NATIONAL ACADEMIES *Sciences Engineering Medicine*

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: The Future of Ferry Electrification in Rural Areas

May 9, 2024

2:00 – 3:30 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

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AICP Credit Information

1.5 American Institute of Certified Planners Certification Maintenance Credits

You must attend the entire webinar

Log into the American Planning Association website to claim your credits

Contact AICP, not TRB, with questions

Purpose Statement

This webinar will explore ferry electrification programs and installations in Greece, Maine, and North Carolina and feature three case studies on the benefits and challenges of ferry electrification as a means to improve the environmental footprints and cost of operation.

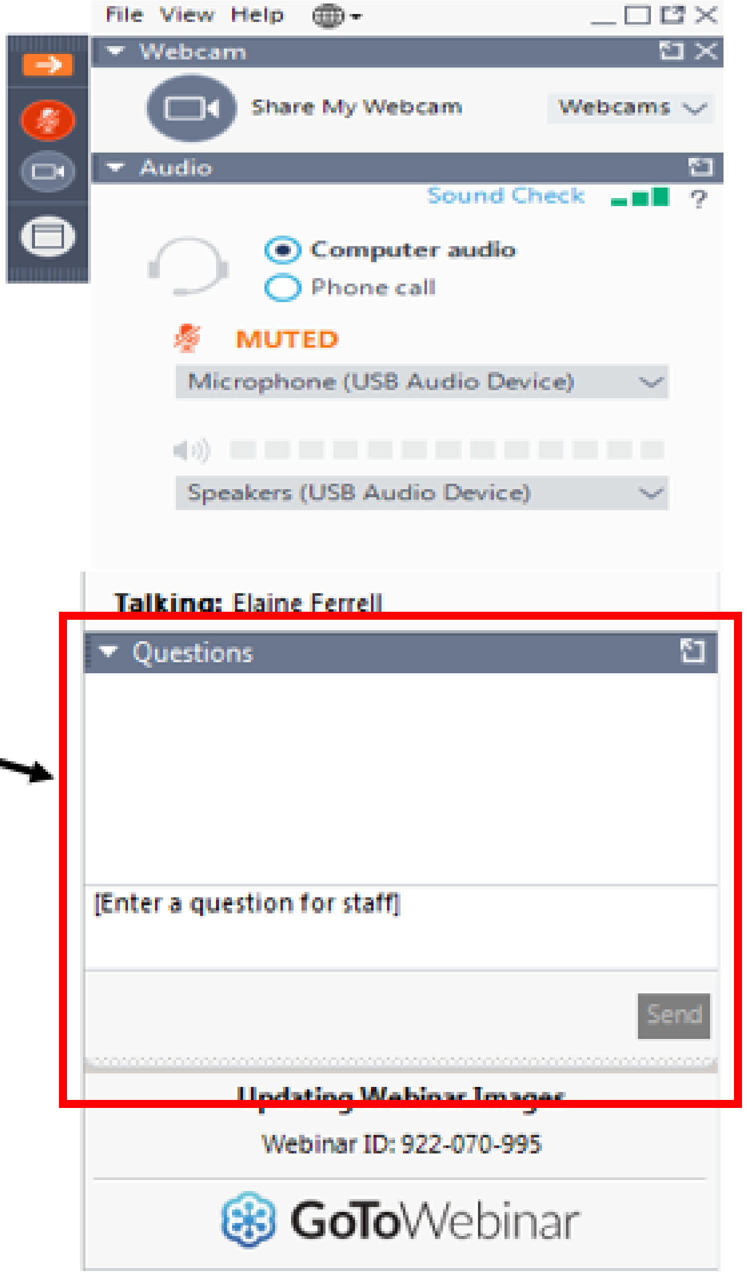
Learning Objectives

At the end of this webinar, you will be able to:

1. Prepare for the challenges of ferry electrification
2. Explain the cost benefits of ferry electrification
3. Use understanding of rural issues for ferry electrification and emerging technologies to address these issues

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Talking: Elaine Ferrell

Updating Webinar Images

Webinar ID: 922-070-995

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NORTH CAROLINA
Department of Transportation

Future of Ferry Electrification in Rural Areas
TRB Webinar

Catherine Peele – AW050 Chairperson

NCDOT Ferry Division – Interim AD Marine Asset Management / Planning and Development Manager

May 9, 2024

Connecting people, products and places safely and efficiently with customer focus, accountability
and environmental sensitivity to enhance the economy and vitality of North Carolina

North Carolina Ferry System

2nd Largest
state-operated Ferry system in the country

75 years
in service in NC

7 year-round
Vehicle Ferry Services

$735 million
annual economic output for North Carolina

$40 million
annual net travel benefits for passengers

23 Ferry Vessels
Hatteras, River & Sound Class, plus 1 Seasonal Passenger Ferry

11 Support Vessels
Tugs, Barges, Dredges

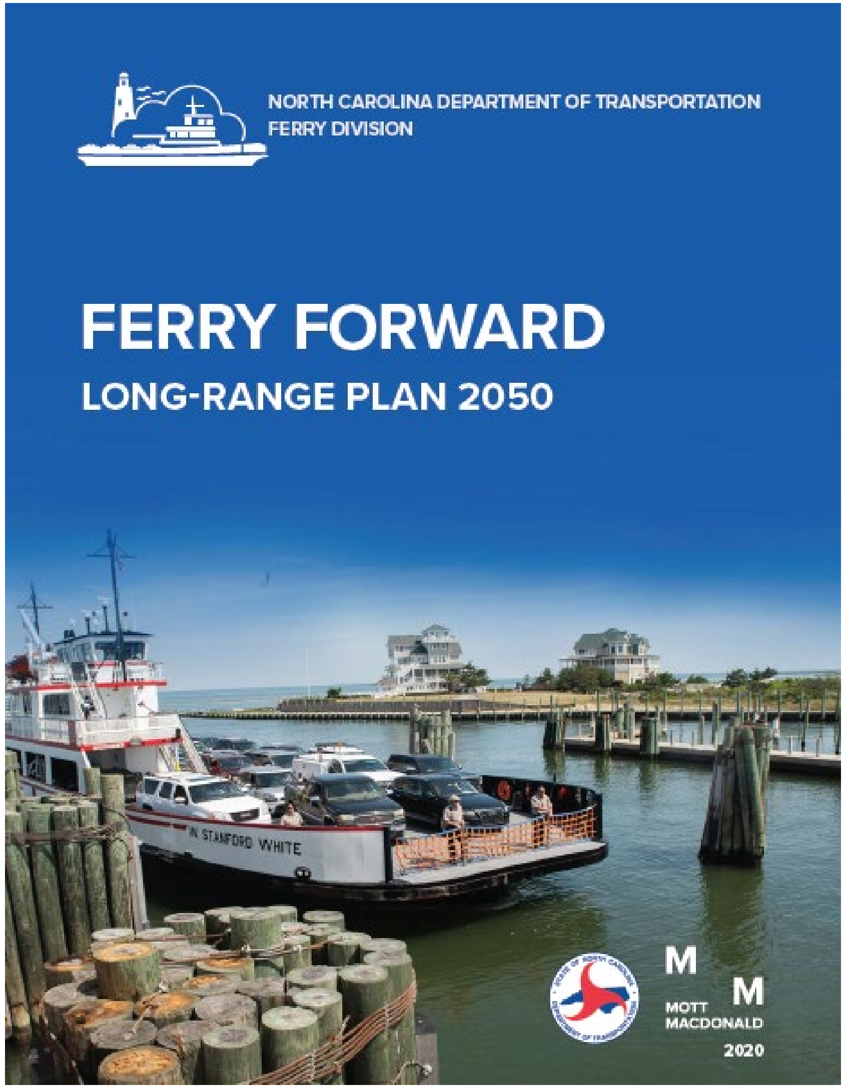
FY2022 – 23 Ridership
1.57 million Passengers

Ferry Forward 2050

Progress the Division’s long-range planning efforts by:

- Focus on planning vs reacting
- Pull together all individual studies to identify gaps
- Develop a comprehensive assessment and evaluation of the historic, current and future system (trends, conditions)
- Better prepare for grant applications, budget expansion requests, and cash spend plans

The Plan is a living document to guide the Ferry Division’s long-range planning



NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
FERRY DIVISION

FERRY FORWARD

LONG-RANGE PLAN 2050

MOTT MACDONALD

2020

Ferry Forward 2050 – Sustainability

Recommendation to Actions

Identify and manage direct Ferry Division impacts on the environment through sustainable investments, resilient planning, and forming lasting partnerships

- Designing future vessels and terminals to be more environmentally friendly and retrofitting existing vessels
- Conducting and reviewing studies of electrical and hybrid propulsion systems
- Promoting non-motorized alternatives at terminals to improve multimodal connections and reduce vehicle usage

- Future vessels will be a diesel hybrid which will reduce emissions
- Current research projects are investigating:
  - Electrification possibilities along short haul routes
  - Natural hazards and making recommendations on how to prepare to be resilient
- Passenger Ferry from Hatteras to Ocracoke has carried over 77,921 passengers over 4 seasons. Removes over 3,000 vehicles from Ocracoke Island each season
- Recently awarded funding for electric charging station at Hatteras

Rural Area Considerations – Utility Coordination

- NC Ferry System interacts with half a dozen utility companies along the various routes
- Aging system components
- Early and upfront conversations about needs and grid improvements
- Co-benefits
- Standardization

Rural Area Considerations – Infrastructure

- Shoreside Improvements
- Standardization
- Timing of funding and implementation
- Plan for future projects
- Coastal considerations

Rural Area Considerations – Future Vessels

- Design
- Coordination with USCG
- Emergency & Disaster Relief
- Funding
- Operational challenges

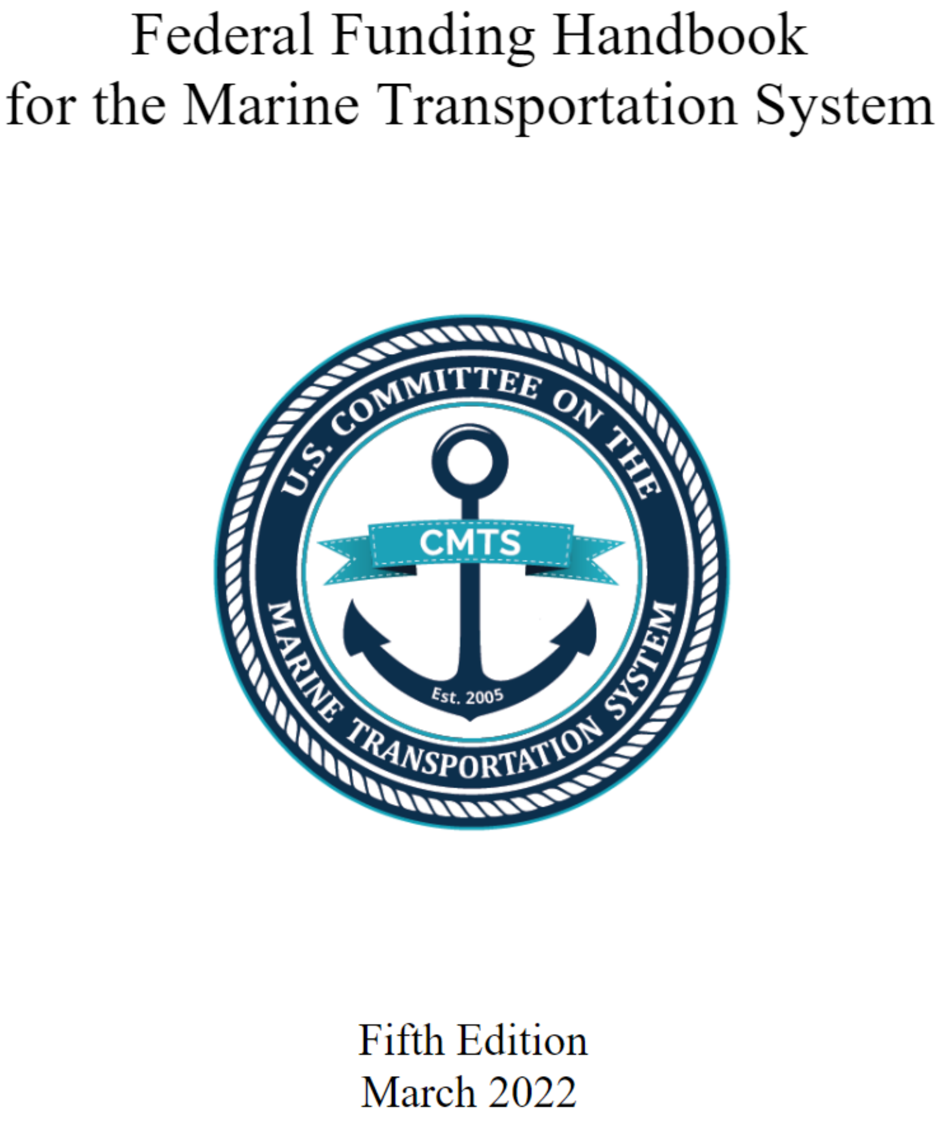
Rural Area Considerations – Workforce Development

