



NTNU – Trondheim
Norwegian University of
Science and Technology



FLEXSHIP

FLEXSHIP Short Course: Electrification and Digital Twins for Green Shipping

Role of electrification in sustainable shipping

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Sustainable maritime transport

Fulfill the present needs while preserving the **environment, economy, and resources** for the future generation

- Save the Environment → Reduce Emissions.
- Save the Economy → Improve Efficiency.
- Save Resource → Increase the share of renewable energy.



Source – Bureau Veritas

Driving factors



Emissions and pollutants

Business

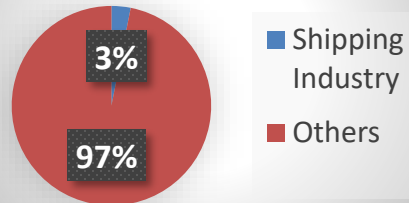


<https://www.marineinsight.com/shipping-news/eu-emission-trading-system-will-inhibit-global-co2-reductions-bimco/>
<https://offshoringtobos.com/understanding-logistics-freight-forwarding-and-their-regulating-bodies/>

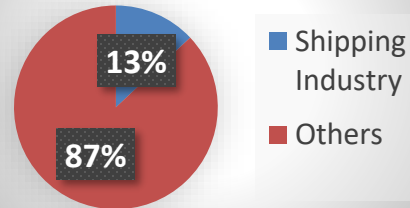
Emissions and pollutants



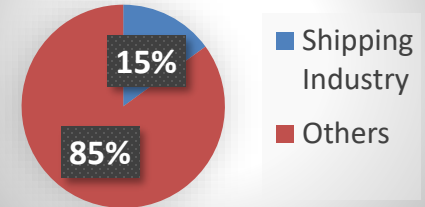
CO₂



SO_x



NO_x



Regulations

International Maritime Organization (IMO)

MARPOL Convention

- ✓ Greenhouse gas (GHG) emission reduction for international shipping
 - 20% reduction by 2023
 - 70% reduction by 2040
 - 100% reduction (net-zero) by 2050
- ✓ Energy Efficiency Design Index (EEDI)
 - 30% improvement by 2025 (compared to 2014).
- ✓ Dedicated SOx and NOx measures → Emission Control Areas (ECA)

Regulations

Regional regulations and legislations

- ✓ EU legally binding targets to reduce emissions by 55% in 2030 (relative to 1990) and become climate-neutral by 2050.
- ✓ EU two main legislations: EU ETS and FuelEU Maritime for ships.
- ✓ The US has a long-term strategy to achieve net-zero emissions by 2050, focusing on renewable energy production, reduced methane emissions, and CO2 removal technologies (shore power, tax credit for clean hydrogen production and carbon capture).

- EU ETS: Emission cap-and-trade system where a limited amount of emission allowances (the cap) is put on the market and can be traded.
- FuelEU Maritime: Requirements on annual average well-to-wake GHG emissions per unit of energy used by the ship.

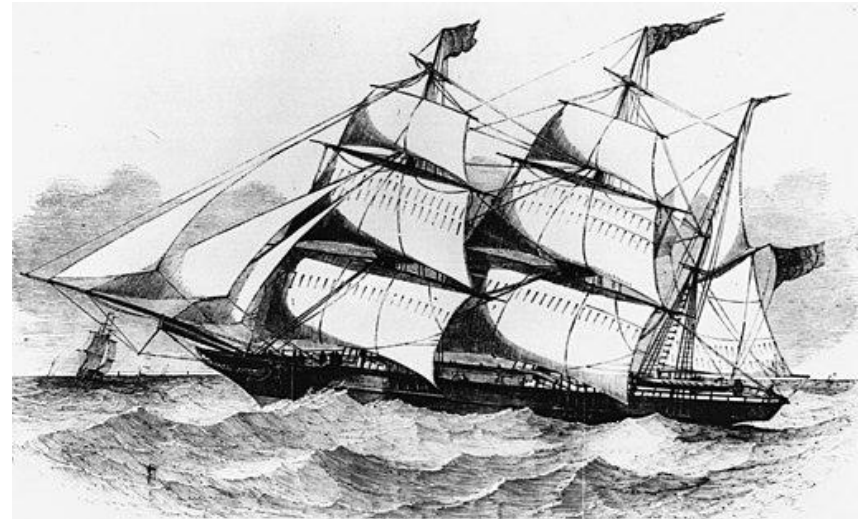
Let's go green!



