E-Ferry Ellen

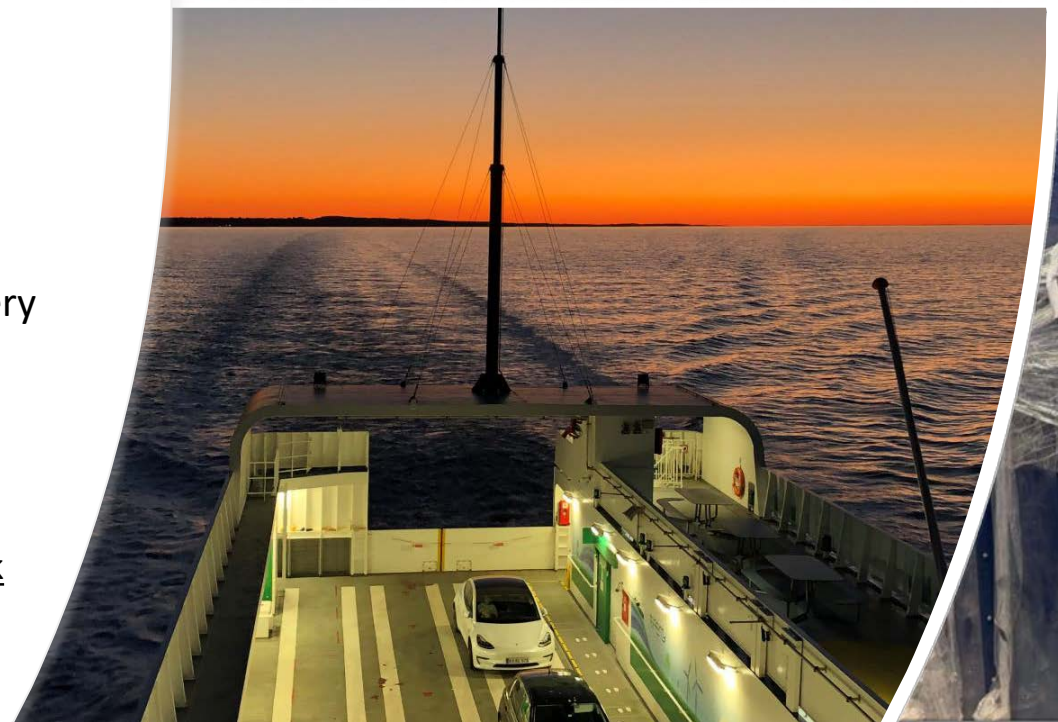
First mover experiences with the implementation, operation, and maintenance of a fully electric ferry