- Existing hiring challenges in trades
- Moving from diesel engines to battery or a hybrid system
- Future training and development
- Change in job tasks and classifications

Funding Opportunities

- Open Now – Due June 17
  - Electric or Low-Emitting Ferry Pilot Program
  - Passenger Ferry Grant Program
  - Ferry Service for Rural Communities Program

- EPA Clean Ports Program
- Maritime Administration – Small Shipyard
- US Marine Highway Program
- Port Infrastructure Development Program
- PROTECT, RAISE, RURAL
- CMTS - https://rosap.ntl.bts.gov/view/dot/61471

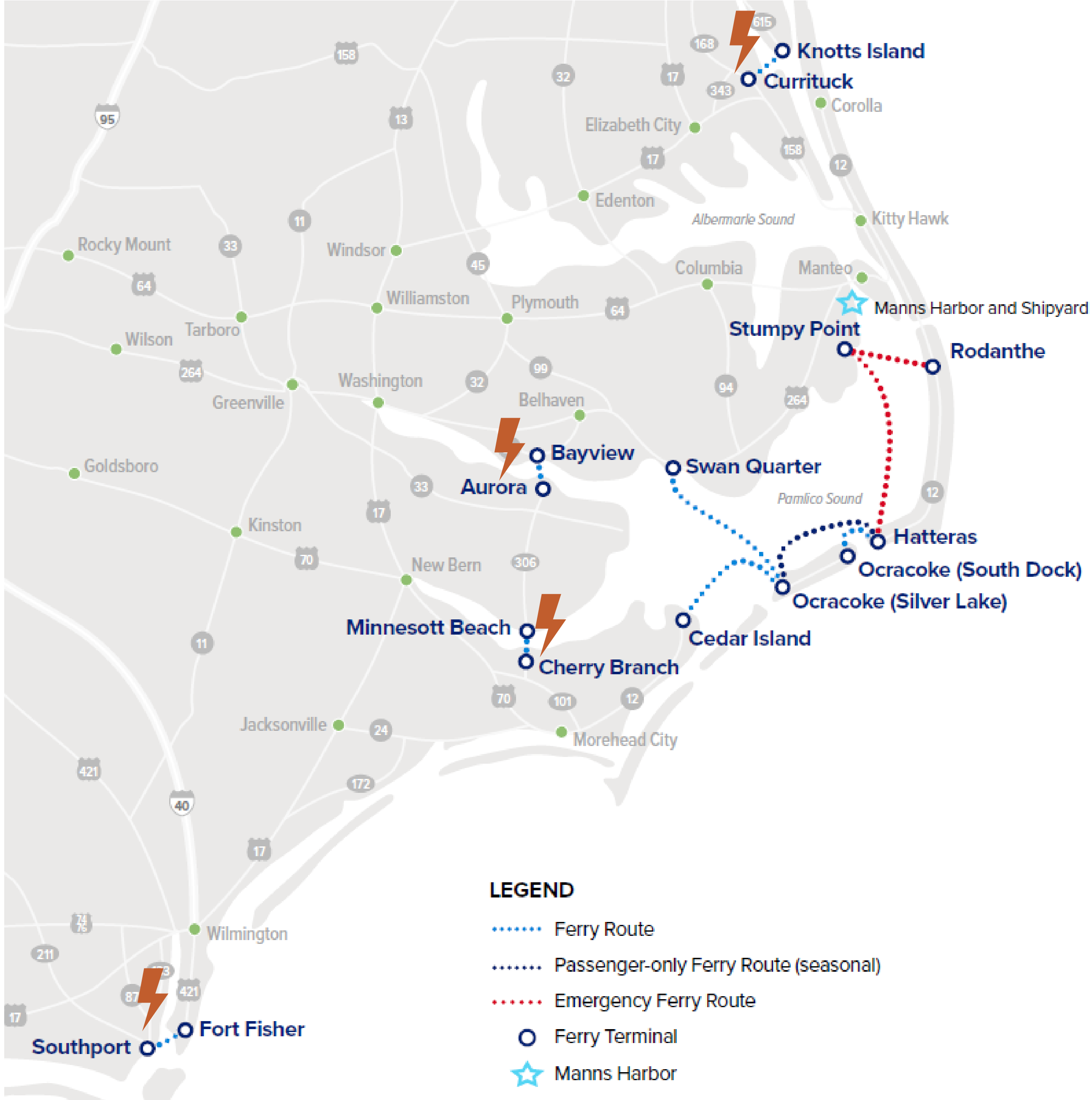


Federal Funding Handbook
for the Marine Transportation System

Fifth Edition
March 2022

Conclusion

- Always planning for the next step
- Close coordination with utilities and USCG
- Training and development
- Not all locations are equal but consider standardization
- Integrator
- Next Presentations



Questions?

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CONNECTING BLUE AND GREEN

Electric Mobility at the Caribbean Lessons learned from Ellen, the electric ferry

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E-ferry Ellen (Halfdan Abrahamsen, Ærø EnergyLab)

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 636027”

Contents of the Presentation

- Brief history of the E-Ferry Project
- Technical Characteristics of Ellen
- Ellen’s operation
- Technical evaluation of Ellen
- Environmental impact of sailing fully electric
- The economy of sailing fully electric
- Societal evaluation of Ellen

Brief History of the E-Ferry project

Brief History of the E-Ferry project

- **2013:** Maritime professionals on the island of Ærø, have the idea of building a fully electric emission-free ferry to replace the aging diesel ferry on the regional route between Søby on Ærø and Fynshav on the island of Als.
- **2014 - Green Ferry Vision:** This was the name of the feasibility study, supported by the European Regional Development fund, presenting the scope and outline for the project.
- This goal was to create a vessel that would cover an unprecedented range for an electric ferry, without relying on fossil fuels, even for use in emergency backup systems.
- **2015 –The Project:** The Municipality of Ærø and partners managed to find the much needed funding through the EU's Horizon 2020 research and innovation programme.

E–Ferry at a glance

E-ferry is a project funded by the EU H2020 programme involving the **design**, **building** & **demonstration** of a **fully electric powered** ‘green’ medium sized ferry for medium range connections.

- Start date: June 1, 2015
- Duration: 48 months
- Total cost: 21,3 M€
- EU funding: 15 M€
- 10 partners

E-ferry builds on the Danish Green Ferry Vision Project (awarded as **Initiative of the year, 2015 Ship Efficiency Awards**!)

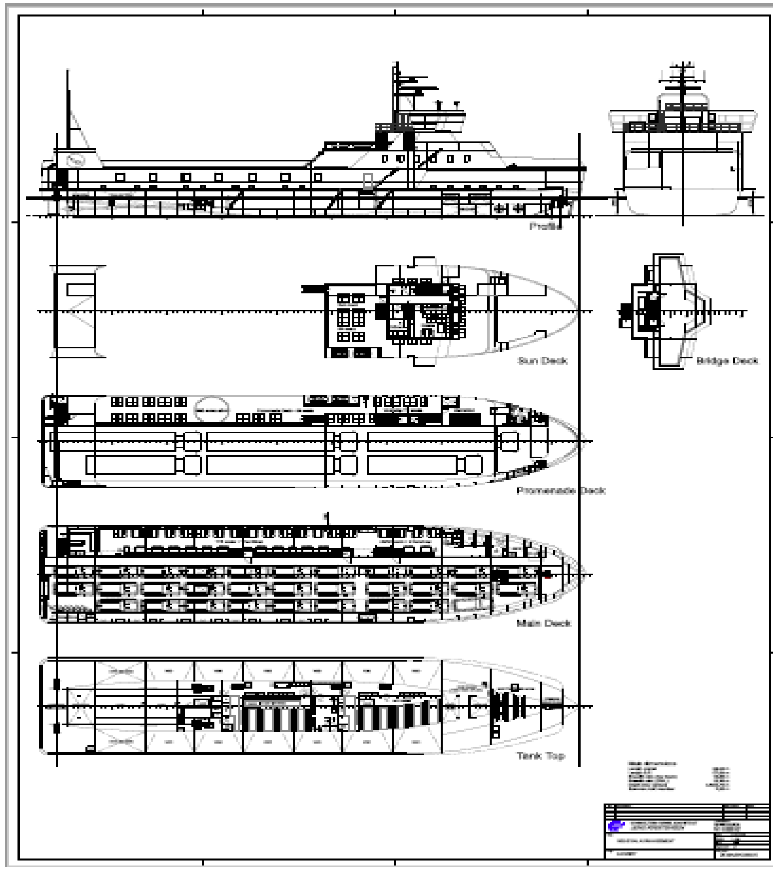
E-ferry team

ÆRØ KOMMUNE
VISEDO electricity in motion
TUCO MARINE GROUP
Leclanché
DANISH MARITIME AUTHORITY
HELLENIC INSTITUTE OF TRANSPORT CERTH / HIT
DBI
CONSULTING NAVAL ARCHITECTS JENS KRISTENSEN ApS
SØBY VÆRFT A/S www.shipyard.dk

The goals of the E-Ferry Project

- ✓ To design and build an innovative vessel that is 100% electric and where the main characteristics are energy efficient design, incorporation of lightweight equipment and materials, and state-of-the-art electric only systems with automated high-power charging system.
- ✓ To validate the feasibility and cost effectiveness of the concept to the industry and ferry operators through demonstrating the vessel’s ability to cover distances of up to 22 nautical miles on connection(s) in the Danish part of the Baltic Sea that are currently operated by conventional diesel driven vessels

Ellen’s Technical Characteristics



E-Ferry Technical Characteristics

	Technical characteristics
Type	Single ended, drive-through Ro-Ro passenger ferry
Class Notation	1A1, Car Ferry B, R4, ICE C, EO, Battery (Power)
Transport capacity	31 cars or 4 trucks and 8 cars, 147 passengers in winter, 196 passengers in summer
Dimensions	Length 59.4 m, breadth 12.8-13.4 m
Speed (draught of 2.30 m)	Service Speed: 13, 5kn, Max speed: 14.2 kn
Deadweight	235 ton
Gross Tonnage	996 GT
Propulsion	2x550kW main motors, 2x250kW thruster motors
Battery capacity	4.3MWh
Charging capability	4MW

