Summary of Workshop Outcomes [DRAFT – do not cite]

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Goal and outputs for this workshop

- Goal:
  - **Identify the most appropriate black carbon control measures for international shipping**
- Outputs:
  - Workshop report
  - PPR 6 INF paper containing the workshop report
  - PPR 6 member state submission identifying “appropriate” control measures for international shipping based on IMO’s BC Correspondence Group and this workshop

Defining terms: control measures vs. control policies

- For the group to consider, we propose:
  - **Control measure** means a technology or operational practice that reduces black carbon from the source.
    - Examples include use of distillate fuel, aftertreatment technologies like scrubbers or DPFs, and slow steaming.
    - This is the proposed scope of this workshop.
  - **Control policy** means a government regulation or policy that requires or promotes a control measure.
    - Examples include Emission Control Areas, the Energy Efficiency Design Index, or carbon pricing.
    - We propose not trying to identify appropriate control policies at this workshop.

Key themes from Day 1 presentations

- General
  - Many BC control measures to consider, some short term. Further prioritization is needed.
  - Not all PM reduction measures reduce BC.
  - Climate impact of BC is complex – science moving away from GWP to more holistic metrics like GTP.
  - Unlikely to be a “one-size fits all” control technology for marine engines.
  - Policy action beyond just IMO, especially for smaller vessels.

Key themes from Day 1 presentations

- Control measures
  - LNG is very effective at reducing BC but methane slip needs to be considered
  - Fuel S content has little direct effect on BC emissions; other fuel properties have a larger influence
  - Oxygenated biofuels can reduce BC compared with residual fuels
  - Scrubbers do not significantly reduce BC in most cases.
  - DPFs have reduced BC by >90% for smaller (< 1 MW) marine engines when paired with distillate fuels
  - ESPs can reduce BC >90% but few ship installations exist at the moment
  - Engine tuning can reduce BC, but quantification of that reduction is difficult.
  - ZEVs are zero emissions and emit no BC or any other air pollutant at the source.

Key themes from Day 1 presentations

- Other
  - Control measures should be evaluated based on a common metric.
  - We need a common baseline to measure effectiveness.
  - Interactions between control measures may need to be considered (e.g. distillate fuels and DPFs)
  - Criteria pollutant and GHG tradeoffs should be considered when identifying appropriate BC control measures
  - A BC measurement protocol will be needed before regulations are finalized

Considerations to identify “appropriate” BC control measures

[Starting note: safety critically important, discussed by the group, integrated into feasibility for this exercise.]

Considerations	Definition
Effectiveness	Magnitude of potential BC emission reductions that can be demonstrated consistently
Feasibility	Can be applied to a new or existing ship without unduly impacting operational performance, cost, or safety
Availability	Can be used in the maritime shipping sector in the short or mid-term[1]
Applicability	The set of engine types, technologies, fuels, and duty cycles where the measure can be used
Co-emitted pollutants	Impact on other air, liquid, and solid waste pollution from the ship
Other	Other considerations, including but not limited to enforceability, scalability, supply, infrastructure, space constraints, and enabling conditions.

[1] Short-term could mean before 2023, mid-term from 2023 to 2030. Other control measures could become available in the future.

Control measures vs. considerations (1 of 4)

Measure	Effectiveness	Feasibility	Availability	Applicability	Co-pollutants	Other
Liquefied Natural Gas (LNG)	High	High (New, N) Low (Existing, E)	Short-term	Gas or Dual-fuel engines	↑ CH4 (magnitude depends on design and duty cycle), ↓ CO2, NOx, SOx, and PM (magnitude depends on design), potential increase in formaldehyde	Limited bunkering infrastructure
Distillate	Low to Medium	High (N&E)	Short-term	All	↓ SOx & PM (magnitude depends on S content)	
Biodiesel	Medium	High (N&E)	Short-term	All	↓ SOx & PM NOx usually increases but magnitude varies	Limited supply and regulatory uncertainty (MARPOL reg. 18)
Water in Fuel Emulsions (WiFE)	Insufficient Evidence	Insufficient Evidence	Short-term	Insufficient Evidence	↓ NOx, ?PM	Needs more research but some ships are using WiFE
Methanol	Medium based on research to date; chemistry suggests could be High	High (N) Med (E)	Short-term	Diesel-cycle, dual-fuel	↓ NOx, SOx, & PM Potential increase in formaldehyde	Limited supply and bunkering infrastructure; IGF code for methanol needs to be completed

Control measures vs. considerations (2 of 4)