Blue Tech Event'26, May 6th hosted by SIMAC

For Aeroe-Ferries and the Battery Life Project

Senior Lecturer
Henrik Hagbarth Mikkelsen
Marstal Navigationsskole

Read more at: www.batterylife.dk



Photos: Henrik Hagbarth Mikkelsen and Ærø Energy Lab

Timeline of the E-ferry Horizon 2020 history

Aug. 2013
Green Ferry Vision start

Jun. 2014
EU Horizon 2020 Application

Jun. 2015
E-ferry Horizon 2020 design start

Jun. 2016
E-ferry Horizon 2020 building start

Okt. 2017
Hull delivery Søby Shipyard

Aug. 2019
Start of operation

Mar. 2023
Upgraded transformer house Søby

Jun. 2023
Battery fire successfully extinguished

Jun. 2024
Battery Life and repair project

Sep. 2024
Litarion cells removed

May. 2026
Installation new Echandia LTO battery system

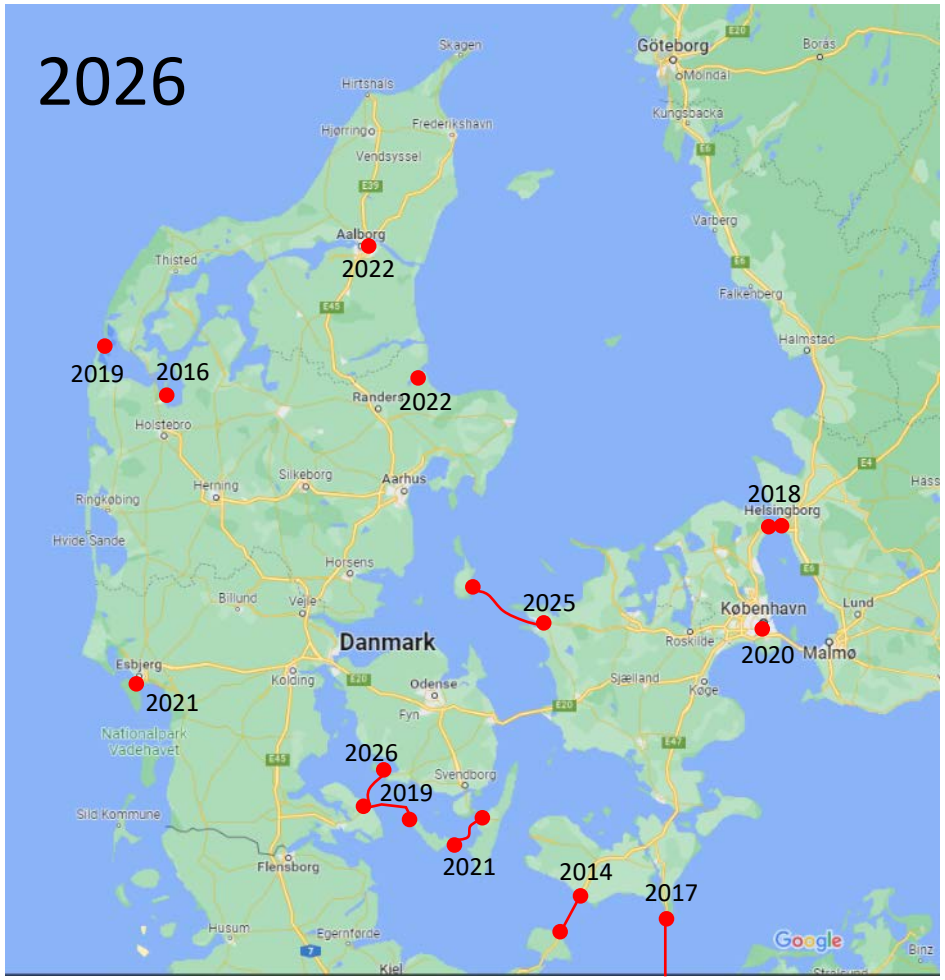

New building process in Søby

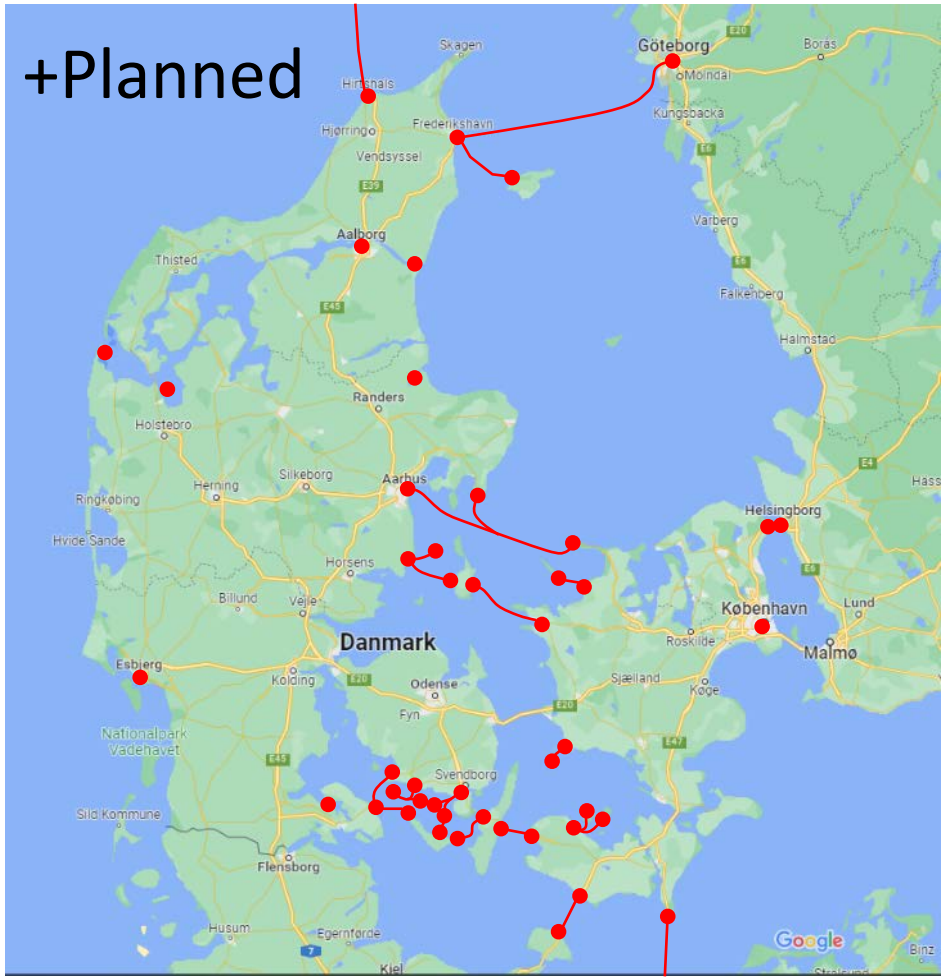

Ellen Ferry in operation with passengers


Battery testing in Søby


New Echandia battery system install

Battery ferry electrification status in 2026



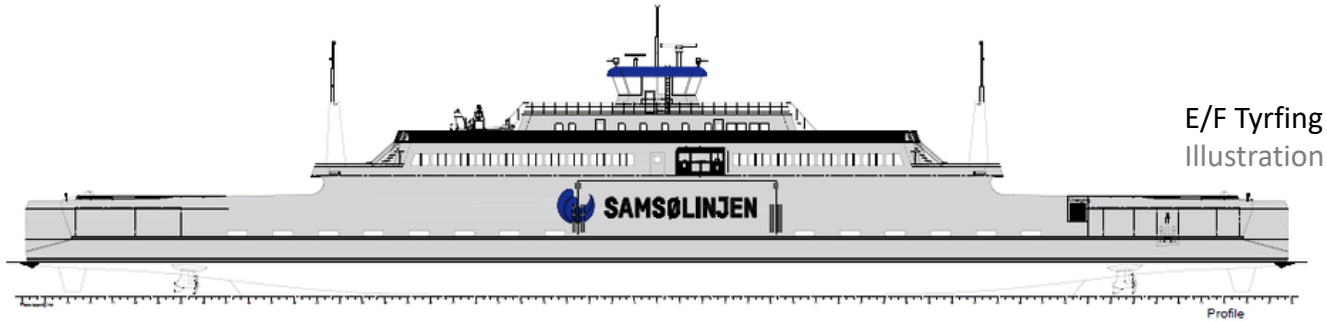


Full battery and plug-in hybrid battery ferries in Denmark

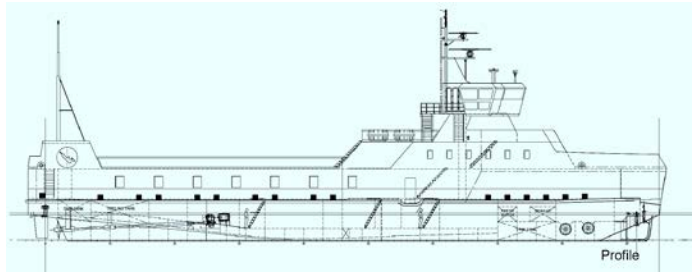
Illustration: Henrik Hagbarth Mikkelsen

Battery ferry sizes anno 2025

E/V The Baltic Whale 2025
Illustration: Scandlines ©



E/F Tyrfing 2025
Illustration: Molslinjen ©



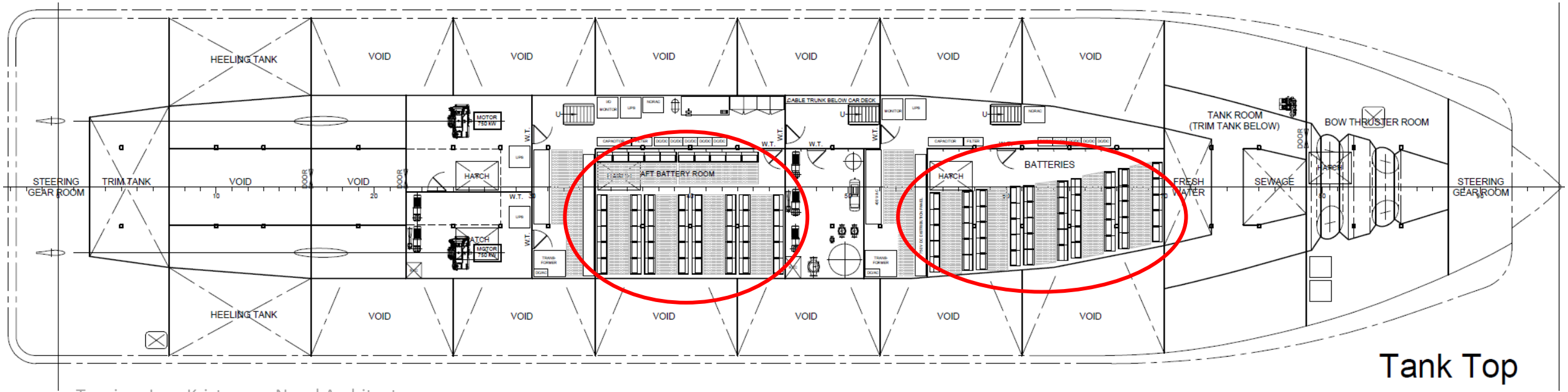
E/F Ellen 2019
Illustration: Jens Kristensen © for Ærøfærgerne

Battery capacity and type:

- 10 MWh, NMC, distance 10 NM
- 3,8 MWh, LTO, distance 36 NM
- 4,3 MWh, NMC, distance 22 NM

E-ferry prototype battery design of Ellen

- 32 cells in each battery modules and 42 modules in each battery string. Two battery rooms with 10 strings = 32 x 42 x 2 x 10 = 26.880 cells
- Weight of cells 27 ton and casing etc. 30 ton, battery system in total 57 ton
- Supplier: Leclanché, battery age 8 years



Tegning: Jens Kristensen Naval Architects

Charging plug and charging station E-ferry prototypes

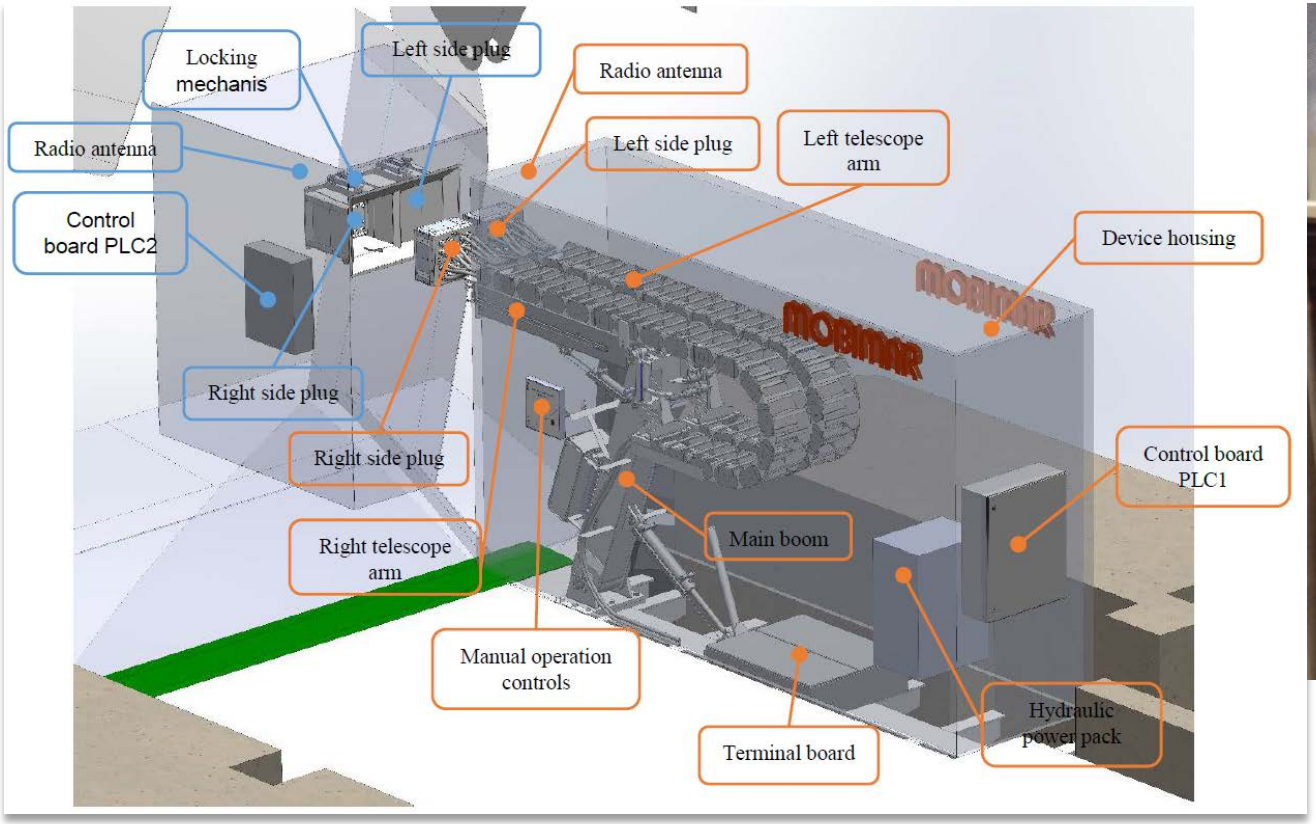


Illustration by 3Mar

MobiMar prototype charging plug has been working reliable for seven years with very limited requirements for maintenance.