E-Ferry Technical Characteristics

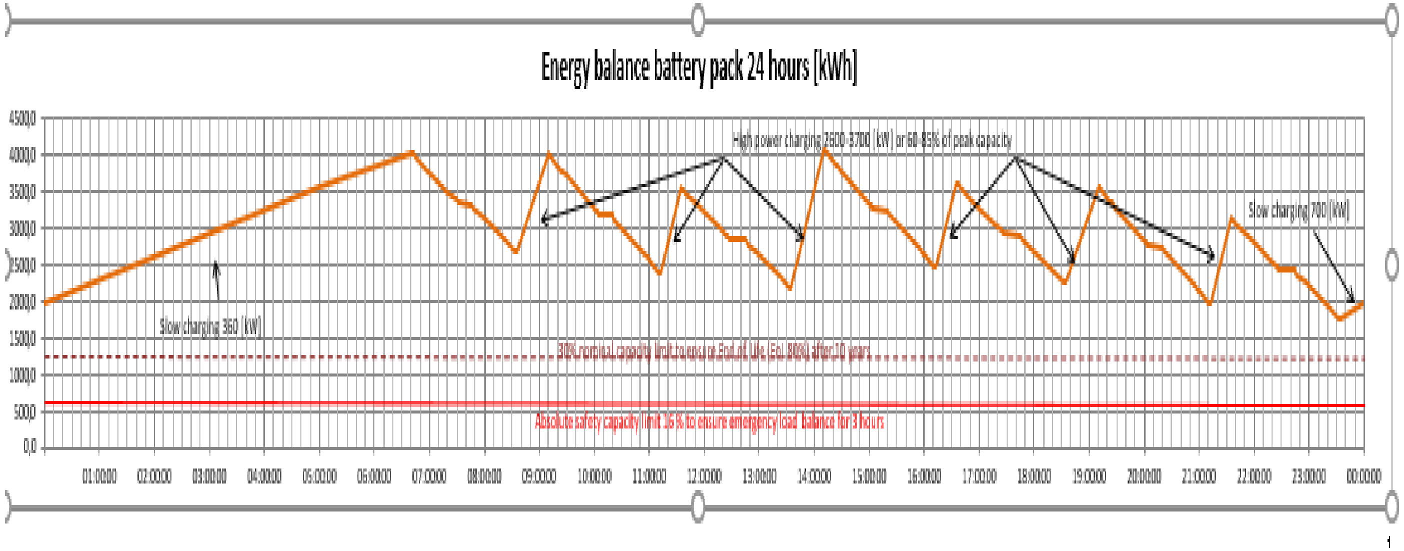
- E-ferry battery capacity has the nominal value of 4.3MWh and can be charged with an effect of up to 4 MW.
- Dimensioning of the battery capacity and charging effect are based on the operator’s requirements for ordinary ferry operation on a route up to 22 nm and with up to 7 trips a day within the operating hours of 06:00-24:00.
- There is no back up emergency generator, for this, a capacity of 2x400 kWh has to be reserved at all times for emergency purposes.

E-Ferry Technical Characteristics

- The system is designed and dimensioned so that Ellen uses an estimate of just over 1/3 of its nominal capacity (1600 kWh) on a trip of 2nm and charge a little less (1100-1300 kWh) than what has been used on a trip during the 20-35-minute harbor stays.
- Ellen leaves the charging harbor in the morning fully charged, gradually diminishes its charged capacity
- By the end of the day it will be around 30% of its nominal capacity.

E-Ferry Technical Characteristics

Simulated values that have been calculated for the E-ferry dimensioning of battery capacity and charging effect



Ellen’s operation

Søby > Fynshav

Overfartstid 60 min.

Man-fre.	Lørdag	Søndag & H. +5/6-20
06:00	06:00	
08:30	08:30	08:30
11:20	11:20	11:20
14:15	14:15	14:15
17:05	17:05	17:05
h) 19:35		19:35

h) Sejler kun fredage i perioden 29/5 - 16/10-2020 inkl.

Fynshav > Søby

Overfartstid 55 min.

Man-fre.	Lørdag	Søndag & H. +5/6-20
07:10	07:10	
09:45	09:45	09:45
12:35	12:35	12:35
15:30	15:30	15:30
18:20	18:20	18:20
h) 20:50		20:50

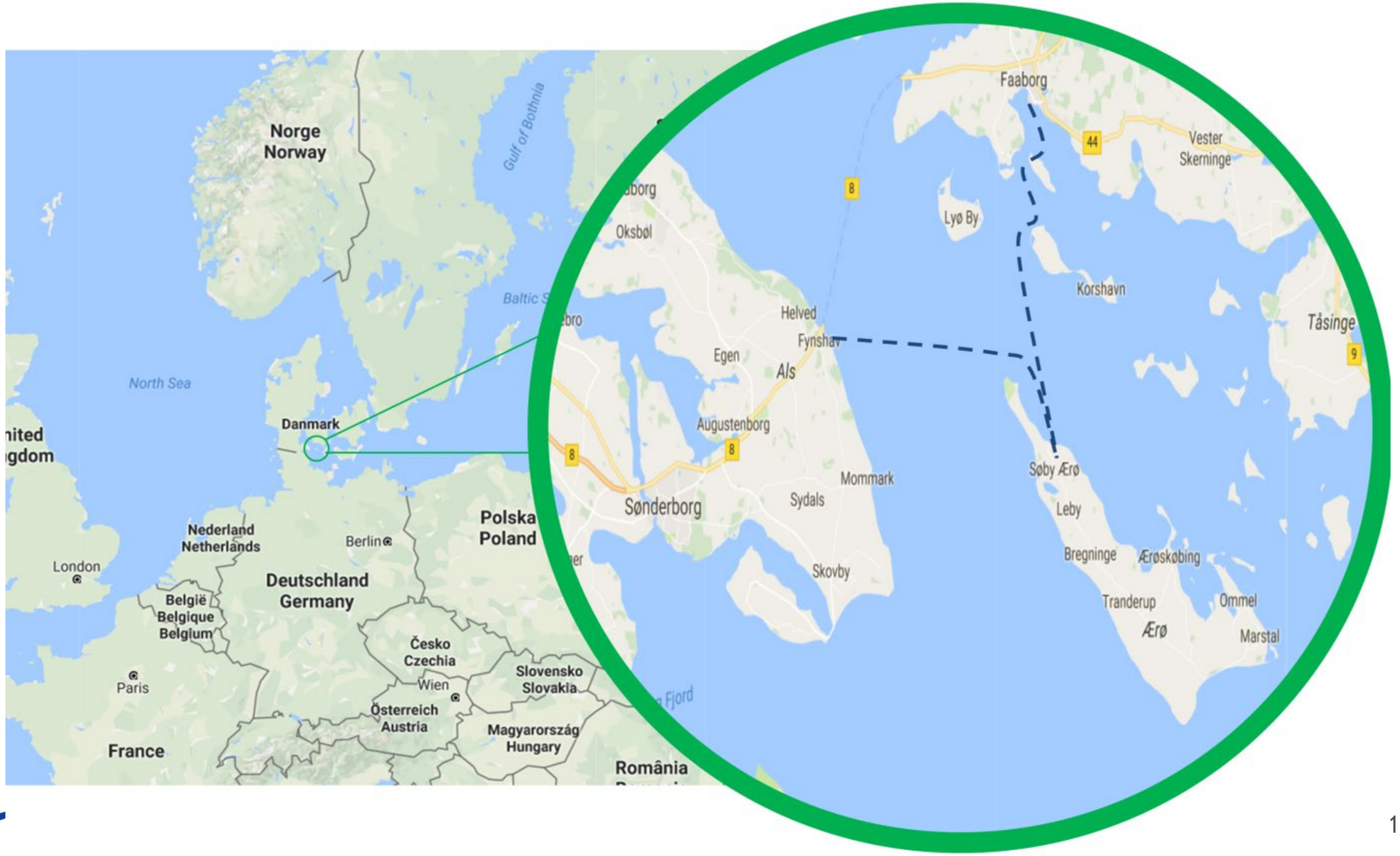
h) Sejler kun fredage i perioden 29/5 - 16/10-2020 inkl.

Ellen’s Operation

- AEROE-ferries received approval by DMA to operate Ellen in the Southern Danish area of the Baltic Sea, on the routes Søby-Fynshav and Søby-Faaborg.
- Distance for both routes is just below 22 nautical miles (return trip), with the route from Søby-Fynshav being slightly longer than the route from Søby-Faaborg.
- The evaluation of the E-ferry prototype in operation has - during the period from July 2019 to May 2020 - focussed exclusively on the longer (and hence more challenging) route from Søby-Fynshav.

Ellen’s Operation

Operation area and 2 routes approved by DMA



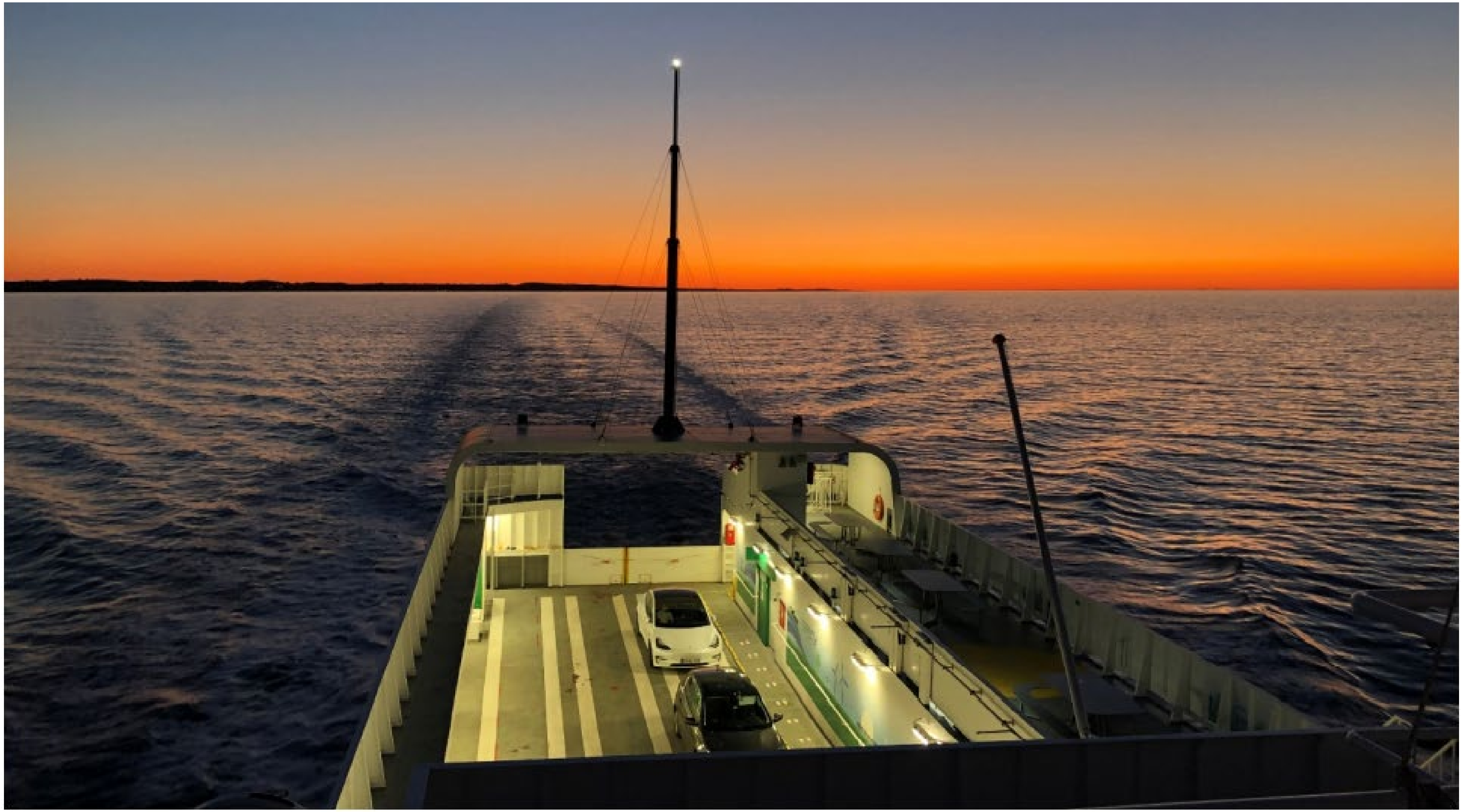
Ellen’s Operation

- On-shore facilities are available in all 3 ports; Søby, Fynshav and Faaborg.
- Each of the harbors has been equipped with an automated mooring system, for faster docking and less crew work.
- Charging is only possible, in the home harbor of Søby,
- Harbor stays in Søby are typically longer than those in Fynshav and Faaborg.

Ellen's Operation

E-ferry prototype charging system is a semi-automated plug-connection, placed on the on-shore ramp and hence charging from the fore end of the ferry.