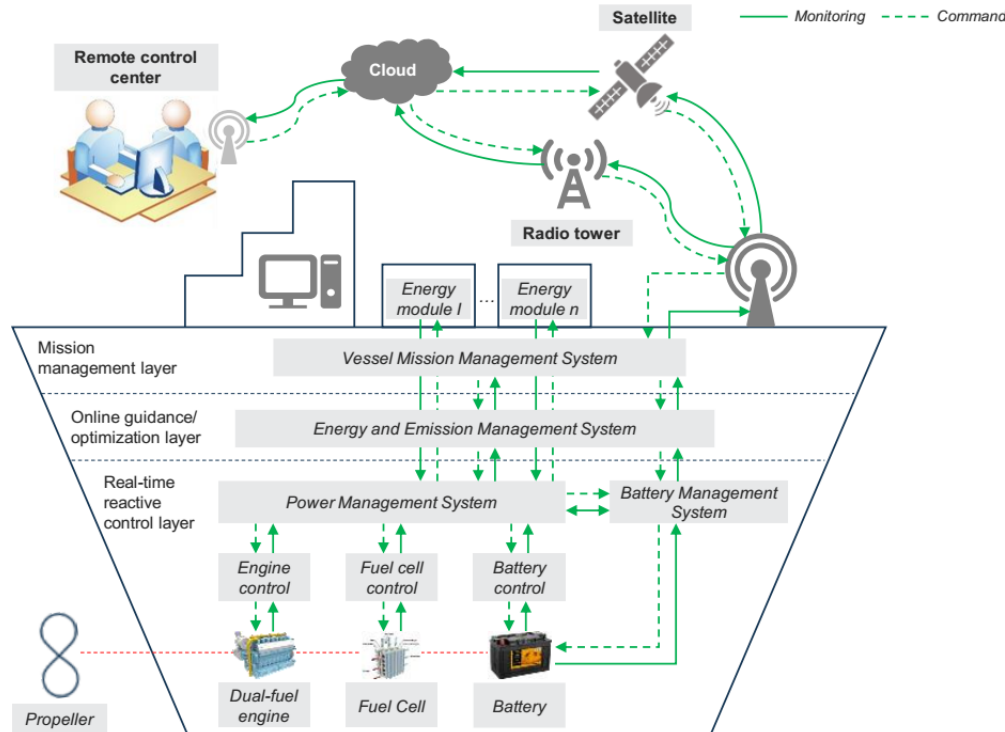
A replica of an ancient galley, at Saronic gulf in southern Athens.
Source: VOA, "Ancient Mariners: Greek Navy Offers Taste of Life in Galleys."

Phoenician ship.

Source: Maritime Manual, "The History of Ships – An Insight into the Ancient Maritime World."



But smart green!



From electrification to sustainability

Integrated power and control system.

Hybrid energy technologies with smart control and monitoring.



