Evaluation of the Feasibility and Costs of Installing Tier 4 Engines and Retrofit Exhaust Aftertreatment on In-Use Commercial Harbor Craft

Report prepared for the California Air Resources Board by:

Keir Moorhead

Ryan Storz

Dinesh Pinisetty

Of the California State University Maritime Academy

September 30, 2019

This page intentionally left blank

Contents

Tables

Figures

Acronyms and Abbreviations

CHC – Commercial Harbor Craft

DEF – Diesel Exhaust Fluid

DPF – Diesel Particulate Filter

ECU – Engine Control Unit

FRP – Fiberglass Reinforced Plastic

GZ – Righting Lever

HP – Horsepower

LCB – Longitudinal Center of Buoyancy

LCG – Longitudinal Center of Gravity

LT - Long Tons = 2,240 pounds

OEM – Original Equipment Manufacturer

SCR – Selective Catalytic Reduction

STBD - Starboard

TCG – Transverse Center of Gravity

USCG - United States Coast Guard

VCG – Vertical Center of Gravity

VDECS - Verified Diesel Emission Control Strategy

Definitions

Damage Stability - Vessel stability of partially flooded ship. The vessel is assumed to meet specific criteria such as minimum GMt (metacentric height), area under the GZ (righting lever) curve, & maximum heel criteria, with extent of damage determined by the size, type, and passenger capacity as specified in 46 CFR 171.066 & 171.070.

Free Surface Effect - The decrease in stability of a vessel caused by freely shifting liquids in a tank or void.

Intact range of stability - The distance between the origin and point of vanishing stability along the GZ/heel curve, usually specified in degrees of heel.

Intact stability - Vessel stability characteristics in normal operational configuration (no compartment flooding). The vessel is assumed to meet specific criteria such as minimum GMt (metacentric height), area under the GZ (righting lever) curve, & range of stability at all trims and displacements the vessel may encounter during normal operation.

Lines Drawing – The drawing that defines the exterior form of a ship's hull.

Protective lagging - Insulating heat wrapping for exhaust piping, mufflers, and associated exhaust system components.

Reserve Buoyancy - The watertight volume of a ship above the waterplane.

Stability - The tendency of a floating vessel to return to its original upright, equilibrium condition when being affected by the forces of weather, wave, damage and passenger/cargo weight shifts.

Stability Booklet - Booklet of calculations and tables defining the loading conditions allowed for the subject vessel.

Stability Letter - Document unique to each vessel issued by controlling authority defining the operational parameters of a commercial vessel. Document usually specifies the recognized lightship characteristics (LCG, VCG, TCG, and displacement), maximum allowed cargo capacities, and maximum allowable drafts.

Subdivision margin line calculations - The margin line is an imaginary line located below the bulkhead deck of the vessel with the location, geometry and dimension defined by 46 CFR 171.015. Subdivision stability assumes an extent of damage to the hull envelope as defined by 46 CFR 171.066 & 171.070, dependent on the type & size of the subject vessel. The subdivision calculation analyses the position of the margin line as each of the flooding conditions is assumed. At no time shall the margin line be shown to submerge.

Waterline - The water level normally reached on the side of a vessel.

Block Coefficient – The ratio of the displaced volume of a ship compared to a rectangular block of the same dimension (draft, length and beam).

Executive Summary

This report presents the feasibility of repowering or retrofitting in-use harbor craft vessels with Tier 4 marine engines or retrofit aftertreatment, respectively. Tier 4 marine engines are generally originally equipped with selective catalytic reduction (SCR) systems, but no diesel particulate filter (DPF). Commercialized retrofit aftertreatment systems are available for Tier 3 marine and some older engines in two configurations: DPF only and combined DPF+SCR systems. A representative vessel was selected to evaluate feasibility for repowering with Tier 4 engines or retrofitting with DPF or DPF+SCR systems for each of thirteen different categories, including: Barge, Dredge, Commercial Fishing, Charter Fishing, Excursion, Slow Speed Ferry, High Speed Ferry, Ship Assist tug, Push Tug, Crew Supply, Pilot, Workboat, and Special Use.

This evaluation looked at the capital costs of the retrofit and/or repower equipment, installation costs, and equipment annual operating costs. A third-party naval architect reviewed the stability implications for the repower/retrofit technologies and then these recommendations were reviewed by a shipyard to quote the installation costs for each evaluated vessel. This report outlines the physical modifications and costs required to repower or retrofit vessels with DPF or DPF+SCR emission control technologies. For comparison, the insured vessel replacement costs were used to estimate the cost of replacing a vessel with new engines meeting current emission standards (as of publishing this report, Tier 3 for below 600 kW and Tier 4 for above 600 kW).

Table 1 outlines the feasibility by each of the 13 vessel types. Feasibility is indicated for repowering and retrofitting. In most cases, the DPF alone is slightly smaller size than the DPF and SCR combined retrofit solution. Unless otherwise indicated, a feasible fitment for the DPF alone and the DPF/SCR solution means that both technologies work. Feasibility is defined as follows:

- Feasible Fitment – The addition of the Tier 4 repower or retrofit aftertreatment equipment can be installed with minimal vessel modification and will likely not impact stability beyond the thresholds determined by USCG to require stability evaluation/review. This determination was made using existing vessel stability documents, lines drawings, equipment data provided by engine manufacturers, emission control technology companies, and thorough analysis by a third party naval architect.
- Moderate Reconfiguration – The addition of the Tier 4 repower with ancillary components or aftertreatment retrofit equipment to the existing vessel design may require changes to machinery/component locations, vessel mechanical/electrical subsystems, bulkhead penetrations, and moderate structural reinforcement to the existing vessel design in component hanging/mounting locations. These changes may have an effect on stability beyond the USCG review thresholds depending on the existing vessel design and the dimensions and weight of the equipment being installed in the vessel. Effect on stability is determined from vessel design and

stability data provided by vessel owners and component data from OEM engine manufacturers, retrofit emission control technology companies, and naval architect analysis.

- Substantial Reconfiguration– The addition of the Tier 4 repower or aftertreatment retrofit equipment will require most if not all of the alterations described under the "Moderate Reconfiguration" determination plus the addition of more significant or extensive redesign and structural fabrication to accommodate the equipment and/or to overcome apparent stability issues. Substantial design changes and structural fabrication may include moving existing bulkheads, creating new bulkheads, augmenting buoyancy by fabricating additional hull structure (up to and including cutting and lengthening the vessel), and/or more substantial structural reinforcement/augmentation to safely support installation of added Tier 4 components in locations. Depending on several business considerations, vessel owners with this scenario may consider replacing their vessel with a new-build Tier 4 powered replacement vessel instead of repowering or retrofitting their in-use vessels.
- No Fitment Identified – This designation indicates that despite thorough analysis of feasibility, the study authors were not able to identify repower or retrofit solutions that would be successful for the combination of vessel design, vessel build material, and physical characteristics of Tier 4 engines and retrofit aftertreatment systems. Additional re-analysis could be performed to identify workable modifications; however, identification of unequivocal modifications through subsequent analysis are not expected.
- Not Applicable (N/A) – This is the designation for indicating that there are no currently available Tier 4 repowers or retrofit DPF or SCR solutions available for the power and service of the vessel studied. For example, U.S. Environmental Protection Agency (EPA) Tier 4 marine emission standards are only required for engines with a rated power greater than 600 kW therefore there are few marine Tier 4 engine options available in the horsepower subcategories below 600kW.

This evaluation focuses on repowering or retrofitting main propulsion engines only, with the exception of Barge and Dredge categories where a diverse set of auxiliary engines perform key functions. Unless otherwise indicated, costs to repower or retrofit engines are for main propulsion engines only.

Table 1. Summary of Feasibility Findings

Vessel Category	Repower: Tier 4 Marine Engines	Retrofit DPF+SCR	Retrofit: DPF	Evaluation Input
Tank Barge -Cargo Pump -Ballast Pump -Generator	 N/A N/A N/A	 Feasible Fitment Feasible Fitment Feasible Fitment	 Feasible Fitment Feasible Fitment Feasible Fitment	3D Scan and Vessel Drawings
Dredge -Pump Engine -Thruster Engine -Generator	 Feasible Fitment N/A N/A	 Moderate Reconfiguration Feasible Fitment Feasible Fitment	 Moderate Reconfiguration Feasible Fitment Feasible Fitment	3D Scan
Commercial Fishing	N/A	No Fitment Identified	No Fitment Identified	3D Scan
Charter Fishing	N/A	No Fitment Identified	No Fitment Identified	3D Scan and Vessel Drawings
Excursion	Feasible Fitment	Feasible Fitment	Feasible Fitment	3D Scan and Vessel Drawings
Slow Speed Ferry	Feasible Fitment	Moderate Reconfiguration	Moderate Reconfiguration	3D Scan and Vessel Drawings
High Speed Ferry	Substantial Reconfiguration	Substantial Reconfiguration	Substantial Reconfiguration	Vessel Drawings
Ship Assist Tug	Feasible Fitment	No Fitment Identified	Moderate Reconfiguration	Vessel Drawings
Push Tug	Moderate Reconfiguration	Substantial Reconfiguration	Moderate Reconfiguration	3D Scan
Crew and Supply	Moderate Reconfiguration	Substantial Reconfiguration	Substantial Reconfiguration	3D Scan
Pilot Boat	Substantial Reconfiguration	Substantial Reconfiguration	Substantial Reconfiguration	3D Scan and Vessel Drawings
Work Boat	N/A	Substantial Reconfiguration	Substantial Reconfiguration	3D Scan
Special Use	Feasible Fitment	Moderate Reconfiguration	Moderate Reconfiguration	3D Scan and Vessel Drawings

Table 2. Summary of Cost Information for Retrofitting, Repowering, or New Vessel Purchases by Category

Vessel Type	Equipment Purchase + Installation Costs for Repower with Tier 4 Engines	Equipment Purchase + Installation Costs to Retrofit with DPF + SCR	Equipment Purchase + Installation Costs to Retrofit with DPF	Average Vessel Replacement Cost
Barge	N/A	$1,064,000	$974,000	$60,000,000
Dredge				$17,000,000
-Pump Engine	$1,160,000	$721,500	$638,500	
-Thruster Engine	DPF/SCR Included Above	Included Above	Included Above	
-Generator Engine	DPF/SCR Included Above	Included Above	Included Above	
Commercial Fishing	N/A	No Fitment Identified	No Fitment Identified	$600,000
Charter Fishing	N/A	No Fitment Identified	No Fitment Identified	$1,300,000
Excursion	$718,000	$459,000	$400,000	$9,000,000
Slow Speed Ferry	$1,009,000	$548,000	$488,000	$5,000,000
High Speed Ferry	$9,500,000	$7,835,500	$7,350,000	$20,000,000
Ship Assist Tug	$2,812,000	No Fitment Identified	$614,000	$15,000,000
Push Tug	$1,021,000	$529,000	$472,000	$6,000,000
Crew and Supply	$950,500	$502,500	$415,000	$3,600,000
Pilot Boat	$1,383,500	$855,500	$758,000	$3,400,000
Work Boat	N/A	$486,500	$458,500	$3,000,000
Special Use	$869,000	$441,500	$356,000	$15,000,000

*Main propulsion engines only, except for barge and dredge categories where costs are shown for main and auxiliary engines.

Introduction and Purpose of Study

The purpose of this evaluation is to conduct a feasibility assessment to inform California Air Resources Board (CARB) staff to develop additional in-use regulatory requirements for Commercial Harbor Craft (CHC) to achieve diesel particulate matter (PM) and oxides of nitrogen (NOx) emission reductions. Substantial emission reductions would be achieved by repowering with cleaner (Tier 4 marine) engines or retrofitting with exhaust aftertreatment.

The feasibility study conducted addressed the following general questions:

1. Would installing new Tier 4 engines on existing vessels create space, weight, and/or stability issues, or other operational or safety issues?
2. Would installing retrofit PM/NOx aftertreatment devices on existing non-Tier 4 engines create space, weight, and/or stability issues, or other operational or safety issues?
3. What would be the expected cost to install and operate Tier 4 engine(s) on existing vessels?
4. What would be the expected cost to install and operate retrofit PM/NOx aftertreatment devices on existing non-Tier 4 engines?

Propulsion engines from most vessel categories produce the majority of PM and NOx emissions from CHC. CARB will be updating inventory modeling that will provide the exact breakdown of emissions between auxiliary and main engines by vessel category. Auxiliary engines produce a small percentage of total PM and NOx from CHC, with the notable exception of barges and dredges. Therefore, the study will primarily focus on propulsion engines for all vessel categories and only address new control strategies for auxiliary engines aboard the barge, dredge, and special use categories.

Methodology

Survey Vessel Selection

One vessel was selected for survey from 13 different vessel categories identified for this study. Vessel categories were identified in consultation with CARB staff to select some of the more common categories of CHC operations within California. It is recognized that not all vessel types were evaluated, and that unique vessel designs and operations exist within each vessel category. However, the scope of this evaluation was to identify some of the potential vessel structural or operational modifications that may be required for a wider range of CHC operating within the state.

Individual vessels were selected by contacting potential owners or operators of vessels to obtain interest and consent to participate in the evaluation. Of the 13 initially selected owners/operators, 12 accepted, and one declined to participate in this evaluation study. Two of the accepted vessel owner/operators recommended the use of a different vessel than the original vessel that was identified, due to accessibility issues. Vessels were selected based upon several considerations: Geography of operation within California, is the vessel a representative vessel for its classification, how responsive are the vessel owners/operators, and are there lines drawings or stability books available for the vessel. Vessels were not selected based on the assumed level of difficulty to install Tier 4 equipment as it is understood that each vessel will have its own unique challenges for Tier 4 implementation.

Table 3. Location of Vessels in Survey

AQMD	Vessel #
Bay Area	10
South Coast	2
San Diego	1
Monterey	1 Vessel Declined

Data Collection Process

The evaluation of each vessel included an in-person visit and inspection of the engine room. A Dot Product 3D scanner was used to produce a working engine room arrangement drawing to assess aftertreatment device fitment. The 3D scanner creates a “point cloud” consisting of millions of dots that are referenced to a 3D space. These dots make up surfaces, pipes, engines, etc. After the point cloud is uploaded to a specific software, a virtual 3D engine room is available for further analysis. Information on the lines drawings and stability calculations were used for the analysis if they were made available by the vessel owner/operator.

Vessel operators self-reported operational regimes anecdotally without providing any engine load histograms that can be downloaded from the engine control unit (ECU) (Table 6). This information was categorized using Table 4 and was used to determine whether a passive or active DPF system would be required.

Table 4. Qualitative Engine Load Definitions

Description	Engine Load
High Load	>70%
Mid Load	25%-70%
Low Load	<25%

Manufacturers of Tier 4 engines and retrofit aftertreatment devices were contacted to provide equipment dimensional sizes, weights, maintenance schedules, installation plans and pricing information.

Table 5. List of Evaluated Vessels

Vessel Category	**Vessel Hull Material**	**Length (ft.) x Width (ft.)**	**3D Scan**	**Drawings/ Stability Information Available?**
Barge	Steel	481’x78’	Yes	Yes/No
Dredge	Steel	230’x55’	Yes	No/No
Commercial Fishing	Fiberglass	40’x11’	Yes	No/No
Charter Fishing	Fiberglass	55’x16.5’	Yes	Yes/Yes
Excursion	Steel	151’x40.5’	Yes	Yes/Yes
Slow Speed Ferry	Steel	131’x34.5’	Yes	Yes/Yes
High Speed Ferry	Aluminum	135’x39.4’	No	Yes/No
Ship Assist Tug	Steel	100’x40’	No	Yes/Yes
Push Tug	Steel	63’x26’	Yes	No/No
Crew and Supply	Aluminum	106’x21’	Yes	No/Yes
Pilot Boat	Aluminum	67’x19’	Yes	Yes/No
Work Boat	Steel	73’x21’	Yes	Yes/Yes
Special Use	Steel	88’x25’	Yes	Yes/Yes

Table 6. List of Evaluated Vessel's Engine Configurations

Vessel Category & Engine Use	**Engine Configuration (Qty. x HP)**	**Qualitative Load Profiles**
Barge -Pump -Ballast -Generator -Aux Generator	 4 x 460 HP 2 x 230 HP 2 x 270 HP 1x 80 HP	Not reported.
Dredge -Pump/Winch -Thruster -Generator -Aux Generator	 1 x 1500 HP 1 x 350 HP 1 x 173 HP 1 x 207 HP	Pump/winch - mid load Thruster – intermittent high load Generator – high load during operations
Commercial Fishing -Propulsion	1 x 400 HP	High load transit. Low load operations.
Charter Fishing -Propulsion	2 x 500 HP	Low load trolling, high load transit. Time equally distributed between profiles
Excursion -Propulsion	2 x 575 HP	Low load evening profile. High load with low load loitering day profile
Slow Speed Ferry -Propulsion	2 x 1000 HP	High load transit with low load loitering and boarding.
High Speed Ferry -Propulsion	2 x 3430 HP	High load transit with low load boarding
Ship Assist Tug -Propulsion	2 x 3425 HP	Low load loitering, intermittent high load during ship assist. Majority of time at low load.
Push Tug -Propulsion	2 x 1000 HP	High load transit, low load operations. Time equally distributed between profiles.
Crew and Supply -Propulsion	3 x 567 HP	High load transit
Pilot Boat -Propulsion	2 x 850 HP	High load
Work Boat -Propulsion	2 x 400 HP	Mid load
Special Use -Propulsion -Pump	 2 x 750 HP 1 x 750 HP	Mid load transit (Propulsion Mode). High load (Pumping Mode)

Vessel Particulars - 3D scans taken with the Dot Product DPI-8S were optimized using the Dot 3D software package. Scans were combined using either Autodesk ReCap or Autodesk AutoCAD. All combined scans were imported into AutoCAD for manipulation. All AutoCAD files were sent along with stability letters, general arrangement drawings and lines plans (as available) to a third-party naval architect that had no ownership affiliation with any of the vessel ownership companies.

Tier 4 Engines - A list of potential Tier 4 engine systems was developed by each of the equipment suppliers. The engine manufacturers provided drawings and weights of their systems. There were multiple power ranges of engines evaluated. Both inline and Vee type engines were considered, however the majority of the engines in the power range considered were Vee type engines.

Table 7 shows each of the Tier 4 engine power ranges that were considered in this evaluation. A single engine may have a wide power range depending on duty cycle that the vessel requires. A major consideration in the duty cycle of the engine is the amount of time spent at or near full load. Due to this range, an engine may be counted in multiple power ranges. The “Min” power ratings are the minimum rating of an engine in that group that can make the required horsepower in the specified range. This may be less than the power range specified. The “Max” power rating is the maximum output of an engine in the group that can meet the required power range.

Table 7. Tier 4 Engines Evaluated - All Originally Equipped with SCR

Power Range	Min/Max Power Rating (HP)	# of Engines Available
< 805 HP	600 / 815 HP	1
805 HP-1500 HP	815 / 2549 HP	5
1500 HP-2500 HP	1200 / 2549 HP	3
>2500 HP	2500 / 3450 HP	2

Retrofit or Aftertreatment Systems - The list of vessel types and engine specifics (horsepower, tier and usage profile) we sent to multiple aftertreatment system manufacturers. All suppliers were requested to provide a solution to achieve or meet a standard more stringent than Tier 4 when installed as a retrofit to an older higher-emitting engine. One aftertreatment supplier did not have an SCR option, only a DPF option. In this case the only focus was on PM reduction achieving or meeting a standard more stringent than Tier 4 PM emissions. The future requirements of CARB's CHC Regulation have not yet been defined; therefore, this analysis of both DPF only and combined DPF+SCR systems provides a wide range of possible fitment options. CARB maintains a list of verified DPF and/or SCR control technologies for marine engines, and is currently implementing the procedure defined in 13 CCR 2700-2711. Technology developers can submit existing solutions for CARB verification, which will likely be required to use retrofit technologies as a compliance approach with CARB's future CHC regulation. In this evaluation, all of the technology developers provided generalized solutions for the vessels. These solutions did not take into account actual condition of engines, measured exhaust temperatures and flow rates. Vessel owners or operators using retrofit DPF or DPF+SCR technology to comply with potential future CHC requirements will work with an authorized installer for the verified device that will account for the logged duty cycle of a particular engine through the Pre-Installation Compatibility Assessment (PICA) process. For this evaluation, all equipment manufacturers recommended active regeneration based on verbal information about duty cycle received from vessel operators. By virtue of their design, active systems are more complex and require more hardware to install. Therefore, by assuming active systems are required, costs evaluated are likely equal or greater than actual costs if a particular vessel should only require a DPF that can passively regenerate using heat of the exhaust system alone.

The power requirements, fuel requirements, and compressed air requirements to operate the aftertreatment devices were calculated using equations supplied by the aftertreatment equipment suppliers. These items are summarized and are reported as a range in each of the vessel categories. See Table 8 for vessel summary table locations.

Table 8. Vessel Modification Summary Table

Vessel	Table
Barge	Table 10. Barge Modification Snapshot
Dredge	Table 16. Dredge Modification Snapshot
Commercial Fishing	Table 25. Commercial Fishing Modification Snapshot
Charter Fishing	Table 27. Charter Fishing Modification Snapshot
Excursion	Table 29. Excursion Vessel Modification Snapshot
Slow Speed Ferry	Table 38. Slow Speed Ferry Vessel Modification Snapshot
High Speed Ferry	Table 47. High Speed Ferry Vessel Modification Snapshot
Ship Assist Tug	Table 54. Ship Assist Tug Vessel Modification Snapshot
Push Tug	*Table 63. Push Tug Vessel Modification Snapshot*
Crew and Supply	Table 72. Crew/Supply Vessel Modification Snapshot
Pilot	Table 81. Pilot Boat Vessel Modification Snapshot
Work Boat	Table 90. Workboat Vessel Modification Snapshot
Special Use	Table 96. Special Use Vessel Modification Snapshot

Naval Architect Analysis - The list of potential equipment was sent to the naval architect along with approximate dimensions and weights to verify if the equipment could physically fit in the existing engine spaces of the vessel (preliminary feasibility evaluation). This evaluation was applied to repower and aftertreatment options. If the repower or aftertreatment option fit in the unmodified engine space, the solution was deemed feasible. If the options failed, it was determined if moderate or substantial reconfiguration of the vessel was required to make the option work. In some cases, no viable option was found to accommodate the new equipment.

After the initial evaluation of fitment, weights of the new equipment, as well as estimated weights of any structural modifications were taken into account. Assumptions for estimation of weights:

- Aftertreatment or Tier 4 equipment system components - Reported by equipment manufacturers.
- DEF and tankage system components (if appropriate for the system) – DEF estimated at 9 lbs/gallon. Tankage assumed to be poly/rotomolded tanks. The DEF quantity was based on 15% of fuel tankage onboard, or what would be required to meet the reported fueling interval. If the fueling interval was not reported, the 15% of fuel tankage calculation was used, which is the higher of the two calculations.
- Exhaust modifications – Based on length and size of pipe required. Additional protective lagging and hangers are included.

- Structural changes (additional enclosures, relocated bulkheads, etc.) – Based on square footage of material required plus a multiplier to account for stiffeners and gussets.
- Margin – A 10% margin was included in estimates to account for additional bracing or equipment modifications not accounted for in the above categories.

Any additional equipment such as upgraded generators or air compressor installation was not included in the weight estimation. Further design with input from vessel owner and system integrator would be required to determine the best approach to solving electrical power and compressed air deficiencies. Possible solutions to electrical deficiencies include increased generator sizing, installation of generator paralleling equipment, or inverter/battery systems.

Depending on usage of the vessel, various methods were used to calculate stability impacts.

- Stability book / lines plan available – Calculate added displacement, LCG, and VCG.
- Stability book / lines plan available for a sister vessel – Calculate added displacement, LCG, and VCG based on sister vessel assuming vessels are still of similar lightship characteristics.
- Vessel dimensions only – Estimate characteristics and displacement of vessel based on length, beam and an assumed block coefficient.

For all cases, it was determined that there was negligible effect on stability if the added equipment was below the threshold of 2% weight change in lightship displacement or a shift in the longitudinal center of gravity (LCG) less than 1% of the vessel's length between perpendiculars (LBP)[1]. Anything exceeding this threshold may result in a deadweight survey or a full stability test. Due to the variability in triggers for testing and testing methods that may be called for by the USCG, costing was not included.

Additionally, added weights can be directly equated to reduced passenger count on passenger vessels and diminished cargo capability on cargo vessels.

Guidance Documents for stability used:

- 46 CFR Subchapter S – Subdivision and Stability
- MTN 04-95 "Lightship Changes Determination: Weight-Moment Calculation vs. Deadweight Survey vs. Full Stability Test"

Guidance Documents for shipbuilding and structure used:

- ABS Steel Vessels under 90 Meters in Length
- ABS Steel Vessel Rules

[1] MTN 04-95 "Lightship Changes Determination: Weight-Moment Calculation vs. Deadweight Survey vs. Full Stability Test"

- First principles calculations with USCG acceptable deck loading

All of the Tier 4 SCR and retrofit aftertreatment equipment has an effect on the electrical system of the vessel. Tier 4 marine engines and SCR systems have the least impact while DPF aftertreatment systems have the largest impact. The size of the generators were recorded in this study and some vessel operators reported estimated electrical loading of the generator. Generally this was reported anecdotally as the vessels did not have data recording equipment on the electrical systems. A full load analysis (reference NVIC 2-89 listed below for example) would need to be conducted for the vessel prior to equipment installation. For each vessel, a note has been made if the electrical equipment can support the aftertreatment equipment.