Ellen's Technical Evaluation



Technical Evaluation – Energy Efficiency and consumption

- ✓ Energy efficiency of total electrical system is 85 % grid-to-propeller - more than twice as high as the efficiency of a typical diesel ferry (tank-to-propeller).
- ✓ At an average consumption of 1600 kWh per return trip used from batteries, Ellen performs better than projected in preliminary studies.
- ✓ Low average energy consumption per trip, in combination with an available battery capacity of more than 3.8 MWh and a fast charger (4 MW peak charge), proves that **Ellen is a valid commercial alternative to traditional diesel- and diesel-electric propelled ferries also on ferry routes of longer distances and a high frequency of daily connections.**

Technical Evaluation – Performance & Charging

- ✓ Ellen performs 5 return trips/day with high reliability and regularity using its higher speed than its predecessors to compensate for charging breaks of 20-40min during port stays in Søby.
- ✓ These five return trips are kept within one 14-hour crew shift only, taking into account rest-hour regulation and crew cost optimization.
- ✓ Ellen stays at night in the port of Søby charging for the next day, but can perform up to 7 return trips in the peak season if needed and another crew shift is added to the daily schedule.
- ✓ Charging plug developed by Mobimar and charging station developed by Danfoss Editron deliver up to 4 MW of power during port stays.
- ✓ The plug is located on the ferry ramp making the system very reliable also during changes in water level.
- ✓ Several extremes has been tested successfully during the demonstration period.

Technical Evaluation – Hydrodynamic performance & impacts of waves, weather & loading condition

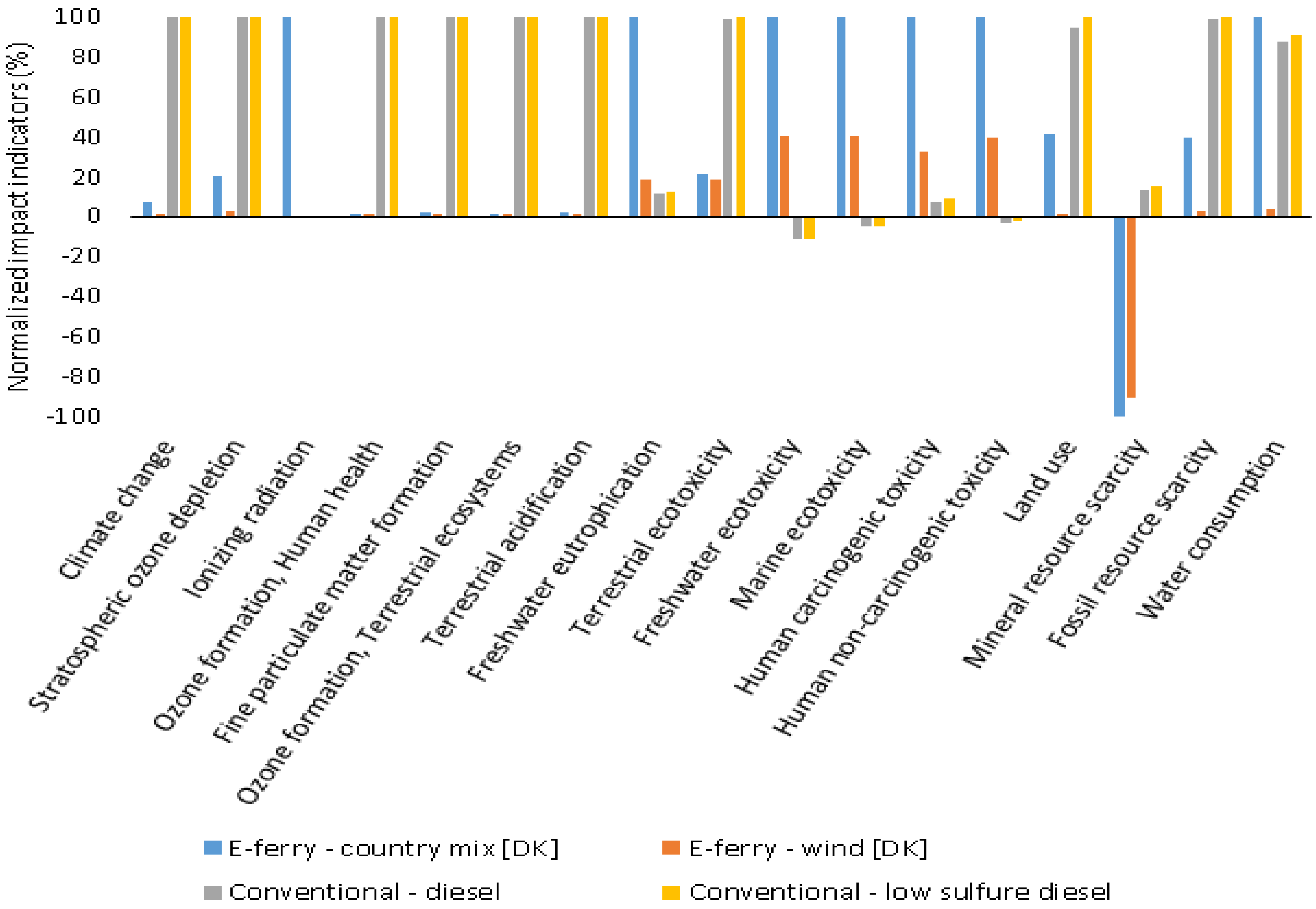
- ✓ Hydrodynamical wave system generated from vessel speed is very low.
- ✓ This is further supported by the low energy consumption measured in the demonstration period, even at relatively high speeds.
- ✓ Ellen’s loading condition has an impact on energy demand.
- ✓ Forward battery room design trim ended up being a little too much “on the nose”.
- ✓ Some ballasting in the aft ship showed to be optimal in normal operation.
- ✓ When heavy loads (trucks) are loaded, they are placed aft so ballast can be reduced. Evaluation analysis didn’t show any significant increase in propulsion consumption when Ellen is heavily loaded.
- ✓ Weather conditions impact energy demand of the E-ferry as for all other ferries.
- ✓ The off-set by head wind and head sea though, will typically be gained back on the returning leg where these effects support the propulsion.

Environmental impact of sailing fully electric

Environmental impact of sailing fully electric

- Based on the LCA, the difference between a fully electric propulsion system and a conventional diesel vessel or a diesel-electric vessel is significant in terms of overall environmental impact over a ferry's lifetime.
- This is regardless if the E-ferry prototype is operating with electricity from the Danish mixed grid or with green energy sourced only from wind energy.
- This is also the case when considering mineral resources (Cobolt, Nickel and Mangan in particular) used for Ellen's batteries, and the resources employed to produce them.

Main results of the LCA



Operational evaluation of the environmental impact

- Aero ferries chose to use certified green electricity for charging Ellen, despite the additional cost (compared to standard Danish grid mix, including about 40-50% electricity generated from fossil fuels).
- The green certificates are the best way of ensuring that Ellen is entirely emission free in a more global perspective (green certificates correspond to extra payments to renewable energy producers putting up new supply of wind, solar or hydro power to the grid).

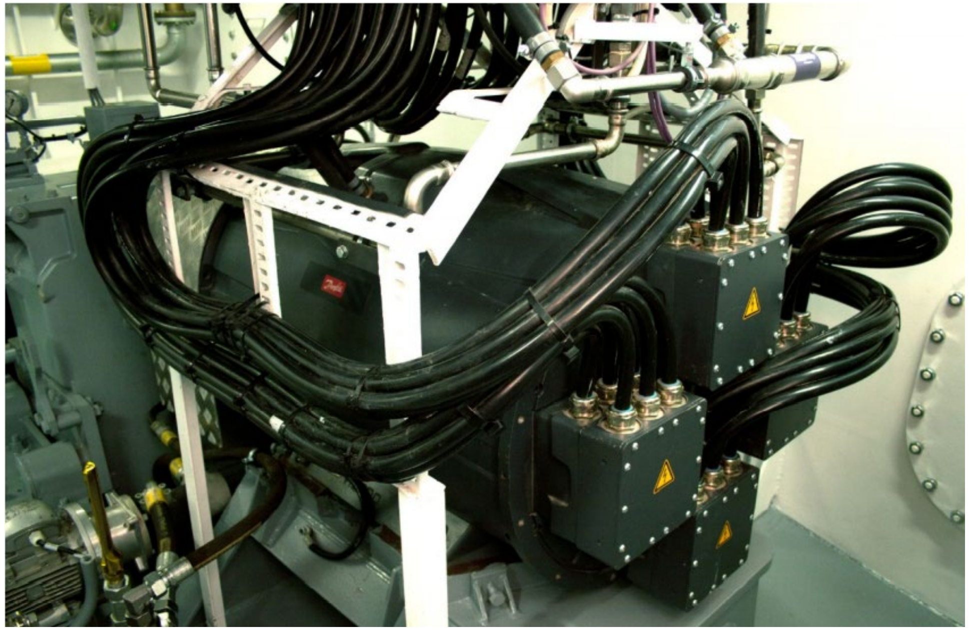
Operational evaluation of the environmental impact

Based on the evaluation:

- ✓ Compared to the BAT (a newbuilt tier III diesel-electric), Ellen saves the environment from 2.520 tons of CO_2, 14,3 tons of NOx, 1,5 tons of SO_2, 1,8 tons of CO and half a ton of particulate matter, using 'green' electricity.
- ✓ Compared to an older, existing ferry of similar type, savings are even bigger, at close to 4000 tons of CO_2, 70,8 tons of NOx, 2,4 tons of SO_2, 3,1 tons of CO and 1,4 tons of particulate matter.

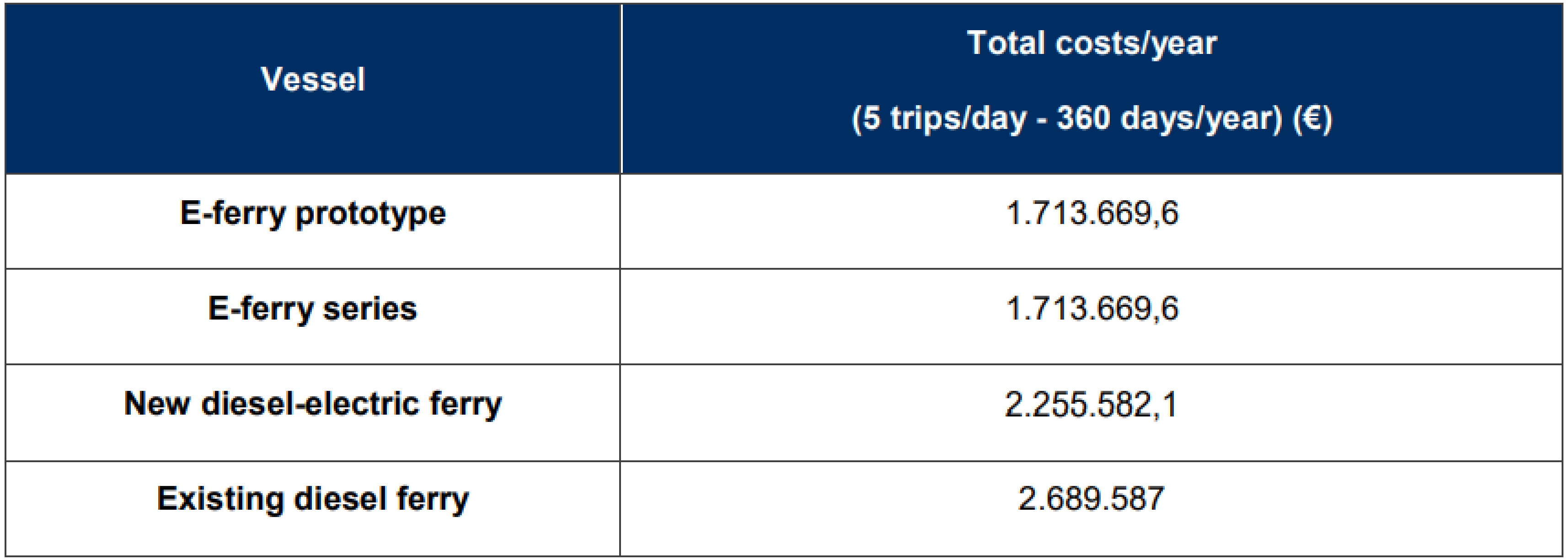
➡ **LCA shows that even when taking into consideration the resources needed for producing batteries, the E-ferry prototype overall fares significantly better than its alternatives.**

The economy of sailing fully electric



The economy of sailing fully electric

- Higher investment costs for building fully electric are compensated for after just 4-8 years of operation, even when taking into account the cost of the charging station and the potential necessity for replacing the battery pack twice over the vessel’s total lifetime.
- Higher investment costs are paid for, early and for the remainder of the ferry's 30-year lifetime, the operator saves 24%-36% in operating cost, compared to operating a diesel or diesel-electric ferry.