Efficiency



Onboard decarbonization



Flexibility

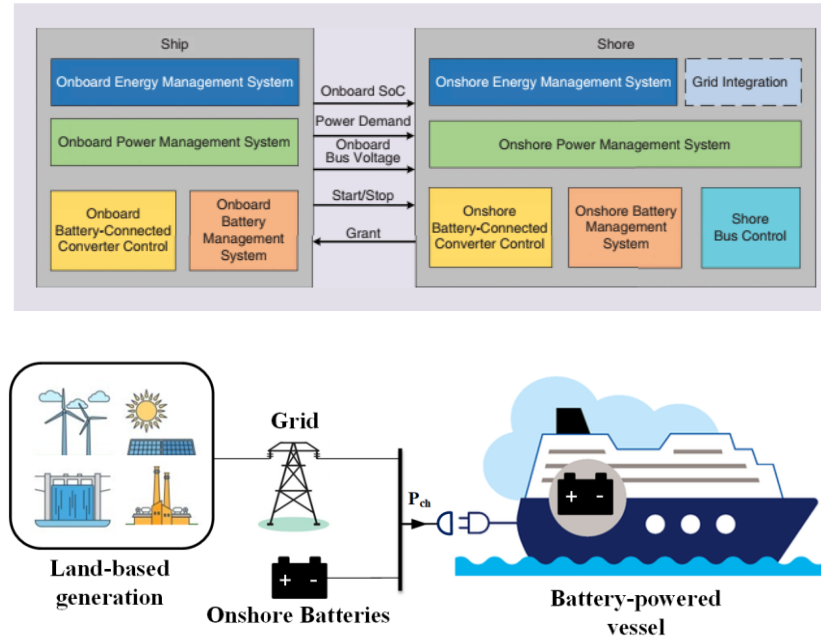


Reliability and autonomy

From shore and offshore to marine propulsion

Electrification for energy connectivity

Onshore power supply.
Bridging renewable energy on land and offshore to the onboard power and propulsion systems.

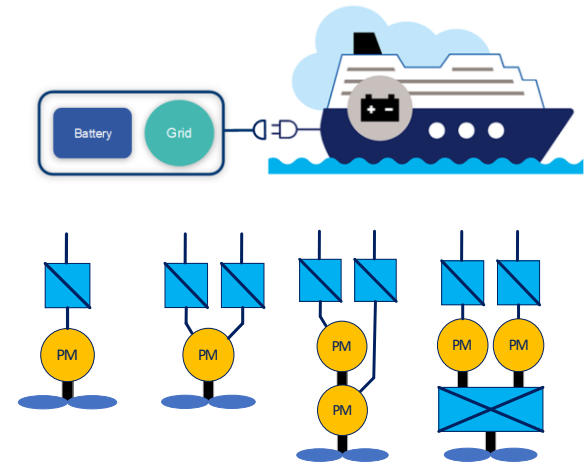
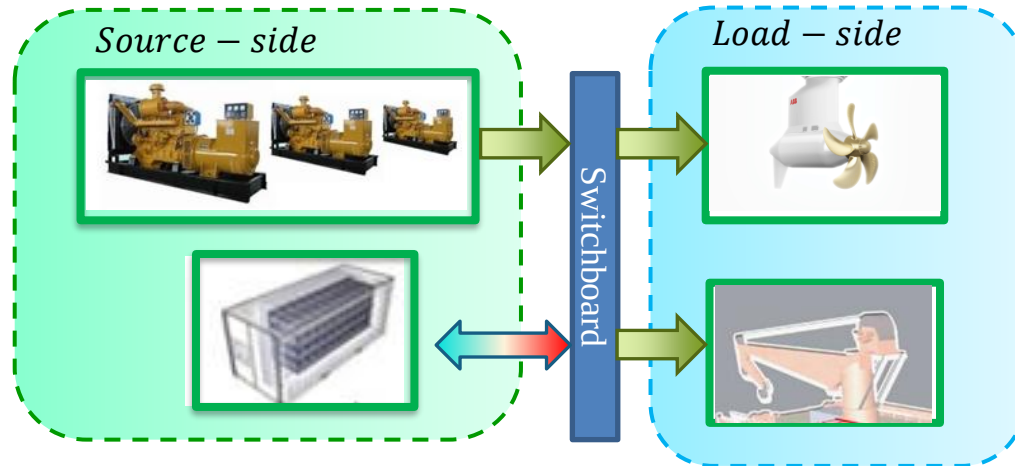


S. Karimi, M. Zadeh and J. A. Suul, "Shore Charging for Plug-In Battery-Powered Ships: Power System Architecture, infrastructure, and Control," in *IEEE Electrification Magazine*, vol. 8, no. 3, pp. 47-61, Sept. 2020.

Electrification $\neq$ "batterification"!

