NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Electrification of Singapore Harbour Craft – Shore and Vessel Power System Considerations

Presented by **Dr Sze Jia Yin**
Research Lead
Maritime Energy & Sustainable Development Centre of Excellence

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Introduction to Electrification of Harbour Craft

Electrification of Harbour Craft explores one or a combination of these possibilities

- Electric propulsion and systems
- Energy storage systems
- Hybrid propulsion or power
- Shore power

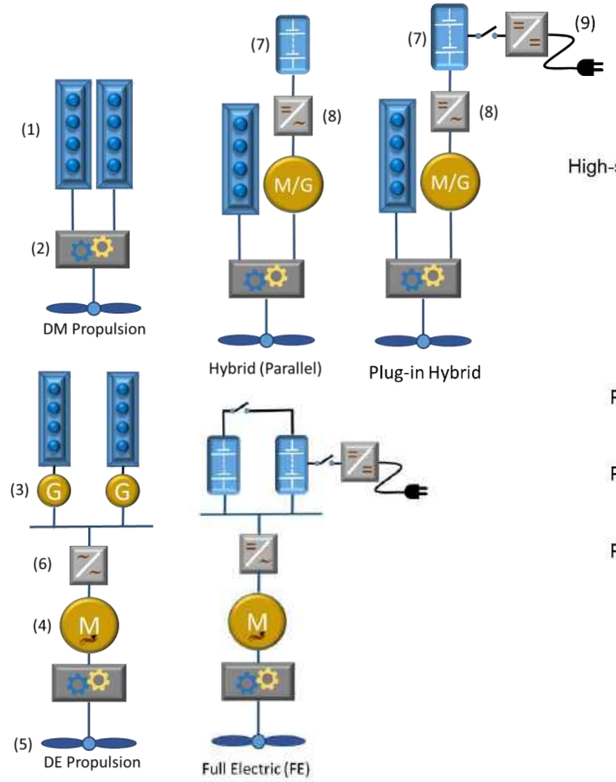
Benefits of electrification beyond carbon emissions reduction:

✓ Improve efficiency of internal combustion engine
✓ High torque at low-speed engine mode
✓ Reduce maintenance costs
✓ Zero ship-board emissions in full-electric mode
✓ Low-noise and vibration levels

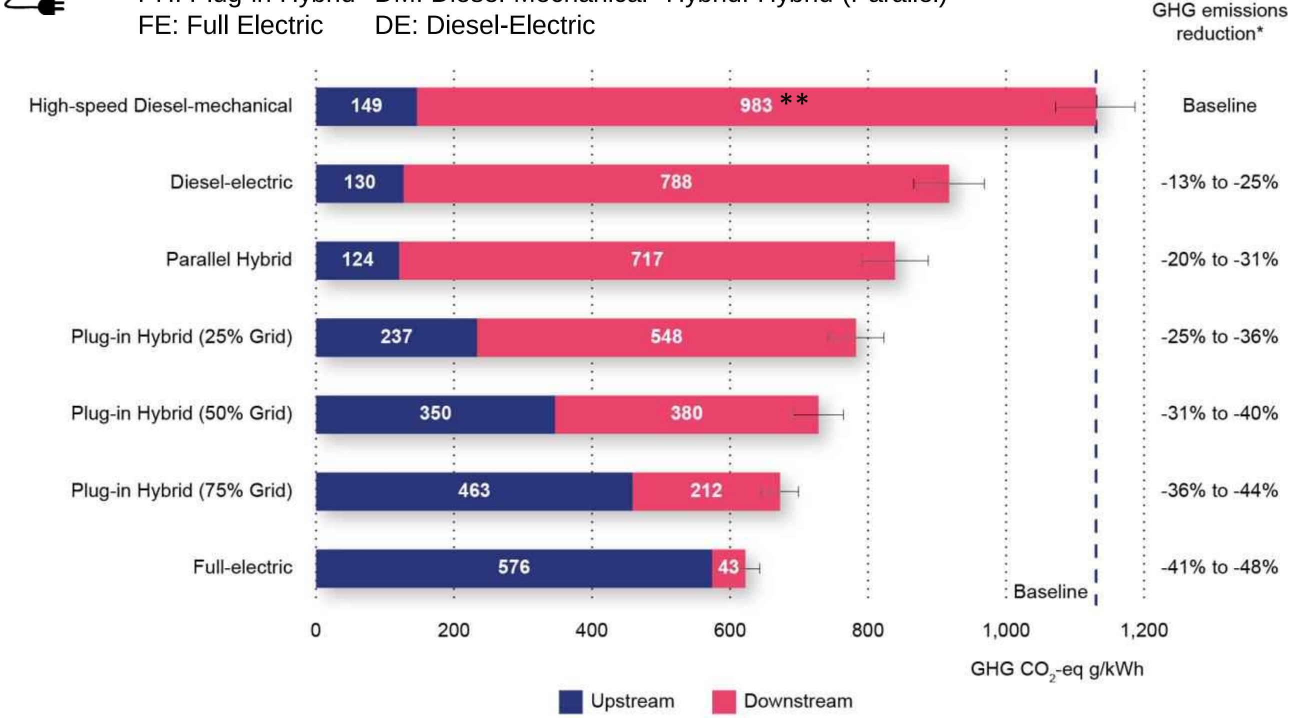
Considerations in the Electrification of Harbour Craft