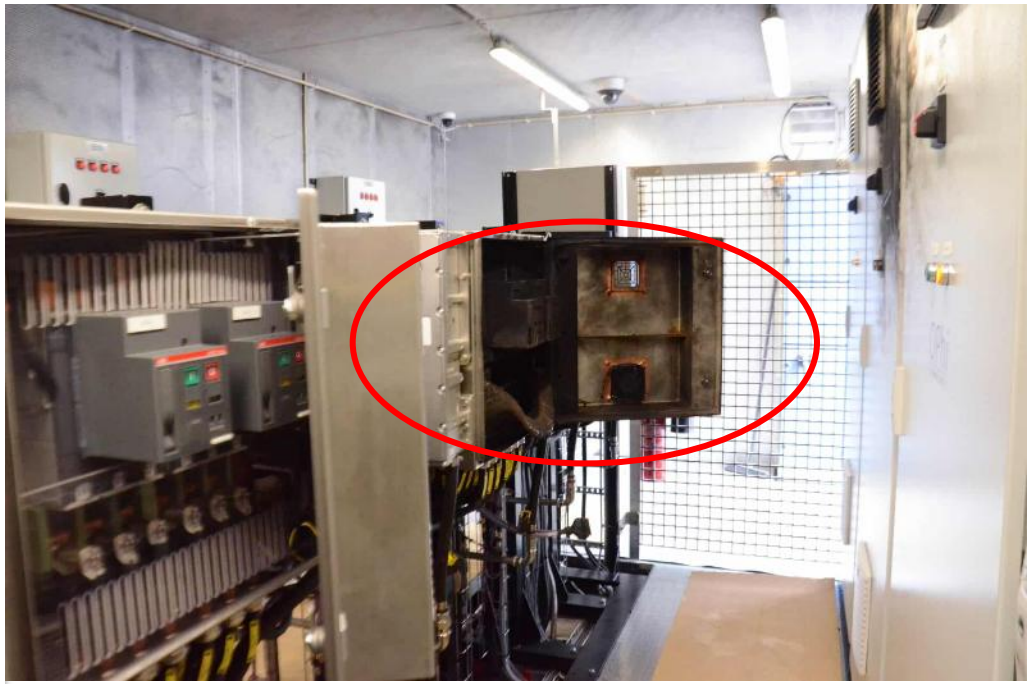
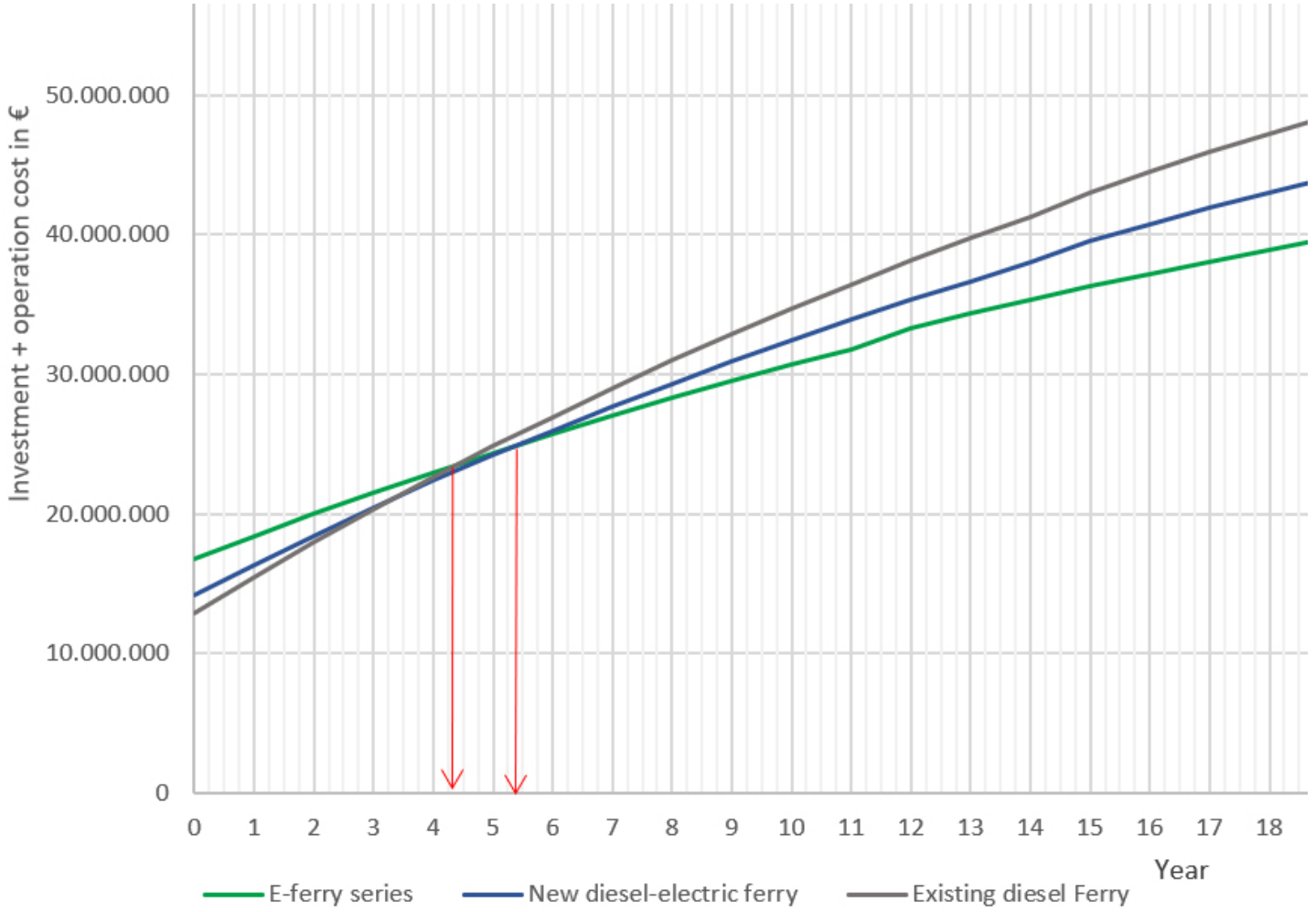


Photo: Ærø-Ferries

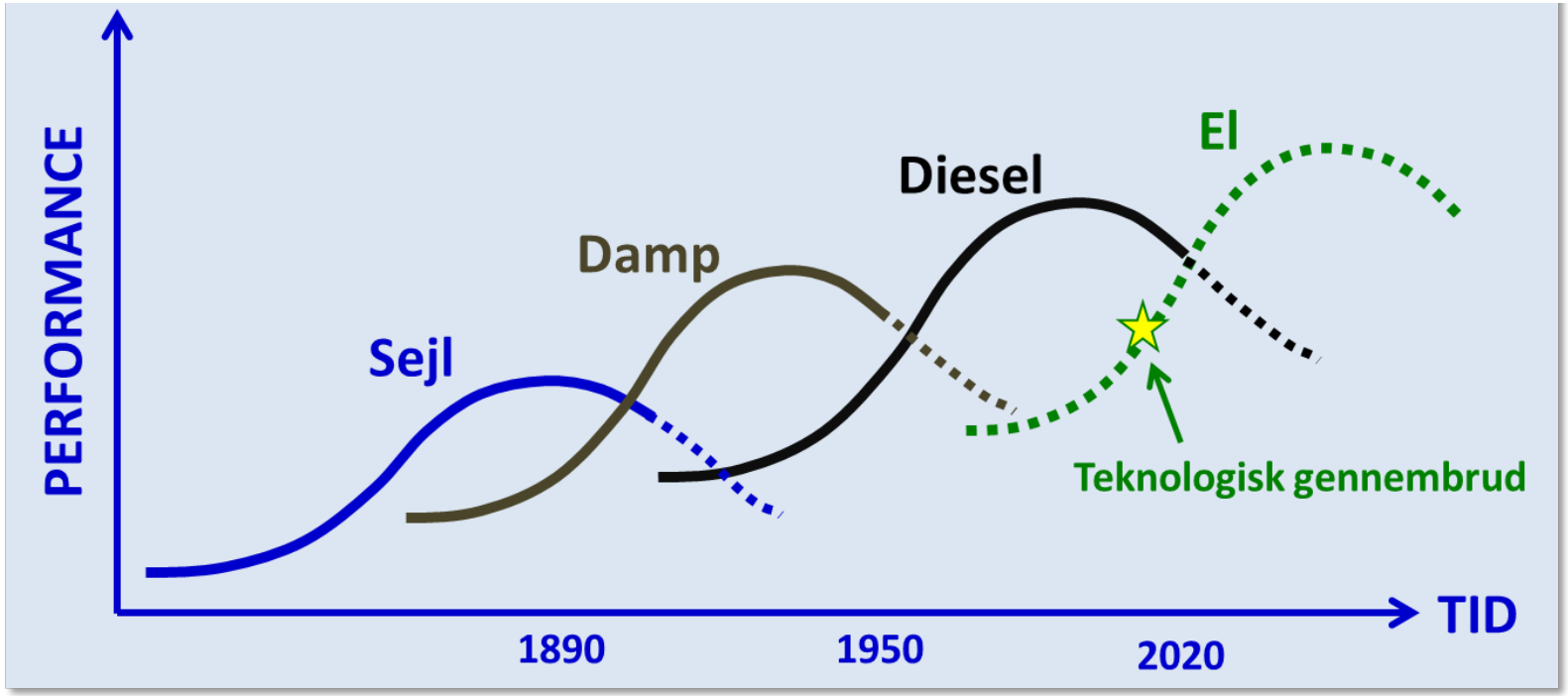
Danfoss prototype charging station was redesigned in 2023 after costly failures inside inverter house. Updated design has been working flawlessly ever since.