Electrification recipe:

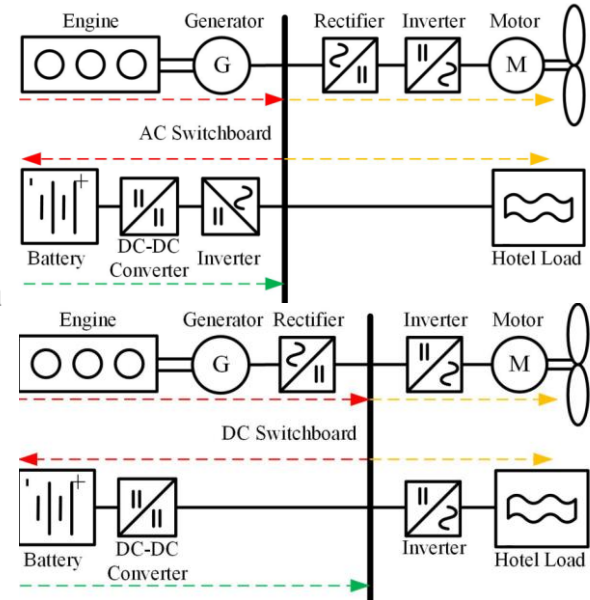
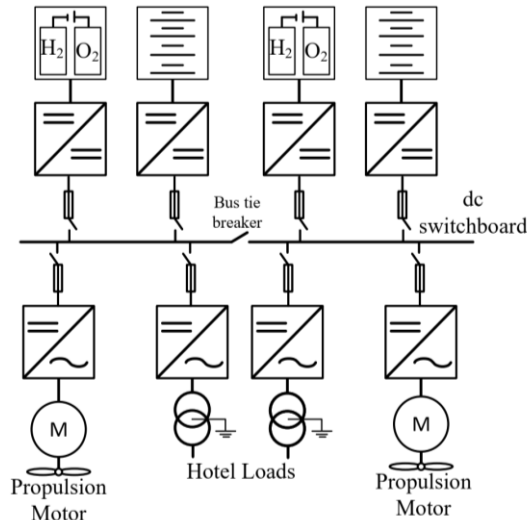
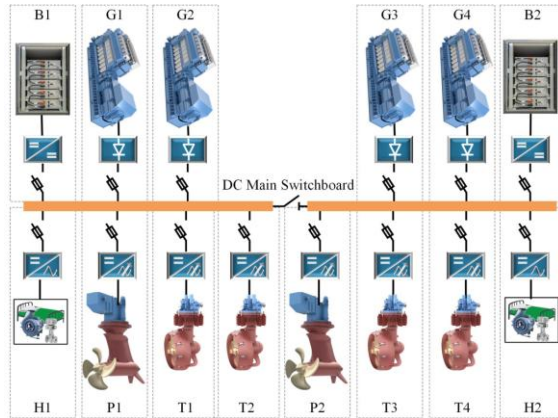
- Establish a pool of electric energy by all electric power transmission and distribution.
- Electrify both the source of power and the load (propulsion system and onboard load).
- Get benefit of Energy Storage Systems (ESS): batteries, supercapacitors, hybrid ESS, etc.
- Design a good control system: power and energy management system (PEMS).
- Establish the connection to shore power.



Battery for everybody, in one way or another!