Harbour craft owners	• Higher capital investment of electrified power systems in comparison to internal combustion engines • Availability and convenience of charging points • Change to the vessels' operation profiles and refuelling frequency • Re-training for the crew on operating shipboard systems, recharging and maintenance • Actual fuel savings during operation and incentives to use electricity
Authorities	• Carbon emissions reduction to meet Singapore's enhanced Nationally Determined Contributions • Uncertainty on standards for fast-charging infrastructure for harbour craft • R&D for electrification to be a competitive alternative fuel or power option • High infrastructural costs to develop a charging network • Impact to the power quality if significant power is drawn simultaneously • A lack of access to the main grid for smaller islands and the anchorage areas

GHG Emissions Reduction Potentials – High Speed Engine



PH: Plug-in Hybrid DM: Diesel-Mechanical Hybrid: Hybrid (Parallel)
FE: Full Electric DE: Diesel-Electric



(1) Combustion Engine
(2) Gearbox
(3) Genset

(4) Electric Motor
(5) Propeller
(6) AC-AC converter

(7) Battery
(8) DC-AC inverter
(9) Plug-in Battery with charge controller

**Based on average thermal efficiency during actual operation

*Excluding emissions from production of battery

Life cycle assessment of energy use = Upstream + Downstream emissions

Shore and Vessel Power Considerations

Types of Charging Infrastructure

Charging Locations	Considerations
I. **Berth** *existing pier structure*	• Often designed with medium or high-power rating to reduce recharging time • Easiest to implement among the four types due to land-based infrastructure and use of existing berths and main grid • Harbour craft require to remain at berth during recharging • Use of medium-voltage equipment requires more safety regulations
II. **HC Anchorage** *anchorage areas for HCs, include breakwater areas*	• Low to medium power charging improves battery life cycles • Low-power stations have lower electrical and electronic components costs • Allow charging to coincide with idle or rest durations • Electrical connection from anchorage to shore power is dependent on actual distances
III. **Floating Platform** *a purpose-built platform extended from the existing pier*	• Often designed with medium or high-power rating to reduce recharging time • Flexible platform may include other functions, such as terminal batteries, the supply of fresh water, etc. and towed to different locations, and for use in areas with no berth and mooring infrastructure • Require design and building of a purpose-built platform
IV. **Floating Power Barge** *powered with alternative fuels*	• Not dependent on grid supply and able to be implemented in areas with no power plant • Require design and building of purpose-built platform with its genset and/or ESS system • Require the supply chain for alternative fuels to be supplied to the power barge

Sizing a Charging Infrastructure

STEPS

1 Understand operations and power requirements of vessels

- Power requirements and load factors during different operation modes and wave conditions
- Average and maximum distances per trip