Vessel	**Total costs/year** **(5 trips/day - 360 days/year) (€)**
E-ferry prototype	1.713.669,6
E-ferry series	1.713.669,6
New diesel-electric ferry	2.255.582,1
Existing diesel ferry	2.689.587

The economy of sailing fully electric

Savings from operational costs accrue from:

- ✓ Lower energy cost due to the better overall energy efficiency of the fully electrical battery drive train.
- ✓ Lower crew cost, as the E-ferry is approved to sail without a marine engineer. Instead a service engineer takes care of running maintenance that is less demanding with the simplicity and few moving parts of the battery drive train compared to fossil fuel engines.
- ✓ Automation also plays a role for operational cost savings especially when compared to the existing diesel ferry also operated by the Municipality operator, used as the second peer in the analysis.

E-technology is constantly becoming cheaper

- ✓ Battery systems were a major contributor to Ellen’s initial investment costs, - decrease in cost has more than halved the price in the project period.
- ✓ The cost of building Ellen in 2020 with current battery prices compared to the prototype cost incurred by the E-ferry partners would be around to 20% less.
- ✓ In the future charging systems can be expected to be installed in some ports as part of the common infrastructure, further reducing the investment cost for electric ferries.
- ✓ Standardization efforts are being exercised already and economies of scale start to apply as environmental requirements dictate the transition away from fossil fuels.
- ✓ Cost of batteries and their replacement is not the main cost driver - emphasis should be put on the cost of charging system, grid infrastructure and other parts of the drive train (power electronics for marine application of batteries, inverters, breakers, sensors, cabling etc.)

Passenger satisfaction and perspectives for the industry

Passenger Satisfaction

- ✓ **Passengers welcomed the emission-free ferry and its sailing characteristics with enthusiasm.**
- ✓ Environmental benefits are highly rated by the passengers, who stated to be either ‘extremely satisfied’ or ‘very satisfied’ with Ellen in operation.
- ✓ Passengers also highly rate the much less noisy and completely smog-free operation.
- ✓ They rate safety, comfort and travel time (reduced by more than 20 % compared to the diesel it replaced) as either ‘extremely satisfying’ or ‘very satisfying’.

The perspective of the industry

- ✓ Companies involved in the development of Ellen expect new jobs to arise in their organizations, due to the introduction of electric propulsion systems in maritime transportation.
- ✓ New job roles to be created relate to new building departments, installation of Battery/DC systems on electric ships (hybrid), installations of power systems and battery management, project managers, lead engineers, project engineers, automation engineers and technical sales engineers for the marine business line.
- ✓ Consensus was achieved among partners to continue attempts towards electric propulsion of ferries, to conduct in-depth research as well as to improve the regulatory framework.

E-ferry project has great potential to be the innovative catalyst to accelerate and drive acceptance of utilizing innovative methods in future electric ferries

Market potential of E-Ferry

- Electric ferries, despite their environmental advantages pose serious limitations in operation range;
- Propulsion challenge met by E-Ferry is that each sailing is up to 10.7 nautical miles and the vessel can complete two sailings .
- The market analysis for the positioning of the E-ferry was based on the fact that the distance that the ferry can cover without being charged is 22 nm.

Market potential of E-Ferry in Europe

	Number of routes up to 22nm	Number of vessels	Due for renewal now	Due for renewal in 10 years
Baltic	85	142	66	31
North Sea	89	185	100	43
Mediterranean	140	369	211	96
Total	314	696	377	170

Based on the strict rules already in force or expected by 2020 ensuring environmental protection and limitation of GHG emissions it is easily concluded that Ellen has significant market potential

Worldwide market potential of E-Ferry

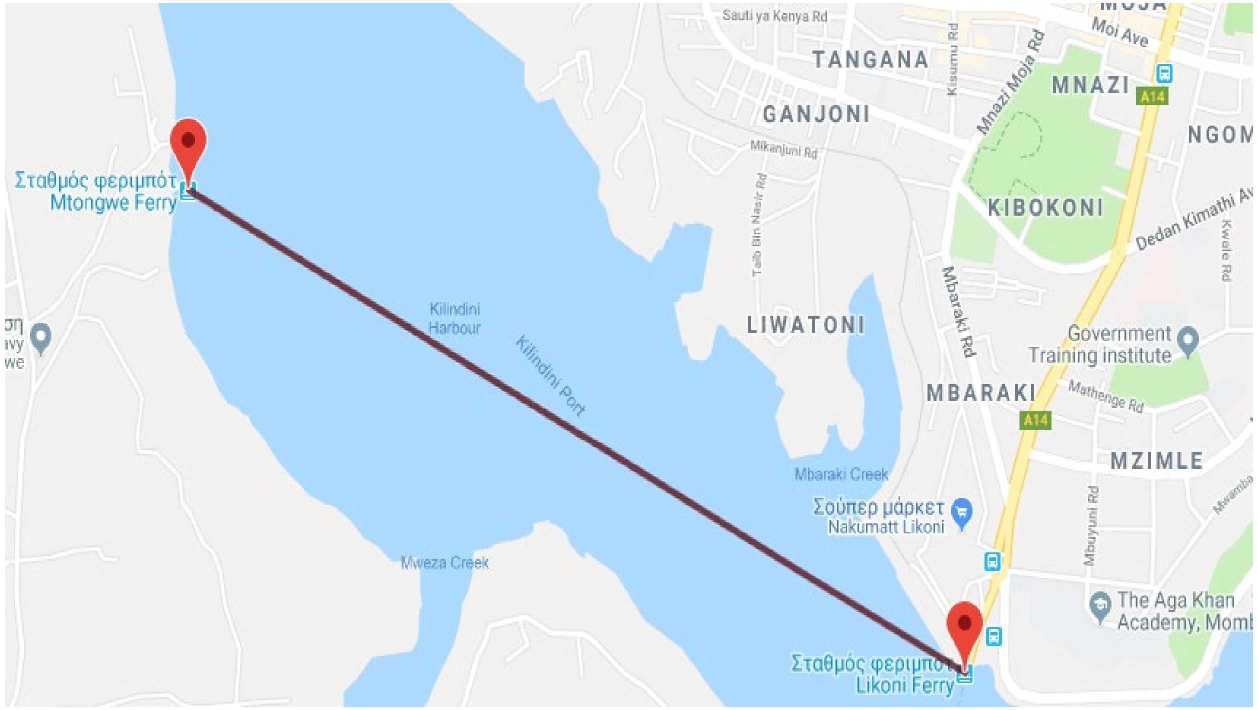
Market	Number of routes up to 22 nm	Number of routes up to 36 nm	Total
The Americas	102	23	125
Central Asia	1	1	2
South East Asia	13	13	26
Pacific	9	6	15
Total	125	45	168

In case of a further optimization of the E-Ferry battery, several routes, up to 36nm, could also comprise a potential market.

Potential operation in the African ferry market

- E-Ferry operation entails a high cost of investment.
- Before attempting to enter the African market it should be investigated if countries/operators/communities can undertake the cost.
- Environmental benefits are indisputable and comprise the basis for any marketing attempt in Africa.
- 2 cases of ferry operations for which Ellen is an eligible candidate have been identified:
  - The domestic line operated by KFS in the route from Mombasa to Likoni and to Mtongwe (3-4 nm in total).
  - Connection between Dar es Salaam (Tanzania) and Kigamboni (≤ 1nm).

Potential operation in the African ferry market



The Mombasa – Likoni – Mtongwe route

This is a ferry service that often faces problems due to the age of operating ferries, with the most recent one occurring last March.

Concluding remarks

- The ferry sector has shown signs of recovery from the financial crisis during the last 3 years.
- There are several challenges to be faced in the coming years, related to environmental policies (regulating levels of GHG emissions, CO_2 and other polluting emissions and substances, noise levels etc)
- Other challenges include fluctuating energy prices and the everlasting need for sustainable, affordable and safe vessels.
- Operation of electric ferries could comprise a viable solution in many cases.

Concluding remarks

- For maritime companies searching for new vessels one of the most important issue is the cost of ownership.
- Economically beneficial, yet highly polluting diesel engines and cheap heavy fuels are often top in the list of choices for maritime power generation.
- Shift towards cleaner fossil fuels & renewable fuels is foreseen; adoption will depend on their availability, infrastructure, environmental impact, safety, price, regulations and technical suitability .
- Market analysis proved that there is a wide range of routes in which Ellen could be competitive.
- Further battery optimization (allowing a range of 36nm) will further widen the market potential.

To sum up…

- Electric ferries are suitable for standard routes, making trips of specific and known length, which ideally last about 3times the duration of the trip.
- They are also ideal in cases of ports located near residential areas or wildlife areas, as the reduced noised and wake protect people and wildlife at the vicinity of the route.
- Electrification of ports where they dock is considered a pre-requisite.

Welcome aboard!!! Video : https://youtu.be/i8LutE2oVzs

Ms. Annie Kortsari – CERTH/HIT

Dr. Georgia Aifadopoulou - CERTH/HIT

Dr. Trine Heinemann – Municipality of Aero

info@e-ferryproject.eu

Sail with us@

www.e-ferryproject.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 636027"

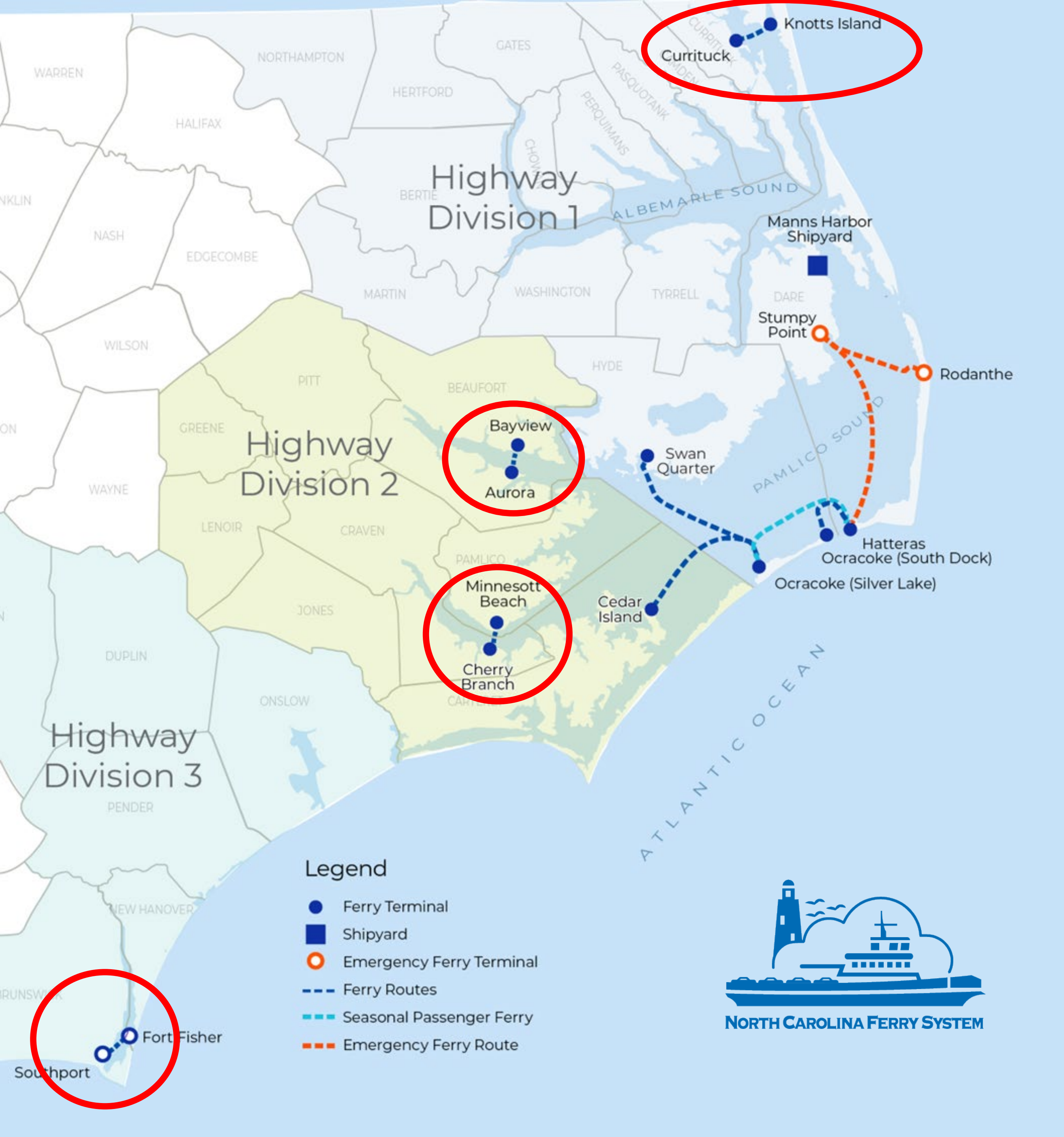
Analyses of RORO Ferry Electrification Configurations