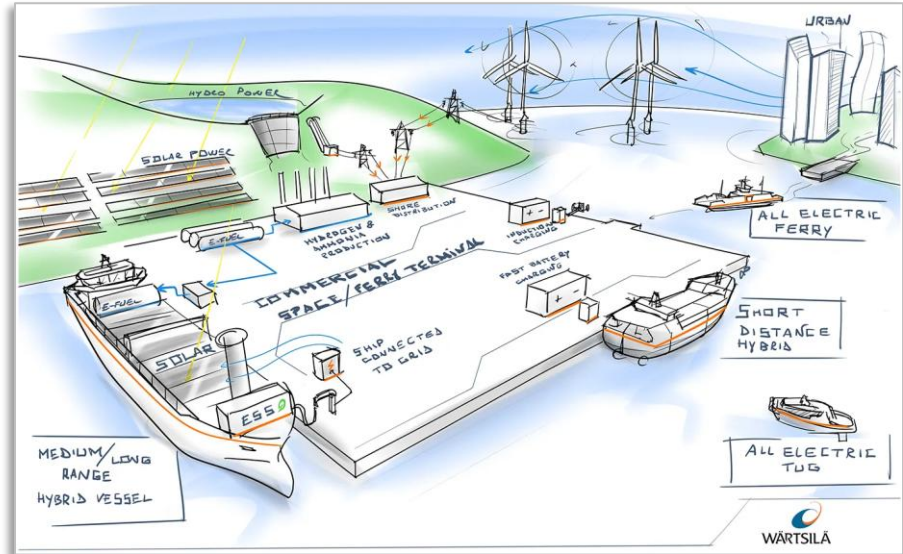
Hybridization comes with the diversity

- Batteries are a key enabler for Hybrid Power Systems.
- Can be integrated to both AC and DC onboard grids.
- Can be energy saving even just as an energy buffer.
- And can be part of various vessel types.



Bridge to net-zero

- Greener energy technologies
 - ✓ Shore connection
 - ✓ Energy storage
 - ✓ Fuel cells
 - ✓ Renewable energy (wind and solar)
- Alternative and emerging fuels
 - ✓ Hydrogen
 - ✓ Ammonia
 - ✓ Bio-Fuel
 - ✓ E-Fuel



Ship Electrification Solutions (Source: Wartsila.com).

Energy efficiency and fuel saving

Efficiency estimation

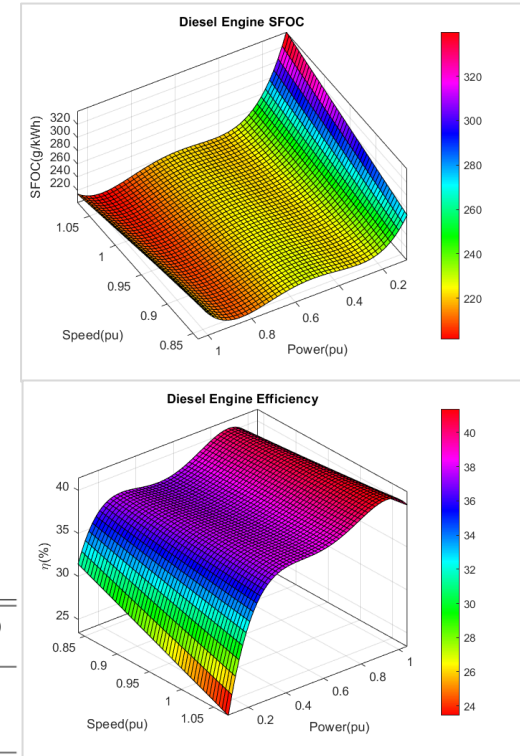
- Load estimation
- Static efficiency or technical efficiency
 - Rated efficiency.
 - Peak efficiency.
 - Full load efficiency.
- Load dependent efficiency
 - Power efficiency and energy efficiency
 - Needs proper modeling!

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{in} - P_{loss}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{loss}}$$

$$\eta_p(t) = \frac{P_{out}(t)}{P_{in}(t)} = \frac{P_{Load}(t) + P_{Batt,ch}(t)}{P_{Fuel}(t) + P_{Batt,disch}(t)}$$