Guidance Documents for shipboard electrical used (also attached in Appendix A.2):

- 46 CFR Subchapter J – Electrical Engineering
- NVIC 02-89

Guidance Documents for vessel regulations based on size and use:

- 46 CFR Subchapter T – Small Passenger Vessels (Under 100 Gross Tons)
- 46 CFR Subchapter K – Small Passenger Vessels Carrying More Than 150 Passengers or With Overnight Accommodations For More Than 49 Passengers
- 46 CFR Subchapter H – Passenger Vessels
- 46 CFR Subchapter M – Towing Vessels
- 46 CFR Subchapter F – Marine Engineering
- 46 CFR Subchapter D – Tank Vessels
- 46 CFR Subchapter I – Cargo and Miscellaneous Vessels
- 46 CFR Subchapter O – Certain Bulk Dangerous Cargoes

Guidance Document for measurement of gross tonnage of vessels:

- 46 CFR Subchapter G Part 69 – Measurement of Vessels

Financial Analysis

A financial analysis was performed for each vessel to accurately estimate the regulatory impact to businesses for OEM Tier 4 repower and/or retrofit options as applicable. This section will detail below how each of the financial values were calculated.

Vessel Replacement - The entire vessel replacement cost is provided and is provided based off of the insured vessel replacement value. The vessel replacement value represents the cost of designing and constructing a new vessel.

Current Vessel Annual Fuel Cost – Fuel usage data was collected for every vessel and calculated based off of $3.00 per gallon.

Capital costs – These costs were received directly from the OEM Tier 4 engine manufacturers and Retrofit companies for each applicable engine application for each vessel. High and low cost estimates are provided for the capital costs based off of the OEM and Retrofit information provided. If multiple solutions were available, only the high and low numbers were selected. This report does not indicate how many possible solutions exist for each engine application. This was done to anonymize the solution providers and not identify who does or does not have a solution.

Installation Costs – A California-based shipyard reviewed the technical data (size, weight, installation requirements) and provided cost estimates for the labor and vessel modifications. These modifications are aligned with the prior experience of the shipyard and any naval architect design recommendations. Installation costing was broken down into five sub-categories:

1. Structural Alterations – This includes adding/modifying bulkheads, adding additional enclosures, foundation modifications, etc.
2. Mechanical Alterations – This includes modifications to piping systems, additional tankage, and exhaust modifications.
3. Engine Room Access – This includes all penetrations required to get equipment in and out of the machinery spaces.
4. Testing & Commissioning - This includes startup and verification of all new equipment prior to equipment supplier arrival and all official sea trials with equipment suppliers onboard. Due to the variability in triggers for stability testing and stability testing methods that may be called for by the USCG, costing was not included.
5. Vessel Haul Out & Shipyard Costs – This includes building drydock cradles (if required), haul out/drydock, and any pierside costs.

For the retrofit installation costs, only the combination DPF and SCR systems were analyzed for installation. The installation cost for DPF only system will therefore be lower in some instances due to the lack of DEF and additional space considerations from the SCR.

Fuel Savings – As many of the vessels surveyed had Tier 3 engines aboard, regardless of actual engine tier levels, in this report fuel savings data is reported for repowering a Tier 3 engine with a Tier 4 engine with aftertreatment. Fuel savings by engine horsepower rating was reported anywhere from 2-6%. No fuel savings or penalty data was provided for retrofitting existing engines with aftertreatment or with repowering Tier 0 or Tier 2 engines to Tier 4. The low and high fuel savings estimates were calculated using the monthly vessel fuel usage provided by each vessel operator, $3.00 per gallon fuel price, and the 2-6% fuel savings range.

Maintenance Costs Associated with Retrofit and OEM Tier 4 SCR – As maintenance interval and costing data was not provided by the companies offering DPF and DPF/SCR aftertreatment products, only the OEM Tier 4 engine information was analyzed. For this costing, only repower or retrofit company self-reported SCR maintenance information is being utilized. Based off of the different system components and sensor packages used with the OEM aftertreatment solutions, without confirmation from the retrofit companies, it was unclear if the same maintenance costing could be assumed to be similar for retrofitted aftertreatment equipment. Utilizing the CARB 2008 Statewide Truck and Bus Regulation for truck engines ranging from 200 HP to 600 HP (400 HP median) and the Appendix J identified DPF maintenance cost of $400 per year per DPF, a DPF maintenance factor of $1/HP/yr could be used ($400 divided by 400 HP). This costing factor was not included in the report due to actual maintenance data not being provided to us by the retrofit companies, however, it could potentially be used as a placeholder for a generalized DPF annual maintenance cost.

For each of the OEM repower aftertreatment systems, based off of horsepower, parts and consumables requiring replacement were inventoried along with their replacement frequency and the cost per part. The quantity of replacement parts were then tabulated over a 30,000 hour (5 year) operational period and divided by 5, for the period years, and the repower engine horsepower to yield a maintenance cost per horsepower per year. By doing this for every engine, a low and high estimated maintenance cost was created regardless of the engine that was deemed feasible for each vessel. This cost estimate range will prevent revealing any inferred maintenance cost data from an OEM in this report.

For example:
OEM A has a urea filter for a 1000 HP engine that costs $300 and lasts 1000 hours.
OEM B has a urea filter for a 1500 HP engine that costs $350 and lasts 1300 hours.
OEM C has a urea filter for a 3000 HP engine that costs $200 and lasts 1000 hours.
During 30,000 hours, over 5 years, an SCR system with OEM A will replace 30 filters at a cost of $9,000, or $1,800 per year. Taking the 1000 HP into consideration, an OEM A aftertreatment system will require $1.80/HP/yr in maintenance cost for filters alone.
OEM B will replace 23.1 filters costing $1,617 per year at $1.08/HP/yr. OEM C will replace 30 filters costing $1,200 per year at $0.40/HP/yr.

OEM A represents the upper maintenance cost range at $1.80/HP/yr with OEM C representing the lower cost range at $0.40/HP/yr. Again, this example only takes into consideration filters, there are other consumables and replacement parts that would be taken into consideration.
To wrap up this example, if a replacement engine for this study is 1350 HP, the annual maintenance upper cost range would be (1350 HP) x ($1.80/HP/yr) = $2,430 and the lower cost range would be (1350 HP) x ($0.40/HP/yr) = $540 per year. The calculated annual cost range for the replacement of filters for a 1350 HP engine example would fall between $540 and $2,430. These are example numbers and by no means represent exact cost numbers that were provided by the OEMs, but show how maintenance cost ranges were calculated.

DEF Cost – The monthly fuel usage, refueling interval and fuel tank capacities were used to determine the size of the DEF tanks. The refueling interval data was primarily used to size the DEF tank. If interval data was not available, the DEF tank was sized based off of the fuel tankage aboard the vessel. A conservative sizing number of 15% was utilized when sizing the DEF tankage. If a vessel had 380 gallons of fuel tankage, the DEF tank would need to have at least a 57 gallon capacity. For example: If the aformentioned example vessel consumed 500 gallons of fuel per month, there would be approximately (1.32 refueling intervals per month) x (57 gallons of DEF) x ($1.75 per gallon of DEF) = $131.25/month for DEF.

DPF Regeneration Fuel Cost – DPF technologies surveyed utilized a combination of diesel fueled regeneration processes or electric heated regeneration processes with varying durations and process sequences.

The operational numbers provided by the retrofit companies were fuel consumption and electrical requirement estimates for DPF regeneration. The generator electrical load and fuel usage directly in the DPF were added together to account for all the fuel use during the regeneration process. To come up with the estimated fuel usage by the generator to support the electrical load, three common 40-kW marine diesel generators were surveyed and their specific fuel consumption was averaged at full load to develop a gallons per kWh to use for this study. The average generation fuel consumption factor used is 0.09226 gallons per kWh. This made it possible to account for the fuel consumed during the DPF regeneration process using realistic marine diesel generator fuel consumption numbers. Operationally, one regeneration per 12 hours of operation at 365 days per year was assumed. If a DPF had any other operational scheme for regeneration, this was also taken into account conservatively. Due to the operational differences between the DPFs reviewed, a high and low regeneration fuel cost were used.

For Example, if a 500 HP engine requires 5kW of power and 3 gallons of diesel of power during a one hour regen cycle, then the total amount of fuel used per hour is: (5 kW) x (1 hr of regeneration) x (0.09226 gallons per kWh) + (3 gallons) = 3.46 gallons of diesel per 12 hours of vessel operation. This includes both the fuel and electrical consumption for regeneration as provided by the retrofit companies.

Assessment of Feasibility - Cost of Repowering or Retrofitting by Vessel Category

1. Barge

1.1. Profile & Summary

This vessel is a petrochemical barge that carries product between ports in California. There are a mix of Tier 3 and pre-Tier 1 engines that are being evaluated for repower and retrofit feasibility. Vessel particulars shown in Table 9. The vessel operator did not provide a breakdown of operation hours of each engine.

There are no Tier 4 engine options available for the engine power subcategory of the auxiliary pump and generators aboard this barge. Therefore, the only retrofit aftertreatment options including the use of a DPF or a DPF+SCR combination were studied.

Eight of the nine engines on this vessel are being considered for retrofit. The 60kW generator is not being considered as it is not used for normal operations. Due to the configuration of the vessel, installation of eight aftertreatment systems will have negligible impacts on vessel stability. However, the vessel's on-board generator will have a significant load increase due to the added load of regenerating DPF filters and may not be able to provide the required power.

Aftertreatment summary shown in Table 10.

Table 9. Barge Vessel Snapshot

Hull	Vessel/Barge Use	Petroleum			
	Passenger Vessel (Y/N)	No			
	USCG Inspected (Y/N)	Yes			
	USCG Subchapter	D & O			
	Hull Material	Steel			
	Hull Design	Barge			
	LOA (ft.)	500’			
	Beam (ft.)	75’			
Main Machinery	Number of Propulsion Engines	0			
	Horsepower of Propulsion Engine	N/A			
	Tier of Propulsion Engine	N/A			
	Exhaust Type	N/A			
	Location of Exhaust	N/A			
	Type of Propulsion	N/A	*Note: If an engine is connected to a pump and a generator, both power ratings will be listed. If the engine is connected to only a generator, the electrical output is documented.		
Auxiliary Machinery	Engine Identifier	A	B	C	N/A
	Number of Auxiliary Engine(s)	4	2	2	1
	Use of Auxiliary Engine	Pump	Pump	Gen/Hydraulics	Aux Generator
	Power Pump (HP)*	460 HP	230 HP	270 HP	N/A
	Power Generator (kW)*	N/A	N/A	200 kW	60 kW
	Tier of Auxiliary Engine	0	3	3	0
	Exhaust Type	Dry	Dry	Dry	Dry
	Exhaust Locations	Stack	Stack	Stack	Stack

Table 10. Barge Modification Snapshot

Engine A

Repower	Option Available	No
	Feasibility	N/A
	Additional Machinery Required	N/A
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Feasible Fitment
	Fuel Burn Required (per engine)	1.3-2 GPH during regeneration
	Electrical Power Required (per engine)	4.5-14 kW during regeneration
	Additional Machinery Required	Switchboard modifications, fuel system modifications, DEF tankage and transfer equipment. New silencers
Retrofit DPF Only	Option Available	Yes
	Feasibility	Feasible Fitment
	Fuel Burn Required (per engine)	1.3-2 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	4-8.5 kW
	Additional Machinery Required	Switchboard modifications. New silencers

Engine B

Repower	Option Available	No
	Feasibility	N/A
	Additional Machinery Required	N/A
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Feasible Fitment
	Fuel Burn Required (per engine)	<1 GPH during regeneration
	Electrical Power Required (per engine)	3.5-7 kW during regeneration
	Additional Machinery Required	Switchboard modifications, fuel system modifications, DEF tankage and transfer equipment. New silencers
Retrofit DPF Only	Option Available	Yes
	Feasibility	Feasible
	Fuel Burn Required (per engine)	<1 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	3.5-4 kW
	Additional Machinery Required	Switchboard modifications. New silencers

Engine C

Repower	Option Available	No
	Feasibility	N/A
	Additional Machinery Required	N/A
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Feasible Fitment
	Fuel Burn Required (per engine)	<1 GPH
	Electrical Power Required (per engine)	3.5-8 kW during regeneration
	Additional Machinery Required	Switchboard modifications, fuel system modifications, DEF tankage and transfer equipment. New silencers
Retrofit DPF Only	Option Available	Yes
	Feasibility	Feasible
	Fuel Burn Required (per engine)	<1 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	3.5-4 kW
	Additional Machinery Required	Switchboard modifications. New silencers
Impacts	Added System Weight Repower	N/A
	Added System Weight Retrofit	4-15 LT
	System weight is for retrofit of all engines. Range includes DPF+SCR and DPF only options.	

1.2. Considerations

1. Machinery Arrangement
   - Figure 1 is a visual representation for the fitment of SCR+DPF units in the port engine room. Figure 2 shows the same fitment, but with the point cloud layer suppressed. The following colors represent the following equipment:
     - The blue represents the aftertreatment device
     - The red represents the new exhaust piping path
     - The green represents the new location of silencers
     - The pink line represents the outline of the equipment and the bulkheads.
     - DEF tankage and dosing cabinets not shown

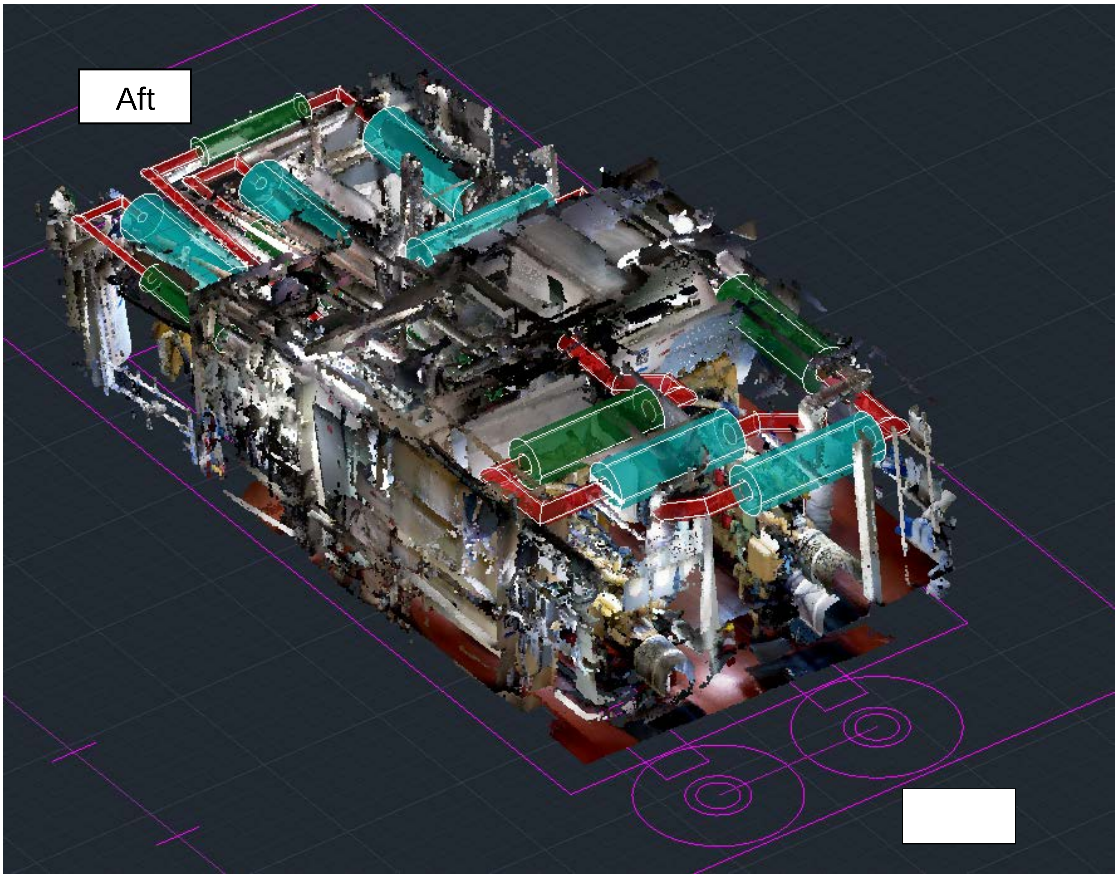

Figure 1. Barge Port Engine Room Retrofit Arrangement

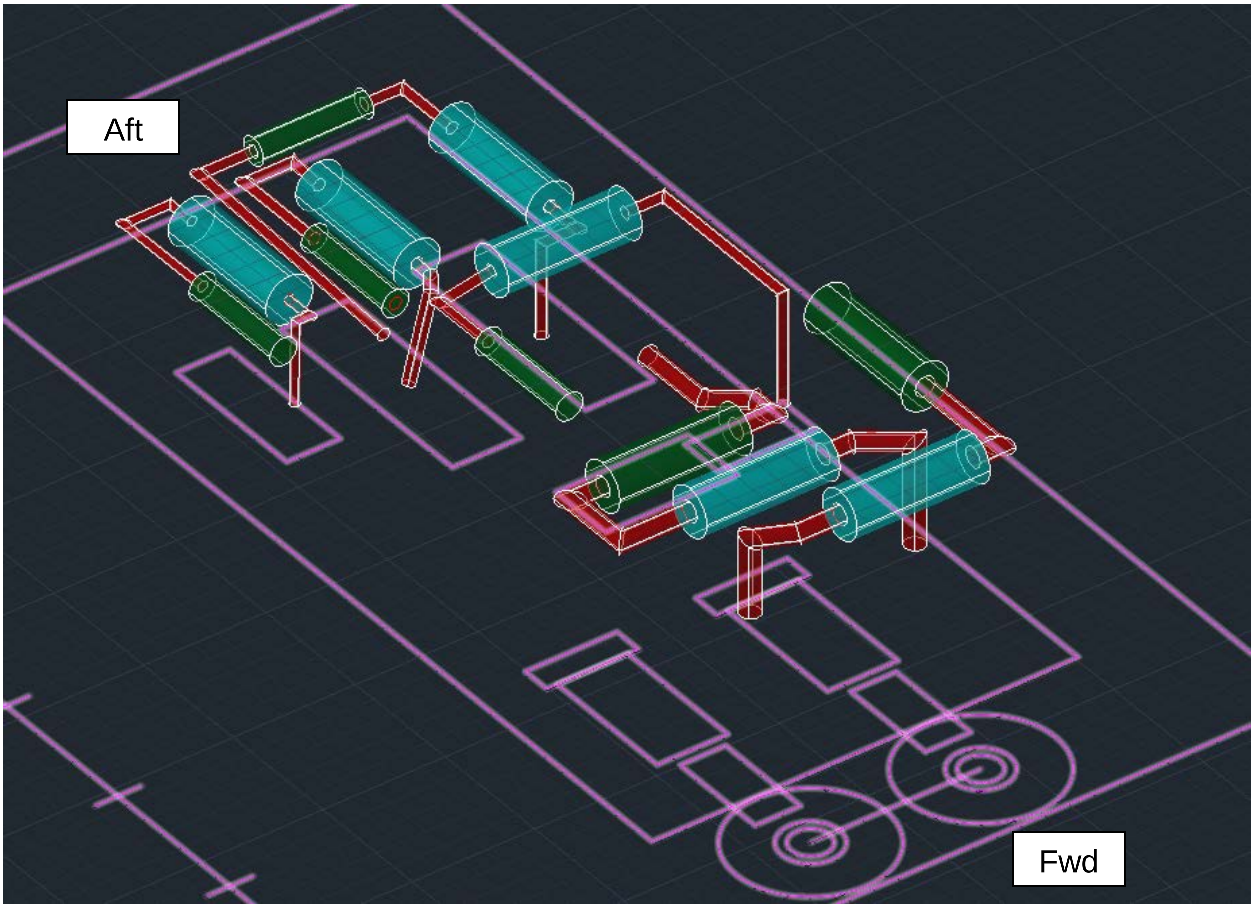

Figure 2. Barge Port Engine Room Retrofit Arrangement with Point Cloud Suppressed

- Figure 3 is a visual representation for the fitment of SCR+DPF units in the Stbd engine room. Figure 4 shows the same fitment, but with the point cloud layer suppressed. The following colors represent the following equipment:
    - The blue represents the aftertreatment device
    - The red represents the new exhaust piping path
    - The green represents the new location of silencers
    - The pink line represents the outline of the equipment and the bulkheads.
    - DEF tankage and dosing cabinets not shown

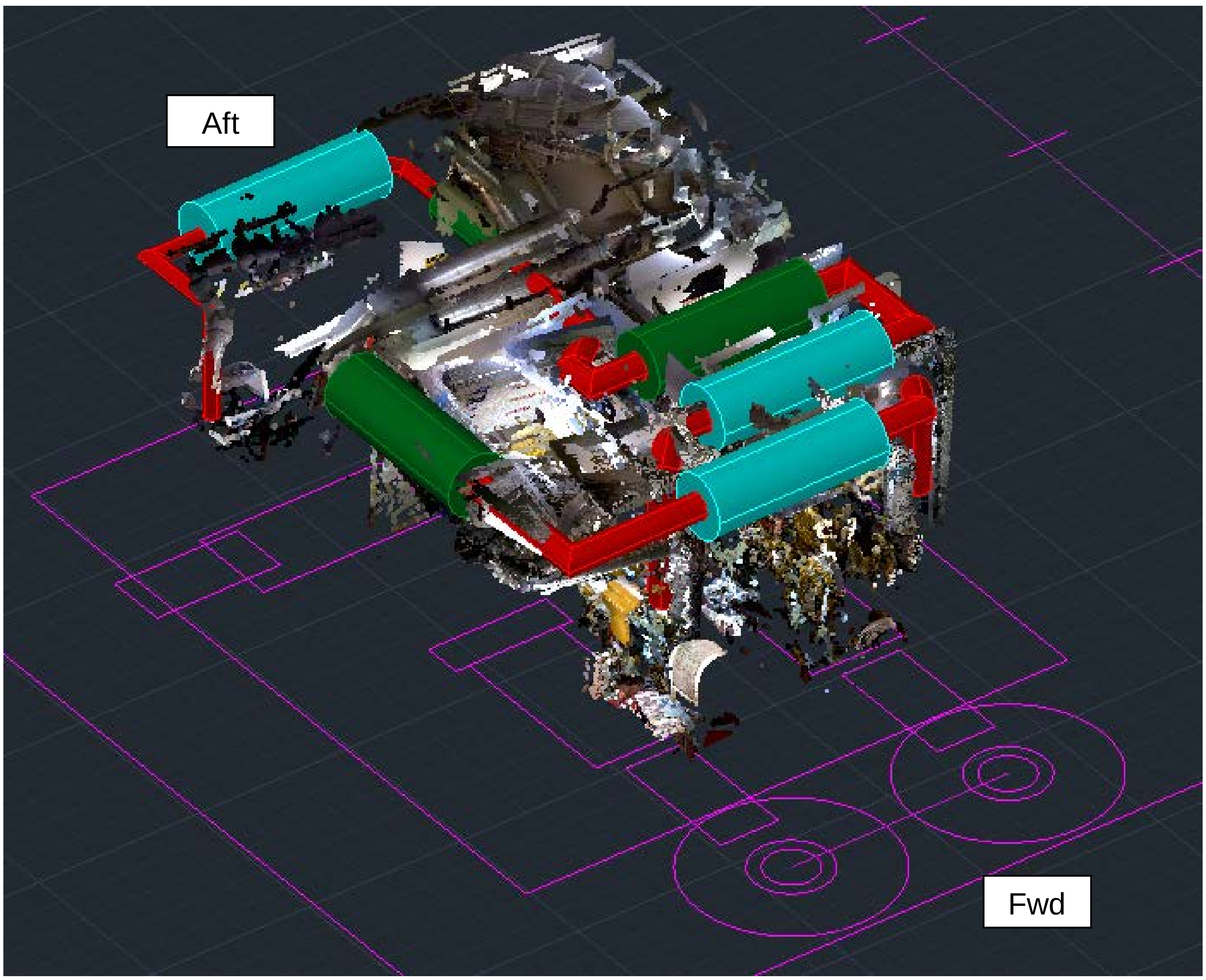

Figure 3. Barge Stbd Engine Room Retrofit Arrangement

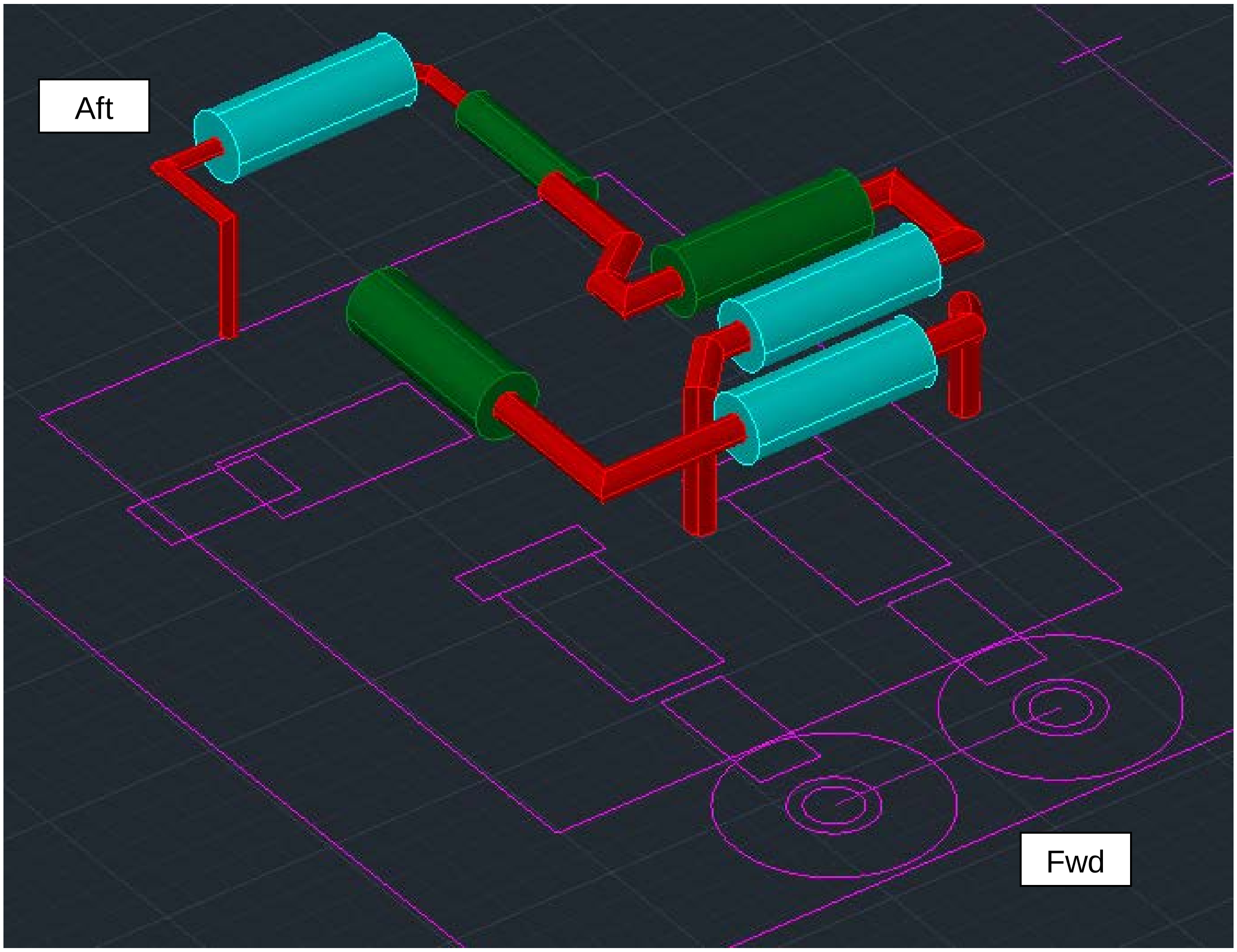

Figure 4. Barge Stbd Engine Room Retrofit Arrangement with Point Cloud Suppressed

2. Space Constraints – As seen in Figure 1 - Figure 4, there is limited open space on the overhead of the engine rooms. The port engine room has greater space constraints due to the amount of equipment in that engine room (6 engines and the main switchboard). The stbd engine room only contains three engines.