Measure	Effectiveness	Feasibility	Availability	Applicability	Co-pollutants	Other
Diesel Particulate Filters (DPF)	High	High (N) Med (E)	Short-term to Mid-term	High-speed diesel and medium-speed diesel for now and should be paired with distillate fuel with low S and ash content	↓ PM ↑ CO2 & solid waste	Space constraints for retrofits and waste storage; backpressure is a concern; need high enough exhaust temperature for regeneration unless burners are used (regeneration concerns in general), scalability to slow-speed diesel should be considered
SOx scrubbers (Exhaust Gas Cleaning Systems, EGCS)	Low but variable with design and fuel	High (N & E)	Short-term	SSD/MSD with HFO	↓ SOx & PM, ↑ CO2, liquid waste, & solid waste	Space constraints for retrofits and for waste storage
Exhaust Gas Recirculation (EGR) w/ Scrubbers	Insufficient Evidence	Insufficient Evidence	Short-term	SSD with HFO	↓ NOx, SOx, & P ↑ CO2, liquid waste, & solid waste	Space constraints for retrofits and for waste storage
Electrostatic Precipitators (ESP)	High	High (N), Medium (E) depending on space	Short-term to Mid-term	SSD with HFO	↓ PM (and SOx for wet ESPs) ↑ CO2, liquid waste, & solid waste	Space constraints for retrofits and waste storage; needs low exhaust temperature

Control measures vs. considerations (3 of 4)

Measure	Effectiveness	Feasibility	Availability	Applicability	Co-pollutants	Other
Diesel Oxidation Catalyst (DOC)	Not effective	High (N & E)	Short-term	HSD w/ ULSD* although one MSD with HFO has a DOC *Note: ULSD is not safe for use in larger marine engines	↓ HC, PAH, and CO, incr in CO2	Space constraints for retrofits, need high exhaust gas temp
DPF coated with Selective Catalytic Reduction (SCR) catalyst	High	High (N) Med (E)	Mid-term	HSD/MSD with distillate fuel for now	↓ NOx, PM ? CO2 ↑ solid waste	Available in road transport; space constraints for retrofits and waste storage; backpressure is a concern; need high enough exhaust temperature for regeneration unless burners are used (regeneration concerns in general), scalability to slow-speed diesel should be considered
Engine tuning with SCR/EGR	Low to Medium	High (N) Med (E)	Short-term	All	↓ NOx, PM, CO2, HC, CO	
Engine Control Technologies	Low to Medium depending on engine type	High (N) Med (E)	Short-term	All	↓ NOx, PM, & CO2	e.g. slide valves, common rail injection, electronically controlled engine
Full battery electric	High	High (N) Low (E)	Short-term to Mid-term depending on size	Short range	Zero Emissions	Weight; chemical leakage potential; materials availability for some battery chemistries

Control measures vs. considerations (4 of 4)

Measure	Effectiveness	Feasibility	Availability	Applicability	Co-pollutants	Other
Hybrid/Energy Storage	Low to Medium depending on duty cycle	High (N) Med (E)	Short-term	For ships with fluctuating load profile	↓ All	Space constraints; chemical leakage potential; materials availability for some battery chemistries
Hydrogen fuel cells	High	High (New) Low (Ex)	Short to Mid depending on size	Short range (compressed H2) Longer range (LH2)	↓ All	Limited supply and bunkering infrastructure; potential safety issues (flammability); limited materials availability for certain fuel cell components; regulatory hurdles
Slow steaming	Not effective to Medium depending on the engine technology and existing slow steaming operations	High (N & E)	Short-term	All	↓ in general, but could increase NOx and PM depending on engine	Enforceability is a concern; system-wide effects (additional vessel movements or vessels to maintain transport supply); safety with minimum power need to be addressed
Shore power	High while at berth	High (N) Medium to High (E) depending on the size of the ship	Short-term	All	Zero emissions from the ship at berth	Only mid-term applicability to near-Arctic ports; infrastructure requirements for ships and ports

Workshop consensus on “appropriate” BC control measures

Appropriate	Not appropriate	No consensus	Not evaluated
Fuel Type ○ LNG ○ Distillate ○ Biodiesel ○ Methanol **Exhaust Gas Treatment** ○ DPF ○ DPF w/ SCR ○ ESP **Engine and Propulsion System Design** ○ Engine tuning w/ EGR/SCR ○ Engine controls ○ Full BEV ○ Hybrid/power storage ○ Fuel cells [hydrogen, ammonia, etc.] **Other Measures** ○ Shore power	DOC	**Fuel Treatment** ○ WiFE **Exhaust Gas Treatment** ○ Scrubbers ○ EGR with scrubbers **Operation Measures** ○ Slow steaming	**Fuel Type** ○ Nuclear **Fuel Treatment** ○ Colloidal catalysts **Exhaust Gas Treatment** ○ SCR with scrubbers ○ EGR or SCR without engine tuning **Engine and Propulsion System Design** ○ Slide valves [already common] ○ Engine stroke type ○ Engine rating **Ship Design** ○ Improving energy efficiency of new ships ○ Improving energy efficiency of existing ships **Operation Measures** [already common] ○ Engine Load ○ Voyage optimization ○ Training and crew awareness ○ Trim optimization ○ Adaptive engine/condition based maintenance **Regulatory Measures** [All – beyond scope] **Other Measures** ○ Promote ship recycling [beyond scope]