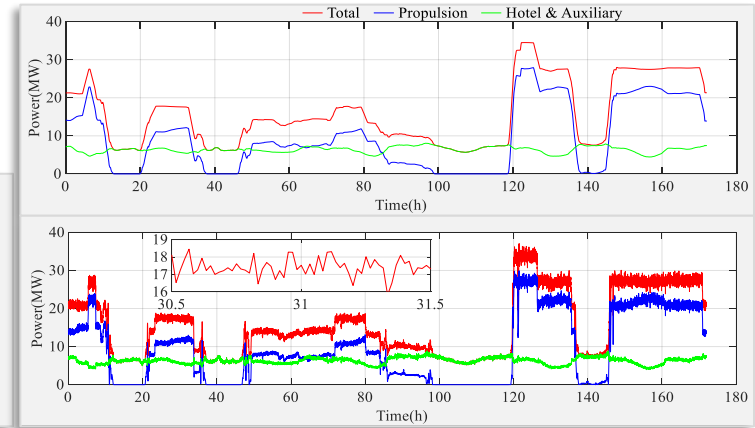
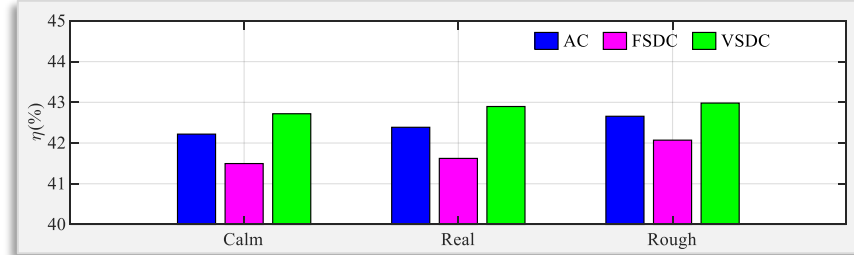
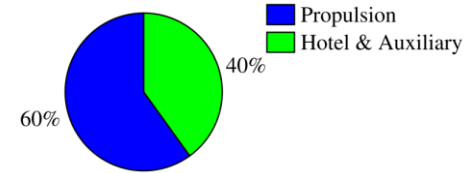
$$\eta_e(t) = \frac{\int P_{out}(t)dt}{\int P_{in}(t)dt}$$

Engine Type	Emission Factor (kg NO _x /Tonne Fuel)	
	NO _x Fund	DNV
Slow speed	73	78
Medium speed	53	55
High speed	41	46



Effect of the power system architecture

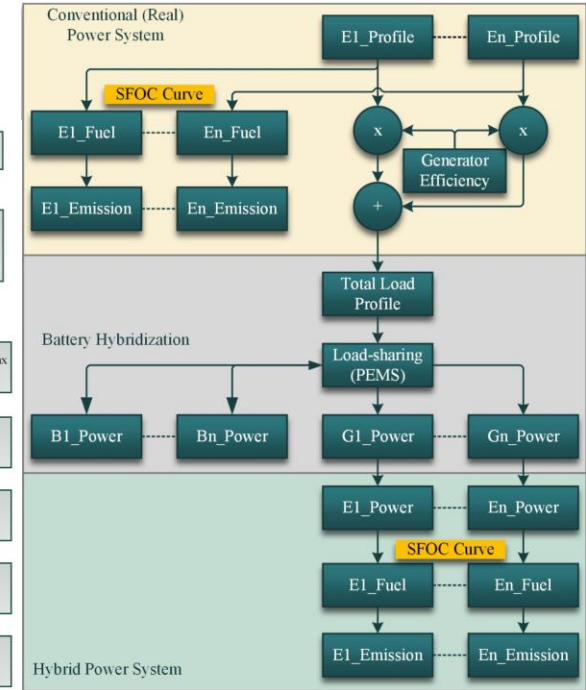
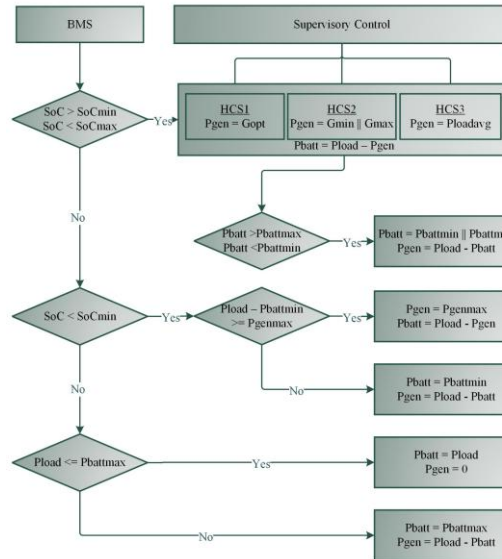
- A case study of a cruise vessel (battery only as energy buffer).
- 3 scenarios: AC, DC with fixed speed machine, and DC with variable speed machine
- Demonstration using smooth and fluctuating load power; representing calm and rough sea
- Similar efficiency trend in all three power system architectures.
- Battery performs slightly better in fluctuating load.