3. Existing Piping – Existing subsystem piping will need to be removed and rerouted to allow adequate access to aftertreatment equipment.

4. Electrical System – No electrical loading information was available for the generators. However, if all systems were to go into regeneration at the same time the electrical load could increase by 32-86 kW depending on the aftertreatment system, in a worst case scenario. Further review will have to be done with the vessel owner to verify normal operating conditions of the vessel prior to implementing this technology.

5. Stability – There are no foreseen impacts to the stability of the vessel. Including DEF tankage, the estimated weight increase of the aftertreatment equipment is 11-15 LT. A DPF only solution does not require the DEF tankage and would result in an increase of 4-5 LT. The draft of the vessel currently will increase by one inch with 67 LT of weight, so the additional weight is negligible. The draft increase estimation was based on dimensions of the barge and an estimated block coefficient.

1.3. Installation

1. Engine Room Access Repower/Retrofit – There are no soft patches or access hatches large enough to allow for equipment to be removed or installed into the engine room. Access need to be made through cutting into the deck house.

2. DEF Tankage – Tankage for the vessel was estimated based on yearly consumption of fuel with a monthly refueling schedule. Tankage required would be approximately 1000 gallons. Cost estimations are based on a single tank. However, two tanks could be utilized.

3. Electrical – Modification of the main switchboard will be required to accommodate additional switchgear. Systems with DPF and active regeneration will have the highest impact on electrical requirements.

4. Mechanical – The vessel is currently equipped with an air compressor system.

5. Fuel System – The combined SCR+DPF systems with active DPF regeneration will require a fuel based system for regeneration. Additional fuel piping and filters will be required for installation of the system. Options are available for electrical only regeneration.

6. Exhaust System – Current piping and silencers for auxiliary engines will need to be removed and replaced. If noise restrictions are not a concern, the silencers could be omitted from the installation altogether. New piping and hangers need to be installed. In addition, new custom lagging is required to be installed on all exposed metal in the exhaust system.

1.4. Costs

Table 11 highlights the insured vessel replacement value as well as the current annual vessel fuel cost. For this application, only retrofit options were available. Table *12* highlights the additional retrofit operating diesel fuel cost incurred from regenerating the DPF and DEF for the SCR. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included. Table *13* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the retrofit technologies shown in Table 14.

Table 11. Barge Cost Information

Insured Vessel Replacement	$60,000,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$248,820

Table 12*. Barge Annual Operational Costs for Retrofit DPF+SCR*

	Low Estimated Cost	High Estimated Cost	$/Year Average Cost
Maint. Cost of SCR per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			$21,772
Regen Fuel Cost	$11,819	$28,682	$20,250
Total Retrofit Operational Cost Impact			$42,022

Table 13. Barge Summary of Capital and Installation Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$373,000	$423,000	$398,000
Capital Costs DPF ONLY	$296,000	$320,000	$308,000
Labor + Installation Costs			$666,000
Total Capital + Installation Costs SCR + DPF			$1,064,000
Total Capital + Installation Costs DPF ONLY			$974,000

Table 14. Barge Detailed Installation Costs for Retrofit

	Estimated Cost
Structural	$126,000
Mechanical	$287,000
Engine Room Access	$48,000
Testing & Commissioning	$84,000
Haulout/Shipyard Cost	$121,000
Total Installation Cost	$666,000

2. Dredge

2.1. Profile & Summary

This vessel is a hopper dredge that operates in inland waterways and is not self-propelled. All engines are certified to the Tier 3 marine engine standards. There is an additional approximately 155-kW generator that is used for emergency power generation. This engine will not be included in this study for aftertreatment upgrade as it is used only in case of main generator failure. However, all compression-ignition engines permanently affixed to dredges are currently subject to CARB's CHC Regulation defined in 17 California Code of Regulations (CCR) 93118.5. Engines used only in an emergency will likely be subjected to future in-use engine requirements, but will likely comply using a low-use compliance pathway. Therefore, it is not necessary to evaluate repower or retrofit options for the emergency engine in this evaluation. Vessel particulars shown in Table 15.

There are existing Tier 4 engine replacements that consist of the engine and a SCR that could be used for the pump/winch engine. Retrofit aftertreatment devices for this engine are also available.

For the thruster and generator engines, only retrofit aftertreatment options were studied as there are no commercially available Tier 4 engine solutions available for this power subcategory.

The aftertreatment summary shown in Table 16.

Table 15. Dredge Vessel Snapshot

Hull	Vessel/Barge Use	Dredge			
	Passenger Vessel (Y/N)	No			
	USCG Inspected (Y/N)	N			
	USCG Subchapter	ABS			
	Hull Material	Steel			
	Hull Design	Barge			
	LOA (ft.)	230'			
	Beam (ft.)	55'			
Main Machinery	Number of Propulsion Engines	0			
	Horsepower of Propulsion Engine	N/A			
	Tier of Propulsion Engine	N/A			
	Exhaust Type	N/A			
	Location of Exhaust	N/A	Note: This vessel is not self-propelled and does not have a propulsion engine.		
	Type of Propulsor	N/A			
Auxiliary Machinery	Engine Identifier	A	B	C	N/A
	Number of Auxiliary Engine(s)	1	1	1	1
	Use of Auxiliary Engine	Pump/Winch	Thruster/Pump	Generator	Aux Generator
	Power Pump (HP)	1500 HP	350 HP	N/A	N/A
	Power Generator (kW)	N/A	N/A	191 kW	155 kW
	Tier of Auxiliary Engine	3	3	3	0
	Exhaust Type	Dry	Dry	Dry	Dry
	Exhaust Locations	Stack	Stack	Stack	Stack

Table 16. Dredge Modification Snapshot

Engine A

Repower	Option Available	Yes
	Feasibility	Feasible Fitment
	Additional Machinery Required	DEF Tankage and Transfer system. Replace Silencers.
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Moderate Reconfiguration
	Fuel Burn Required	8-9 GPM during regeneration
	Electrical Power Required	8 kW during regeneration
	Additional Machinery Required	Possible upgrade to generator. Switchboard modifications. Fuel system. DEF Tankage and Transfer. Replace Silencers
Retrofit DPF Only	Option Available	Yes
	Feasibility	Moderate Reconfiguration
	Fuel Burn Required	8-9 GPM during regeneration Option for no fuel
	Electrical Power Required	8-25 kW
	Additional Machinery Required	Possible generator upgrade. Switchboard modifications. New silencers

Engine B

Repower	Option Available	No
	Feasibility	N/A
	Additional Machinery Required	N/A
	Added Weight	N/A
	Total Installed Cost	N/A
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Feasible Fitment
	Fuel Burn Required (per engine)	1-1.5 GPH during regeneration
	Electrical Power Required (per engine)	3-10 kW during regeneration
	Additional Machinery Required	Possible generator upgrade. Switchboard modifications, fuel system modifications, DEF tankage and transfer equipment. New silencers
Retrofit DPF Only	Option Available	Yes
	Feasibility	Feasible Fitment
	Fuel Burn Required (per engine)	1-1.5 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	3-8 kW
	Additional Machinery Required	Possible generator upgrade. Switchboard modifications. New silencers

Engine C

Repower	Option Available	No
	Feasibility	N/A
	Additional Machinery Required	N/A
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Feasible Fitment
	Fuel Burn Required (per engine)	0.5-1 GPH during regeneration
	Electrical Power Required (per engine)	3-8 kW during regeneration
	Additional Machinery Required	Possible generator upgrade. Switchboard modifications, fuel system modifications, DEF tankage and transfer equipment. New silencers
Retrofit DPF Only	Option Available	Yes
	Feasibility	Feasible Fitment
	Fuel Burn Required (per engine)	0.5-1 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	3-4 kW
	Additional Machinery Required	Possible generator upgrade. Switchboard modifications. New silencers
Impacts	Added System Weight Repower (DPF+SCR or DPF systems for Engine B&C)	4-6 LT
	Added System Weight Retrofit (DPF+SCR or DPF systems for all engines)	2-8 LT
	Note: 1) Repower system weight assumes a repower of Engine A and retrofit of Engine B and Engine C. 2) Retrofit system weight assumes a retrofit of all engines. Range includes DPF+SCR and DPF only options	

2.2. Considerations

1. Machinery Arrangement
    - Figure 5 is a visual representations for the fitment of the SCR unit for a pump/winch engine repower. Figure 6 shows the same fitment, but with the scanned image layer suppressed. The following colors represent the following equipment:
        - The black box is the estimated size for the 250 gallon DEF tank.
        - The yellow box is the OEM repower option.
        - The red represents the new exhaust piping path.
        - The cyan box is the DEF dosing cabinet.

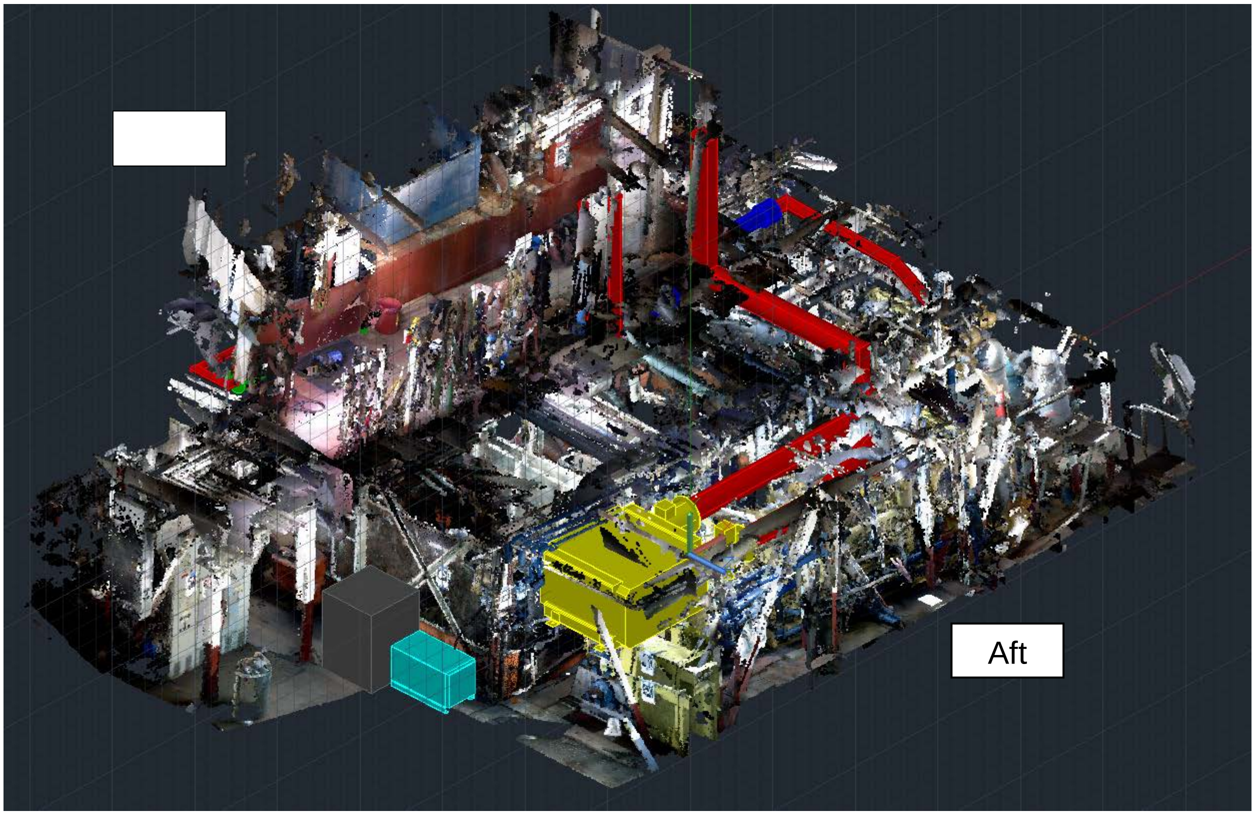

Figure 5. Dredge Pump/Winch Engine Repower Arrangement

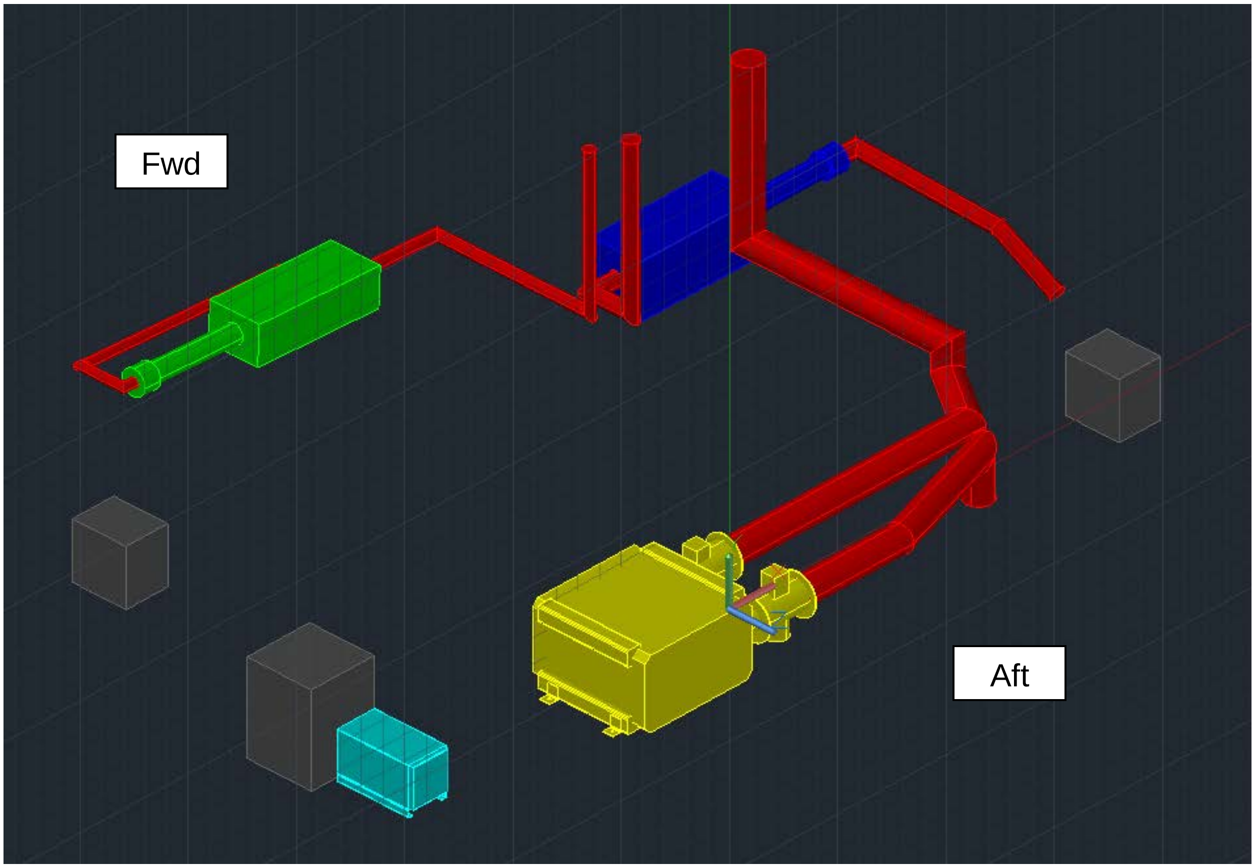

Figure 6. Dredge Pump/Winch Engine Repower Arrangement with Point Cloud Suppressed

- Figure 7 is a visual representation for a retrofit aftertreatment system on the thruster and generator engines. Figure 8 shows the same fitment, but with the scanned image layer suppressed. The following colors represent the following equipment:
    - The black box is the estimated size for the 250 gallon DEF tank.
    - The blue box is a retrofit option for the thruster engine.
    - The green box is a retrofit option for the generator engine.
    - The red represents the new exhaust piping path.
    - Dosing cabinet not shown.

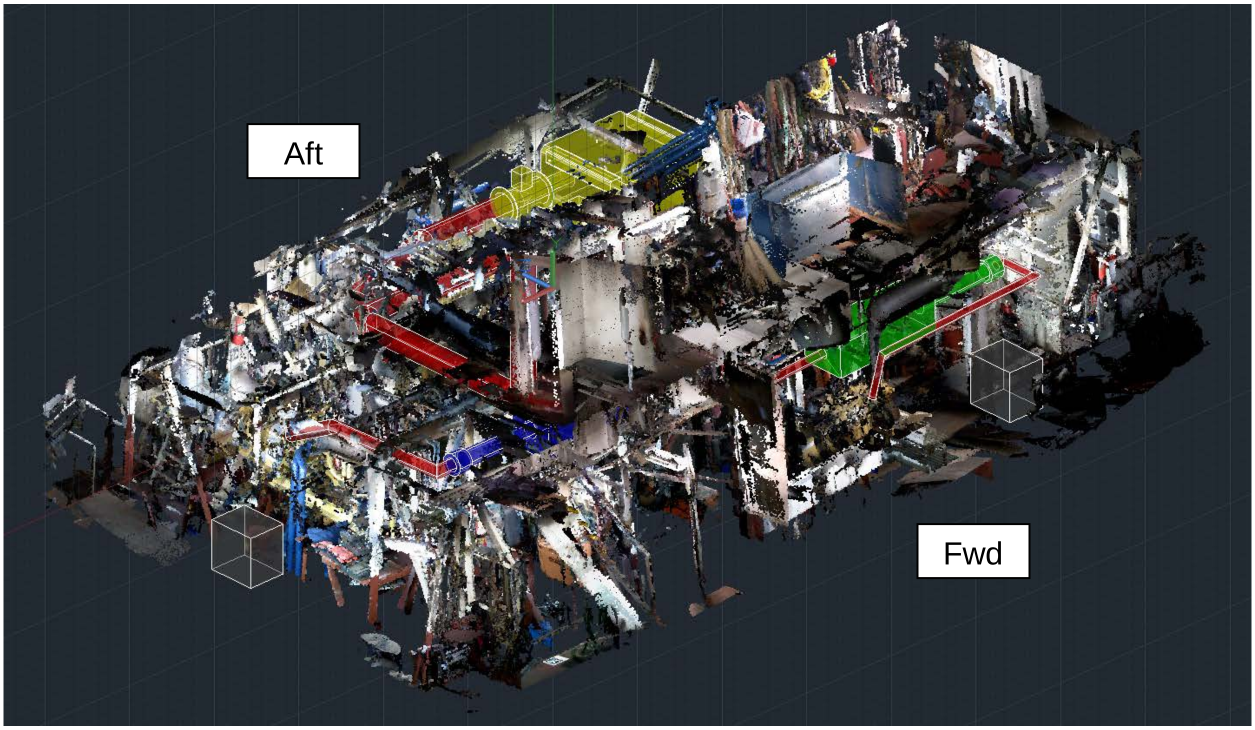

Figure 7. Dredge Thruster and Generator Engine Retrofit Arrangement

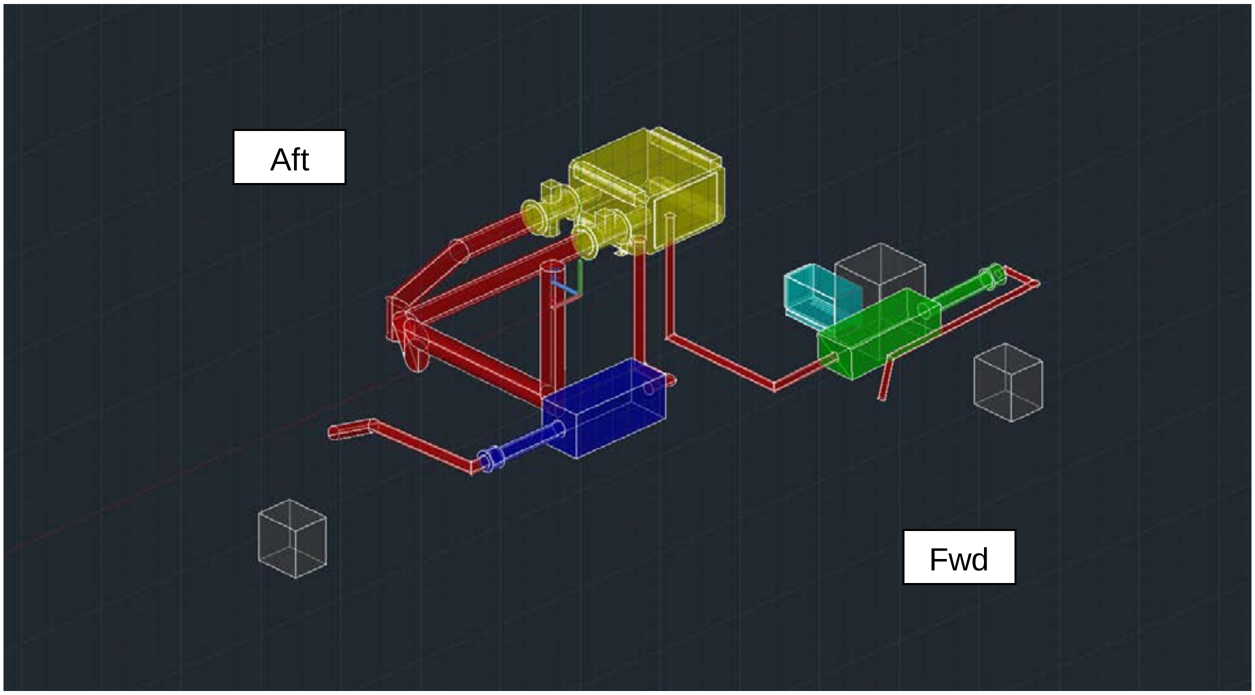

Figure 8. Dredge Thruster and Generator Engine Retrofit Arrangement with Point Cloud Suppressed

2. Space Constraints – As seen in Figure 5 - Figure 8, open space is limited in the engine room. There are many subsystems in the engine room that occupy the overhead areas. There are pockets of open area in the vicinity of the engines to allow installation of the aftertreatment devices.

3. Existing Piping - For all the retrofit options in the engines as depicted above, DPF alone or DPF/SCR in combination, existing subsystem piping will need to be rerouted to allow for adequate access to equipment.

4. Electrical System – The current generator is reported to operate at >85% load during peak demand. The modeled after treatment systems would require 15-37 kW of additional power during regeneration of all filters. There may not be adequate margin for this generator to handle regeneration operations.

5. Stability - The retrofit and repower options contain known weights going into known locations. The weight of the new equipment will add approximately 7 LT to the weight of the vessel. This would have less than a 1% impact on cargo capacity of the vessel.

2.3. Installation

1. Engine Room Access Repower/Retrofit – There are no soft patches or access hatches large enough to allow for equipment to be removed or installed into the engine room. Access need to be made through cutting into the hull in dry dock.

2. DEF Tankage – Tankage for the vessel was estimated based on the refueling interval and total fuel onboard. This vessel runs consistent routes and has a consistent fueling schedule. The DEF tank is shown as (3) tanks in Figure 6 adjacent to machinery, but could possibly be combined into one tank in the fuel tank compartment in the aft end of the vessel.

3. Electrical – Modification of the main switchboard will be required to accommodate additional switchgear. Modifications will vary based on the type of aftertreatment system. Systems with DPF and active regeneration will have the highest impact on electrical requirements.

4. Mechanical – The vessel is currently equipped with an air compressor system.

5. Fuel System – The combined SCR+DPF systems with active DPF regeneration will require a fuel based system for regeneration. Additional fuel piping and filters will be required for installation of the system.

6. Exhaust System – In the case of the repower or the aftertreatment system, current piping and silencers for main and auxiliary engines will need to be removed and replaced. The exhaust piping exists the engine room via the overhead in the forward end of the compartment. The exhaust does pass through a crew compartment that is located above the engine room. If new silencers are required due to sound emission restrictions, some space may be compromised. New piping and hangers will be installed. In addition, new custom lagging will be required to be installed on all exposed metal in the exhaust system.

2.4. Costs

Table 17 highlights the insured vessel replacement value as well as the current annual vessel fuel cost.

The dredge represents a unique costing case due to the various repower and retrofit options available. For the first scenario analyzed (Scenario #1), the pump/winch engine is repowered with a Tier 4 engine and the thruster and generator engines are both retrofitted with a DPF and SCR. For the second scenario analyzed (Scenario #2), the pump/winch engine is retrofitted with a DPF and SCR and the thruster and generator engines are also retrofitted with a DPF and SCR. In both Scenario #1 and #2, retrofit options were only investigated for the generator and thruster engines because there are no Tier 4 engine options available in this power subcategory.

