Maritime Sustainability Journey to Net Zero

CARES 10 Year Symposium

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Professor Ric Parker CBE, PBM, FREng

Chairman Science & Technology Advisory Panel

Technology Centre for Offshore and Marine Singapore (TCOMS)

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Agenda

- Problem definition
- Pathways to zero carbon for maritime
- Fleet modernization
- Technology improvements for design and operation
- Future fuels for zero carbon
- Decarbonizing shipbuilding and rig construction
- Decarbonizing ports
- Technology priorities for Singapore
- Conclusion.

Is there a problem?

- Marine transport is already one of the lowest carbon/tonne/km

BUT

- The total km are huge and the total tonnage is huge
- Marine transport produces 5% of anthropogenic CO2
  - The same as all land transport
  - Nearly twice as much as air travel
- Land and air have credible strategies to get to net zero.

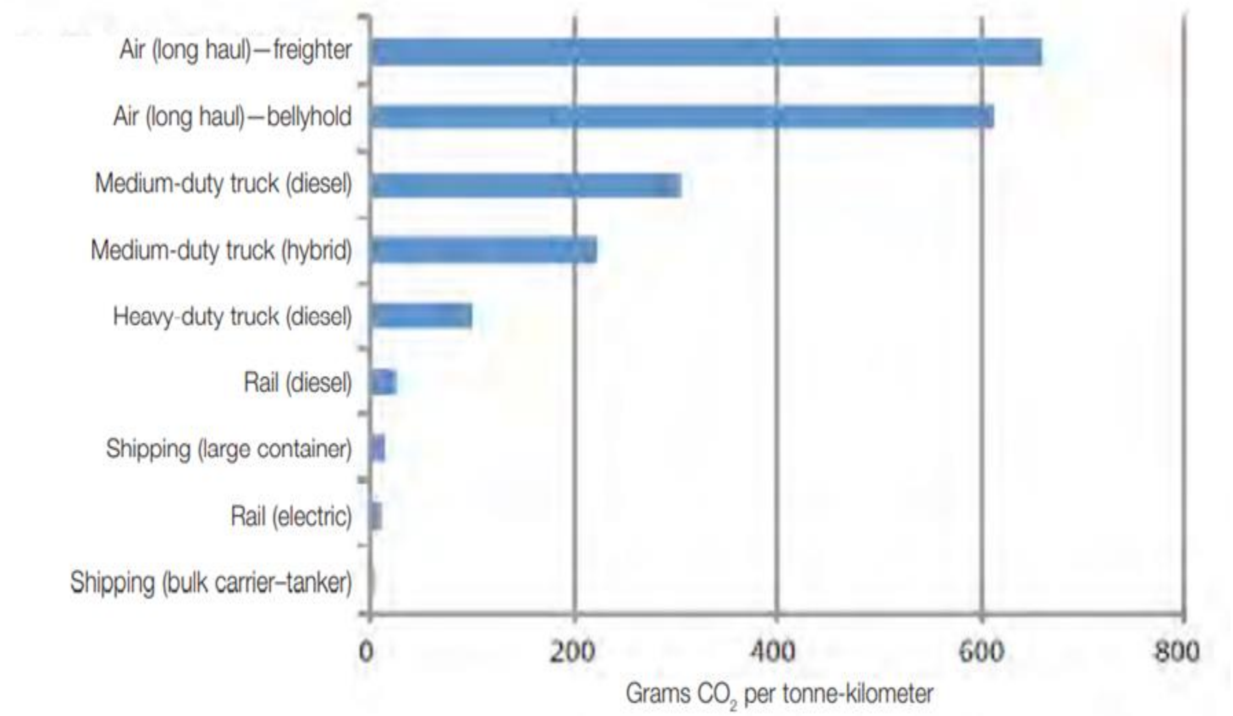
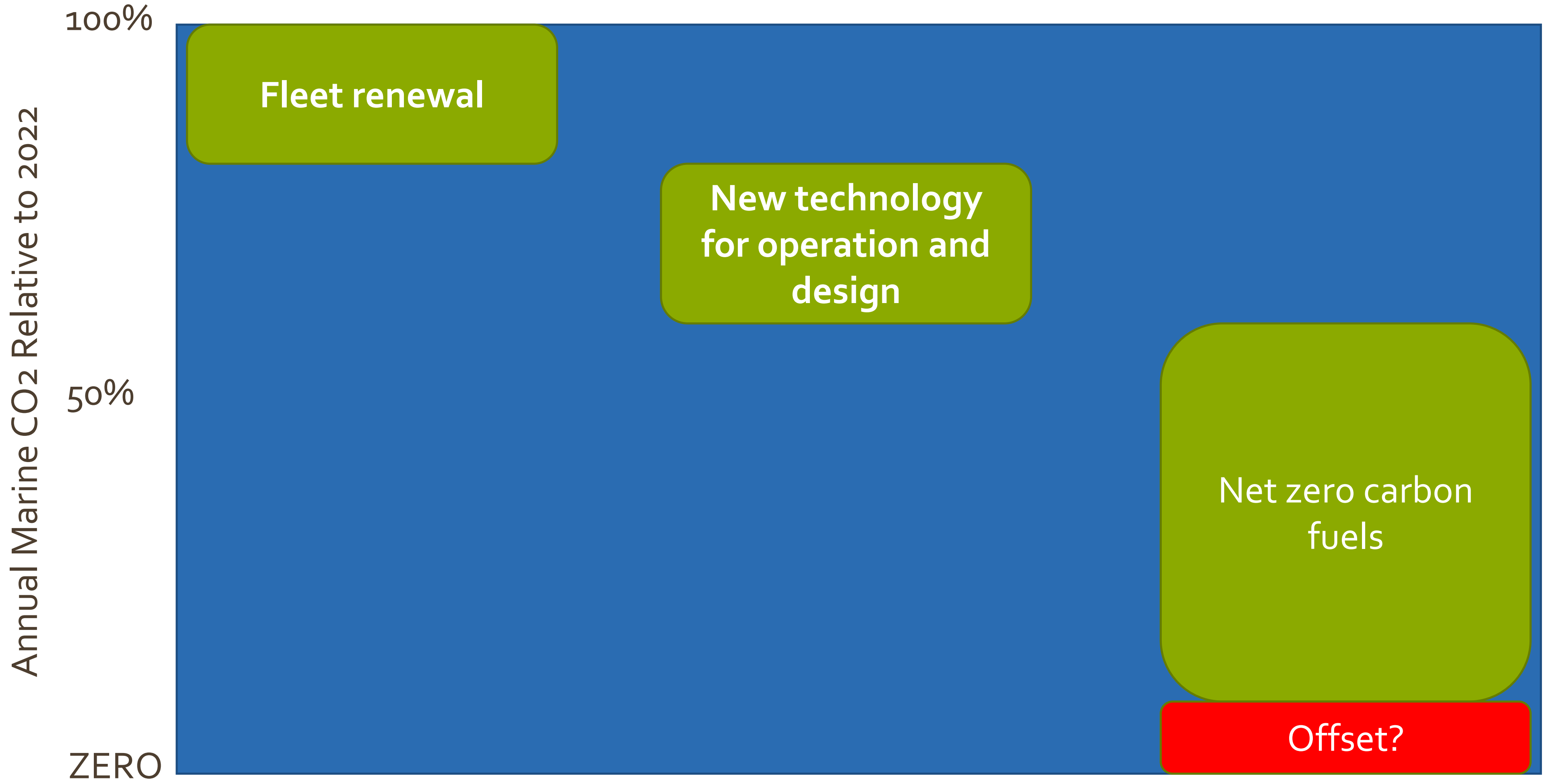