2 Sizing the storage capacity of ship batteries

- Sizing of batteries to meet operations + spare capacity
- Select type of batteries to optimise power and energy
- Decide plug-in hybrid or full-electric

3 Selecting rated power and AC/DC type for charging station

- Charging time determines the rated power, current rating and HT/LT
- Voltage/Current determines feasibility and safety of connections

4 Planning the power load (kVA) required during peak loads

- Peak loads determine the switchroom's designed load
- Sufficiency of grid supply determines the need to build terminal batteries

Use of Li-ion batteries

- ✓ Storage capacity expected to be in the range of 100 kWh to 6 MWh
- ✓ Encourage frequent recharge
- ✓ Mature Li-ion cell technologies expected in the short-term
- ✓ Expect continuous improvements to be made for auxiliary systems to reduce size and weight
- ✓ Second-life use of battery system and battery recycling is encouraged

Case Studies of Local Harbour Craft

Case Studies of Local Harbour Craft

Vessel	Fast Launch SP (≤12 pax)	Passenger Ferry SP (>12pax)	Lighter	Tugboat Bollard pull 57 tonnes
Type of Main Engine	Four-stroke, high-speed diesel	Four-stroke, high-speed diesel	Four-stroke, high-speed diesel	Four-stroke, high-speed diesel
Main Engine (kW) x No	331 x 2	320 x 2	167 x 2	1,864 x 2
SFOC g/kWh	215	215	220	209
GT	30.5	59	30	473
Cruise Speed (knots)	20-23	10-11	11-14	9-10

Fast Launch

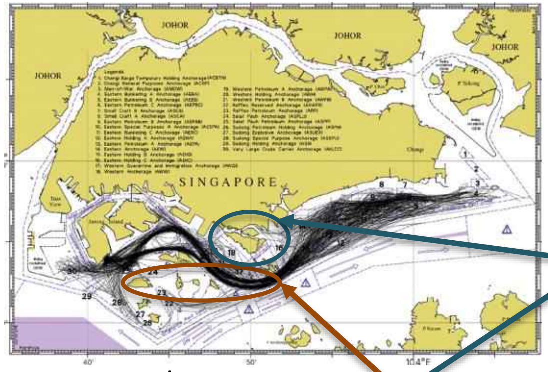
Passenger Ferry*

Lighter

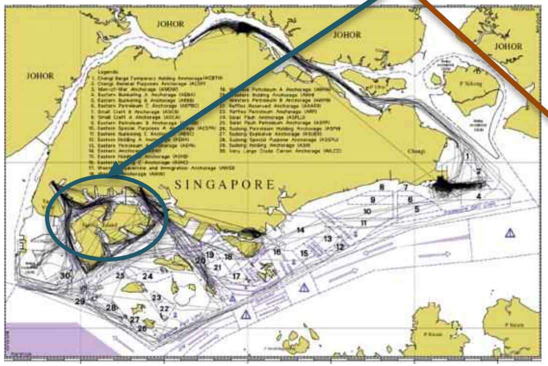
Tugboat

Generic photos of harbour craft in their categories, Source: MESD
*Photo courtesy: Singapore Island Cruise and Ferry Services

Power Infrastructure for High-power Charging Stations



*SP: Passenger



*ST: Tug boat

Sufficient & reliable?

Potential charging locations for harbour craft in case studies

Main Grid (port terminal, jetty, piers, sheltered breakwaters as anchorages for HC)

- ✓ Reliable and Available
- ✓ Grid Emission Factor 0.4188 kg CO_2/kWh
- ✓ Integration with renewables and CO_2 capture technologies

*Jetty and piers have limited power demand

Southern Islands

- ✓ Harbour Craft routes are well-distributed
- ✓ Some islands are connected by underwater utility lines