May 9, 2024

John Hildreth, PhD, PE
Western Carolina University
jhildreth@wcu.edu

Agenda

1. System & Project Overview
2. Electrification Configurations
3. Results
4. Analysis Inputs
5. Conclusions



North Carolina Ferry System

2nd Largest
state-operated Ferry system in the country

75 years in service in NC

7 year-round Vehicle Ferry Services

$735 million annual economic output for North Carolina

$40 million annual net travel benefits for passengers

23 Ferry Vessels – Including 1 Seasonal Passenger Ferry

11 Support Vessels Tugs, Barges, Dredges

FY2022 – 23 Ridership
1.57 million Passengers

1. Analysis Method

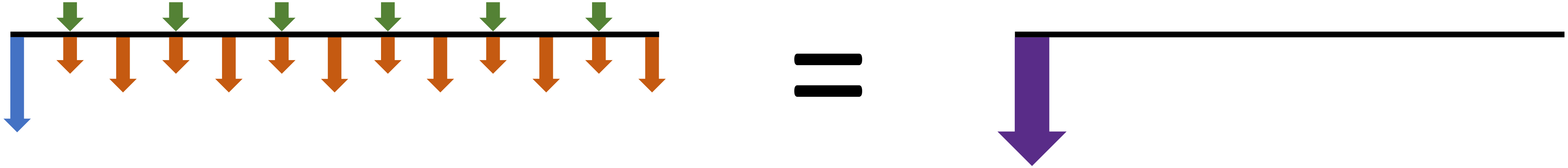
Net Present Value

Equivalent value of cash inflows and outflows at present time

of

Life Cycle Costs

Recurring and nonrecurring costs throughout asset life



2. Vessel Electrification Options

Diesel Mechanical

- Diesel powered
- Mechanical drive

- Dual ICE propulsion
- Primary & backup ICE generator sets

Diesel Electric

- Diesel powered
- Electric drive

- Improved load matching
  - Smaller ICE
  - Reduced maintenance

Diesel Electric w/ Peak Shaving

- Diesel powered
- Electric drive
- On-board ESS

- Optimized ICE generator sets
  - Increased fuel efficiency
  - Reduced maintenance
- ESS for low load and peak power requirements

Plug-In Hybrid

- Electric power
- Electric drive
- On-board ESS

- ESS charged from shore
- On-board generation for backup and/or range extension
- Low-cost electric power
- “Unlimited” range

Plug-In Electric

- Electric powered
- Electric drive
- On-board ESS

- ESS charged from shore
- Low-cost electric power
- Zero local emissions
- No ICE maintenance

Fuel Cell Electric

- Electric powered
- Electric drive

- On-board fuel cell generation
- Refueled from shore connection
- Zero local emissions
- No ICE maintenance

Increasing Diesel Engine Efficiency

Replace Diesel Fuel with Alternative Fuels

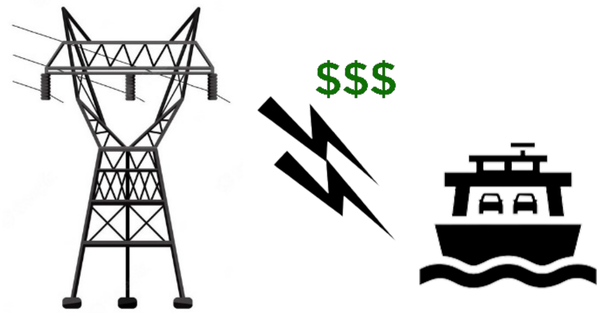
2. Vessel Electrification Options

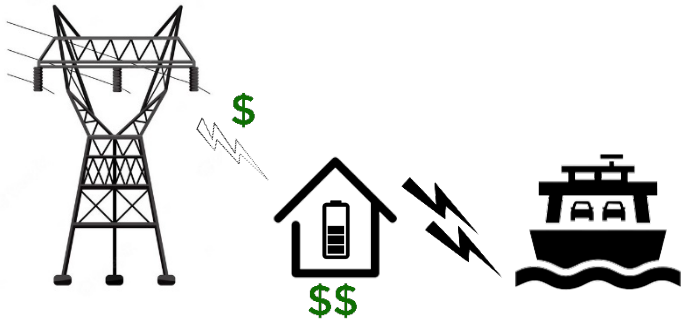
Diesel Mechanical	Diesel Electric	Diesel Electric w/ Peak Shaving	Plug-In Hybrid	Plug-In Electric	Fuel Cell Electric
• Diesel powered • Mechanical drive	• Diesel powered • Electric drive	• Diesel powered • Electric drive • On-board ESS	• Electric power • Electric drive • On-board ESS	• Electric powered • Electric drive • On-board ESS	• Electric powered • Electric drive

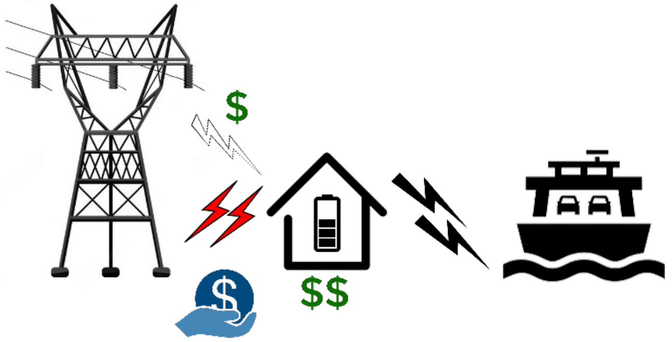
• Dual ICE propulsion
• Primary & backup ICE generator sets
	• Improved load matching
	  • Smaller ICE
	  • Reduced maintenance
		• Optimized ICE generator sets
		  • Increased fuel efficiency
		  • Reduced maintenance
		• ESS for low load and peak power requirements
			• ESS charged from shore
			• On-board generation for backup and/or range extension
			• Low-cost electric power
			• “Unlimited” range
				• ESS charged from shore
				• Low-cost electric power
				• Zero local emissions
				• No ICE maintenance
					• On-board fuel cell generation
					• Refueled from shore connection
					• Zero local emissions
					• No ICE maintenance

Baseline		Option 1	Option 2		

2. Charging Options







Grid → Vessel

- Grid connection through stepdown transformers, AC/DC conversion, filters, rapid charging system, etc.
- High power demand
- High demand charges

Grid → Shoreside ESS → Vessel

- Grid connection to ESS
- ESS capital and replacement costs
- Low power demand / demand charges
- High power from ESS to vessel

Grid → Shoreside ESS → Vessel
Grid ← Shoreside ESS

- Grid connection to ESS
- ESS capital and replacement costs
- Low power demand / demand charges
- High power from ESS to vessel
- Periodic utility access for demand response → Revenue generated

2. Life Cycle Costs

Cost components

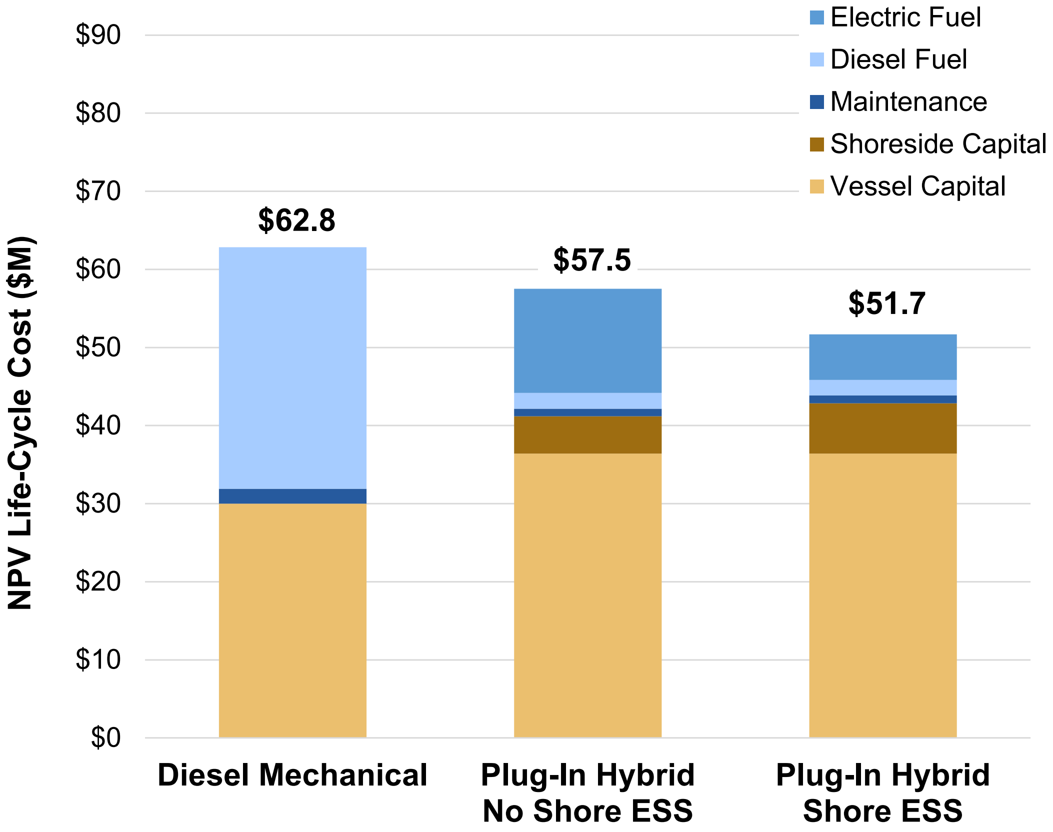
Diesel Mechanical

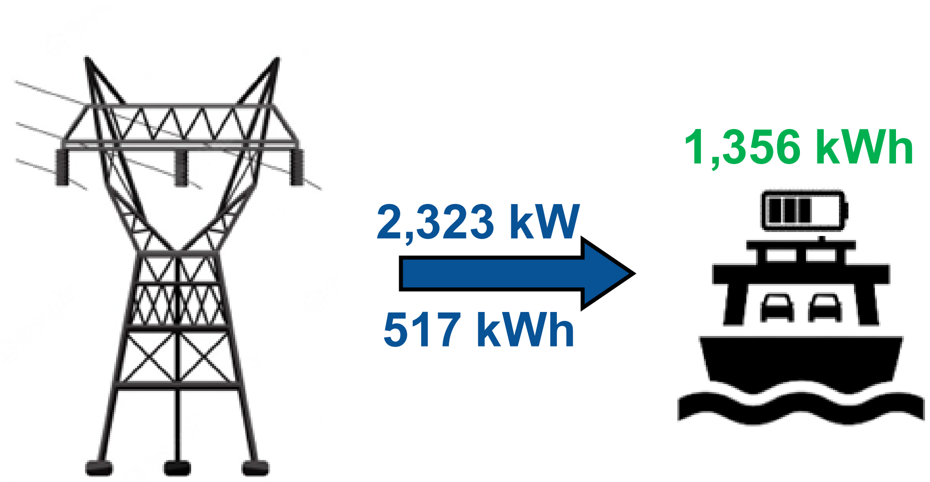
- Equipment capital
- Fuel
- Maintenance