FIGURE 2 Average carbon intensity of freight transport modes (2, 4).

Pathways to zero carbon



Fleet modernisation

- Current average age of fleet:
  - Bulk carriers, container ships, tankers, *

    9.3-10.4 years
  - General cargo

    20 years
- Replacing all ships over 10 years old would reduce global CO_2 emissions by

  Approximately 15-20%**
- Technology: Ship design and propulsion system efficiency.
  - e.g. Xbow™ and Wevepiercer™ designs reduce fuel burn by 10-15%
- Larger ships produce less CO_2/T/km

*85% of world cargo dead-weight ton percentage
** This will happen naturally by ~2035, but may need to be accelerated

Technology improvements in design and operation

- Further improvements in ship design
  - Active control, better sea-state data.
  - Improved propulsion systems: surface-breaking propellers, exhaust recirculation, etc.
- Autonomous shipping
  - Reduces hotel load, more space for cargo, cleaner superstructure reduces wind resistance.
- Just-in-time port operations:
  - reduce waiting time, reduce average speeds, increase utilisation.

Zero carbon and net zero fuels

	MJ/kg	MJ/L	Wt of Fuel[1] Tonnes	Volume of fuel M3	CO2 T/T	CO2 T	Tank to Shaft Efficiency
HFO	41	39	16,186	17,037	3.11	50,402	50%
Marine Diesel	44	40	15,082	16,758	3.21	48,353	50%
LNG	52	22	12,762	29,678	2.76	35,222	50%
LPG	46	23	14,426	24,873	2.60	37,552	50%
Methanol	22	17.5	30,164	38,134	1.37	41,325	40%
Synthetic Marine Diesel	44	40	15,082	16,758	Net Zero[3]	Net Zero[3]	50%
Ammonia (Combustion)	19	11	34,927	57,257	0.00	0	40%
Ammonia (Fuel Cell)	19	11	23,284	38,171	0.00	0	60%
Liquid H2 (combustion)	120	8.5	5,530	77,888	0.00	0	40%
Liquid H2 (Fuel Cell)	120	8.5	3,687	51,926	0.00	0	60%
Battery today (200wh/kg)	0.72	1.8	485,094	420,187	0.00 [2]	0	95%
Battery 2035 (500wh/kg)	1.8	5.2	194,037	168,075	0.00 [2]	0	95%
Uranium	3,900,000	74,100,000	0.24	0.01	0.00 [2]	0	35%

