

> **"The ROYPOW team demonstrated exceptional technical capability and responsiveness. Their DNV-certified solution gave us confidence in both safety and long-term reliability."**

8.1 Market Drivers

Driver	Impact
IMO targets	40% carbon intensity reduction by 2030 (vs 2008)
AFIR deadlines	2025/2030 shore power mandates
NAIADES III	25% freight growth by 2030, 50% by 2050
Battery costs	90% cost reduction over past decade
Charging infrastructure	Rapidly expanding at TEN-T ports





High C-rate, liquid-cooled system:
- Superior thermal management for high-power applications
- Enables 3C continuous charge/discharge
- Extends cycle life through uniform temperature distribution

AI-enabled BMS:
- Predictive maintenance based on operational data
- Optimized battery usage for extended life
- Real-time fleet management via cloud connectivit

Containerized battery swapping & energy storage system:
- Potential for "battery-as-a-service" model
- Reduces upfront investment for shipowners
- Enables flexible capacity management

Step 1

Assess Your Route

Question	What to Consider
Is your route fixed?	**Ferries and scheduled services are ideal for all-electric**
What is the trip duration?	**Under 4 hours is suitable for current battery range**
Are return-to-port opportunities available?	**Enables opportunity charging during turnaround**
Do ports have shore power?	**Check AFIR compliance timelines for your ports**

Step 2

Calculate Economic Return

Use this formula to estimate your payback:

Annual savings = (Fuel savings + Maintenance savings + Subsidies)

Payback period = Additional investment ÷ Annual savings

Note: The above calculation is provided for preliminary reference only. Actual results may vary based on operating profiles, regional fuel costs, available incentives, and project-specific conditions. A comprehensive evaluation is required to determine accurate economic returns.

Typical ranges based on EU research:

- Fuel savings: 30-70% depending on hybrid/electric ratio
- Maintenance savings: Up to 100% for all-electric
- OPEX reduction: 45% achievable
- Payback period: 3.5-5 years typical

Step 3

Select Your Technology Path

Vessel Type	Recommended Path	Certification Needed
Large vessel requiring class	**DNV-certified system**	**Mandatory for operation**
Small vessel (<15m, boat)	**Flexible solution**	**Not required for classification**
Retrofit project	**Drop-in replacement**	**Match existing vessel class**
New build	**Integrated design**	**Specify class upfront**

Step 4

Partner with Experienced Integrators

ROYPOW works with leading shipyards and system integrators including:

- **traditional marine integrators**
- **Local partners in key European markets**
- **Direct engineering support for complex projects**

Delivery advantage:

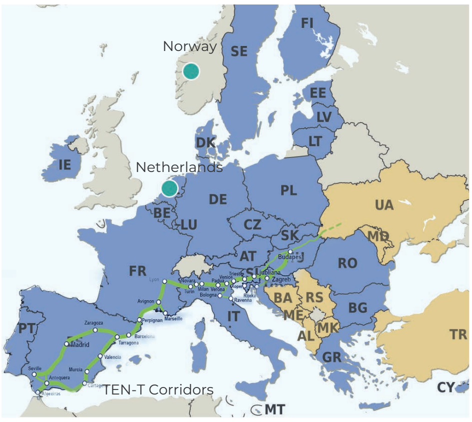
ROYPOW's 3.5-4 month delivery cycle significantly outperforms industry average of 6+ months.

Step 5

Apply for EU Funding

Many EU member states offer subsidies covering **30-40%** of vessel electrification costs:

Program	Region	
Various national programs	**EU member states**	30-40% **investment subsidy**
Horizon Europe	**EU-wide**	Up to 40% **subsidy (green shipping)**
Connecting Europe Facility (CEF)	**TEN-T corridors**	Up to 40% **subsidy (green shipping)**
Green shipping programs	**Norway, Netherlands, others**	**CEF funding for infrastructure & vessels**



10. About us

17+ worldwide subsidiaries and service centers ensuring local delivery and after-sales support.

750+	**200+**	**105,000 m²**	**2,500 m²**	**364**
Employees	R&D People	Headquarters Floor Area	Testing Center	Patents

About ROYPOW

Who We Are

ROYPOW is a global leader in lithium battery and energy storage solutions, with over 750 employees and 200+ R&D engineers. Founded in 2016 and designated as a National "Little Giant" Enterprise, we specialize in R&D, manufacturing, and sales of motive power systems and energy storage solutions.

Core business:

One-stop solutions for off-road vehicles, marine power systems, job site ESS, vehicle-mounted ESS, and electric retrofit solutions.

Manufacturing Excellence

- Fully automated production lines
- Advanced MES (Manufacturing Execution System)
- In-house R&D: BMS, PCS, EMS, motor and controller algorithms
- Automotive-grade quality certified to IATF 16949

Ready to electrify your fleet?

High-Volt Lithium Marine Battery System

Contact your local ROYPOW marine team:

Website: https://www.roypow.com/contact-us/

Email: sales@roypow.com

Visit us at major marine exhibitions worldwide