Table 18 highlights the average fuel savings when repowering the Tier 3 pump winch engine with a Tier 4 engine, additional maintenance and DEF operating costs associated with repowering/retrofit SCR, and the retrofit DPF regeneration costs for the thruster and generator engines.

Table 19 highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the available repower technologies for the pump/winch engine and DPF/SCR retrofit solutions for the thruster and generator engines shown in Table 22.

Table *20* highlights the estimated additional retrofit operating diesel fuel cost incurred from regenerating the DPF and DEF for the SCR for the pump/winch engine, thruster and generator engines. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included.

Table *21* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the retrofit technologies shown in Table 23.

Table 17. Dredge Vessel Cost Information

Insured Vessel Replacement	$17,000,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$345,600

Table 18. Dredge Annual Operational Costs for Pump/Winch Engine Repower with Tier 4 Engine and Thruster/Generator Engine Retrofits (Scenario #1)

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Pump/Winch Engine Fuel Cost (Tier 3 to Tier 4 only) per year	-$6,912	-$20,736	-$13,824
Maint. Cost of Tier 4 SCR (Main Engine) per year	$6,804	$13,276	$10,040
DEF @ $1.75/gal - All Engines			$30,240
DPF Regen Fuel Cost - Thruster & Generator	$2,125	$5,750	$3,937
Total Repower Operational Cost Impact			$30,393

Table 19*. Dredge Summary of Capital/Installation Costs for Pump/Winch Engine Repower with Tier 4 Engine and Thruster/Generator Engine Retrofits (Scenario #1)*

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs - Repower Pump Engine	$484,500	$547,500	$516,000
Capital Cost - Retrofit DPF/SCR for Thruster & Generator	$50,000	$76,000	$63,000
Labor + Installation Costs			$581,000
Total Capital + Installation Costs			$1,160,000

Table 20. Dredge Annual Operational Costs for Retrofit DPF+SCR on All Engines (Scenario #2)

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Maint. Cost of SCR per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			$30,240
Regen Fuel Cost	$2,125	$19,958	$11,041
Total Retrofit Operational Cost Impact			$41,281

Table 21. Dredge Summary of Capital and Installation Costs for Retrofit DPF+SCR on All Engines (Scenario #2)

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$249,400	$293,335	$272,500
Capital Costs DPF ONLY	$174,000	$205,000	$189,500
Labor + Installation Costs			$449,000
Total Capital + Installation Costs SCR + DPF			$721,500
Total Capital + Installation Costs DPF ONLY			$638,500

Table 22. Dredge Detailed Installation Costs for Pump/Winch Engine Repower and Thruster and Generator Engine Retrofit (Scenario #1)

	Estimated Cost
Structural	$90,000
Mechanical	$251,000
Engine Room Access	$65,000
Testing & Commissioning	$60,000
Haulout/Shipyard Cost	$115,000
Total Installation Cost	$581,000

Table 23. Dredge Detailed Installation Costs for Retrofit of All Engines (Scenario #2)

	Estimated Cost
Structural	$54,000
Mechanical	$179,000
Engine Room Access	$65,000
Testing & Commissioning	$36,000
Haulout/Shipyard Cost	$115,000
Total Installation Cost	$449,000

3. Fishing – Commercial

3.1. Profile & Summary

This vessel is used for fishing and crabbing and is representative of the most common size of fishing vessel in California. Additionally, due to its smaller size, the operation is closer to the shore compared to the larger vessels in the fishing fleet having the greatest impact on emissions in California waters. Vessel particulars shown in Table 24.

The owner is currently operating a pre-Tier 1 engine, but is considering repowering to a new Tier 3 marine engine of equivalent horsepower. Due to its rated power, there are no Tier 4 engine options available for this power subcategory.

Retrofit aftertreatment options including the use of just a DPF or a combined DPF+SCR were studied. No fitment was identified to retrofit this vessel with either a standalone DPF or combined DPF+SCR based on required equipment volume and associated equipment weight. Retrofit will have adverse and non-addressable impacts on vessel stability and substantial modifications, such as extending the fiberglass hull, are modifications not currently performed by ship yards.

Additionally the vessel does not have an auxiliary engine to provide power to regenerate the DPF.

For commercial fishing vessels with similar properties and designs, this evaluation shows that only newly constructed vessels would be required to operate with either Tier 4 marine engines and existing vessels would be limited to Tier 3.

Options for aftertreatment are shown in Table 25 to illustrate the impacts and requirements retrofit aftertreatment equipment would have on a vessel of this category.

Table 24. Commercial Fishing Vessel Snapshot

Hull	Vessel/Barge Use	Fishing-Commercial
	Passenger Vessel (Y/N)	No
	USCG Inspected (Y/N)	No
	USCG Subchapter	N/A
	Hull Material	Fiberglass
	Hull Design	Monohull
	LOA (ft.)	40'
	Beam (ft.)	11’
Main Machinery	Number of Propulsion Engines	1
	Horsepower of Propulsion Engine	~350 HP
	Tier of Propulsion Engine	0
	Exhaust Type	Dry
	Location of Exhaust	Stack
	Type of Propulsion	Propeller
Auxiliary Machinery	Number of Auxiliary Engine(s)	0
	Use of Auxiliary Engine	N/A
	Power Pump (HP)	N/A
	Power Generator (kW)	N/A
	Tier of Auxiliary Engine	N/A
	Exhaust Type	N/A
	Exhaust Locations	N/A

Table 25. Commercial Fishing Modification Snapshot

Repower	Option Available	No
	Feasibility	N/A
	Additional Machinery Required	N/A
	Added Weight	N/A
	Total Installed Cost	N/A
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	No Fitment Identified
	Fuel Burn Required	1-1.5 GPH during regeneration
	Electrical Power Required	3-10 kW during regeneration
	Additional Machinery Required	Requires the addition of a generator, switchboard, air compressor, DEF tankage.
Retrofit DPF Only	Option Available	Yes
	Feasibility	No Fitment Identified
	Fuel Burn Required	1-1.5 GPH during regeneration Option for no fuel
	Electrical Power Required	3-8 kW
	Additional Machinery Required	Requires the addition of a generator and switchboard.
Impacts	Added System Weight Repower	N/A
	Added System Weight Retrofit	N/A

3.2. Considerations

1. Machinery Arrangement
   - Figure 9 is a partial vessel 3D scan showing the opening to the engine compartment in the interior of the vessel. This view is in the main compartment looking aft. The engine exhaust runs vertically behind the bulkhead directly above the engine compartment.

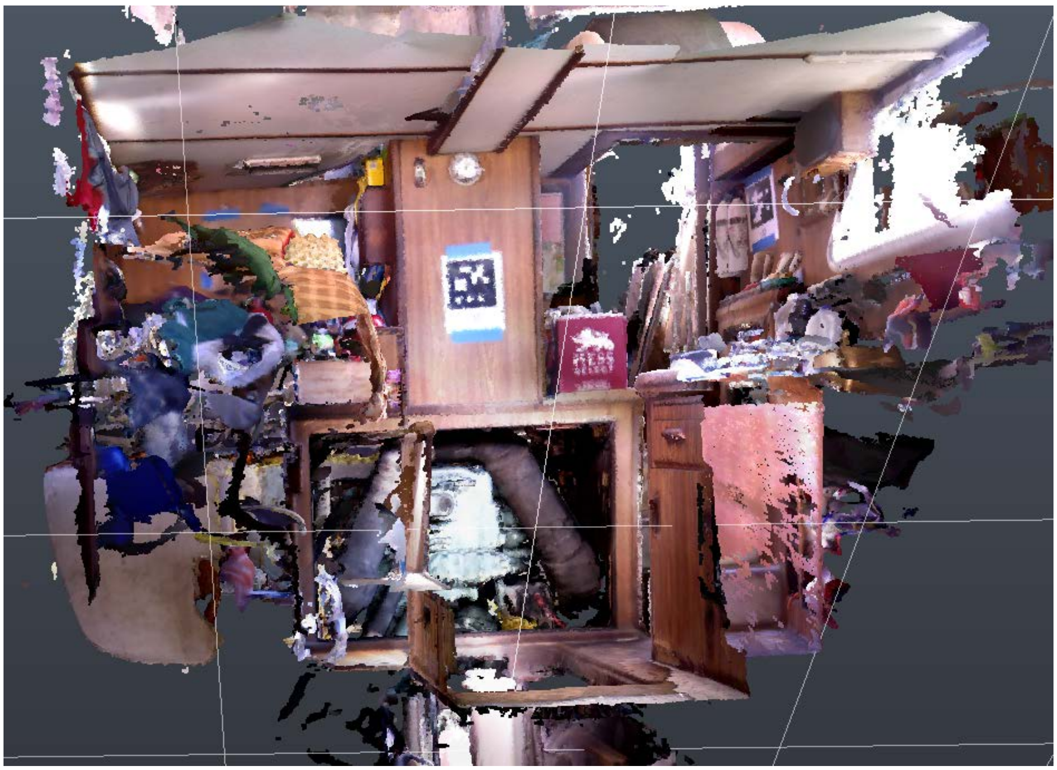

Figure 9. Commercial Fishing Vessel Existing Arrangement

2. Space Constraints – This vessel has a very small engine compartment that is marginally sized to fit the main engine and gearbox. It is challenging to access the engine for maintenance activities. Currently engine service to the rear half of the engine requires crawling behind a tank and removing a fixed panel on the exterior of the vessel. Any additional machinery would require encroachment on the kitchenette in the main cabin. The main boom for the vessel is on the aft side of the bulkhead that encases the exhaust. There is no available space above the cabin either. The kitchenette would likely have to be removed to make way for the aftertreatment equipment.

3. Existing Piping – The vessel has a dry stack that passes through a compartment just aft of the main cabin. Any additional equipment would require encroachment into interior living quarters.

   There is no air compressor onboard the vessel. An engine driven air compressor and pressure vessel would be required to be fit in the engine compartment.

4. Electrical System – There is no AC electrical system to support regeneration of a DPF. Potentially multiple alternators could be installed to support house loads on the vessel plus the additional aftertreatment load.

5. Stability – This vessel does not have current stability calculations. Any substantial change of weight would require stability measurements to ensure safety. Additional weight from either retrofit or repower aftertreatment would reduce the fish carrying capacity of the vessel.

6. Structure – There is no interior space to add additional equipment. Available area in the vessel aft of the engine room and below the main deck is used for fish and ice storage.

3.3. Installation

No fitment was identified for installation of additional equipment.

3.4. Costs

1. There are no Tier 4 engines or currently feasible retrofit options available for this vessel category.

2. Capital Cost of New Replacement Vessel with Tier 4 engines
   - $600,000

Installation Costs

There is currently no aftertreatment system available for this vessel category.

4. Fishing – Charter

4.1. Profile & Summary

This vessel conducts day charter fishing excursions and does not have overnight accommodations. The vessel can accommodate 72 passengers. The vessel is equipped with Tier 2 engines currently and does have a small auxiliary generator. Vessel particulars shown in Table 26.

There are no Tier 4 engine options available for this engine power subcategory, only retrofit aftertreatment systems are available.

Retrofit aftertreatment systems using just DPF or DPF/SCR were investigated. No fitment was identified to retrofit this specific vessel with aftertreatment devices based on required equipment volume and associated equipment weight. Retrofit will have adverse effects on vessel stability and will reduce passenger count by 8 - 30 persons depending on the technology implemented.

Options for aftertreatment are shown in Table 27 to illustrate the impacts and requirements retrofit aftertreatment equipment would have on a vessel of this design.

Table 26. Charter Fishing Vessel Snapshot

Hull	Vessel/Barge Use	Fishing-Charter
	Passenger Vessel (Y/N)	Yes
	USCG Inspected (Y/N)	Yes
	USCG Subchapter	Subchapter T
	Hull Material	Fiberglass
	Hull Design	Monohull
	LOA (ft.)	55'
	Beam (ft.)	16.5"
Main Machinery	Number of Propulsion Engines	2
	Horsepower of Propulsion Engine	500 HP
	Tier of Propulsion Engine	2
	Exhaust Type	Wet
	Location of Exhaust	Stern
	Type of Propulsion	Propellers
Auxiliary Machinery	Number of Auxiliary Engine(s)	1
	Use of Auxiliary Engine	Generator
	Power Pump (HP)	N/A
	Power Generator (kW)	5 kW
	Tier of Auxiliary Engine	2
	Exhaust Type	Wet
	Exhaust Locations	Stern

Table 27. Charter Fishing Modification Snapshot

Repower	Option Available	No
	Feasibility	N/A
	Additional Machinery Required	N/A
	Added Weight	N/A
	Total Installed Cost	N/A
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	No Fitment Identified
	Fuel Burn Required (per engine)	2 GPH during regeneration
	Electrical Power Required (per engine)	4-15 kw during regeneration
	Additional Machinery Required	Requires the replacement of the generator and switchboard. Air compressor, Urea tankage.
Retrofit DPF Only	Option Available	Yes
	Feasibility	No Fitment Identified
	Fuel Burn Required (per engine)	2 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	4-8 kW
	Additional Machinery Required	Requires the replacement of the generator and switchboard.
Impacts	Added System Weight Repower	N/A
	Added System Weight Retrofit	0.7-2.5 LT
	System weight is for retrofit of all engines. Range includes DPF+SCR and DPF only options.	

4.2. Considerations

1. Machinery Arrangement
   - Figure 10 is a visual representation showing an aftertreatment system in the vessel. The following colors represent the following equipment:
     - o The green represents the retrofit of the aftertreatment system.

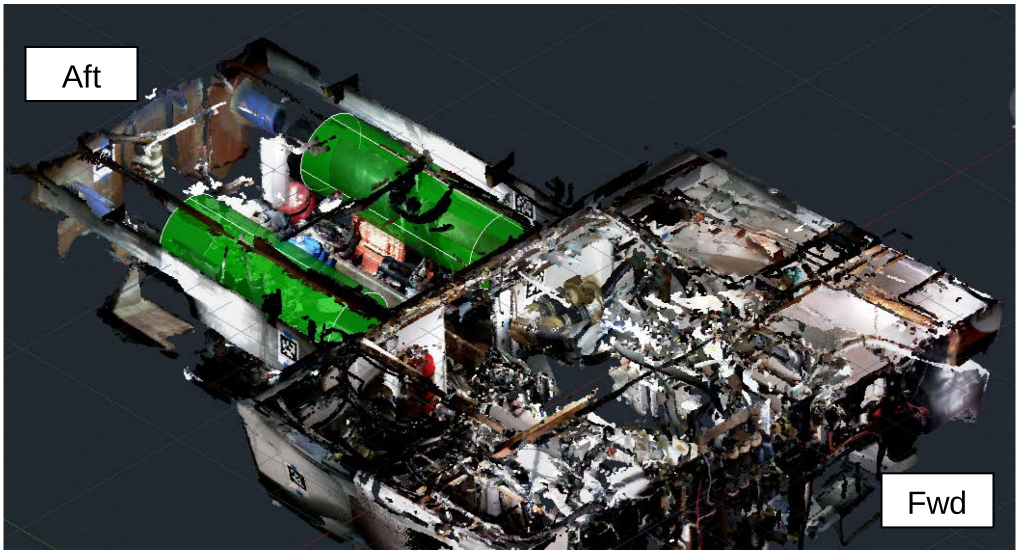

Figure 10. Charter Fishing Vessel Retrofit Arrangement

2. Space Constraints – For all of the retrofit options, the physical size ranges provided for the equipment are too large to fit inside the engine room. While it is shown in Figure 10 that equipment can physically fit in the vessel in the lazarette, there is no piping or DEF storage shown.

3. Existing Piping – Existing silencers are too large to fit in lazarette with aftertreatment system. Maintaining low exhaust noise level is critical to operation of the vessel. The aftertreatment system will provide noise attenuation, but there are concerns with the additional exhaust backpressure caused by the aftertreatment system. A suitable silencer likely will not be appreciably smaller than current silencer.

   Currently water is injected into the exhaust post turbocharger in the engine room. The exhaust runs in fiberglass piping through a FRP watertight bulkhead in the aft of the engine room to the lazarette where the exhaust enters water-lift style mufflers before exiting the hull of the vessel. Due to the aftertreatment system's potential placement in the lazarette, the exhaust would have to remain dry until after the aftertreatment system. The exhaust would then be dry and high temperature as new metallic piping penetrated the aft bulkhead. This exhaust piping would require new custom exhaust insulation. Specialty collars would be required if watertight integrity were to be maintained. New water injection piping would need to be fabricated to inject water into exhaust after the aftertreatment system.

The vessel currently does not have a compressed air system. An engine drive compressor and pressure vessels would be required. This additional weight was not taken into consideration when reviewing the vessel stability as the aftertreatment equipment alone significantly impacts the vessel's stability.

4. Electrical System – Power draw would require a significant upgrade of the generator aboard. Aftertreatment would require an additional 4.5-15 kW per engine for regeneration. The added weight for equipment to supply the additional power was not taken into consideration when reviewing the vessel stability as the aftertreatment equipment alone significantly impacts the vessel's stability.

5. Stability – No stability information was provided for the vessel. The weight addition of 0.7 LT - 2.5 LT (Equipment, DEF, Exhaust modifications/insulation) will require a reduction in passenger count by 8-30 persons when installing a retrofit DPF+SCR or DPF only aftertreatment system. The vessel does have a passenger count greater than 49 passengers and less than the maximum of 150, so the assumption was made that the vessel is displacement limited and any added weight would result in a reduction of allowable passenger count. The reductions in passenger count were calculated using the USCG typical per person weight of 185 lbs[2]. If the penetration in the aft bulkhead of the engine room were not able to be maintained as a watertight bulkhead due to exhaust modifications, the passenger count would be required to be reduced by 33 persons, from a current total of 72 persons as required by the Certificate of Inspection.

6. Structure – Structural modifications would be required to the hull in order to support the added weight in the lazarette.

4.3. Installation

There is currently no aftertreatment system available for this vessel category.

[2] USCG. CG-543 Policy Letter 11-03. 8 April 2011.

4.4. Costs

1. There are currently no Tier 4 engines available for this vessel category and no retrofit options that will fit.

2. Capital Cost of New Replacement Vessel with Tier 4
   - $1,300,000

5. Excursion

5.1. Profile & Summary

This vessel is used in multiple excursion modes including harbor tours and charter cruises. It can carry greater than 150 passengers, but does not have overnight accommodations. Vessel particulars shown in Table 28.

There are currently developed engines that are not yet available for purchase, but are undergoing testing for Tier 4 EPA certification. These engines are equipped with SCR aftertreatment to meet U.S. EPA Tier 4 standards. Additionally these engines do not require compressed air for the urea injection. This engine, however is larger than the existing engine in the vessel and has a weight disadvantage.

The utilization a DPF only retrofit system and a combination SCR+DPF retrofit system were investigated. The DPF only system has a size advantage over the combined SCR+DPF system, but does not address NOx. All systems considered have active DPF filter regeneration. In this evaluation, actively regenerated DPFs were evaluated only due this vessels low average load factor.

The additional 1.4 - 4.4 LT of weight shouldn’t, but has the possibility to trigger stability testing. Because we do not anticipate the modifications to independently trigger stability testing, no cost of stability testing was included. The greater concern is that many passenger vessels are operating off of older stability letters. The new stability test may reveal that the vessel is no longer in the condition when the initial stability test was conducted and in fact has changed characteristics. Vessels typically get heavier as they age due to new equipment being added and/or relocated. So even if only 1.4 LT are added, which may have negligible effect on stability, it may be found that there are other vessel characteristics that will have to be mitigated by reduction in passenger count, limits on passenger locations, or loss in operating capabilities.

The aftertreatment summary shown in Table 29.

Table 28. Excursion Vessel Snapshot

Hull	Vessel/Barge Use	Excursion
	Passenger Vessel (Y/N)	Yes
	USCG Inspected (Y/N)	Yes
	USCG Subchapter	Subchapter K
	Hull Material	Steel
	Hull Design	Monohull
	LOA (ft.)	151'
	Beam (ft.)	40.5'
Main Machinery	Number of Propulsion Engines	2
	Horsepower of Propulsion Engine	575HP
	Tier of Propulsion Engine	2
	Exhaust Type	Dry
	Location of Exhaust	Stack
	Type of Propulsor	Propellers
Auxiliary Machinery	Number of Auxiliary Engine(s)	2
	Use of Auxiliary Engine	Generator
	Power Pump (HP)	N/A
	Power Generator (kW)	150 kW
	Tier of Auxiliary Engine	3
	Exhaust Type	Dry
	Exhaust Locations	Stack

Table 29. Excursion Vessel Modification Snapshot

Repower	Option Available	Yes
	Feasibility	Fitment Feasible
	Additional Machinery Required	DEF Tankage and transfer equipment. New silencers
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Fitment Feasible
	Fuel Burn Required (per engine)	2.5 GPH during regeneration
	Electrical Power Required (per engine)	5-17 kW during regeneration
	Additional Machinery Required	Switchboard modifications, fuel system modifications, DEF tankage and transfer equipment. New silencers
Retrofit DPF Only	Option Available	Yes
	Feasibility	Fitment Feasible
	Fuel Burn Required (per engine)	2.5 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	5-8 kW
	Additional Machinery Required	Switchboard modifications. New silencers
Impacts	Added System Weight Repower	3.7 LT
	Added System Weight Retrofit	1.6-4.4 LT
	Note: 1) Repower system weight assumes a repower of both main engines. 2) Retrofit system weight assumes a retrofit of both main engines. Range includes DPF+SCR and DPF only options.	

5.2. Considerations

1. Machinery Arrangement
   - Figure 11 is a visual representation for a feasible DPF retrofit. The following colors represent the following equipment:
     - o The green components are the DPFs for each main engine.
     - o The yellow components are the mufflers that have been relocated to accommodate the DPF.
     - o The red represents the new exhaust piping path.

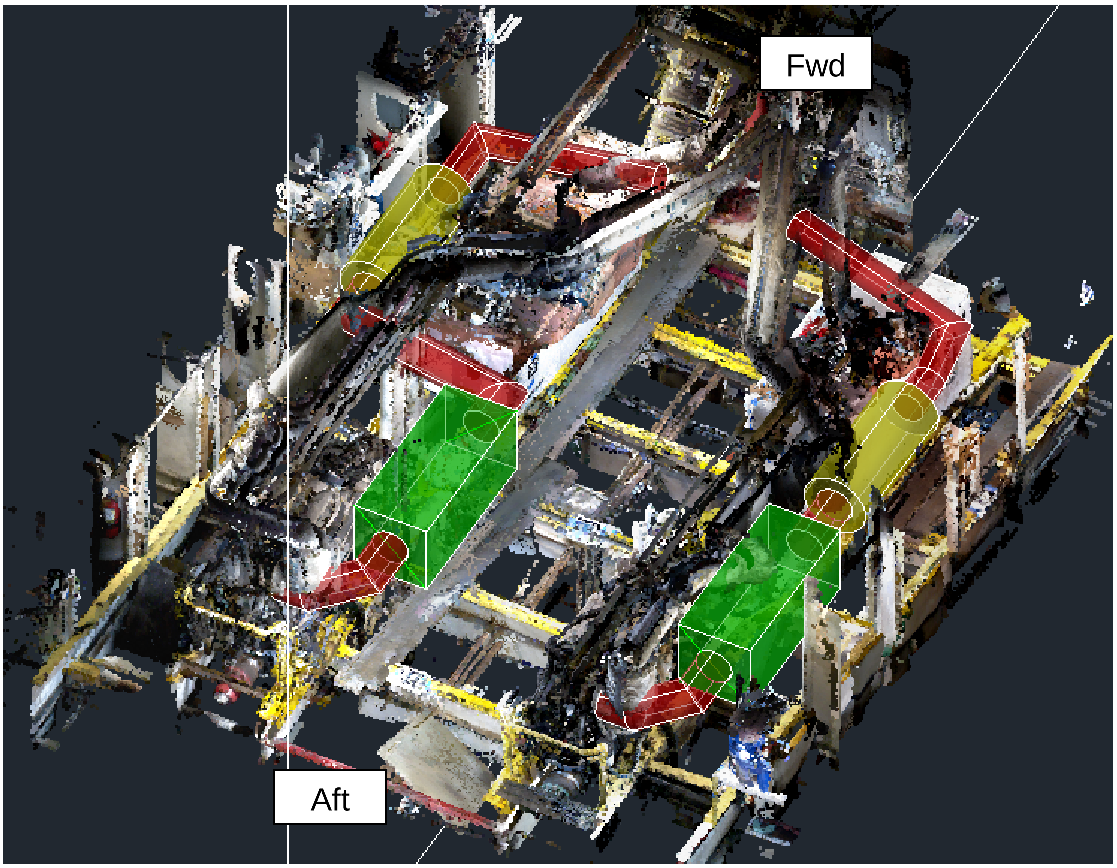

Figure 11. Excursion Vessel Retrofit Arrangement

2. Space Constraints – The combined DPF+SCR devices can marginally fit in the engine room. The silencers for this vessel are located in the engine spaces and cannot be relocated to the stack. The size and critical dimensions of the equipment will have impacts on headroom in certain walkways and will limit access to existing engine and systems equipment.

3. Existing Piping - The exhaust system for the main engines, including the exhaust of the existing generator sets, will require modifications. Further acoustical information is needed to determine if the silencers could be omitted.

This vessel is a large passenger vessel and engine sound attenuation is critical to the business model. There are no other major piping concerns in the space.

4. Electrical System - This vessel has excess electrical generation capacity. As an excursion vessel, this vessel has larger generators than other comparable vessels due to the passenger load. The generators are also tasked with running the bow thruster. An interlock system may be required to prevent regeneration of both systems from occurring during bow thruster operation.

5. Stability
    - With the installation of the retrofit aftertreatment equipment, the additional weight of 1.6-4.4 LT may require the redistribution of passengers aboard.
    - A repower with Tier 4 equipment will add an additional 3.7 LT and may require the redistribution of passengers aboard.
    - It is the intention that these systems are known weights going into known locations and therefore should NOT count against the 2% weight change, 1% LCG requirement that triggers a USCG stability test.[3] If addition of this equipment triggers a stability test, there will be significant additional costs added, as well as the possibility of unfavorable results leading to loss of operational capabilities.