*Limited electrical power demand on most islands

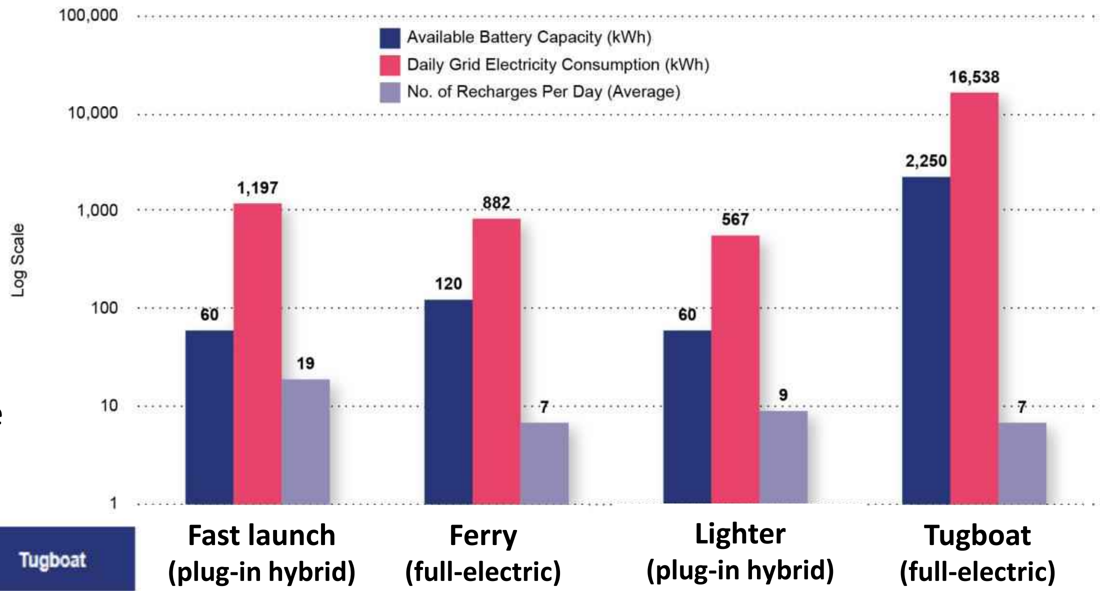
*Some islands still rely on diesel generators or has limited solar capacity for high-power charging stations

*Source: MESD “A Study on the Future Energy Options of Singapore Harbour Craft”

Number of Recharges for Electrified Harbour Craft?

Case Studies estimate:

- ✓ The battery capacity in kWh available to the harbour craft at full recharge
- ✓ No. of recharges per day is based on no. of round-trips for plug-in hybrid
- ✓ No. of recharges per day for full-electric needs sufficient ESS capacity to travel to next stop
- ✓ Grid electricity consumption determines the recharge time



Vessel	Fast Launch	Passenger Ferry	Lighter	Tugboat
	SP (≤12 pax)	SP (>12pax)		Bollard pull 57 tonnes
Installed ESS (kWh)	75	270	75	5,000
Available ESS (kWh)	60	120	60	2,250
Charger Power (kW)	350	350	350	4,000
Recharging Time (min)	17	34	17	34

Based on the assumptions

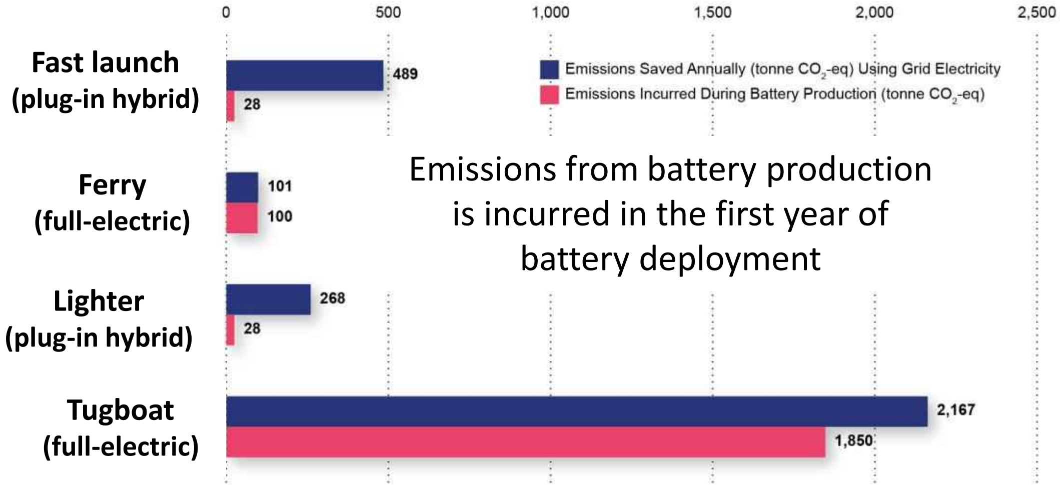
- Power requirements similar to average daily loads
- ESS occupies as much volume as current fuel tanks
- Mass of ESS is not considered a design factor
- Recharging schedule should not affect round-trip operation