[1]Ship = Emma Maersk Container Ship 6284L/Hour 80MW 123 days at optimum efficiency

[2]Assumes zero-carbon footprint of production

[3]Assumes air-capture CO2, green hydrogen and green power to produce

New and zero-carbon fuels - 1

Fuel	Pros	Cons
LNG	Engines already available. Dual fuel possible. Relatively low cost	Still very significant carbon footprint (73%)
LPG	Engines already available. Dual fuel possible. High cost	Still very significant carbon footprint (78%)
Methanol	Minor modification to existing engine types. Relatively cheaply produced from bio-feedstock	Half range for a given vessel Limited CO_2 impact if fossil derived – 15% Bio-fuel ~-80% net carbon
Synthetic marine diesel	Drop-in for existing ships. Net zero carbon if produced from CO_2 capture and green hydrogen	No established supply chain Likely to be very expensive initially (pending higher carbon tax)

New and zero carbon fuels - 2

Fuel	Pros	Cons
Ammonia	Established world supply chain Easy to store Vessels for transport of ammonia established Zero-carbon, if made using green energy NOx and carbon-free in fuel cells.	Toxic Stress-corrosion cracking in fuel systems and engines. Need to optimise combustion. Significantly reduced range for given tankage. Possibly higher NOx if combusted.
Hydrogen	Zero carbon Can be produced relatively cheaply with SRM and CCS Options for combustion, or fuel cells. Significant weight advantage increasing tonnage of cargo.	Explosive Expensive currently with green production. Reduced range for give volume of tankage Storage at very low temperature and/or high pressures.

New and zero carbon fuels - 3

Fuel	Pros	Cons
Battery electric	Zero carbon	Safe? Very heavy. Very expensive. Limited world supply chain.
Nuclear	Zero carbon Very low fuel cost over lifetime	Public perception Very high capital cost (off-set by fuel cost over lifetime)

Introduction of alternative fuels by ship type and year

2025 2030 2035 2040 2045 2050

Ferries
- Hydrogen fuel cell
- Battery

Tugs and harbour boats
- Battery
- Hydrogen fuel cell

Cruise liners
- Hydrogen fuel cell (for hotel load)
- Ammonia/Hydrogen main engines

Bulk carriers, container, tankers
- Synthetic sustainable fuels
- Ammonia

General cargo
- Fuel cell (hydrogen/ammonia)
- Synesthetic sustainable fuel

Industrial/offshore
- Hydrogen/ammonia combustion
- Synthetic sustainable fuel

Zero-carbon ship/offshore construction

- The most CO_2-intensive element of construction is steel.
- Can wait for the steel industry to decarbonize (this will increase the cost of steel)
- Alternatives:
  - Carbon-composite superstructures – reduce steel content and overall weight of the vessel/rig. Greater cargo capacity and less steel below the waterline
  - Current standards for shipping are a major barrier*
  - Return to wood. Locks away carbon for the life of the vessel and beyond.

* Standards for aerospace are functional (you can demonstrate equivalence for any new material), whereas standards for shipping are proscriptive (use this steel, this gauge)

Sustainable offshore operations

- The greatest problem is fugitive methane
  - ~30X worse per tonne than CO_2 for global warming.
- Reduce energy requirements offshore
  - Battery/hydrogen powered service vessels
  - Reduce steel in rig construction
  - Better processing of waste water
  - Composite risers
  - Rope instead of chains for anchoring
- Offshore energy generation
  - Offshore solar
  - Offshore wind (floating?)
  - Offshore biofuel (algae)
  - Offshore nuclear

Sustainable port operations

- Reduce energy and use green energy
- Hydrogen/battery-powered port vessels, vehicles and equipment
  - Electric vehicles for shoreside operation
  - Electric/hydrogen tugs
  - Electric barges for in-port/inter-port container transport
  - Hydrogen/battery vessels for local bunker transfer
- Reduce use of concrete in construction
  - Wood is good!
- Use AI for just-in-time operation to reduce waiting time and steaming speeds.

Technology/Research priorities for Singapore - 1

- Decarbonisation of hydrogen production through CCUS
- Decarbonization of Ammonia production through CCUS
- Hydrogen/battery powered port vehicles and equipment
- Catalysis for release of hydrogen from carriers (MCH, Ammonia, etc)
- Efficient Ammonia combustion (low NOx)
- Fuel cells to work directly with Ammonia
- Effective and safe Hydrogen combustion (low NOx)
- Bunkering systems for Ammonia and Hydrogen
- On ship storage of Hydrogen
- Effective and accurate metering of liquid Hydrogen and Ammonia

Technology/Research priorities for Singapore - 2

- Marine electrification
  - especially power electronics and battery management systems.
- On ship carbon capture
- Offshore/floating solar
- Offshore/floating wind
- Offshore biofuel (algae)
- Offshore nuclear
- Transport and at-sea disposal of captured CO_2
  - Carbon hydrates?

Thank You