6. Structure - The systems modelled are shown hanging from deck structure. Analysis of each location and surrounding deck structure should be performed to ensure adequate strength to support the equipment and exhaust run hangers to meet specifics from system vendors. It may be feasible to use deck pedestals in lieu or in combination with the exhaust hangers.

[3] MTN 04-95 “Lightship Changes Determination: Weight-Moment Calculation vs. Deadweight Survey vs. Full Stability Test”

5.3. Installation

1. Engine Room Access Repower – The vessel is equipped with soft patches over the engine compartment. Engine replacement access does not require cutting steel as engines can be brought in via the main boarding doors. However, flooring will be required to be removed to access the soft patches. All interior finishes will need to be covered prior to work commencing.

2. Engine Room Access Retrofit – The vessel has a large engine access hatch. Per the owner of the vessel, they have been able to remove and replace generators without having to remove the soft patches. Most likely the retrofit system can be brought into the engine space via the main engine room door.

3. DEF Tankage – Tankage for the vessel was estimated based on the refueling interval and not total fuel onboard. This vessel has a consistent fueling schedule. Tankage, approximately 200 gallons to be located in the main machinery space. Exterior location of DEF piping for fill need to be determined.

4. Electrical – Modification to the main switchboard will be required to accommodate additional switchgear. Modifications will vary based on type of retrofit aftertreatment system. Systems with DPF and active regeneration will have the highest impact on electrical requirements.

5. Mechanical – Air compressor system will be required to be added for the retrofit aftertreatment system. The repower option does not require an air compressor.

6. Fuel System – The combined SCR+DPF systems with active DPF regeneration will require a fuel based system for regeneration. Additional fuel piping and filters will be required for installation of system.

7. Exhaust System – In the case of repower or the retrofit aftertreatment system, current piping and silencers for main engines and generators will need to be removed. All exhaust piping exits the machinery space at the forward end of the engine room via a stack to the upper decks of the vessel. New piping and hangers need to be installed. In addition, new custom lagging will be required to be installed on all exposed metal in the exhaust system.

5.4. Costs

Table 30 highlights the insured vessel replacement value as well as the current annual vessel fuel cost. For this application, there were both repower and retrofit options available. Table *31* highlights the average fuel savings when repowering a Tier 3 engine with a Tier 4 engine as well as the additional maintenance and DEF operating costs associated with repowering.

Table 32 highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the available repower technologies shown in Table 35. Table *33* highlights the estimated additional retrofit operating diesel fuel cost incurred from regenerating the DPF and DEF for the SCR. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included. Table *34* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the retrofit technologies shown in Table 36.

Table 30. Excursion Vessel Cost Information

Insured Vessel Replacement	$9,000,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$136,800

Table 31*. Excursion Vessel Annual Operational Costs for Main Engine Repower and SCR*

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Main Engine Fuel Cost (Tier 3 to Tier 4 only) per year	-$2,736	-$8,208	-$5,472
Maint. Cost of Tier 4 SCR (Main Engine) per year	$5,216	$10,178	$7,697
DEF @ $1.75/gal			$11,970
Total Repower Operational Cost Impact			$14,195

Table 32. Excursion Vessel Summary of Capital/Installation Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs	$280,000	$322,000	$301,000
Labor + Installation Costs			$417,000
Total Capital + Installation Costs			$718,000

Table 33. Excursion Vessel Annual Operational Costs for Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Maint. Cost of SCR per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			$11,970
Regen Fuel Cost	$4,526	$10,893	$7,710
Total Retrofit Operational Cost Impact			$19,680

Table 34. Excursion Vessel Summary of Capital and Installation Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$144,000	$166,000	$155,000
Capital Costs DPF ONLY	$92,000	$100,000	$96,000
Labor + Installation Costs			$304,000
Total Capital + Installation Costs SCR + DPF			$459,000
Total Capital + Installation Costs DPF ONLY			$400,000

Table 35. Excursion Vessel Detailed Installation Costs for Main Engine Repower-

	Estimated Cost
Structural	$60,000
Mechanical	$188,000
Engine Room Access	$30,000
Testing & Commissioning	$48,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$417,000

Table 36. Excursion Vessel Detailed Installation Costs for Retrofit

	Estimated Cost
Structural	$18,000
Mechanical	$141,000
Engine Room Access	$30,000
Testing & Commissioning	$24,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$304,000

6. Ferry – Slow/Medium Speed

6.1. Profile & Summary

This vessel is used in short, lower speed ferry runs (<20 kts). It can carry greater than 150 passengers and does not have overnight accommodations. Vessel particulars shown in Table 37.

There are commercially available OEM Tier 4 marine engine options available in the power subcategory applicable to this vessel. These engines are equipped with SCR aftertreatment only. There are engine options available that do and do not require compressed air for DEF injection.

The utilization a DPF only retrofit system and a combination SCR+DPF retrofit system were investigated. All systems considered have active DPF filter regeneration. Passive regeneration may be an option, but further analysis of load profile and exhaust temperatures/flow rates would be required to determine feasibility.

Retrofit may have an effect on stability or passenger count however, repower options may have a negligible impact.

Aftertreatment summary shown in Table 38.

Table 37. Slow Speed Ferry Vessel Snapshot

Hull	Vessel/Barge Use	Ferry - Slow
	Passenger Vessel (Y/N)	Yes
	USCG Inspected (Y/N)	Yes
	USCG Subchapter	Subchapter K
	Hull Material	Steel
	Hull Design	Monohull
	LOA (ft.)	131'
	Beam (ft.)	34.5'
Main Machinery	Number of Propulsion Engines	2
	Horsepower of Propulsion Engine	1000HP
	Tier of Propulsion Engine	2
	Exhaust Type	Dry
	Location of Exhaust	Stack
	Type of Propulsor	Propellers
Auxiliary Machinery	Number of Auxiliary Engine(s)	2
	Use of Auxiliary Engine	Generator
	Power Pump (HP)	N/A
	Power Generator (kW)	55 kW
	Tier of Auxiliary Engine	2 & 3
	Exhaust Type	Dry
	Exhaust Locations	Stack

Table 38. Slow Speed Ferry Vessel Modification Snapshot

Repower	Option Available	Yes
	Feasibility	Fitment Feasible
	Additional Machinery Required	DEF tankage and transfer, silencer replacement, modified compressed air system
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Moderate Reconfiguration
	Fuel Burn Required (per engine)	5.5 GPH during regeneration
	Electrical Power Required (per engine)	6-30 kW during regeneration
	Additional Machinery Required	Switchboard modifications, fuel system, silencer replacement, DEF tankage
Retrofit DPF Only	Option Available	Yes
	Feasibility	Moderate Reconfiguration
	Fuel Burn Required (per engine)	5.5 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	6.3-25 kW
	Additional Machinery Required	Switchboard modifications, silencer replacement
Impacts	Added System Weight Repower	Negligible
	Added System Weight Retrofit	1.8-5 LT
	Note: 1) Repower system weight assumes a repower of both main engines. 2) Retrofit system weight assumes a retrofit of both main engines. Range includes DPF+SCR and DPF only options.	

6.2. Considerations

1. Machinery Arrangement
   - Figure 12 is a visual representation for a DPF/SCR retrofit. Figure 13 shows the same fitment, but with the scanned image layer suppressed. The following colors represent the following equipment:
     - o The grey boxes are the existing stack structure that is also used for engine room access.
     - o The blue cylinders are retrofit after-treatment devices
     - o The red represents the new exhaust piping path.

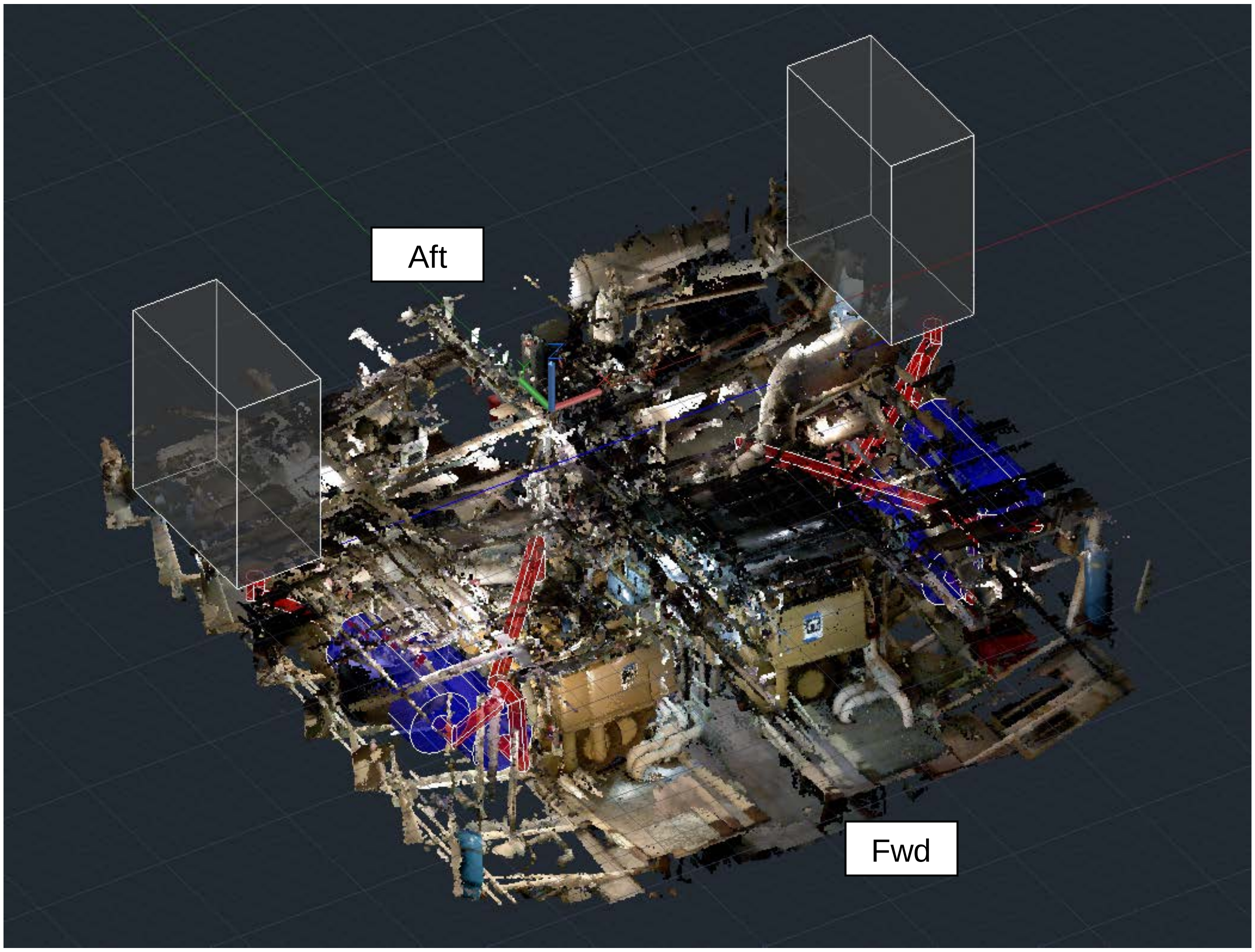

Figure 12. Slow Speed Ferry Retrofit Arrangement

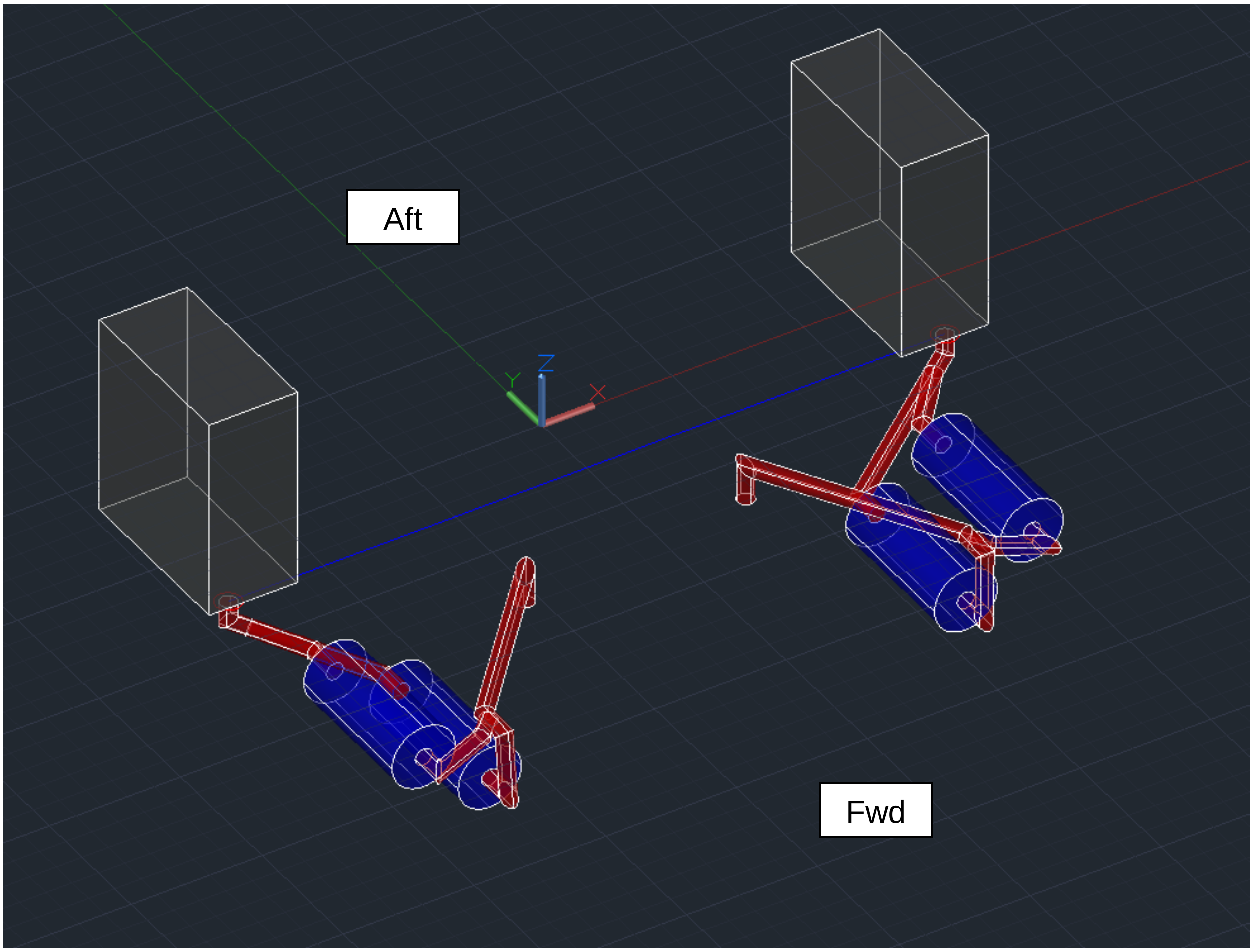

Figure 13. Slow Speed Ferry Retrofit Arrangement with Point Cloud Suppressed

- Figure 14 is a visual representation for an OEM repower. Figure 15 shows the same fitment, but with the point cloud suppressed. The following colors represent the following equipment:
    - The grey boxes are the existing stack structure that is also used for engine room access.
    - The green is the OEM Tier 4 SCR. Note that the engines are not shown as replaced, but new engines will fit within envelope of existing engines
    - The red represents the new exhaust piping path.
    - The yellow box is the DEF tank
    - The cyan boxes are the DEF dosing cabinets
    - The original engines are shown in this image. The replacement engines are slightly smaller than the engines shown.

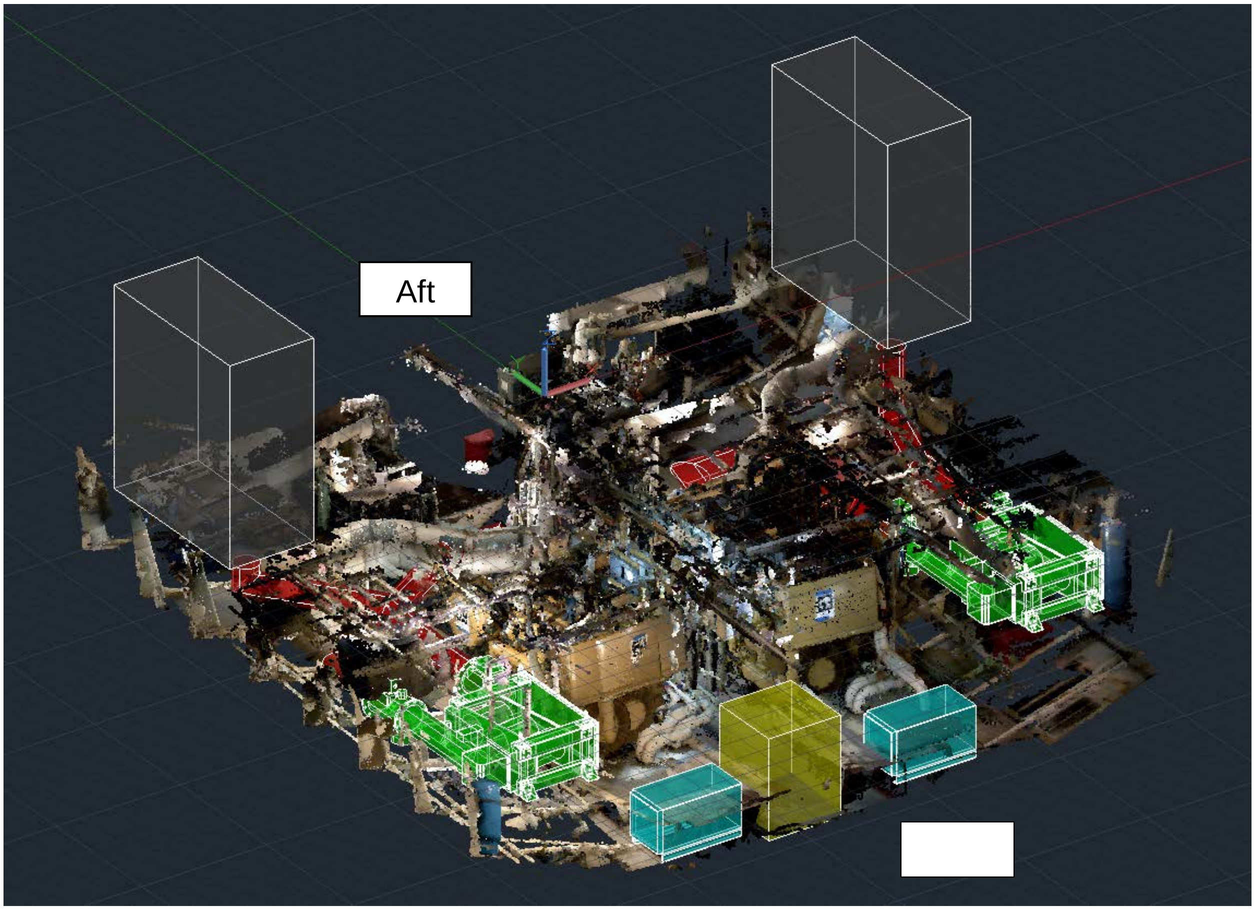

Figure 14. Slow Speed Ferry Repower Arrangement

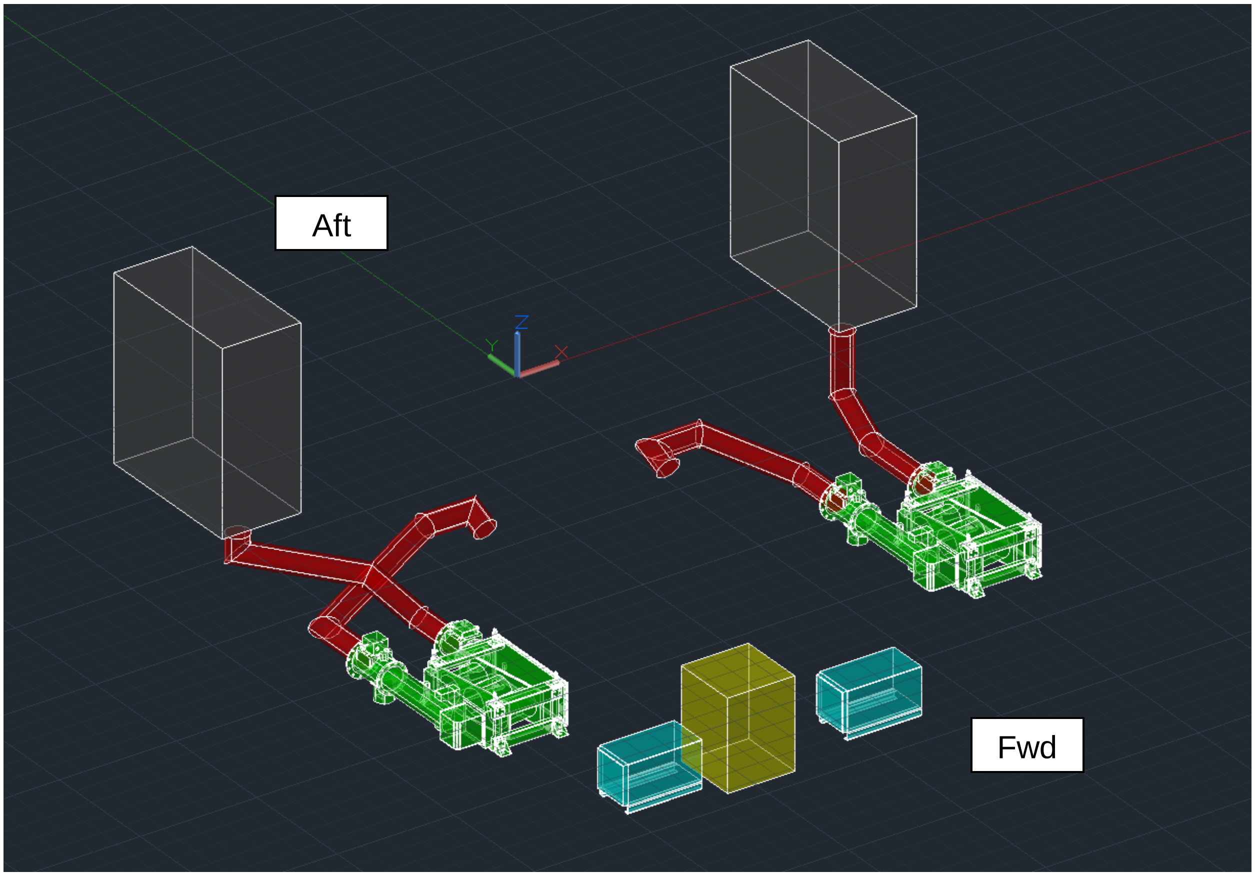

Figure 15. Slow Speed Ferry Repower Arrangement with Point Cloud Suppressed

2. Space Constraints – The combined DPF/SCR devices can fit in the engine room. This particular vessel has available room outboard and forward of the main engines, but is limited in the height of the engine room. The silencers for this vessel are located in the stack. The size and critical dimensions of the equipment will have impacts on engine access on the outboard sides of the main engines and may cause challenge with access to aftertreatment devices. The stacks likely will not be able to accommodate the aftertreatment devices due to the fact that they provide person access to the engine room.

3. Existing Piping – The exhaust system for the main engines would require significant modifications, likely requiring a complete exhaust system overhaul. There is potential that existing subsystem piping may need to be rerouted to allow adequate access to Tier 4 equipment and maintenance panels. Hydraulic, air, and water systems are the subsystems that may need to be relocated.

4. Electrical System – The vessel is equipped with two 55kW generator sets. This vessel typically runs a single generator at a time and does not have the required equipment for paralleling/load sharing between two generators. Typical

instantaneous power requirement for a regeneration cycle for an active DPF device is 6kW-30kW per engine. There may not be enough electrical capacity to conduct a full electrical regeneration of the DPF/SCR related after-treatment options.

5. Stability –
   - A comparison to sister vessels indicate potential impacts to stability. The stability of a vessel is analyzed in a theoretical damaged condition. Part of this analysis includes theoretical flooding of compartments or void spaces. With the added weight of the equipment plus the current maximum passenger count, there are flooding scenarios where the vessel does not meet minimum criteria for safety. The added weight could be counteracted with additions to limit flooding in void spaces.
   - Additional equipment weight for the repower scenario is negligible. The replacement engines are approximately 25% lighter than the existing engines. This reduces the overall weight gain of the vessel and will have a much less significant effect on stability.
   - Additional equipment for adding retrofit aftertreatment to equipment adds 1.8-6.3 LT to the vessel depending on the system. This weight gain is the equivalent of 22-77 passengers.

6.3. Installation

1. Engine Room Access Repower – The vessel is equipped with soft patches over the engine compartment. Engine replacement access does not require cutting steel as engines can be brought in via the main boarding doors. However, flooring will be required to be removed to access the soft patches. All interior finishes will need to be covered prior to work commencing.

2. Engine Room Access Retrofit – The person access hatches to the engine room of this vessel are not of sufficient size to bring large equipment into the engine room. At least one soft patch will need to be removed to install retrofit equipment.

3. DEF Tankage – Tankage for the vessel was estimated based on the refueling interval and total fuel onboard. Tankage should be in the range of 100-200 gallons. This vessel runs consistent routes and has a consistent fueling schedule. Tankage to be located in the main machinery space. Exterior location of DEF piping for fill will have to be determined. Overall DEF tank size may be able to be reduced based on closer evaluation of daily fuel burn.

4. Electrical – Modification to the main switchboard will be required to accommodate additional switchgear. Modifications will vary based on type of

retrofit aftertreatment system. Systems with DPF and active regeneration will have the highest impact on electrical requirements. Interlocks may be required to prevent two regenerations cycles from occurring concurrently.

5. Mechanical – The vessel is currently equipped with an air compressor system but it will need to be upgraded if the new aftertreatment system requires compressed air. There are fresh air intakes into the engine room that likely will conflict with the installation of the new aftertreatment devices and will need to be relocated.