Electrical

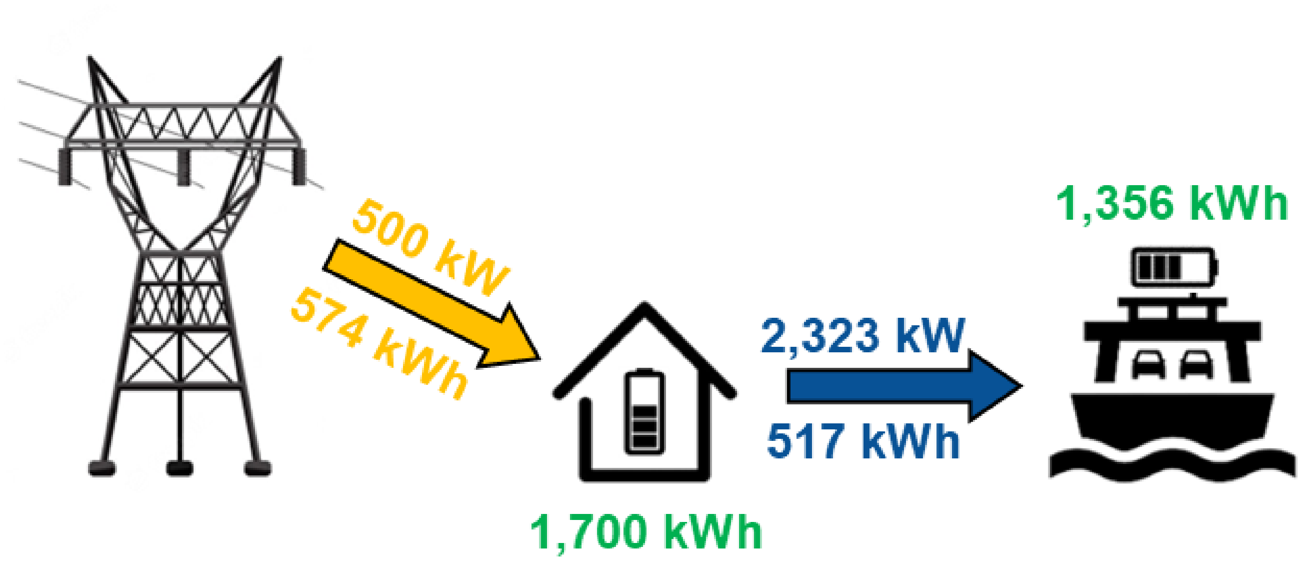
- ↑ Equipment capital
- ↓↓ Fuel
- ↓↓ Maintenance
- Facilities capital
- Batteries (with replacement)
- Electricity

3. Pamlico River

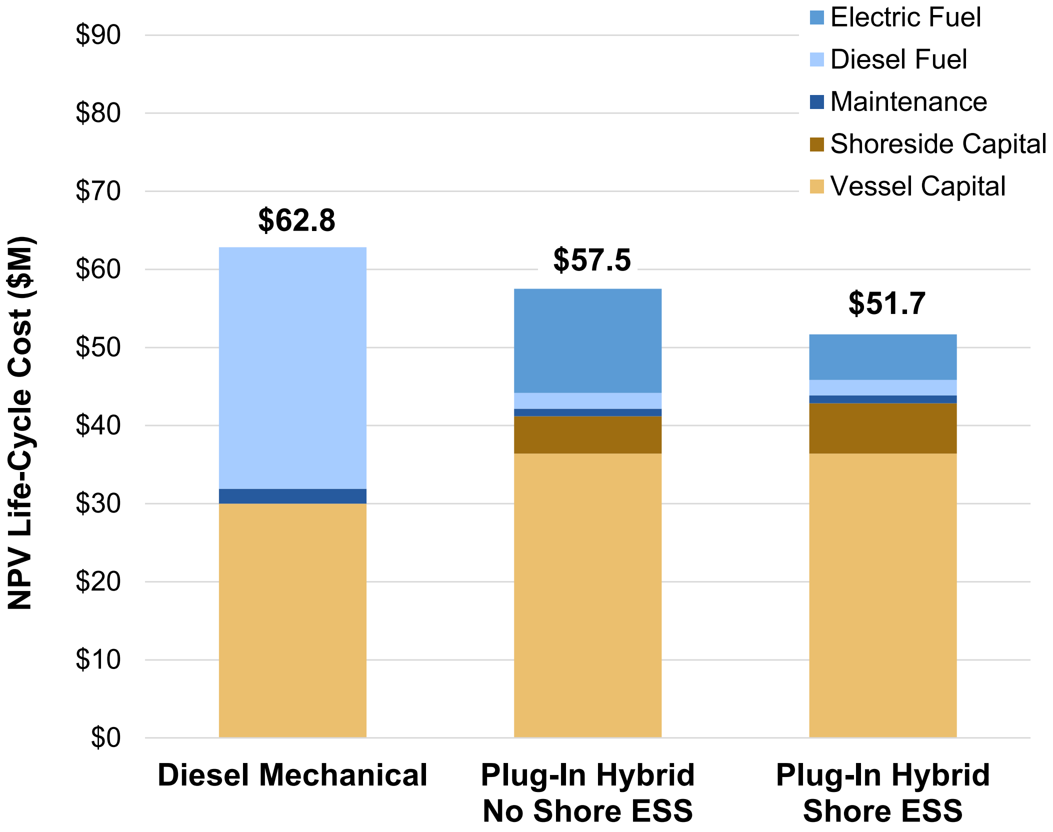




12 min charge time

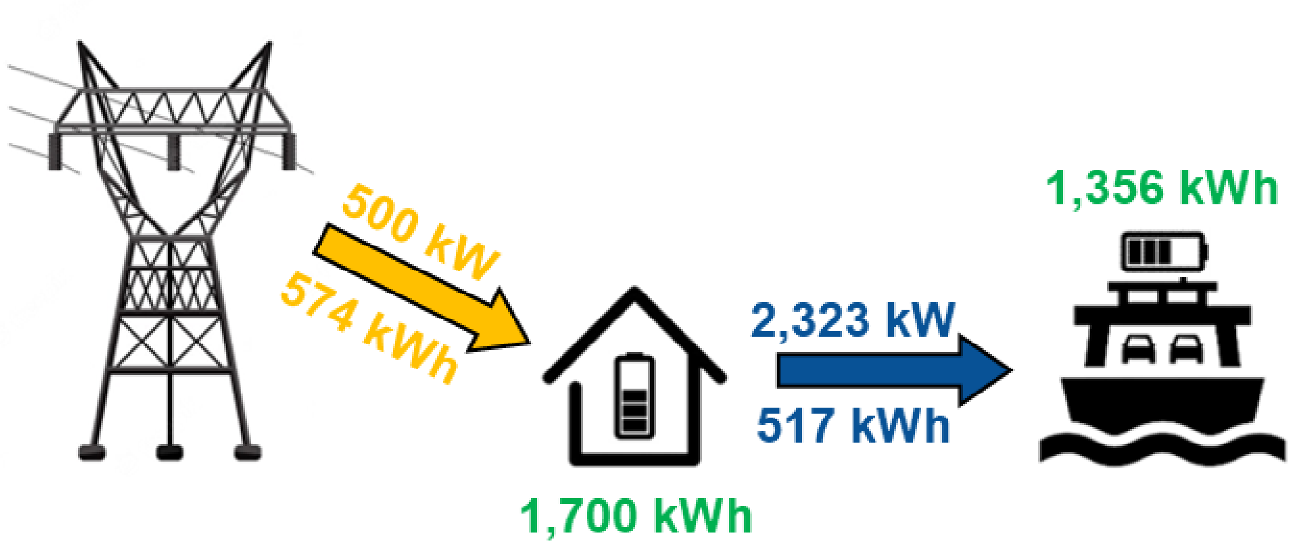


3. Pamlico River



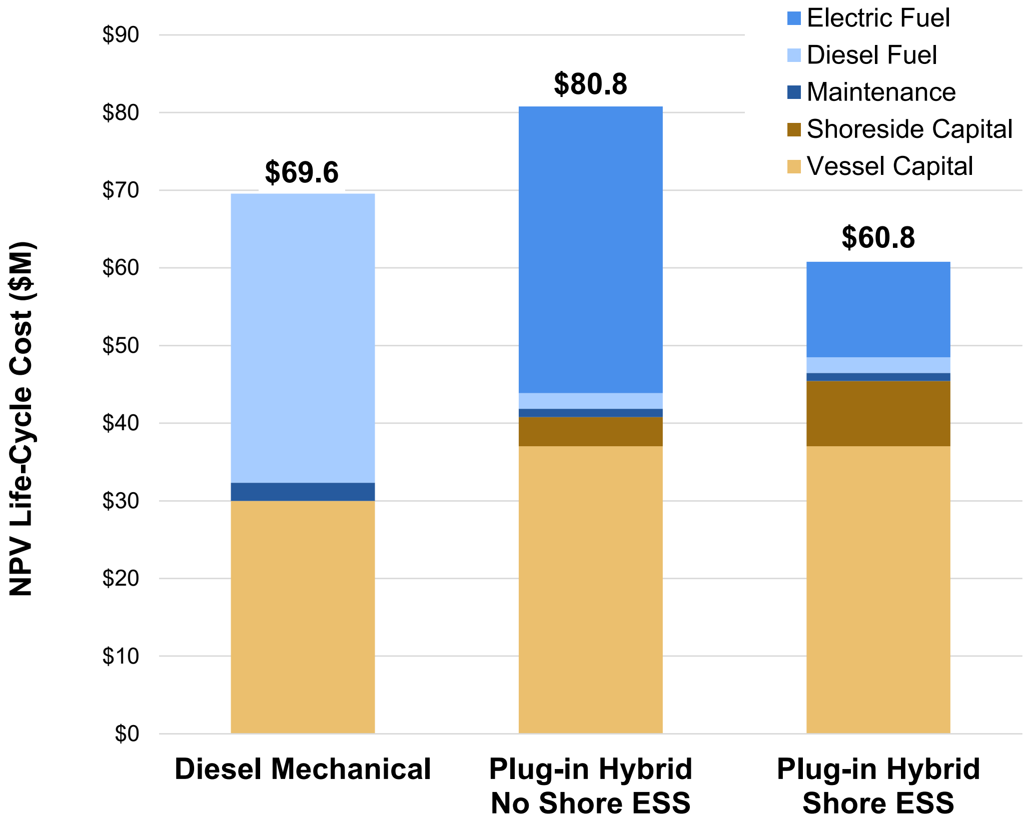
Life Cycle Savings	Annual CO_2e Reduction	Annual Human Health Benefit
$12.4M	2,700 m tons	$317k - $718k