Result of comparative study shows break-even after only 5 years of operation



Discount rate 4% p.a.

Comparative advantages from full battery operation



CO2 savings 2.500 ton/year

No emissions in ports

Noise reductions

Simple drive train with low maintenance requirements

Ancillary services for grid from charging stations

Safety for the people on board must always be part of the mission statement for battery operation

Lifetime expectancy should be balanced against:

1. Risk of cells overheating, gassing or internal short circuit.
2. Degrading energy capacity in batteries = lower distance and lower roundtrip efficiency.
3. Cost of battery renewals.
4. Potential for second-life value chain for used battery modules.

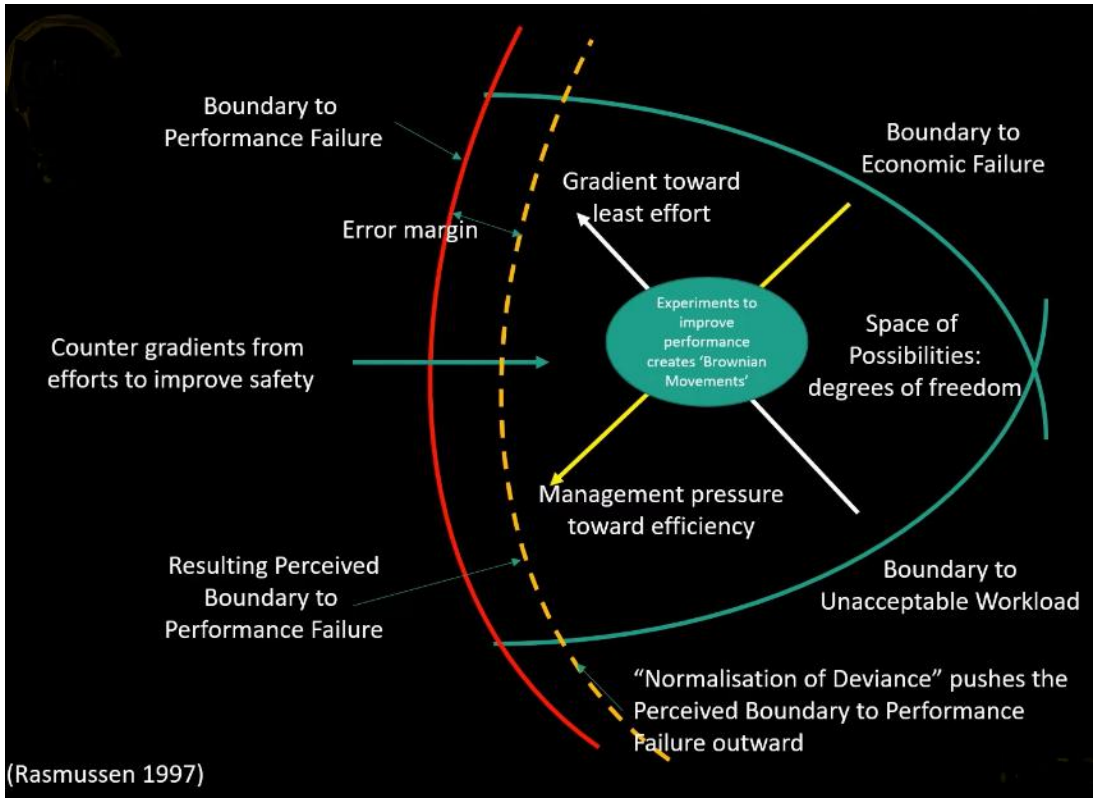
Royal visit to the Ellen battery ferry in June 2024.
Photo: Anne Jørgensen, Municipality of Ærø

Safety philosophy when batteries are near End of Life

Challenges:

1. Limited experience.
2. Often skepticism in beginning when battery are at their safest but the risk increases with aging when you have gained trust in the battery system.
3. Monitoring 26.800 cells requires advanced data analysis methods and high degree of automation.
4. Some degradation mechanisms are non-linear, and some does not lead to immediate decline in battery performance.

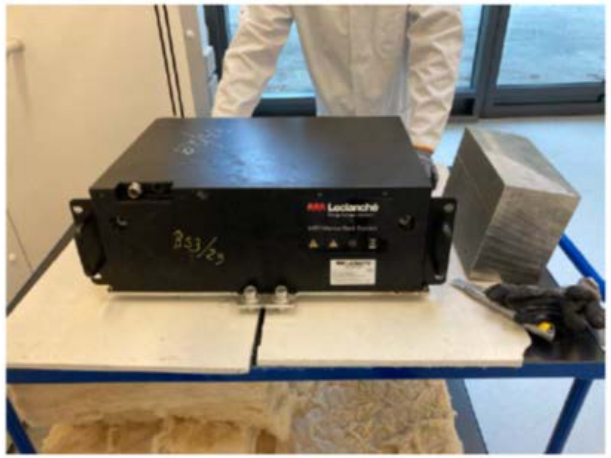
The drift-to-danger phenomenon identified by Danish safety researcher Jens Rasmussen, a migration model.



The risk is real, and consequences can be severe

Thermal event with two cells overheating in July 2023:

1. Thermal runaway 8-900°C stopped by automated foam firefighting system.
2. No people were injured, but firefighting foam harmed five battery strings of twenty.
3. Very long lead-time for delivery of new strings.



Why so many firetrucks?

- There were 3 foam injected battery strings. Thus, suspicion of several TR’s
- It turned out that foam also entered neighboring strings and sensors by accident (foam and ventilation system redesigned and upgraded since)