P. Ghimire, M. Zadeh, J. Thorstensen and E. Pedersen, "Data-Driven Efficiency Modeling and Analysis of All-Electric Ship Powertrain: A Comparison of Power System Architectures," in *IEEE Transactions on Transportation Electrification*, vol. 8, no. 2, pp. 1930-1943, June 2022.

Effect of the control strategies

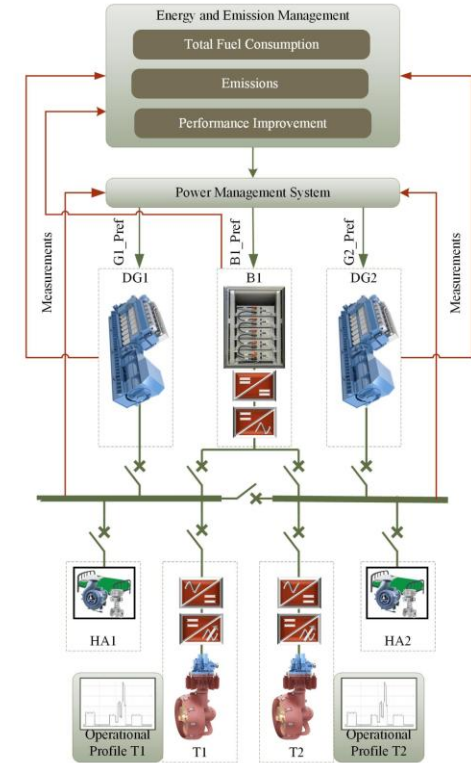
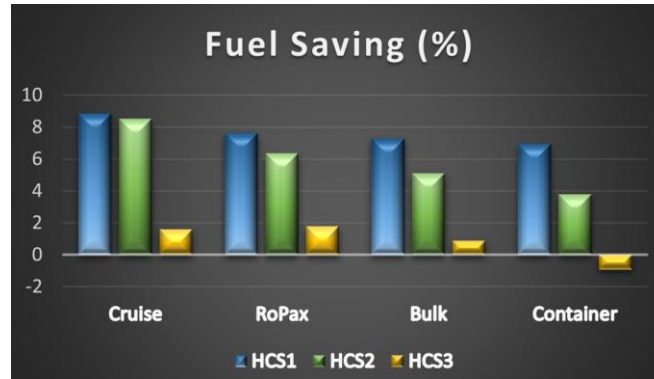
- A systematic methodology for efficiency and emissions analysis.
- Including the effect of power and energy management system: load sharing (PEMS).



P. Ghimire, M. Zadeh, S. Thapa, J. Thorstensen and E. Pedersen, "Operational Efficiency and Emissions Assessment of Ship Hybrid Power Systems with Battery: Effect of Control Strategies," in *IEEE Transactions on Transportation Electrification*, vol. 10, no. 4, pp. 8543-8556, Dec. 2024.