Emissions Savings from the Case Studies

Emissions savings from

- ✓ Higher efficiency of electric drivetrain
- ✓ Peak shaving with energy storage
- ✓ Lower emission factor of grid electricity using existing power plants
- ✓ Frequent recharging using high-power charging station

Emissions in the first year (tonne CO_2-eq)



Emissions from battery production is incurred in the first year of battery deployment

Baseline

- Current fuel consumptions, MGO as fuel and average thermal efficiencies of engines in operation

Electrification of harbour craft

- Plug-in hybrid: Onboard ICE and recharges ESS with grid electricity
- Full-electric: Grid electricity recharging after a round-trip or at each stop

Total Cost of Ownership

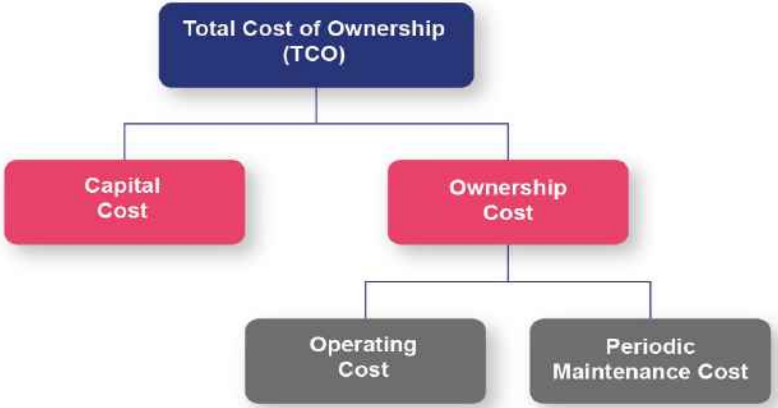


Photo courtesy: Singapore Island Cruise and Ferry Services

Cost parameters for electric harbour craft

Capital	Operating	Periodic Maintenance
• Pre-acquisition • Initial price • BMS, battery packs • Residual value • Disposal cost	• Financing • Licensing • Manpower • Consumables • Insurance • Others	• Battery replacement • Others

Total Cost of Ownership Model (TCO) – on-going work

- ✓ Total costs in owning and operating an asset
- ✓ Look beyond purchase price and short-term savings
- ✓ Focuses on the long-term benefits for acquiring a product with a long lifetime
- ✓ Identification of key cost parameters and estimation of unknown costs are the critical parts of the model

Electrification of Harbour Craft | Conclusion

Source: MESD

- ✓ Promising GHG emissions reduction
- ✓ Increasing global trend by short-sea or coastal vessels
- ✓ Power generation is moving towards low-carbon future and use of electrified vessels complement alternative fuels

A holistic approach to work towards

- More favourable economic and operating profiles for harbour craft owners
- Off-grid power generation infrastructure to support high-power and frequent recharging
- Standardisation in electrical system integration and charging infrastructure
- Development of innovative charging infrastructure for sheltered port waters and near harbour craft's anchorage areas

Thank you

Contact MESD:
D-MESD@ntu.edu.sg

For more information, please visit MESD website http://coe.ntu.edu.sg/MESD_CoE