6. Fuel System – The combined DPF/SCR systems with active DPF regeneration will require a fuel based system for regeneration. Additional fuel piping and filters will be required for installation of system.

7. Exhaust System – In the case of the repower or the retrofit aftertreatment system, current piping and silencers for main engines and generators will need to be removed and replaced. The port side machinery (main engine and generator) exhausts through the port stack, while the STBD machinery exhausts through the STBD stack.

6.4. Costs

Table 39 highlights the insured vessel replacement value as well as the current annual vessel fuel cost. For this application, there were both repower and retrofit options available. Table *40* highlights the average fuel savings when repowering a Tier 3 engine with a Tier 4 engine as well as the additional maintenance and DEF operating costs associated with repowering.

Table 41 highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the available repower technologies shown in Table 44. Table *42* highlights the estimated additional retrofit operating diesel fuel cost incurred from regenerating the DPF and DEF for the SCR. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included. Table *43* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the retrofit technologies shown in Table 45.

Table 39. Slow Speed Ferry Vessel Cost Information

Insured Vessel Replacement	$5,000,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$360,000

Table 40. Slow Speed Ferry Annual Operational Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Main Engine Fuel Cost (Tier 3 to Tier 4 only) per year	-$7,200	-$21,600	-$14,400
Maint. Cost of Tier 4 SCR (Main Engine) per year	$9,072	$17,702	$13,387
DEF @ $1.75/gal			$31,500
Total Repower Operational Cost Impact			$30,487

Table 41. Slow Speed Ferry Summary of Capital/Installation Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs	$520,000	$730,000	$625,000
Labor/Installation Costs			$384,000
Total Capital + Installation Costs			$1,009,000

Table 42. Slow Speed Ferry Annual Operational Costs for Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Maint. Cost of SCR per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			$31,500
Regen Fuel Cost	$7,072	$18,944	$13,008
Total Retrofit Operational Cost Impact			$44,508

Table 43. Slow Speed Ferry Summary of Capital and Installation Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$240,000	$290,000	$268,000
Capital Costs DPF ONLY	$120,000	$296,000	$208,000
Labor + Installation Costs			$280,000
Total Capital + Installation Costs SCR + DPF			$548,000
Total Capital + Installation Costs DPF ONLY			$488,000

Table 44. Slow Speed Ferry Detailed Installation Costs for Main Engine Repower

	Estimated Cost
Structural	$54,000
Mechanical	$161,000
Engine Room Access	$30,000
Testing & Commissioning	$24,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$384,000

Table 45. Slow Speed Ferry Detailed Installation Costs for Retrofit

	Estimated Cost
Structural	$36,000
Mechanical	$99,000
Engine Room Access	$30,000
Testing & Commissioning	$24,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$280,000

7. Ferry – Fast

7.1. Profile & Summary

This vessel is used in long, high speed ferry runs (>30 kts). It can carry greater than 150 passengers and does not have overnight accommodations. Vessel particulars shown in Table 46.

There are commercially available OEM Tier 4 marine engine options available in the power subcategory applicable to this vessel. The utilization of a DPF only system and DPF/SCR were investigated. All systems considered have active DPF filter regeneration. Passive regeneration may be an option due to the high load profile of the vessel, but further analysis of load profile and exhaust temperatures/flow rates would be required to determine feasibility.

The existing hull form cannot support new equipment due to space and weight limitations. If it were physically possible to install the aftertreatment equipment, the stability would be adversely impacted with the addition of 5-12 LT of weight in the stern of the vessel. The additional weight would also affect the speed performance of vessel, increasing resistance/fuel consumption and diminishing schedule keeping.

Table 46. High Speed Ferry Vessel Snapshot

Hull	Vessel/Barge Use	Ferry - Fast
	Passenger Vessel (Y/N)	Yes
	USCG Inspected (Y/N)	Yes
	USCG Subchapter	Subchapter K
	Hull Material	Aluminum
	Hull Design	Catamaran
	LOA (ft.)	135'
	Beam (ft.)	39.4'
Main Machinery	Number of Propulsion Engines	2
	Horsepower of Propulsion Engine	3430 HP
	Tier of Propulsion Engine	2
	Exhaust Type	Dry
	Location of Exhaust	Stern
	Type of Propulsor	Waterjet
Auxiliary Machinery	Number of Auxiliary Engine(s)	2
	Use of Auxiliary Engine	Generator
	Power Pump (HP)	N/A
	Power Generator (kW)	112 kW
	Tier of Auxiliary Engine	2
	Exhaust Type	Wet
	Exhaust Locations	Sideshell

Table 47. High Speed Ferry Vessel Modification Snapshot

Repower	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Additional Machinery Required	Air compressor, DEF tankage and transfer system. Replace silencers. Extensions to hull form. Relocation of engine girders and engines. Extended drive shafts
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Fuel Burn Required (per engine)	22 GPH during regeneration
	Electrical Power Required (per engine)	16 kW during regeneration
	Additional Machinery Required	Switchboard modifications, fuel system, DEF tankage and transfer system. Replace silencers Extensions to hull form. Relocation of engine girders and engines. Extended drive shafts
Retrofit DPF Only	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Fuel Burn Required (per engine)	22 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	16-37 kW
	Additional Machinery Required	Switchboard modifications. Extensions to hull form. Relocation of engine girders and engines. Extended drive shafts
Impacts	Added System Weight Repower	6.6 LT
	Added System Weight Retrofit	5-12.4 LT
	Note: 1) Repower system weight assumes a repower of both main engines. 2) Retrofit system weight assumes a retrofit of both main engines. Range includes DPF+SCR and DPF only options.	

7.2. Considerations

1. Machinery Arrangement - Scans were not conducted for this vessel. Original drawings were used to check equipment sizing. Note that the aft engine room transverse bulkhead is not visible and is called out. The engine silencer in the compartment aft of the engine room (jet room) is not shown. The Tier 4 SCR after-treatment device as shown does not fit in the engine room and is shown penetrating the aft engine room bulkhead.

   - Figure 16 is a visual representation for a repower. The following colors represent the following equipment:
     - The pink box is a SCR option.
     - The brown box is representative of the volume of the gear box.
     - The black box represents the volume of the main engine and exhaust outlet of the engine.

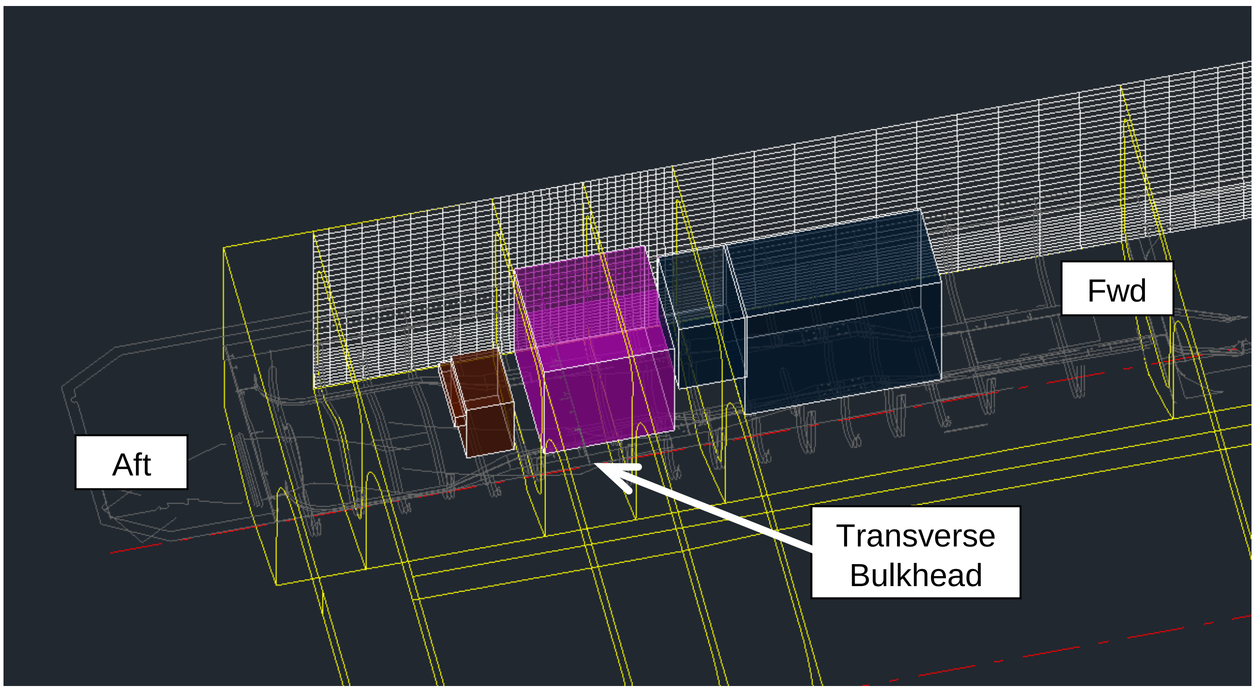

Figure 16. High Speed Ferry Repower Arrangement (Port Hull Shown)

- Figure 17
    - The green and red boxes are DPF/SCR units for reference.
    - The blue box represents the volume of the main engine and exhaust.
    - The brown box is represents the volume of the gearbox. Note that its location was modified to accommodate the aftertreatment device.

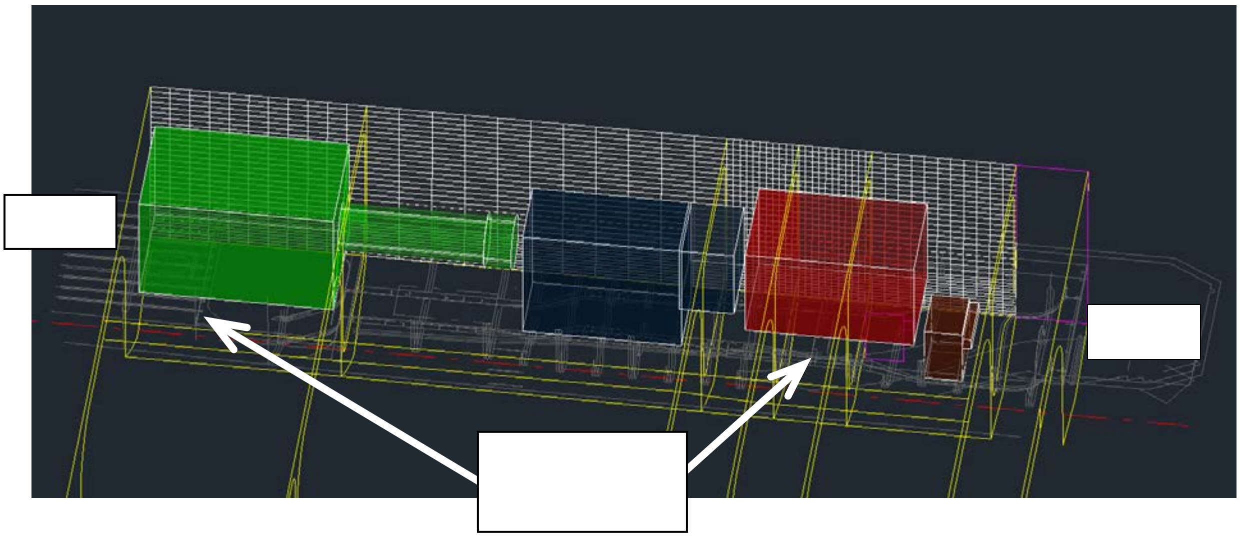

Figure 17. High Speed Ferry Retrofit Arrangements (Stbd Hull Shown)

2. Space Constraints - For all of the combined SCR and DPF retrofit options, the OEM SCRs, and the DPFs, the physical size ranges provided for the equipment are too large to fit inside the engine room or in the compartment aft of the engine room without significant modifications. Significant reconfiguration, such as lengthening would be required. Engines may need to be relocated forward to allow for after-treatment installation in engine rooms.

3. Existing Piping - The exhaust system for the main engines would require significant modifications, requiring a complete exhaust system overhaul. The existing silencers are located in the compartment behind the engine room and not shown in Figure 16 or Figure 17.

4. Electrical System – The vessel is equipped with two 112 kW generators. DPF systems will require 16-37.5 kW of electrical power, per engine, for regeneration operations.

5. Stability – Aftertreatment system would add approximately 6.6-12.4 LT to the aft end of the vessel which would likely affect both intact and damage stability calculations. Additionally, added weight adversely affects the speed

performance of vessel, increasing resistance and diminishing schedule keeping. Overcoming stability issues may require extending the length of the vessel.

6. Structure – Current structure of vessel cannot support the aftertreatment systems available without substantial modifications.

7.3. Installation

The vessel would need to be significantly reconfigured to fit retrofit aftertreatment systems or Tier 4 OEM engines. Expected work would require relocating main engines and extending the hull to accommodate the additional weight. Exact details are beyond the scope of this project.

7.4. Costs

Table 48 highlights the insured vessel replacement value as well as the current annual vessel fuel cost. For this application, there were both repower and retrofit options available. Table *49* highlights the average fuel savings when repowering a Tier 3 engine with a Tier 4 engine as well as the additional maintenance and DEF operating costs associated with repowering. Table *50* highlights the cost ranges for the capital and labor/installation cost of $7,000,000, which is near the actual number for a similar vessel requiring similar significant vessel modifications.

Table *51* highlights the estimated additional retrofit operating diesel fuel cost incurred from regenerating the DPF and DEF for the SCR. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included. Table *52* highlights the cost ranges for the capital and labor/installation cost, which remains at $7,000,000 due to a similar vessel requiring similar significant vessel modifications.

Table 48. High Speed Ferry Vessel Cost Information

Insured Vessel Replacement	$20,000,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$1,971,000

Table 49. High Speed Ferry Annual Operational Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Main Engine Fuel Cost (Tier 3 to Tier 4 only) per year	-$39,420	-$118,260	-$78,840
Maint. Cost of Tier 4 SCR (Main Engine) per year	$31,117	$60,716	$45,917
DEF @ $1.75/gal			$172,463
Total Repower Operational Cost Impact			$139,540

Table 50. High Speed Ferry Summary of Capital/Installation Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs	$2,200,000	$2,800,000	$2,500,000
Labor + Installation Costs			$7,000,000
Total Capital + Installation Costs			$9,500,000

Table 51*. High Speed Ferry Annual Operational Costs for Retrofit DPF+SCR*

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Maint. Cost of SCR per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			$172,463
Regen Fuel Cost	$7,072	$64,979	$36,025
Total Retrofit Operational Cost Impact			$208,488

Table 52*. High Speed Ferry Summary of Capital and Installation Retrofit DPF+SCR*

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$676,000	$995,000	$835,500
Capital Costs DPF ONLY	$340,000	$360,000	$350,000
Labor + Installation Costs			$7,000,000
Total Capital + Installation Costs SCR + DPF			$7,835,500
Total Capital + Installation Costs DPF ONLY			$7,350,000

The installation cost breakdown for the fast ferry was not completed. Near actual numbers were used for this study for a similar vessel that required similar significant vessel reconfiguration, which amounted to approximately $7,000,000. The modifications planned for that vessel included lengthening, revised engine bed rails, relocated engine location, new shafting to waterjets, etc.

8. Tug – Ship Assist

8.1. Profile & Summary

This vessel is used for ship assist and is of a common design. Vessel particulars shown in Table 53.

There are commercially available OEM Tier 4 marine engine options available in the power subcategory applicable to this vessel. The Tier 4 engine systems studied for this application are feasible, however this would require a repower to a different model of engine. This replacement engine is significantly lighter than the current engine. If the repower of a sister vessel involved an engine of the similar make as the repower engine, the vessel could expect a weight increase of 13 LT.

The utilization of a DPF only system and DPF+SCR combination were investigated. All systems considered have active DPF filter regeneration. No fitment was identified for a DPF+SCR combination system, however, DPF only systems were found to fit with moderate reconfiguration.

Aftertreatment summary shown in Table 54.

Table 53. Ship Assist Tug Vessel Snapshot

Hull	Vessel/Barge Use	Tug - Ship Assist		
	Passenger Vessel (Y/N)	No		
	USCG Inspected (Y/N)	Yes		
	USCG Subchapter	Subchapter M		
	Hull Material	Steel		
	Hull Design	Monohull		
	LOA (ft.)	100'		
	Beam (ft.)	40'		
Main Machinery	Number of Propulsion Engines	2		
	Horsepower of Propulsion Engine	3425 HP		
	Tier of Propulsion Engine	3		
	Exhaust Type	Dry		
	Location of Exhaust	Stack		
	Type of Propulsor	Azimuth		
Auxiliary Machinery	Number of Auxiliary Engine(s)	1	1	1
	Use of Auxiliary Engine	Generator	Generator	Generator
	Power Pump (HP)	N/A	N/A	N/A
	Power Generator (kW)	175 kW	215 kW	41 kW
	Tier of Auxiliary Engine	3	3	2
	Exhaust Type	Dry	Dry	Dry
	Exhaust Locations	Stack	Stack	Stack

Table 54. Ship Assist Tug Vessel Modification Snapshot

Repower	Option Available	Yes
	Feasibility	Feasible Fitment
	Additional Machinery Required	DEF tankage and transfer system. Replace silencers
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	No Fitment Identified
	Fuel Burn Required (per engine)	22 GPH during regeneration
	Electrical Power Required (per engine)	16 kW during regeneration
	Additional Machinery Required	Switchboard modifications, fuel system, DEF tankage and transfer system. Replace silencers. Possible generator upgrade
Retrofit DPF Only	Option Available	Yes
	Feasibility	Moderate Reconfiguration
	Fuel Burn Required (per engine)	22 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	16-37.5 kW
	Additional Machinery Required	Switchboard modifications. Replace silencers. Possible generator upgrade.
Impacts	Added System Weight Repower	2 LT (Replacement of larger engines) 13 LT (Weight increase excluding engines)
	Added System Weight Retrofit	5-20 LT
	Note: 1) Repower system weight assumes a repower of both main engines. 2) Retrofit system weight assumes a retrofit of both main engines. Range includes DPF+SCR and DPF only options.	

8.2. Considerations

1. Machinery Arrangement - Scans were not conducted for this vessel. Original drawings were used to check equipment sizing.
   - Figure 18 is a visual representation for a feasible repower. The following colors represent the following equipment:
     - The green represents the repowered SCR system.
     - The grey represents the outline of the new Tier 4 engine
     - The cyan represents the SCR dosing cabinets.
     - The red represents the new exhaust piping path.

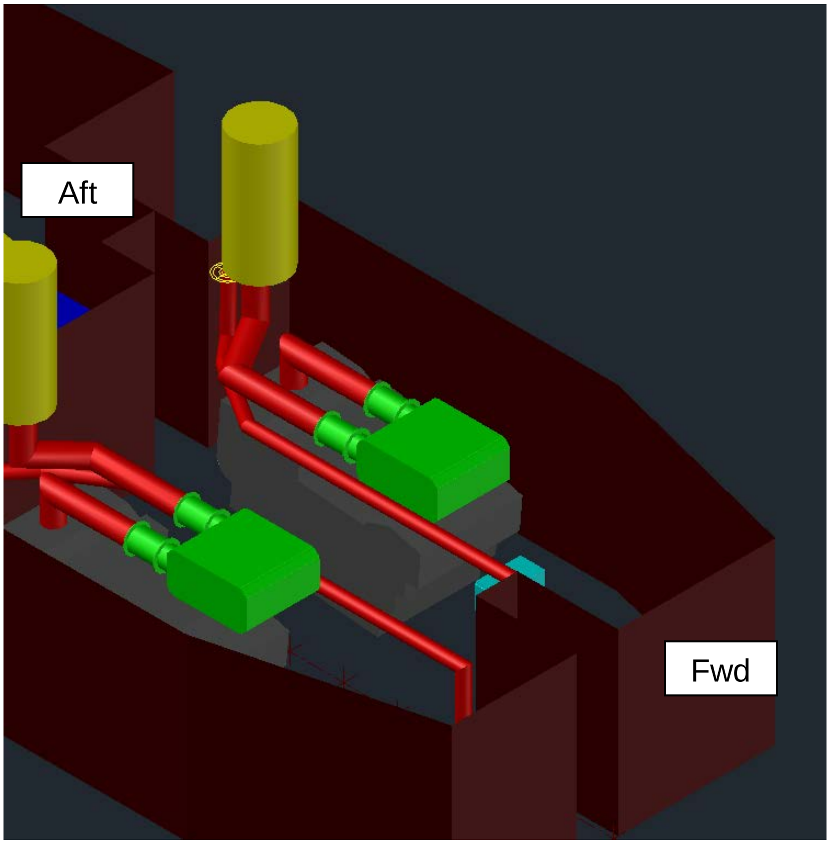

Figure 18. Ship Assist Tug Repower Arrangement

2. Space Constraints – As seen in Figure 18, there is space above the front of the main engines. DPF+SCR aftertreatment systems were found to be too large to fit in this area. All equipment in the engine room was not modeled, but it was determined from ships drawings that there is no space available for a DEF tank in the engine room. There is a possible location in the compartment aft of the engine room that contains the Z-drives.

3. Existing Piping - The exhaust system for the main engines would require modifications, likely requiring a complete exhaust system overhaul. The silencer backpressure would need to be analyzed, potentially causing the need for replacement of silencers.

   Other mechanical systems in the engine room pass within close proximity to the aftertreatment system and would require rerouting.

4. Electrical System – The vessel has approximately 70% loading of the generator while underway. OEM Tier 4 repower would not significantly affect the vessel's power system. DPF+SCR combination and DPF only systems may require more power than is available from the current generator configuration.

5. Stability -
   a. The size and shape of the DEF tank(s) has an effect on vessel stability. The effect of the DEF fluid weight shifting while the tank is slack could impact the stability of the vessel (free surface effect). Additional calculations will be required for final tank placement on vessel per 46 CFR 170.285.
   b. The vessel is primarily limited by 25 degrees of range, so by adding the aftertreatment equipment at a height just under the main deck, and reducing the weight of the main engines, the VCG will be raised, impacting intact range of stability as required by 46 CFR 170 & 46 CFR 173.095 (Towing).

6. Structure - The systems modelled are shown hanging from deck structure. Analysis of each location and surrounding deck structure should be performed to ensure adequate strength to support the equipment and exhaust run hangers to meet specifics from system vendors. It may be feasible to use deck pedestals in lieu of or in combination with exhaust hangers.

8.3. Installation

1. Engine Room Access – The vessel would require access holes to be cut into hull for engine removal and replacement. Dry docking of the vessel will be required.

2. DEF Tankage – Tankage was calculated to be 2000 gallons. This is based on current fuel usage and refuel interval and not the total tankage of the vessel.

3. Electrical – No major work will be required for the AC power system of the vessel for Tier 4 engine installation. The DEF transfer equipment will require minor integration into the electrical system. DPF system would require modification to switchboard and may require a generator upgrade.

4. Mechanical - Engine room ventilation ductwork runs outboard and parallel to the main engines. This ductwork likely will require modification to clear the new aftertreatment system.

   Generator exhaust piping will pass in close proximity to aftertreatment devices. Piping may require relocation.

   Vessel is equipped with a compressed air system that would be integrated with the aftertreatment devices.

5. Fuel System – No major changes to the fuel system will be required.

6. Exhaust System - There will be significant modifications to the current exhaust configurations, routing, and insulation.

8.4. Costs

Table 55 highlights the insured vessel replacement value as well as the current annual vessel fuel cost. For this application, there were both repower and retrofit options available.

Table *56* highlights the average fuel savings when repowering a Tier 3 engine with a Tier 4 engine as well as the additional maintenance and DEF operating costs associated with repowering. Table *57* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the available repower technologies shown in Table 60. Table *58* highlights the estimated additional retrofit operating cost incurred from regenerating the DPF. For this application, the DPF/SCR combination retrofit technologies did not fit in the engine room and no vessel modification fitment was identified to accommodate these options. The DPF only options were the only retrofit technologies that fit. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included. Table 59 highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the DPF only retrofit technologies shown in Table 61.

Table 55. Ship Assist Tug Cost Information

Insured Vessel Replacement	$15,000,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$360,000

Table 56. Ship Assist Tug Annual Operational Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Main Engine Fuel Cost (Tier 3 to Tier 4 only) per year	-$7,200	-$21,600	-$14,400
Maint. Cost of Tier 4 SCR (Main Engine) per year	$31,072	$60,628	$45,850
DEF @ $1.75/gal			$31,500
Total Repower Operational Cost Impact			$62,950

Table 57. Ship Assist Tug Summary of Capital/Installation Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs	$2,200,000	$2,600,000	$2,400,000
Labor + Installation Costs			$412,000
Total Capital + Installation Costs			$2,812,000

Table 58. Ship Assist Tug Annual Operational Costs for Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Maint. Cost of DPF per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			N/A
Regen Fuel Cost	$7,072	$64,884	$35,978
Total Retrofit Operational Cost Impact			$35,978

Table 59. Ship Assist Tug Summary of Capital/Installation Costs for Main Engine Retrofit

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$676,000	$993,000	$834,500
Capital Costs DPF ONLY	$340,000	$360,000	$350,000
Labor + Installation DPF Only			$264,000
Total Capital + Installation Costs SCR + DPF			N/A
Total Capital + Installation Costs DPF ONLY			$614,000

Table 60. Ship Assist Tug Detailed Installation Costs for Main Engine Repower

	Estimated Cost
Structural	$54,000
Mechanical	$154,000
Engine Room Access	$65,000
Testing & Commissioning	$48,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$412,000

Table 61. Ship Assist Tug Detailed Installation Costs for Main Engine Retrofit

	Estimated Cost
Structural	$18,000
Mechanical	$66,000
Engine Room Access	$65,000
Testing & Commissioning	$24,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$264,000

9. Tug – Push/Tow

9.1. Profile & Summary

This vessel is used to push a specific barge in inland waters. It is not used for coastal voyages. Vessel particulars shown in Table 62.

There are commercially available OEM Tier 4 marine engine options available in the power subcategory applicable to this vessel. These engines are equipped with SCR aftertreatment only to achieve Tier 4 rating. The Tier 4 OEM systems studied for this application are feasible with moderate reconfiguration required.