Photo: Henrik Hagbarth Mikkelsen

Crew observed smell, but no visible smoke on deck

Photo: Ærøfærgerne

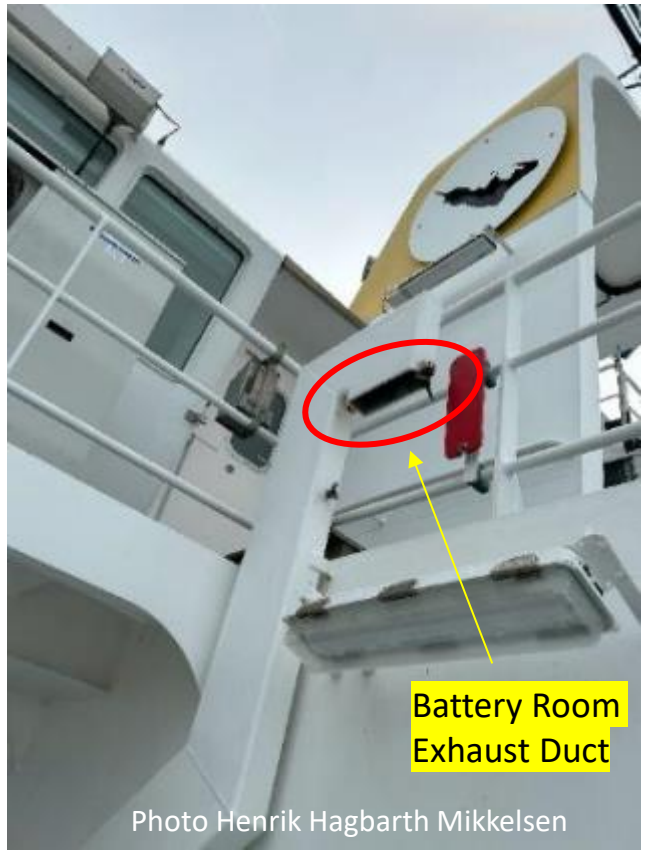
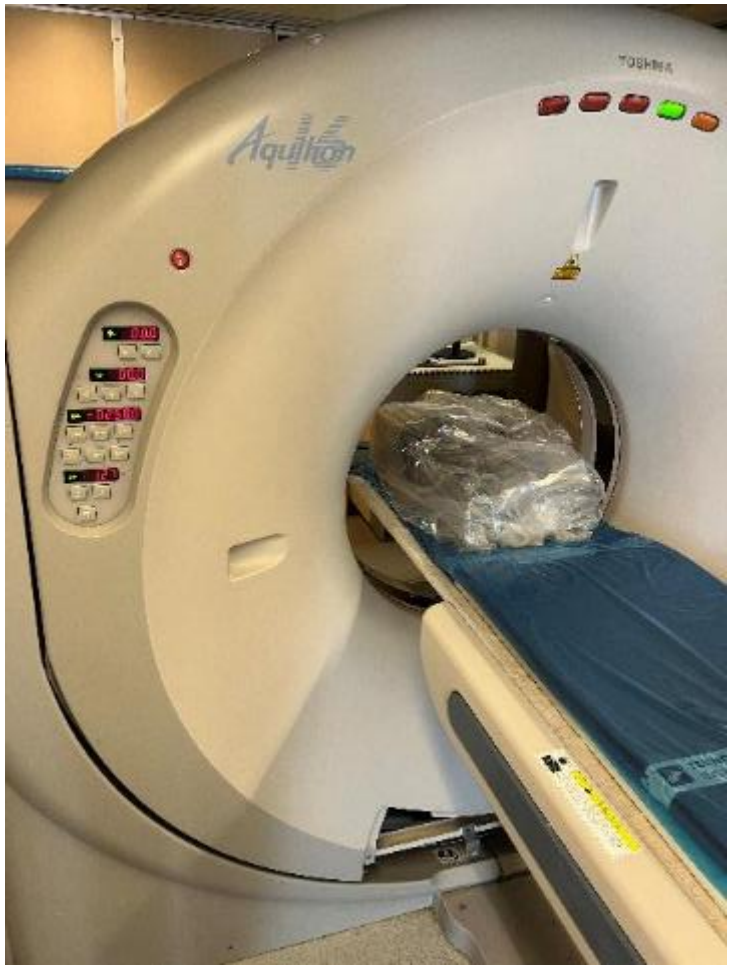
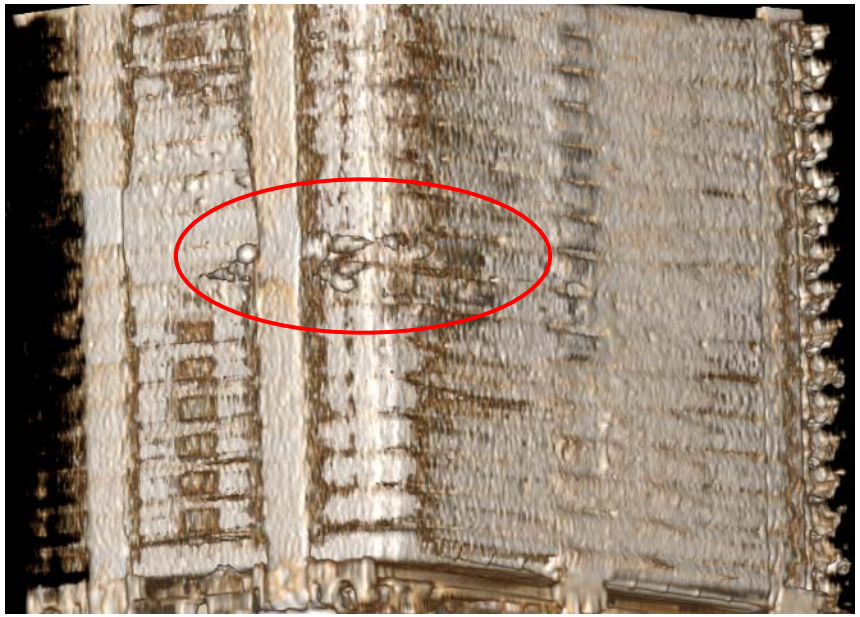


Photo Henrik Hagbarth Mikkelsen

The fire scenario have been trained on crew courses and with local emergency respons units in advance.

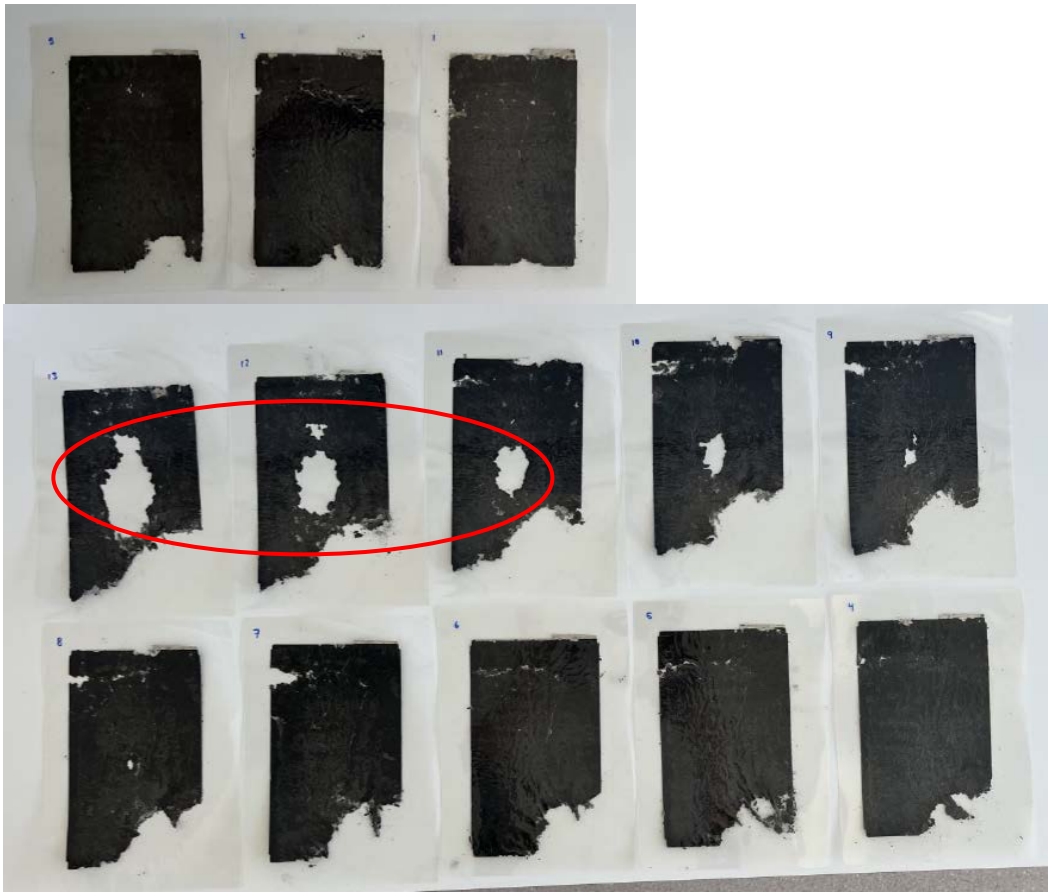
CT-scanning revealed exotherm process in one pouch cell and part of neighboring pouch