12 min charge time

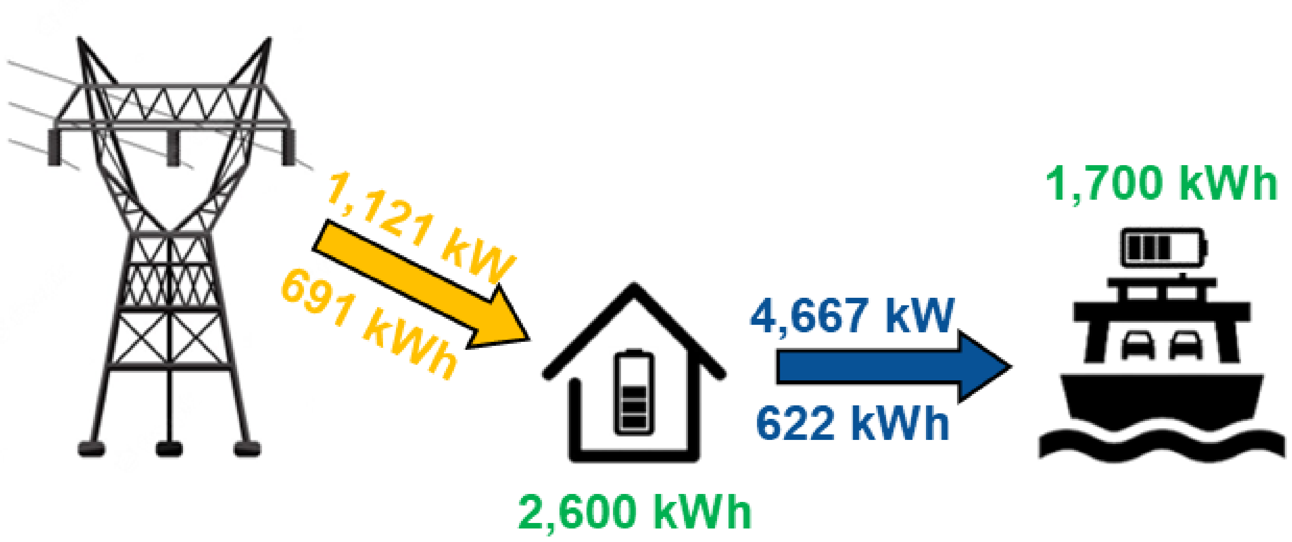


3. Cape Fear River

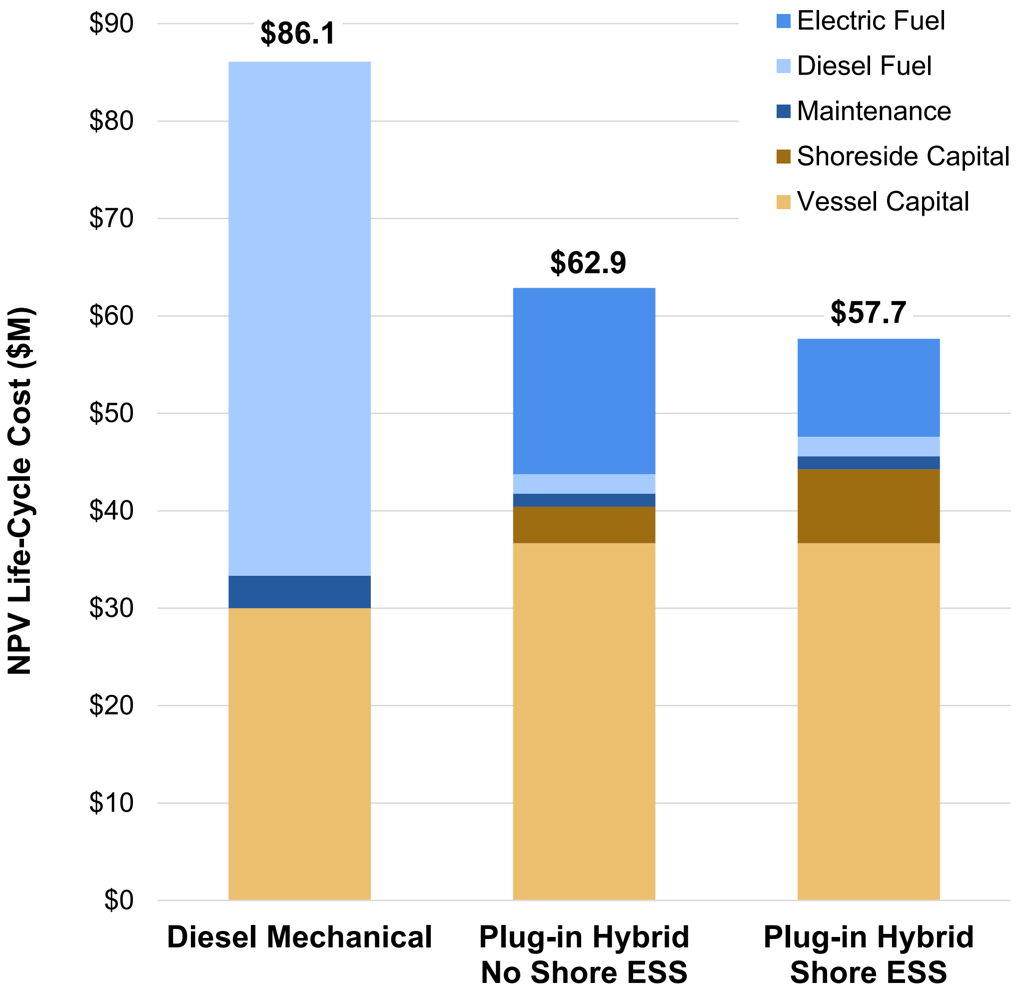
Life Cycle Savings	Annual CO_2e Reduction	Annual Human Health Benefit
$17.6M	5,600 m tons	$1.0M - $2.3M



8 min charge time

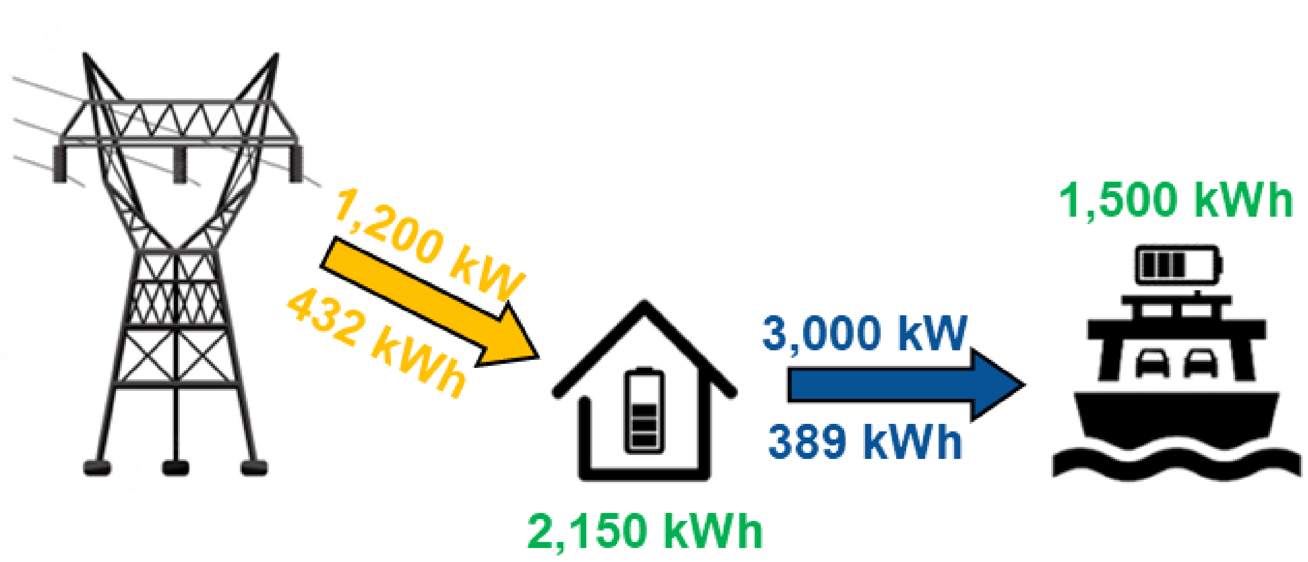


3. Neuse River



Life Cycle Savings	Annual CO_2e Reduction	Annual Human Health Benefit
$54.2M	8,400 m tons	$1.2M - $2.6M

8 min charge time



Agenda

1. Project Overview
2. Electrification Configurations
3. Results
4. Analysis Inputs
5. Conclusions

4. Analysis Inputs

Capital Costs

- $30M Vessel
  - $4M for elec.
- Batteries
  - $700/kWh to $500/kWh
- Site specific grid improvements
- Elec upgrade - $1.25M
- Rapid charging system - $1.5M

Diesel Fuel

- $3.25/gal increasing $0.10 annually
- Based on recent costs and historical trends

Electrical

- Utility specific rate structures
  - Service Fees
  - Demand Charge
  - Energy Charge
- 2% annual cost increase based on historical trends

Maintenance

- ICE preventive maintenance
- Electrical component maintenance schedules
- Rapid charging

5. Conclusions

- Substantial economic benefits through vessel life cycle
  - Trade annual operating costs for capital costs
- Not all locations are equal
  - Not just the economics – energy, schedule, grid
  - Fleet standardization – design for a location mashup
- Partnership with utility extremely valuable
- One side charging – function of energy, pricing, grid improvements

Analyses of RORO Ferry Electrification Configurations

May 9, 2024

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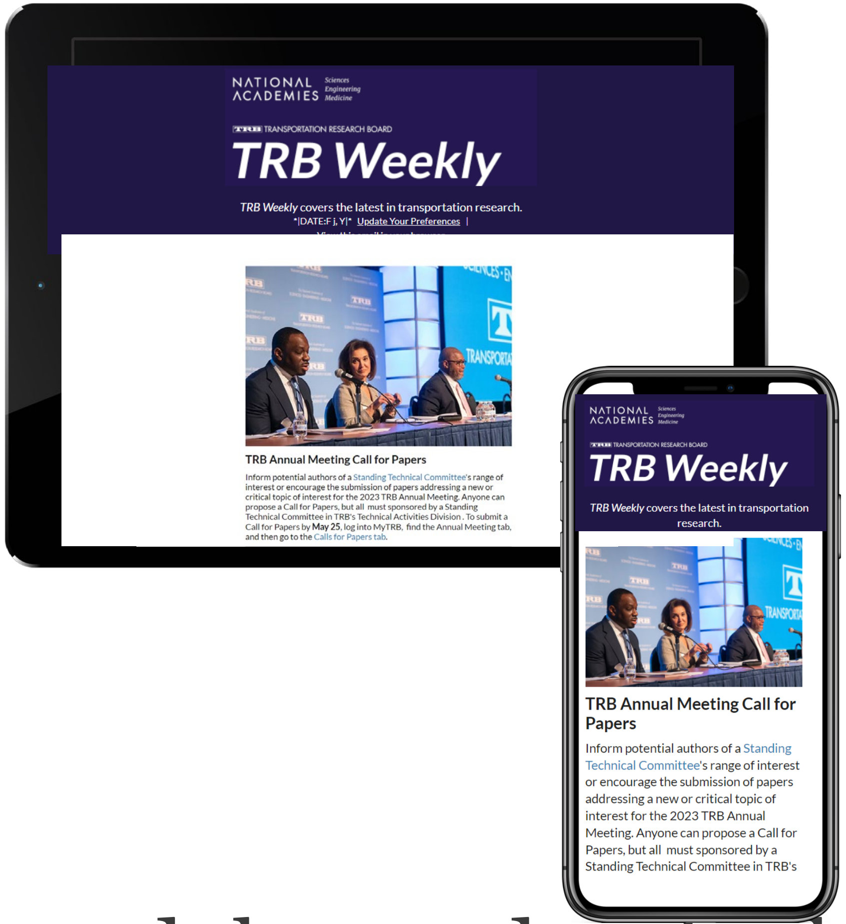

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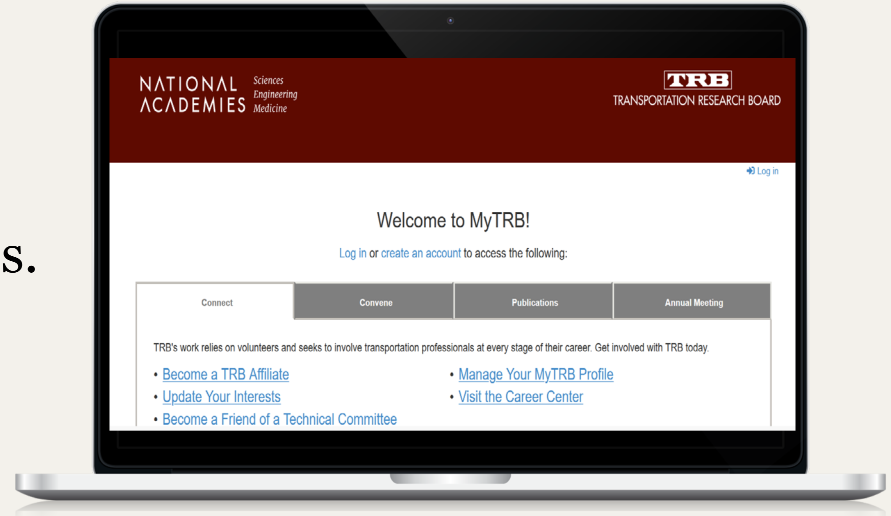

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