The utilization a DPF only system and DPF+SCR combination were investigated. The DPF only system has a size advantage over the combined DPF/SCR system, but does not address NOx. All systems considered have active DPF filter regeneration. Passive regeneration was deemed not to be an option, due to the load profile of the vessel. The DPF only system is feasible with moderate reconfiguration required while the DPF+SCR combination is feasible with substantial reconfiguration required due to the size of the equipment.

Aftertreatment summary shown in Table 63.

Table 62. Push Tug Vessel Snapshot

Hull	Vessel/Barge Use	Tug - Push
	Passenger Vessel (Y/N)	No
	USCG Inspected (Y/N)	Yes
	USCG Subchapter	Subchapter M
	Hull Material	Steel
	Hull Design	Monohull
	LOA (ft.)	63'
	Beam (ft.)	26’
Main Machinery	Number of Propulsion Engines	2
	Horsepower of Propulsion Engine	1000 HP
	Tier of Propulsion Engine	3
	Exhaust Type	Dry
	Location of Exhaust	Stack
	Type of Propulsor	Propellers
Auxiliary Machinery	Number of Auxiliary Engine(s)	2
	Use of Auxiliary Engine	Generator
	Power Pump (HP)	N/A
	Power Generator (kW)	65 kW
	Tier of Auxiliary Engine	3
	Exhaust Type	Dry
	Exhaust Locations	Stack

Table 63. Push Tug Vessel Modification Snapshot

Repower	Option Available	Yes
	Feasibility	Moderate Reconfiguration
	Additional Machinery Required	DEF tankage and transfer system. Replace silencers. Possible air compressor upgrade
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Fuel Burn Required (per engine)	5-6 GPH during regeneration
	Electrical Power Required (per engine)	6-30 kW during regeneration
	Additional Machinery Required	Generator replacement. Switchboard modifications. Fuel system. DEF tankage and transfer system. Replace silencers. Possible air compressor upgrade
Retrofit DPF Only	Option Available	Yes
	Feasibility	Moderate Reconfiguration
	Fuel Burn Required (per engine)	5-6 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	6.3-25 kW
	Additional Machinery Required	Generator replacement. Switchboard modifications.
Impacts	Added System Weight Repower	7 LT
	Added System Weight Retrofit	2-10 LT
	Note: 1) Repower system weight assumes a repower of both main engines. 2) Retrofit system weight assumes a retrofit of both main engines. Range includes DPF+SCR and DPF only options.	

9.2. Considerations

1. Machinery Arrangement
   - Figure 19 is a visual representation for a Tier 4 repower. The following colors represent the following equipment:
     - The green represents the OEM Tier 4 SCR system. The engines were not modeled in this diagram
     - The cyan represents the SCR dosing cabinets.
     - The red represents the new exhaust piping path.
     - The blue represents the proposed centerline location of the DEF storage tank.

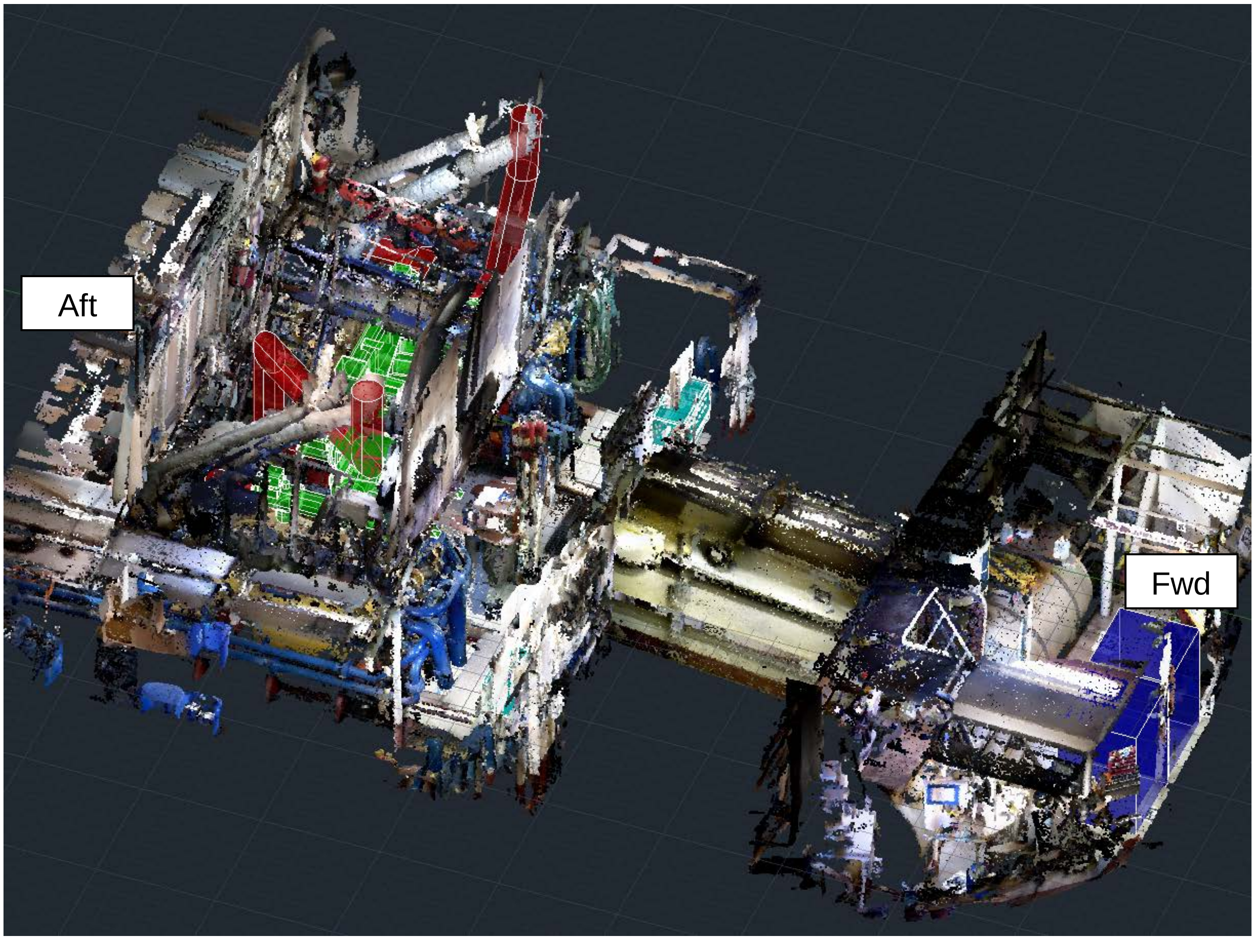

Figure 19. Push Tug Repower Arrangement

- Figure 20 is a visual representation for a Tier 4 repower with the point cloud suppressed showing only the SCR related equipment. The following colors represent the following equipment:
    - The green represents the OEM Tier 4 SCR system. The engines were not modeled in this diagram
    - The cyan represents the SCR dosing cabinets.
    - The red represents the new exhaust piping path.
    - The blue represents the proposed centerline location of the DEF storage tank.

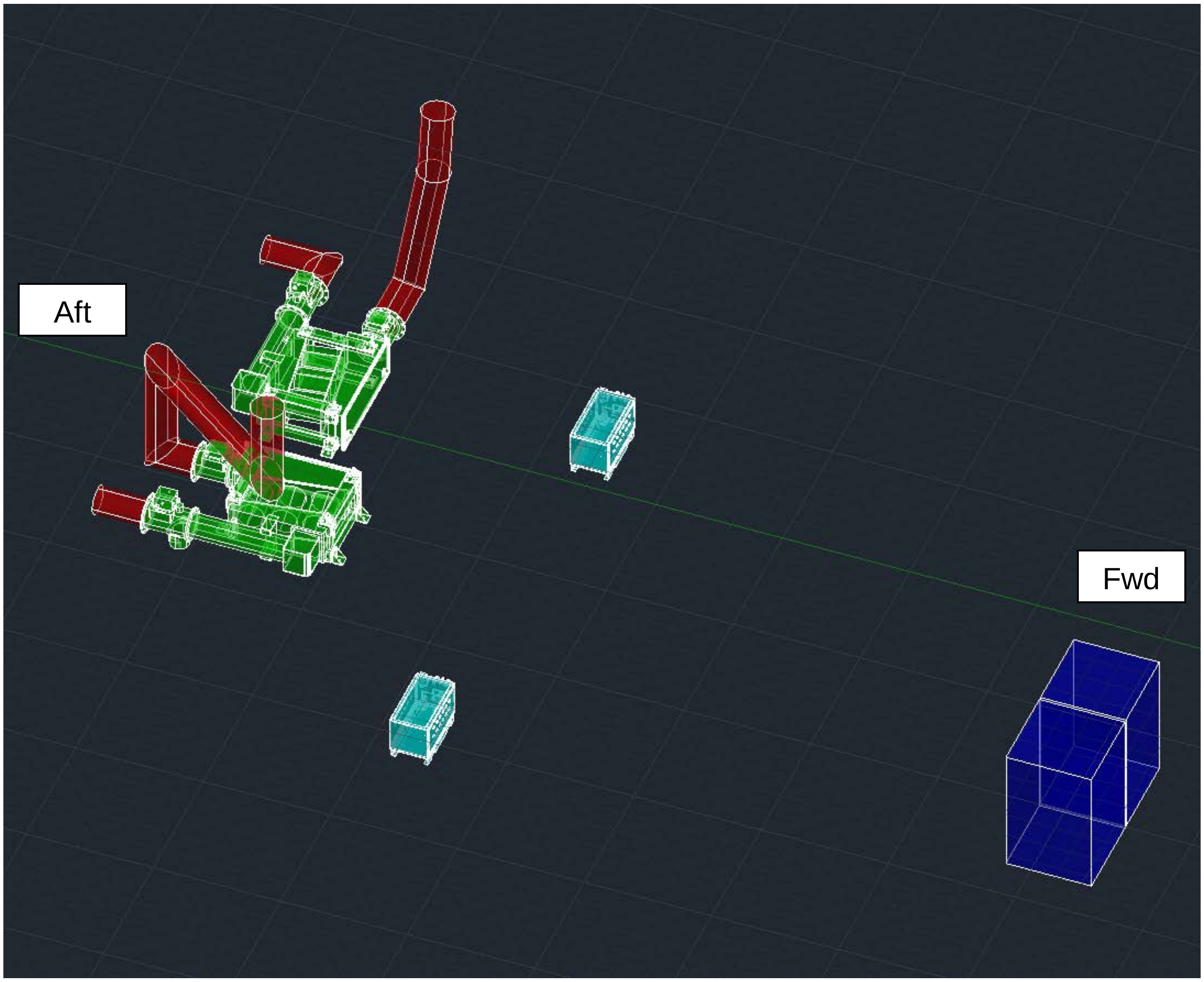

Figure 20. Push Tug Repower Arrangement with Point Cloud Suppressed

2. Space Constraints – All equipment must be located over the main engines as there is no available space surrounding main engines. The OEM engine system offers the smallest footprint of all of the surveyed Tier 4 systems.

3. Existing Piping – The exhaust system for the main engines would require significant modifications, likely requiring a complete exhaust system overhaul. There is potential that existing subsystem piping may need to be rerouted to allow adequate access to Tier 4 equipment filters and maintenance panels.

4. Electrical System – The vessel is equipped with two generator sets. It is reported that a single generator is loaded to greater than 85% when the vessel is operating at peak power demand. This vessel typically runs a single generator at a time and does not have the required equipment for paralleling/load sharing between two generators. There is likely not a safe margin for additional load to be placed on a generator for a regeneration cycle of an active regeneration cycle. Typical power requirement for a regeneration cycle for this size of device ranges from 6-30 kW per engine.

   OEM repower options with SCR do not require the higher power required by the DPF systems and present a negligible additional load to the power system on this vessel.

5. Stability –
   - It is estimated to be 7 LT of displacement added to the vessel from the OEM Tier 4 equipment and DEF or 2-10 LT for retrofit equipment. No stability information was available for this vessel, however estimations were made based on the dimensions of the vessel. The additional weight likely will not cause stability issues. A detailed stability analysis would be required prior to commencement of work on the vessel.

6. Structure – The systems modelled are shown hanging in the middle of only available open space and will need structure added to adequately support the added weight of equipment.

9.3. Installation

1. Engine Room Access Repower – The vessel is equipped with a soft patch in the engine room overhead. Additional openings may be required to be cut in the overhead for an engine replacement.

2. DEF Tankage – Tankage for the vessel was estimated to be 500 gallons and was based on the refueling interval and total fuel onboard. This vessel runs a consistent route and has a consistent fueling schedule. The DEF tanks can be installed in the front compartment of the engine room, which is currently designated as a crew area. Final tank size(s) and location(s) would have to be determined if it is not feasible to reduce the crew area to house the DEF tank.

3. Electrical – Connections to 24 VDC and 110VAC connections will be required. New engine wiring harnesses that interconnect with aftertreatment system will be required to be installed. DPF based aftertreatment systems will require generator upgrades and switchboard upgrades.

4. Mechanical – The vessel is currently equipped with an air compressor system. Upgrades to the system may be required based on the exact requirements of the aftertreatment system.

   Stainless piping will be required to pipe DEF from the forward tank area to the dosing/control cabinets in the engine room. This piping will penetrate a watertight bulkhead.

5. Fuel System – No modification will be required for the OEM engine system repower and minor work would be required for installation of a diesel fuel based DPF regeneration system.

6. Exhaust System – The current piping and silencers for main engines and generators will need to be removed. New piping and hangers will be installed. In addition, new custom lagging will be required to be installed on all exposed metal in the exhaust system. Main engine silencers will need to be upgraded to maintain appropriate backpressure on main engines.

9.4. Costs

Table 64 highlights the insured vessel replacement value as well as the current annual vessel fuel cost. For this application, there were both repower and retrofit options available. Table 65 highlights the average fuel savings when repowering a Tier 3 engine with a Tier 4 engine as well as the additional maintenance and DEF operating costs associated with repowering. Table 66 highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the available repower technologies shown in Table 69. Table 67 highlights the estimated additional retrofit operating diesel fuel cost incurred from regenerating the DPF and DEF for the SCR. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included. Table 68 highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the retrofit technologies shown in Table 70.

Table 64. Push Tug Cost Information

Insured Vessel Replacement	$6,000,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$129,600

Table 65. Push Tug Annual Operational Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Main Engine Fuel Cost (Tier 3 to Tier 4 only) per year	-$2,592	-$7,776	-$5,184
Maint. Cost of Tier 4 SCR (Main Engine) per year	$9,072	$17,702	$13,387
DEF @ $1.75/gal			$7,560
Total Repower Operational Cost Impact			$15,763

Table 66. Push Tug Summary of Capital/Installation Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs	$520,000	$730,000	$625,000
Labor + Installation Costs			$396,000
Total Capital + Installation Costs			$1,021,000

Table 67. Push Tug Annual Operational Costs for Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Maint. Cost of SCR per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			$7,560
Regen Fuel Cost	$7,072	$18,944	$13,008
Total Retrofit Operational Cost Impact			$20,568

Table 68. Push Tug Summary of Capital and Installation Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$240,000	$290,000	$265,000
Capital Costs DPF ONLY	$120,000	$296,000	$208,000
Labor + Installation Costs			$264,000
Total Capital + Installation Costs SCR + DPF			$529,000
Total Capital + Installation Costs DPF ONLY			$472,000

Table 69. Push Tug Detailed Installation Costs for Main Engine Repower

	Estimated Cost
Structural	$54,000
Mechanical	$138,000
Engine Room Access	$65,000
Testing & Commissioning	$48,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$396,000

Table 70. Push Tug Detailed Installation Costs for Retrofit

	Estimated Cost
Structural	$18,000
Mechanical	$66,000
Engine Room Access	$65,000
Testing & Commissioning	$24,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$264,000

10. Crew/Supply

10.1. Profile & Summary

This vessel is used to carry supplies and crew to vessels off of the coast of California. Vessel particulars shown in Table 71.

Commercially available OEM Tier 4 marine engines from one manufacturer are currently in testing for Tier 4 EPA certification. These engines are equipped with SCR aftertreatment. The minimum HP rating of the OEM engines is higher than the rating of the existing vessel's main engines, but there is less than a 5% difference. Additionally these OEM Tier 4 engines do not require compressed air for the urea injection. The replacement engines do weigh more than the existing engines.

Retrofit aftertreatment options including the use of just a DPF or a DPF+SCRcombined system were investigated. The aftermarket retrofit systems studied for this application are feasible but there are sizing limitations. It is likely the aftertreatment systems would need to be located in the generator room aft of the engine compartment resulting in substantial modifications to vessel. Retrofit may also have an adverse effect on vessel cargo capacity, and possibly noise emissions.

Aftertreatment summary shown in Table 72**.**

Table 71. Crew/Supply Vessel Snapshot

Hull	Vessel/Barge Use	Crew Supply
	Passenger Vessel (Y/N)	Yes
	USCG Inspected (Y/N)	Yes
	USCG Subchapter	Subchapter T
	Hull Material	Aluminum
	Hull Design	Monohull
	LOA (ft.)	106'
	Beam (ft.)	21'
Main Machinery	Number of Propulsion Engines	3
	Horsepower of Propulsion Engine	567 HP
	Tier of Propulsion Engine	2
	Exhaust Type	Wet
	Location of Exhaust	Sideshell
	Type of Propulsor	Propellers
Auxiliary Machinery	Number of Auxiliary Engine(s)	2
	Use of Auxiliary Engine	Generator
	Power Pump (HP)	N/A
	Power Generator (kW)	32 kW
	Tier of Auxiliary Engine	2
	Exhaust Type	Wet
	Exhaust Locations	Sideshell

Table 72. Crew/Supply Vessel Modification Snapshot

Repower	Option Available	Yes
	Feasibility	Moderate Reconfiguration
	Additional Machinery Required	DEF tankage and transfer system. Replace silencers. Relocate exhaust to generator compartment
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Fuel Burn Required (per engine)	2.5 GPH during regeneration
	Electrical Power Required (per engine)	5-17 kW during regeneration
	Additional Machinery Required	Generator replacement. Switchboard modifications. Fuel system. DEF tankage and transfer system. Replace silencers. Possible air compressor upgrade. Relocate exhaust to generator compartment
Retrofit DPF Only	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Fuel Burn Required (per engine)	2.5 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	5-8 kW
	Additional Machinery Required	Generator replacement. Switchboard modifications. Replace silencers. Relocate exhaust to generator compartment
Impacts	Added System Weight Repower	4 LT
	Added System Weight Retrofit	1.5-6 LT
	Note: 1) Repower system weight assumes a repower of three main engines. 2) Retrofit system weight assumes a retrofit of three main engines. Range includes DPF+SCR and DPF only options.	

10.2. Considerations

1. Machinery Arrangement-
   - Figure 21 is a visual representation for a feasible aftertreatment retrofit. The following colors represent the following equipment:
     - The green represents the retrofit of the DPF (or) DPF/SCR system.
     - The cyan represents modified generator exhaust piping.
     - The red cylinders represent the new exhaust piping path.
     - The red boxes represent tankage that must be relocated in the space.
     - The gray grid represents the hull structure in the area aft of the engine room. This area is aft of the engine room bulkhead (bulkhead not shown)

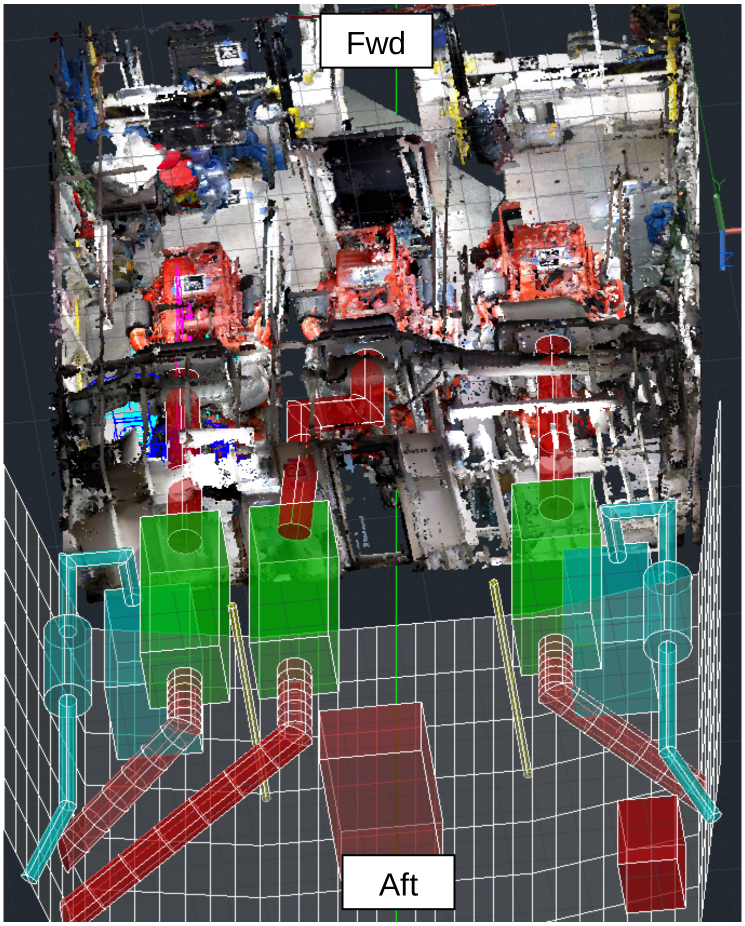

Figure 21. Crew Supply Boat Retrofit Arrangement

2. Space Constraints – The retrofit DPF only or the combined retrofit DPF+SCR devices do not fit in the engine room. The silencers for this vessel are located in the engine room aft of the main engines. The OEM SCR option will marginally fit in the engine room, but do not allow room for silencers.

3. Existing Piping – The exhaust system for the main engines, including the exhaust of the existing gensets, will require significant modifications. The current system has silencers located in the engine room as well as water injection post silencer leading to wet exhaust in the aft areas of the engine room. Exhaust piping side shell penetrations will need to be relocated to the generator room aft of the engine room and will conflict with much of the currently installed equipment. This would also require the relocation of the cooling water exhaust injection to the generator room.

4. Electrical System – Modification of the switchboard will be required for operation of retrofit aftertreatment solutions. The regeneration of a DPF would require between 5-17 kW for each of the three engines depending on the solution. The OEM Tier 4 repower solution will require negligible modifications to the electrical system onboard.

5. Stability –
    - There is estimated to be 1.6-6 LT of displacement added to the vessel from the Tier 4 equipment and DEF.
    - Because the cargo carrying capacity is limited by stability criteria, and specifically compartment flooding in damaged conditions, the weight of aftertreatment equipment added to the vessel will need to be subtracted from its currently allowed cargo capacities. This business impact wasn't quantified within the scope of this study.

10.3. Installation

1. Engine Room Access Repower/Retrofit – The vessel is equipped with soft patches over the engine compartment. Engine replacement access does not require cutting metal as engines can be craned onto the back deck of the vessel and into the engine compartment.

2. DEF Tankage – Tankage for the vessel was estimated based on the refueling interval and not total fuel onboard. Tankage needs to be located in the main machinery space. Exterior location of DEF piping for fill will have to be determined. It is estimated that there is a need of 300 gallons of DEF.

3. Electrical – Modification to the main switchboard will be required to accommodate additional switchgear. Modifications will vary based on type of retrofit aftertreatment system. Systems with DPF and active regeneration will have the highest impact on electrical requirements. Additional equipment may be required to prevent no more than one DPF regeneration at a time.

4. Mechanical – An air compressor system will be required to be added for the retrofit aftertreatment system. The repower option does not require an air compressor. There is existing lube oil tankage in the generator room that would need to be relocated to the forward area of the engine room. Existing hydraulic systems may require relocation.

5. Fuel System – The combined DPF/SCR systems with active DPF regeneration will require a fuel based system for regeneration. Additional fuel piping and filters will be required for installation of system.

6. Exhaust System Retrofit –The DPF/SCR aftertreatment is to be located in the generator room. New watertight penetrations will be required in the aft engine room bulkhead for the exhaust and cooling water for each of the three engines. The wet exhaust water injection would occur post aftertreatment in the generator room. The existing exhaust penetrations in the hull would be cropped out and new penetrations added in the generator compartment. The existing generator exhaust system would need to be replaced to accommodate the new piping systems. There may not be adequate space to accommodate silencers with this aftertreatment system. Exhaust noise has been a reported problem with these vessels, so additional calculations to maximize attenuation will need to be conducted.

7. Exhaust System Repower – The OEM SCR aftertreatment is to be located in the engine room with silencers located in the generator room. New watertight penetrations will be required in the aft engine room bulkhead for the exhaust

and cooling water for each engine. The wet exhaust water injection would occur post silencer in the generator room. The existing exhaust penetrations would be cropped out and new penetrations added in the generator compartment. The existing generator exhaust system would need to be replaced to accommodate the new piping systems. Exhaust noise has been a reported problem with these vessels, so additional calculations to maximize attenuation will need to be conducted.

10.4. Costs

Table 73 highlights the insured vessel replacement value as well as the current annual vessel fuel cost. For this application, there were both repower and retrofit options available. Table *74* highlights the average fuel savings when repowering a Tier 3 engine with a Tier 4 engine as well as the additional maintenance and DEF operating costs associated with repowering. Table *75* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the available repower technologies shown in Table 78. Table *76* highlights the estimated additional retrofit operating diesel fuel cost incurred from regenerating the DPF and DEF for the SCR. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included. Table *77* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the retrofit technologies shown in Table 79.