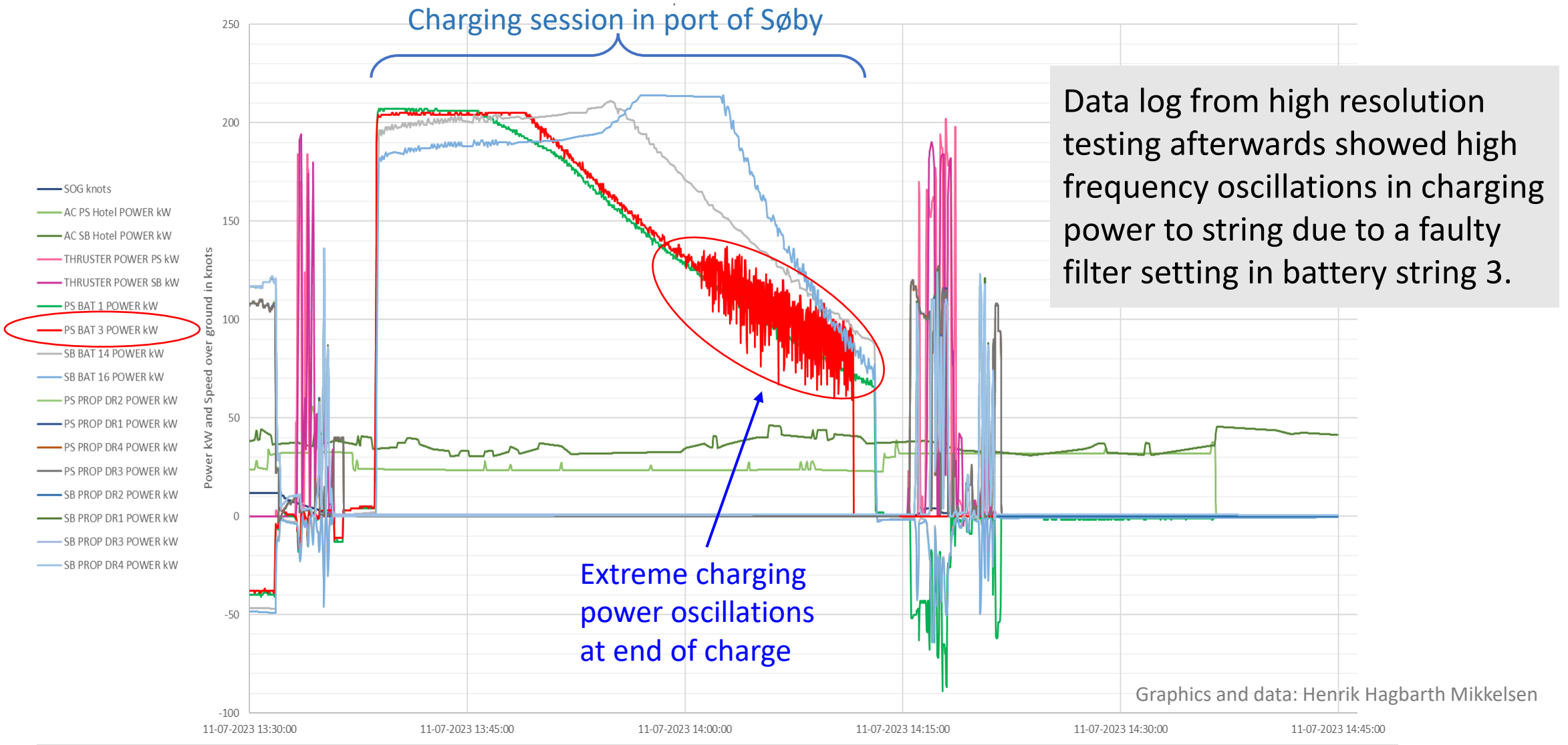
Melted drops of aluminium (Temp.>660°C) in lowest corner of the two pouch cells.
8 pouch cells of 32 in battery module were at normal voltage.

Invasive test of affected cell done for the forensic analysis



Invasive test on burned cell pouch indicated origin from thermal hot spot in geometric center of the cell

What happened? – Root Cause Analysis

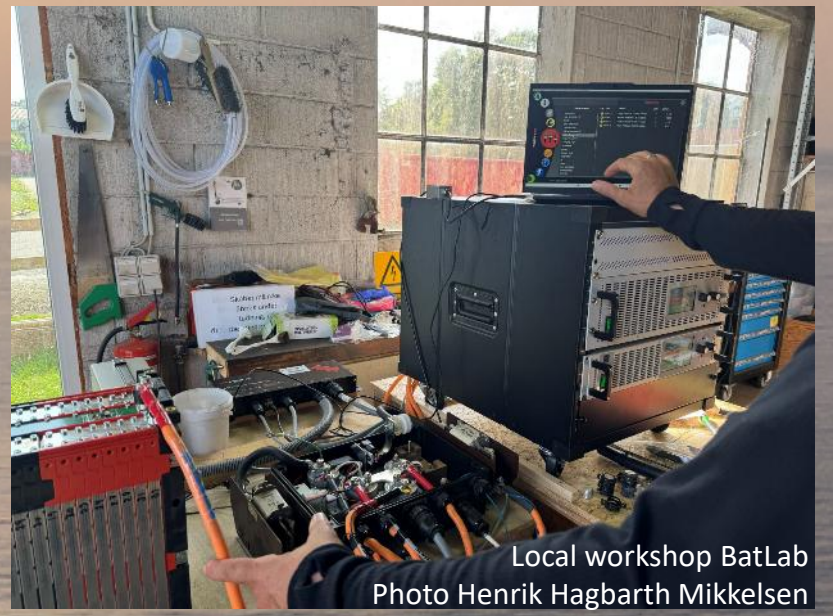


Data log from high resolution testing afterwards showed high frequency oscillations in charging power to string due to a faulty filter setting in battery string 3.

Graphics and data: Henrik Hagbarth Mikkelsen

Battery Life Project phase one

Crew from Ærøfærgerne monitoring trends and degradation with the assistance of SDU CIE, Danish Technological Institute, AAMS, Marstal Navigationsskole and battery supplier



Local workshop BatLab
Photo Henrik Hagbarth Mikkelsen

Aarhus Maskinmesterskole
School of Marine and Technical Engineering

ÆRØFÆRGERNE

Leclanché Energy Storage Solutions

MARSTAL NAVIGATIONSSKOLE

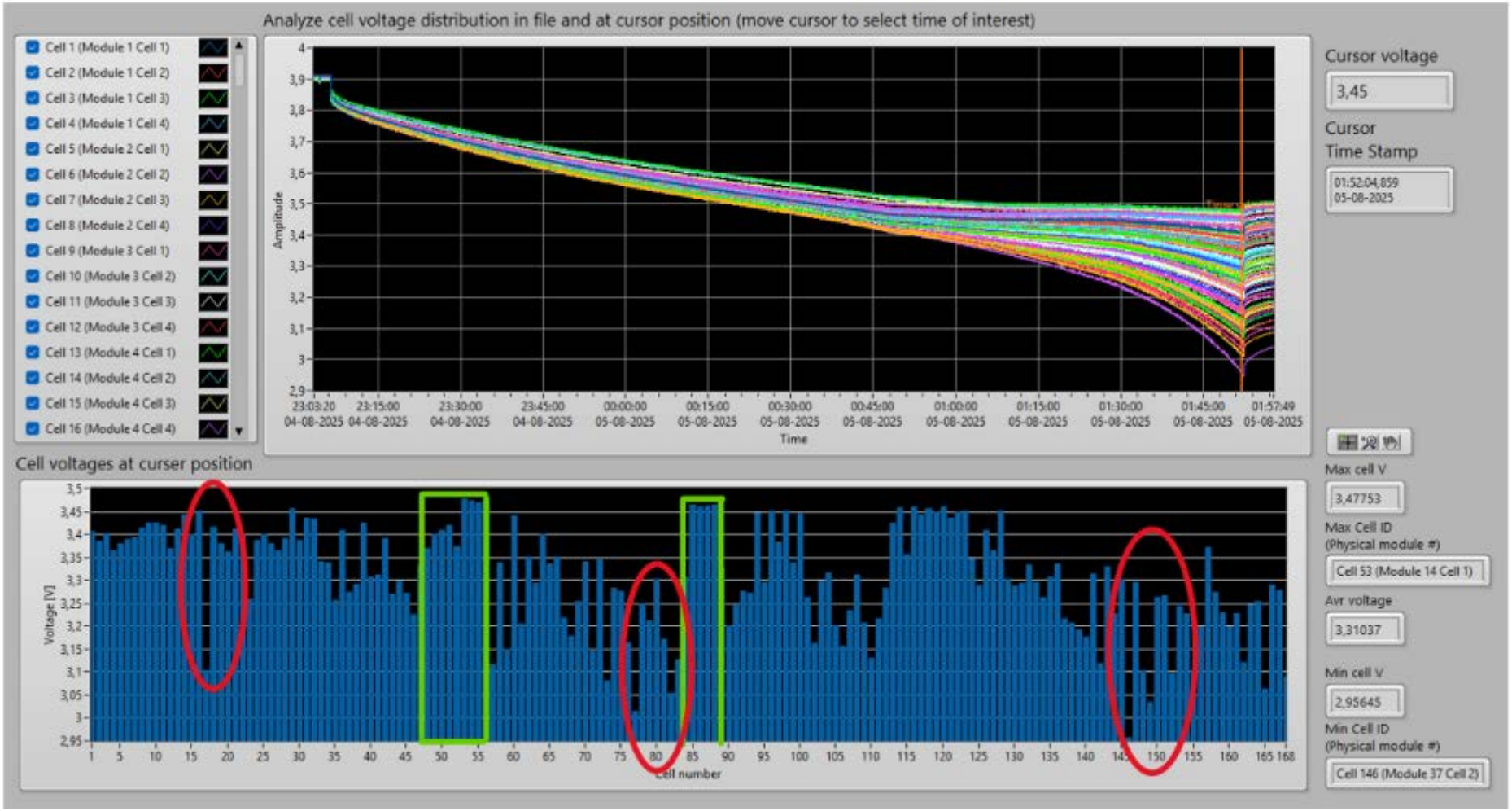
SDU SYDDANSK UNIVERSITET

TEKNOLOGISK INSTITUT

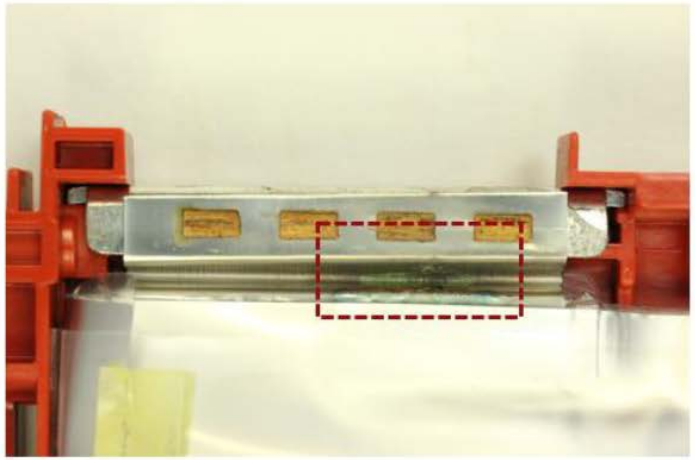
Photo: Danfoss, provider of the power train