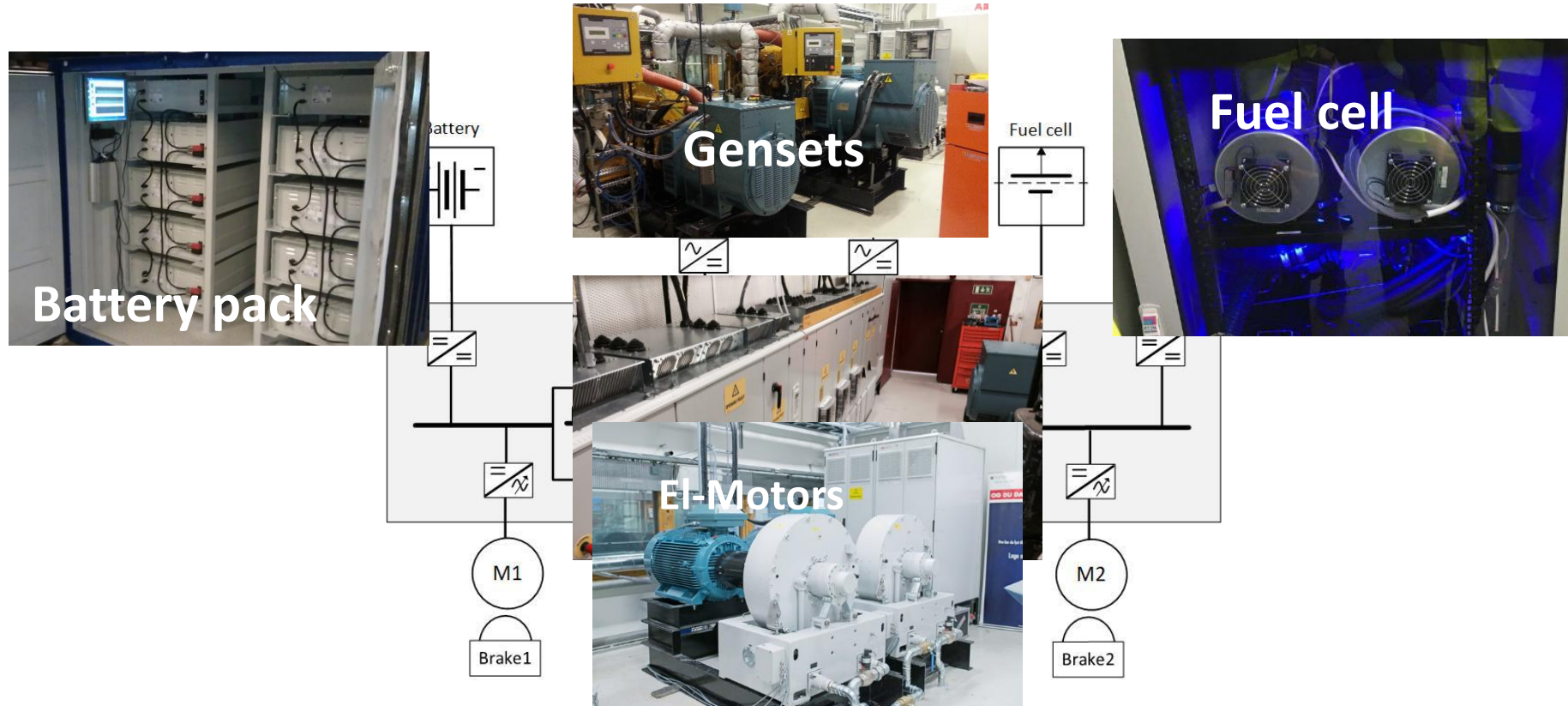
Effect of the control strategies

- Fuel saving is highly dependent on the load sharing scenarios.
- Although it is hard to make the battery unprofitable!



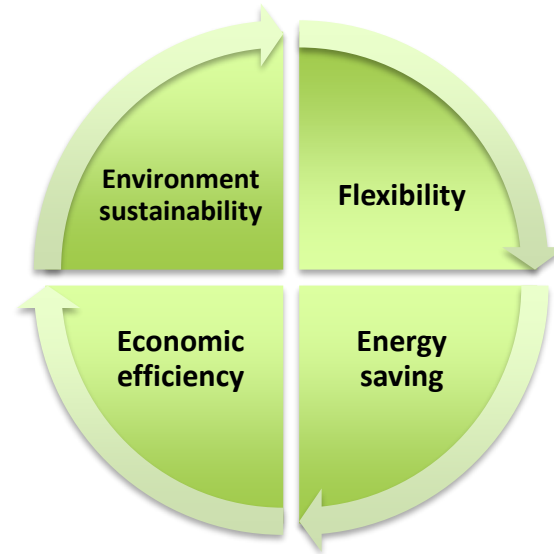
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Fuel saving by experiment (Hybrid Power Lab)



Summary

- Shift in energy scenarios
 - ✓ Electrification
 - ✓ Alternative fuels
- Technical and technological solutions
 - ✓ Power and propulsion design, grid architecture, hybrid and DC grid
 - ✓ Control strategies (PEMS)
 - ✓ Modeling and monitoring tools



Thank you for your attention!

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