New data tools for quality assurance from DTI

Semi-automated analysis of logs to help crew with search for rogue cells



SDU CIE identifies corrosion on Litarion cell anodes



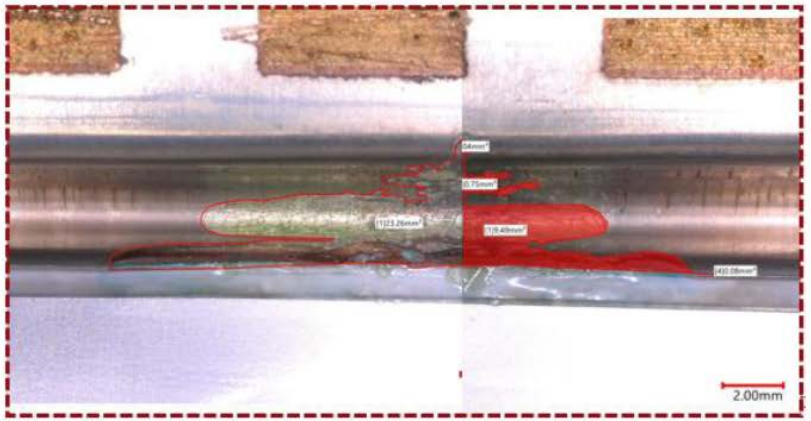


Photo: DBI laboratory

- During module disassembly for individual cell testing SDU CIE identified corrosion in the shape of green areas of nickel salts on some anodes.
- All four strings with German Litarion cells (not Leclanché) were removed from vessel immediately and sailing schedule reduced accordingly.
- Leclanché and DTI found root cause to be production failure, thus liable to owners H&M insurance.

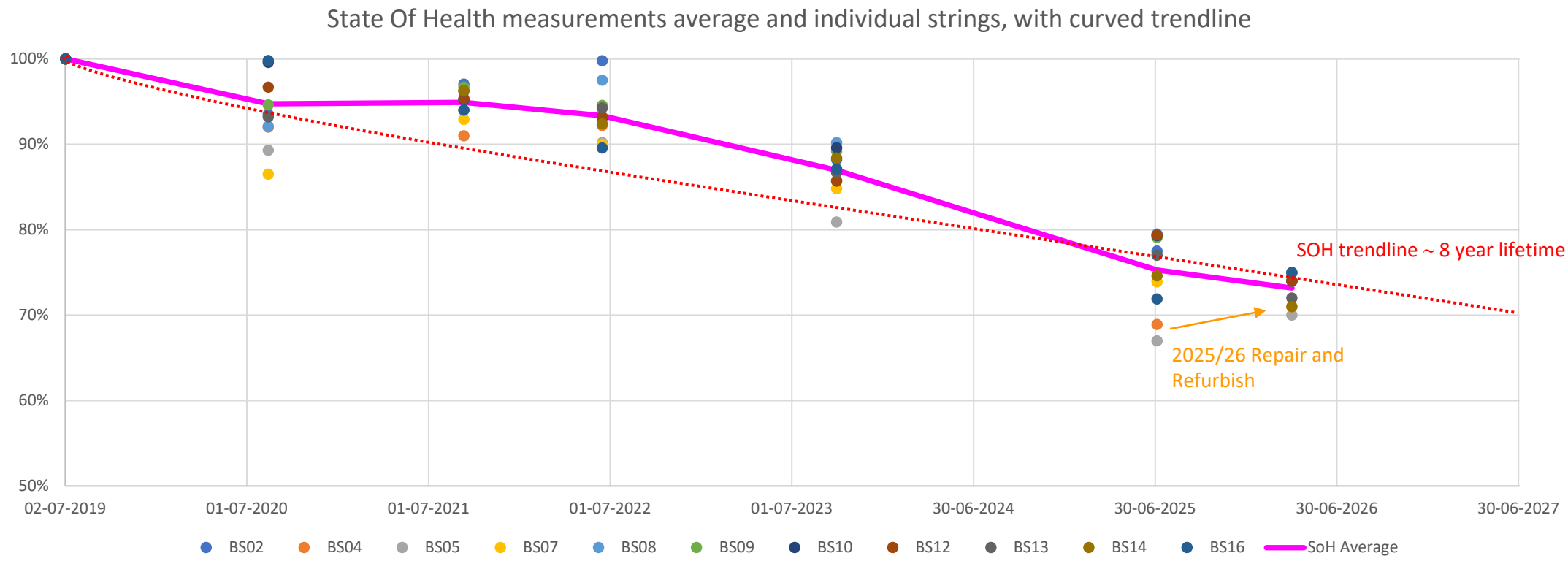
Battery Life project

Refurbishing and reuse of battery modules from Ellen

Photos: Henrik Hagbarth Mikkelsen

- Mobile battery cycling test set-up, excludes freight cost and transport risk
- Degradation analysis and tailormade tools enables crew to test 10 x faster

Accelerated degradation did accelerate the project!

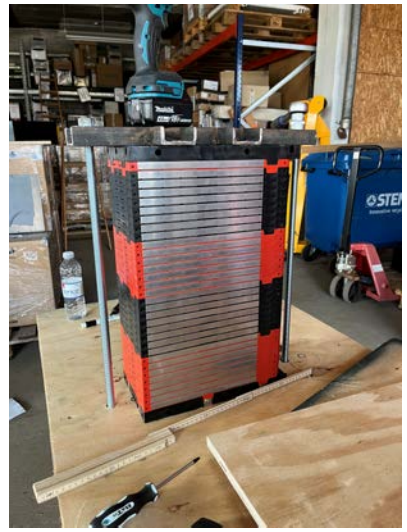


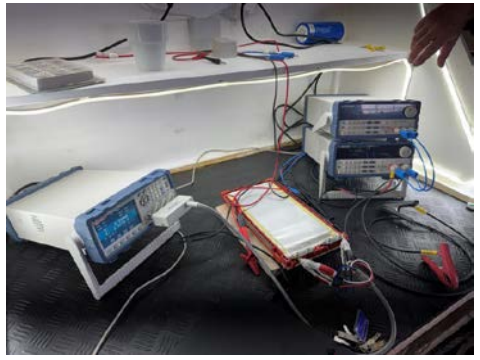
Observations and achievements:

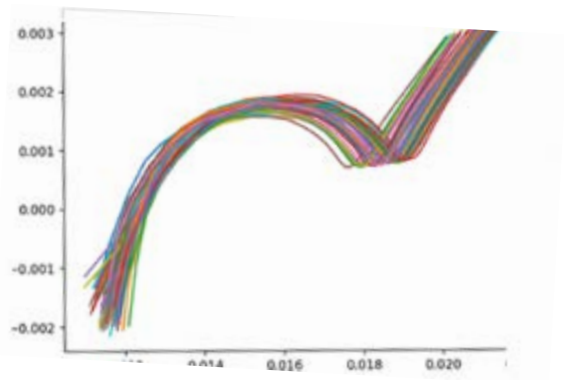
- Worst battery modules from strings dropping below 70 % SoH in tests were taken out for repair in summer 2025.
- Proof-of-concept; project partners succeeded upcycling and repairing modules to get string 4 and 5 back over 70%.
- Lifetime extension was done by marine engineers from Ellen in mobile BatLab locally on the island of Ærø!

Battery Life phase one

- Scaling up battery repair capacity to cope with demand.
- Scientific articles from EIS* and pulse testing of used batteries with SDU.
- Building up large data sets for modelling and machine learning.
- Safe battery test method optimized at local BatLab using automation from SDU CIE and DTI.







**Electrochemical Impedance Spectroscopy*

New Echandia LTO battery system for Ellen

- Exchange takes place two years early due to battery supply constraints for the original MRS2 system (too long lead times on spares).
- New system involves updated regulation (since 2016) and update of auxiliary systems as well.
- Lifetime of new system with 15-year warranty.
- 3,2 MWh of LTO/NMC chemistry cells allow for much faster charging.
- Usable energy density at system level better than 2016 original battery system = weight savings.

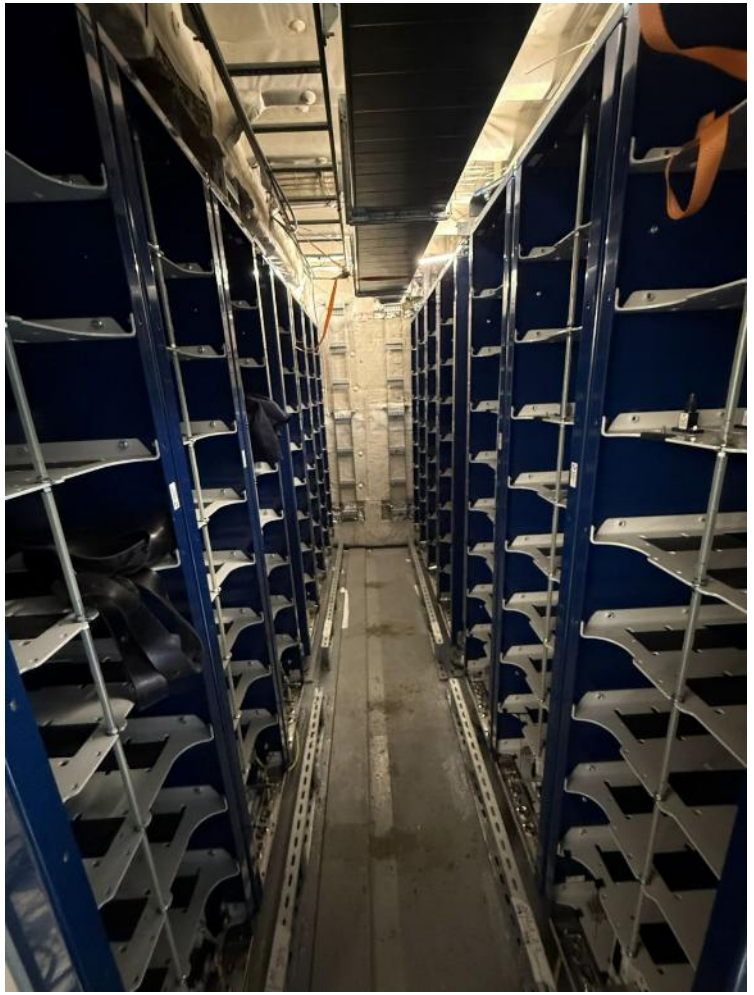
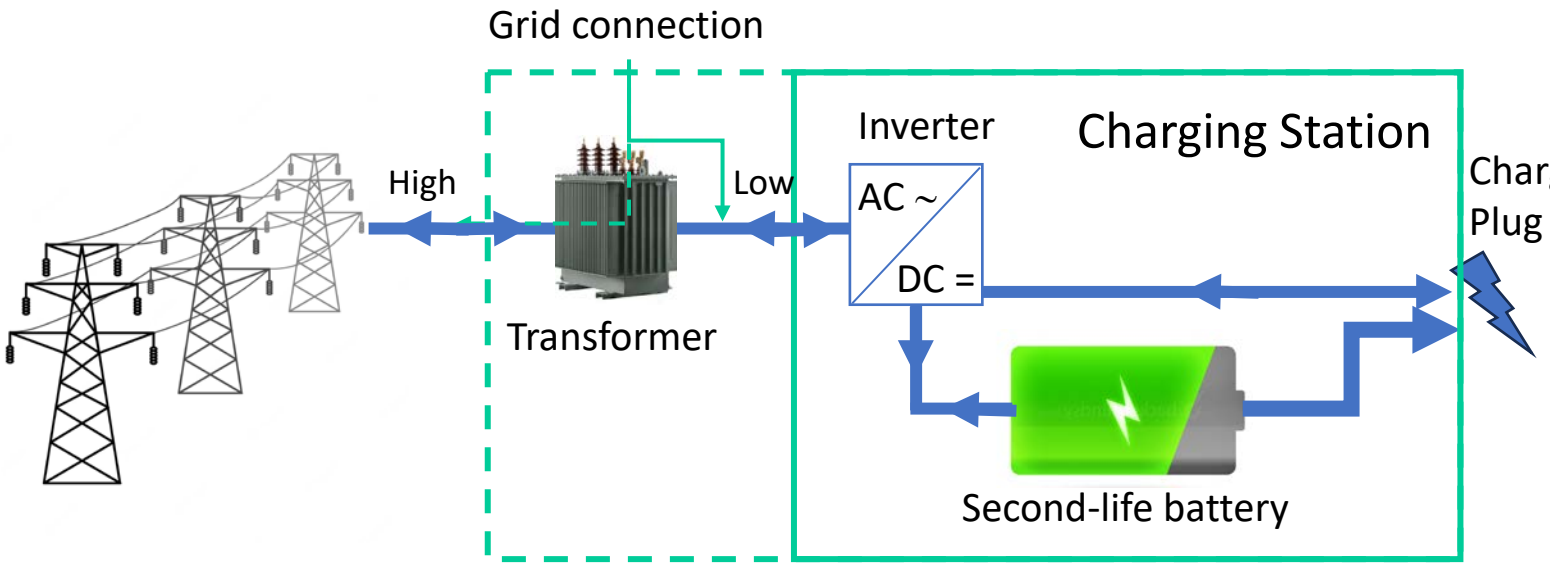
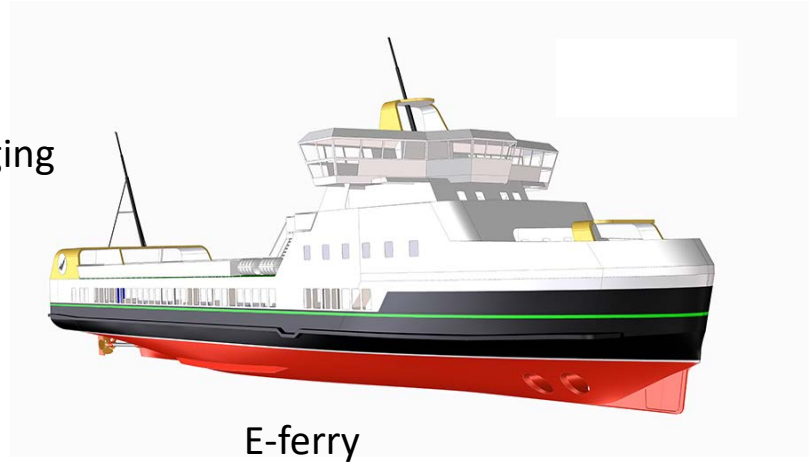


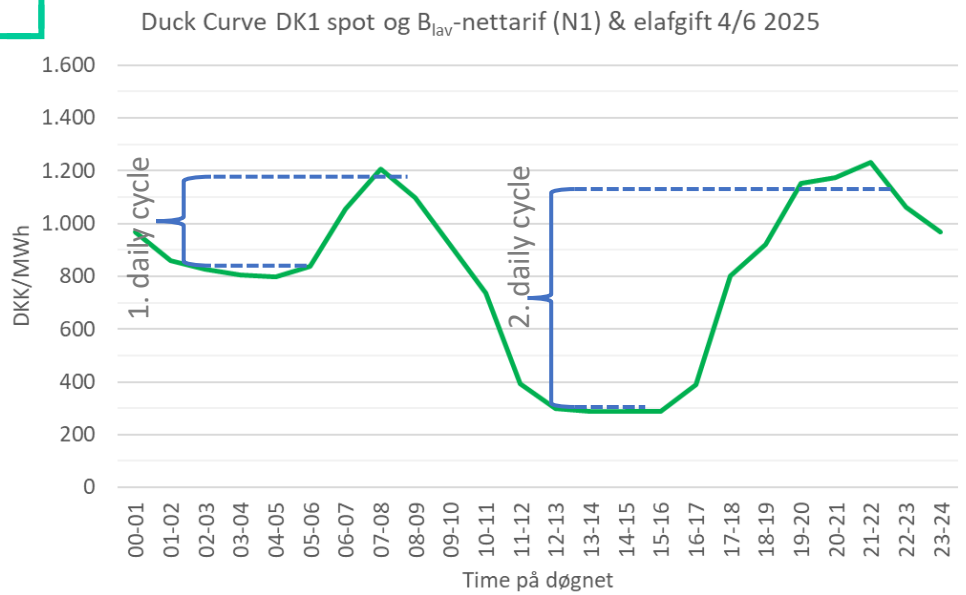
Photo: Henrik Hagbarth Mikkelsen

Second-life use of best maritime batteries from Ellen





- **Peak shaving**
- **Load or peak shifting**
- **Ancillary grid services**
- **Arbitrage trading**
- **Backup power**



Questions or comments

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