Table 73. Crew/Supply Vessel Cost Information

Insured Vessel Replacement	$3,600,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$378,000

Table 74. Crew/Supply Vessel Annual Operational Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Main Engine Fuel Cost (Tier 3 to Tier 4 only) per year	-$7,560	-$22,680	-$15,120
Maint. Cost of Tier 4 SCR (Main Engine) per year	$7,716	$15,055	$11,385
DEF @ $1.75/gal			$33,075
Total Repower Operational Cost Impact			$29,340

Table 75. Crew/Supply Vessel Summary of Capital/Installation Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs	$420,000	$483,000	$451,500
Labor + Installation Costs			$499,000
Total Capital + Installation Costs			$950,500

Table 76. Crew/Supply Vessel Annual Operational Costs for Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Maint. Cost of SCR per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			$33,075
Regen Fuel Cost	$5,494	$11,367	$8,430
Total Retrofit Operational Cost Impact			$41,505

Table 77. Crew/Supply Vessel Summary of Capital and Installation Retrofit DPF+SCR-

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$213,000	$250,000	$231,500
Capital Costs DPF ONLY	$138,000	$150,000	$144,000
Labor + Installation Costs			$271,000
Total Capital + Installation Costs SCR + DPF			$502,500
Total Capital + Installation Costs DPF ONLY			$415,000

Table 78. Crew/Supply Vessel Detailed Installation Costs for Main Engine Repower

	Estimated Cost
Structural	$72,000
Mechanical	$227,000
Engine Room Access	$30,000
Testing & Commissioning	$60,000
Haulout/Shipyard Cost	$110,000
Total Installation Cost	$499,000

Table 79. Crew/Supply Vessel Detailed Installation Costs for Retrofit

	Estimated Cost
Structural	$48,000
Mechanical	$78,000
Engine Room Access	$30,000
Testing & Commissioning	$24,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$271,000

11. Pilot

11.1. Profile & Summary

This vessel is used to run vessel pilots to the pilot station as well as deliver or retrieve pilots from vessels that have moored or anchored. Vessel particulars shown in Table 80.

This vessel does not have adequate space aboard to house OEM Tier 4 equipment or retrofit aftertreatment equipment in its current configuration.

There are existing commercially available OEM Tier 4 marine engine replacements for this power subcategory. These engines are equipped with SCR aftertreatment only to achieve Tier 4 rating. However the aftertreatment devices do not fit in the engine room and marginally would fit in a heavily modified structure over the engine room.

The utilization of a DPF only system and DPF+SCR combined system were investigated. The DPF only system has a size advantage over the combined DPF/SCR system, but does not address NOx. All systems considered have active DPF filter regeneration. The aftertreatment devices can marginally fit if the rear structure of the vessel is rebuilt. Stability of the vessel would need further investigation to determine feasibility. No stability information was provided by the vessel owner/operator.

The aftertreatment summary shown in Table 81.

Table 80. Pilot Boat Vessel Snapshot

Hull	Vessel/Barge Use	Pilot
	Passenger Vessel (Y/N)	No
	USCG Inspected (Y/N)	No
	USCG Subchapter	N/A
	Hull Material	Aluminum
	Hull Design	Monohull
	LOA (ft.)	67'
	Beam (ft.)	19’
Main Machinery	Number of Propulsion Engines	2
	Horsepower of Propulsion Engine	850 HP
	Tier of Propulsion Engine	2
	Exhaust Type	Dry
	Location of Exhaust	Stack
	Type of Propulsor	Propellers
Auxiliary Machinery	Number of Auxiliary Engine(s)	2
	Use of Auxiliary Engine	Generator
	Power Pump (HP)	N/A
	Power Generator (kW)	27 kW
	Tier of Auxiliary Engine	2
	Exhaust Type	Dry
	Exhaust Locations	Stack

Table 81. Pilot Boat Vessel Modification Snapshot

Repower	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Additional Machinery Required	DEF tankage and transfer system. Replace silencers. Possible air compressor upgrade.
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Fuel Burn Required (per engine)	4-5 GPH during regeneration
	Electrical Power Required (per engine)	6-25 kW during regeneration
	Additional Machinery Required	Generator replacement. Switchboard modifications. Fuel system. DEF tankage and transfer system. Replace silencers. Possible air compressor upgrade.
Retrofit DPF Only	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Fuel Burn Required	4-5 GPH during regeneration Option for no fuel
	Electrical Power Required	6-8 kW
	Additional Machinery Required	Generator replacement. Switchboard modifications. Replace silencers.
Impacts	Added System Weight Repower	3 LT
	Added System Weight Retrofit	1.8-5.2 LT
	Note: 1) Repower system weight assumes a repower of both main engines. 2) Retrofit system weight assumes a retrofit of both main engines. Range includes DPF+SCR and DPF only options.	

11.2. Considerations

1. Machinery Arrangement-
   - Figure 22 is a visual representation for a DPF/SCR retrofit as well as a Tier 4 OEM system. The following colors represent the following equipment:
     - The red represents modified exhaust piping.
     - The green represents the retrofit of the DPF/SCR system.
     - The blue represents the OEM Tier 4 after-treatment device
     - The white grids represent the additional structure additions above the engine room.
     - The DEF tanks are not shown as a feasible location could not be identified.

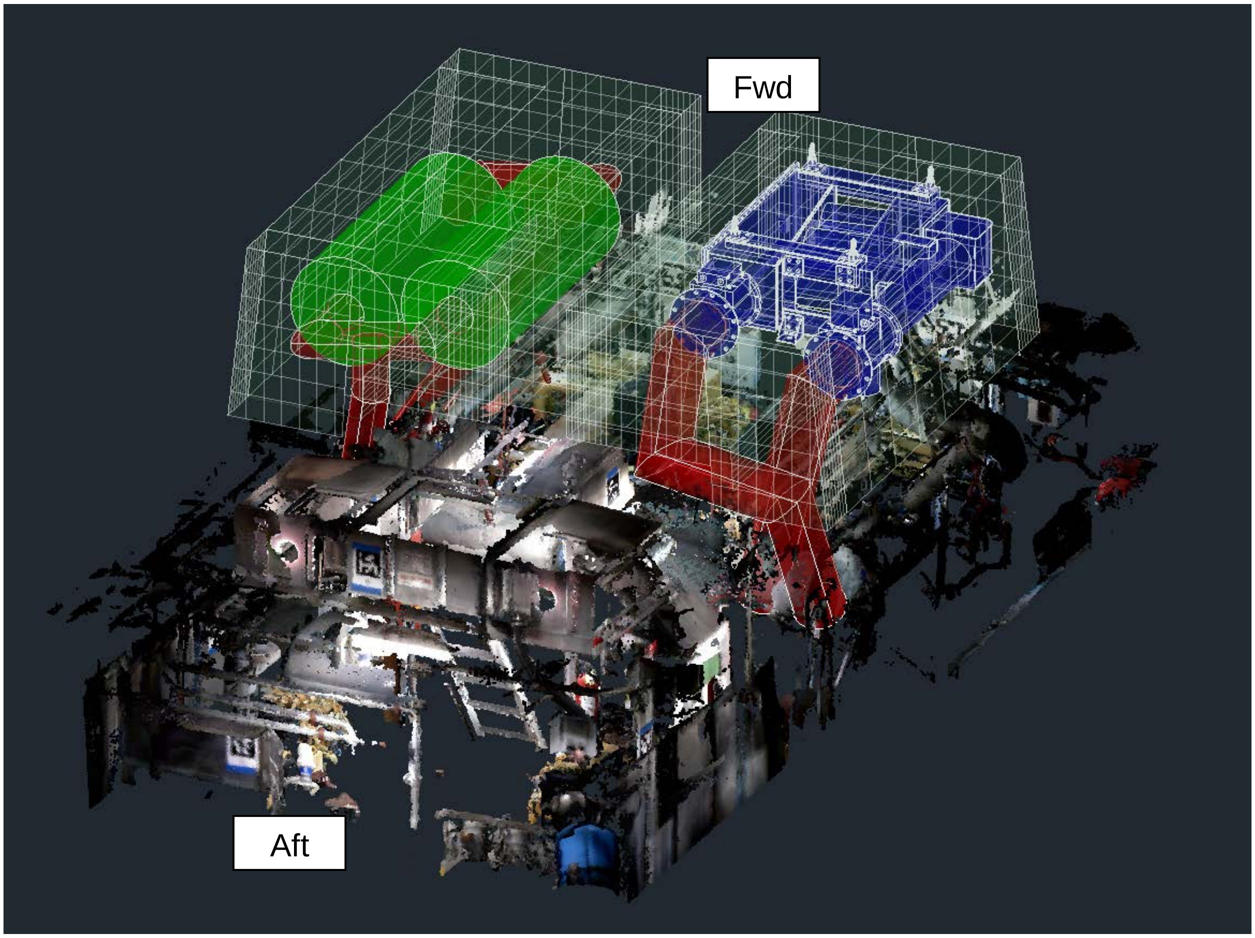

Figure 22. Pilot Boat Retrofit and Repower Arrangement

2. Space Constraints – As the replacement Tier 4 engines are similar in size, there is little concern that they will fit. The issue arises when considering the OEM SCR or aftermarket SCR and/or DPF. The small vessel size, engine room and stack arrangement make this application for aftertreatment devices particularly difficult.

3. Existing Piping – All exhaust piping would require removal and replacement. The existing compressed air system requires upgrades.

4. Electrical System – This vessel is equipped with two generators that are not likely to be able to support the electrical load of a DPF based system. New, larger generators would be required. This additional weight was not taken into consideration when reviewing the vessel stability.

5. Stability – Stability information was not provided for this vessel. Estimations were made based on vessel dimensions and an assumed block coefficient. The added weight, approximately 1.5-5.2 LT, is aft of vessel's longitudinal center of buoyancy (LCB) and located well above current vessel's vertical center of gravity (VCG). For these reasons the boat will trim farther aft and have a higher VCG. Additionally, the added weight increased draft, effecting the overall vessel speed and fuel consumption.

6. Structure – The existing air intake structure over the engine room would need to be removed and reconstructed to support the aftertreatment devices.

7. Operations - This vessel makes critical maneuvers next to large oceangoing vessels while underway. The emissions equipment may require an emergency bypass or safety system to prevent an engine failure during normal operation if a DPF plugs while the vessel is in a critical situation. The design of DPF bypass system was not considered for this application, but should be considered for critical applications.

11.3. Installation

1. Engine Room Access Repower – Engine replacement access require cutting through the vessel structure as the engines must be brought in aft in the area of the existing air intakes and then swung forward in the engine room.

2. Engine Room Access Retrofit – Installing aftertreatment devices require cutting through the vessel structure as the aftermarket equipment must be brought in aft in the area of the existing air intakes and then swung forward in the engine room.

3. DEF Tankage – It is estimated that the vessel would need approximately a 100 gallon DEF tank. Tankage for the vessel was estimated based on the refueling interval and not total fuel onboard.

4. Electrical – Modification to the main switchboard will be required to accommodate additional switchgear. Modifications will vary based on type of retrofit aftertreatment system. Systems with DPF and active regeneration will have the highest impact on electrical requirements. In addition to the existing generators replacement, interlocks may be required to prevent two systems from regenerating at the same time. This does not apply to a SCR only based system.

5. Mechanical – Air compressor system will be upgraded for the retrofit aftertreatment system. One repower option does not require an air compressor.

6. Fuel System – The combined SCR+DPF systems with active DPF regeneration will require a fuel based system for regeneration. Additional fuel piping and filters will be required for installation of system.

7. Exhaust System – In the case of the repower or the retrofit aftertreatment system, current piping and silencers for main engines and generators will need to be removed and replaced. New piping and hangers will be installed. In addition, new custom lagging will be required to be installed on all exposed metal in the exhaust system. Due to the operation of this vessel in close proximity to other vessels, an aftertreatment exhaust bypass may be required to ensure full operational availability in the event of an aftertreatment system failure. The installation of a bypass is likely to be approved on a case by case basis and monitored by CARB.

11.4. Costs

Table 82 highlights the insured vessel replacement value as well as the current annual vessel fuel cost. For this application, there were both repower and retrofit options available. Table *83* highlights the average fuel savings when repowering a Tier 3 engine with a Tier 4 engine as well as the additional maintenance and DEF operating costs associated with repowering. Table *84* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the available repower technologies shown in Table 87.

Table *85* highlights the estimated additional retrofit operating diesel fuel cost incurred from regenerating the DPF and DEF for the SCR. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included. Table *86* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the retrofit technologies shown in Table 88.

Table 82. Pilot Boat Cost Information

Insured Vessel Replacement	$3,400,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$515,880

Table 83*. Pilot Boat Annual Operational Costs for Main Engine Repower and SCR*

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Main Engine Fuel Cost (Tier 3 to Tier 4 only) per year	-$10,318	-$30,953	-$20,636
Maint. Cost of Tier 4 SCR (Main Engine) per year	$7,711	$15,046	$11,379
DEF @ $1.75/gal			$45,140
Total Repower Operational Cost Impact			$35,884

Table 84*. Pilot Boat Summary of Capital/Installation Costs for Main Engine Repower and SCR*

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs	$522,000	$727,000	$624,500
Labor + Installation Costs			$759,000
Total Capital + Installation Costs			$1,383,500

Table 85. Pilot Boat Annual Operational Costs for Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Maint. Cost of SCR per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			$45,140
Regen Fuel Cost	$4,526	$16,103	$10,314
Total Retrofit Operational Cost Impact			$55,454

Table 86. Pilot Boat Summary of Capital and Installation Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$208,000	$247,000	$227,500
Capital Costs DPF ONLY	$120,000	$140,000	$130,000
Labor + Installation Costs			$628,000
Total Capital + Installation Costs SCR + DPF			$855,500
Total Capital + Installation Costs DPF ONLY			$758,000

Table 87. Pilot Boat Detailed Installation Costs for Main Engine Repower

	Estimated Cost
Structural	$311,000
Mechanical	$191,000
Engine Room Access	$95,000
Testing & Commissioning	$60,000
Haulout/Shipyard Cost	$102,000
Total Installation Cost	$759,000

Table 88. Pilot Boat Detailed Installation Costs for Retrofit

	Estimated Cost
Structural	$275,000
Mechanical	$120,000
Engine Room Access	$95,000
Testing & Commissioning	$36,000
Haulout/Shipyard Cost	$102,000
Total Installation Cost	$628,000

12. Workboat

12.1. Profile & Summary

This vessel carries liquid cargo, is equipped with a crane for delivering hard goods and additionally has push knees to allow the vessel to do light tug assist. It only operates in inland waters. Vessel particulars shown in Table 89.

There are no Tier 4 marine engine options available for this engine power subcategory, only retrofit aftertreatment systems are available.

For any possible retrofit technology, DPF+SCR or DPF alone, substantial reconfiguration of the vessel over the engine room would be required. Any DPF option would also require the addition of generator and any DPF+SCR option would require the addition of an air compressor.

Aftertreatment summary shown in Table 90.

Table 89. Workboat Vessel Snapshot

Hull	Vessel/Barge Use	Workboat
	Passenger Vessel (Y/N)	No
	USCG Inspected (Y/N)	No
	USCG Subchapter	N/A
	Hull Material	Steel
	Hull Design	Monohull
	LOA (ft.)	73'
	Beam (ft.)	21'
Main Machinery	Number of Propulsion Engines	2
	Horsepower of Propulsion Engine	400 HP
	Tier of Propulsion Engine	2
	Exhaust Type	Wet
	Location of Exhaust	Sideshell
	Type of Propulsor	Propellers
Auxiliary Machinery	Number of Auxiliary Engine(s)	0
	Use of Auxiliary Engine	N/A
	Power Pump (HP)	N/A
	Power Generator (kW)	N/A
	Tier of Auxiliary Engine	N/A
	Exhaust Type	N/A
	Exhaust Locations	N/A

Table 90. Workboat Vessel Modification Snapshot

Repower	Option Available	No
	Feasibility	N/A
	Additional Machinery Required	N/A
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Fuel Burn Required (per engine)	1.3-2 GPH during regeneration
	Electrical Power Required (per engine)	4-12 kW during regeneration
	Additional Machinery Required	Generator and switchboard installation. Fuel system. External compartment for aftertreatment. DEF storage and transfer system
Retrofit DPF Only	Option Available	Yes
	Feasibility	Substantial Reconfiguration
	Fuel Burn Required (per engine)	1.3-2 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	4-8 kW
	Additional Machinery Required	Generator and switchboard installation. External compartment for aftertreatment.
Impacts	Added System Weight Repower	N/A
	Added System Weight Retrofit	3.8-5.9 LT
	Note: 1) Retrofit system weight assumes a retrofit of both main engines. Range includes DPF+SCR and DPF only options. This also include the weight of the additional structure.	

12.2. Considerations

1. Machinery Arrangement –
   - Figure 23 is a visual representation for a DPF/SCR retrofit. The following colors represent the following equipment:
     - o The yellow cylinders are the existing mufflers.
     - o The blue cylinders represent the aftertreatment devices.
     - o The white grids represent the additional structure additions above the engine room.
     - o The red represents the new exhaust piping path.

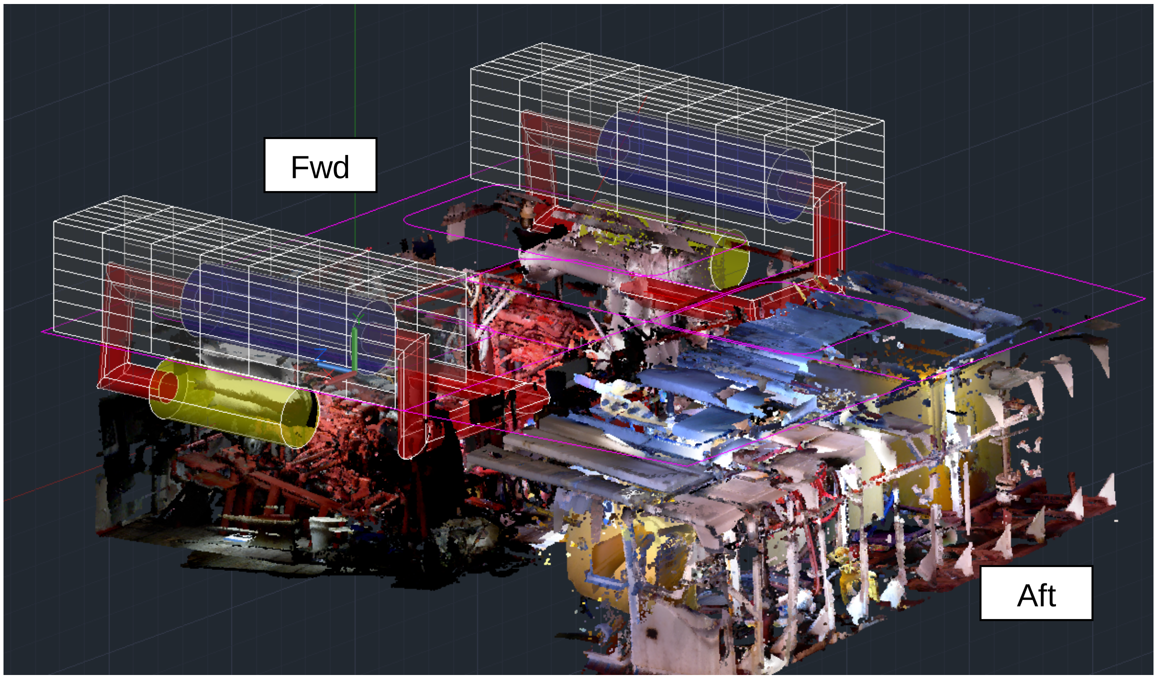

Figure 23. Workboat Retrofit Arrangement

2. Space Constraints – The engine room of this vessel is not adequate to accommodate the size of a retrofit aftertreatment system.

3. Existing Piping – The exhaust system for the main engines, will require significant modifications. There are no other major piping concerns in the space. The vessel is equipped with wet exhaust which will require modification.

4. Electrical System – The vessel is not equipped with an AC power system. This presents a challenge as all of the active DPF systems require power to operate. Even if a fuel based DPF regeneration system were to be used, a new generator would likely need to be installed.

5. Stability – There are currently no stability documents available for the vessel for exact calculations. Any weight added will be subtracted from the current cargo capabilities of the vessel. The addition of the required generator was not taken into account in the weight calculations for this installation.

6. Structure – The vessel in the current configuration cannot accommodate any aftertreatment equipment in the current structure due to size.

12.3. Installation

1. Engine Room Access Retrofit – The vessel has a small hatch in the deck for engine room access. Soft patches will need to be removed over the engine room to facilitate the installation of equipment.

2. DEF Tankage – Tankage for the vessel was based total tankage. DEF required is approximately 200 gallons. Tankage to be located in the compartment aft of the engine room. Exterior location of DEF piping for fill may not be required for this vessel.

3. Electrical – Significant changes will be required for the electrical system to support a system with active regeneration. The specific system installed will determine the modifications required. Options are:
   - Both main engines to be equipped with aftermarket high power alternators. 24VDC availability would limit the type of aftertreatment system.
   - Equip vessel with a 10-25 kW generator. Possible locations are in the engine room centerline or on the main deck forward of the pilot house. Installation of an AC generator would require a main switchboard to be installed.

4. Mechanical – An engine driven air compressor and tank will be required to be added for the retrofit aftertreatment system.

5. Fuel System – The combined DPF/SCR systems with active DPF regeneration will require a fuel based system for regeneration. Additional fuel piping and filters will be required for installation of system.

6. Exhaust System – In the case of the repower or the retrofit aftertreatment system, current piping and silencers for main engines will need to be removed. The main engine exhaust piping exits to the port and STBD side hull. There is water injection into each of the exhaust lines to cool the exhaust prior to penetrating the hull. The limited spacing of the engine room would require the addition of enclosures on the deck in the area above the engine room. These

enclosures would be considered extensions of the engine room therefore requiring them to be watertight. The aftertreatment system would be located in these enclosures. The exhaust piping would exit the engine room, route up to the aftertreatment compartments, both port and stbd, and would route back down to the engine room to pass through the silencers. The water injection would occur after the silencer just before penetrating the hull for discharge. New piping and hangers will be installed. In addition, new custom lagging will be required to be installed on all exposed metal in the exhaust system.

12.4. Costs

Table 91 highlights the insured vessel replacement value as well as the current annual vessel fuel cost. For this application, only retrofit options were available. Table *92* highlights the estimated additional retrofit operating diesel fuel cost incurred from regenerating the DPF and DEF for the SCR. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included.

Table *93* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the retrofit technologies shown in Table 94.

Table 91. Workboat Cost Information

Insured Vessel Replacement	$3,000,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$18,000

Table 92*. Workboat Annual Operational Costs for Retrofit DPF+SCR*

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Maint. Cost of SCR per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			$1,575
Regen Fuel Cost	$3,662	$7,578	$5,620
Total Retrofit Operational Cost Impact			$7,195

Table 93. Workboat Summary of Capital and Installation Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$101,000	$116,000	$108,500
Capital Costs DPF ONLY	$61,000	$100,000	$80,500
Labor + Installation Costs			$378,000
Total Capital + Installation Costs SCR + DPF			$486,500
Total Capital + Installation Costs DPF ONLY			$458,500

Table 94. Workboat Detailed Installation Costs for Retrofit

	Estimated Cost
Structural	$132,000
Mechanical	$54,000
Engine Room Access	$65,000
Testing & Commissioning	$36,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$378,000

13. Special Use

13.1. Profile & Summary

This vessel is used primarily for emergency pumping. There are three similarly sized engines; two are for propulsion and pumping, and the third is for pumping only. Vessel particulars shown in Table 95.

There are potential Tier 4 marine engine options available for this engine power subcategory. The OEM repower engine solution is feasible for all three engines.

Aftertreatment retrofits including the use of just a DPF or a DPF/SCR were investigated. The Tier 4 engine and aftermarket retrofit systems studied for this application are feasible but there are sizing limitations.

Tier 4 replacement or retrofit of the pump only engine were modeled, however all weight and costing calculations were based on modifying the propulsion engines only.

Aftertreatment summary shown in Table 96.

Table 95. Special Use Vessel Snapshot

Hull	Vessel/Barge Use	Special Use	
	Passenger Vessel (Y/N)	No	
	USCG Inspected (Y/N)	No	
	USCG Subchapter	N/A	
	Hull Material	Steel	
	Hull Design	Monohull	
	LOA (ft.)	73'	
	Beam (ft.)	21'	
Main Machinery	Number of Propulsion Engines	2	
	Horsepower of Propulsion Engine	750 HP	
	Tier of Propulsion Engine	2	
	Exhaust Type	Dry	
	Location of Exhaust	Stack	
	Type of Propulsor	Propellers	
Auxiliary Machinery	Number of Auxiliary Engine(s)	1	2
	Use of Auxiliary Engine	Pump	Generator/Hydraulic
	Power Pump (HP)	750 HP	N/A
	Power Generator (kW)	N/A	99kW
	Tier of Auxiliary Engine	2	2
	Exhaust Type	Dry	Dry
	Exhaust Locations	Stack	Stack

Table 96. Special Use Vessel Modification Snapshot

Repower	Option Available	Yes
	Feasibility	Feasible Fitment
	Additional Machinery Required	DEF tankage and transfer system. Replace silencers.
Retrofit DPF+SCR	Option Available	Yes
	Feasibility	Moderate Reconfiguration
	Fuel Burn Required (per engine)	3-4 GPH during regeneration
	Electrical Power Required (per engine)	5-22 kW during regeneration
	Additional Machinery Required	Fuel system. DEF tankage and transfer system. Replace silencers.
Retrofit DPF Only	Option Available	Yes
	Feasibility	Moderate Reconfiguration
	Fuel Burn Required (per engine)	3-4 GPH during regeneration Option for no fuel
	Electrical Power Required (per engine)	5-8 kW
	Additional Machinery Required	Replace silencers.
Impacts	Added System Weight Repower	3 LT
	Added System Weight Retrofit	1-6.2 LT
	Note: 1) Repower system weight assumes a repower of both main propulsion engines. 2) Retrofit system weight assumes a retrofit of both main propulsion engines. Range includes DPF+SCR and DPF only options.	

13.2. Considerations

1. Machinery Arrangement-
   - For all retrofitted options, the pumping only engine that is located aft of the other two engines, along the centerline, has limited room for the associated equipment to be installed. Figure 24 is a visual representation for a feasible DPF+SCR retrofit with the pumping only engine's aftertreatment equipment solution shown mounted perpendicular to the other two engine's aftertreatment. The following colors represent the following equipment:
     - o The blue represents the DPF+SCR
     - o The green represents the retrofit of the DPF system.
     - o The red represents the new exhaust piping path.
     - o The DEF tank is not shown.

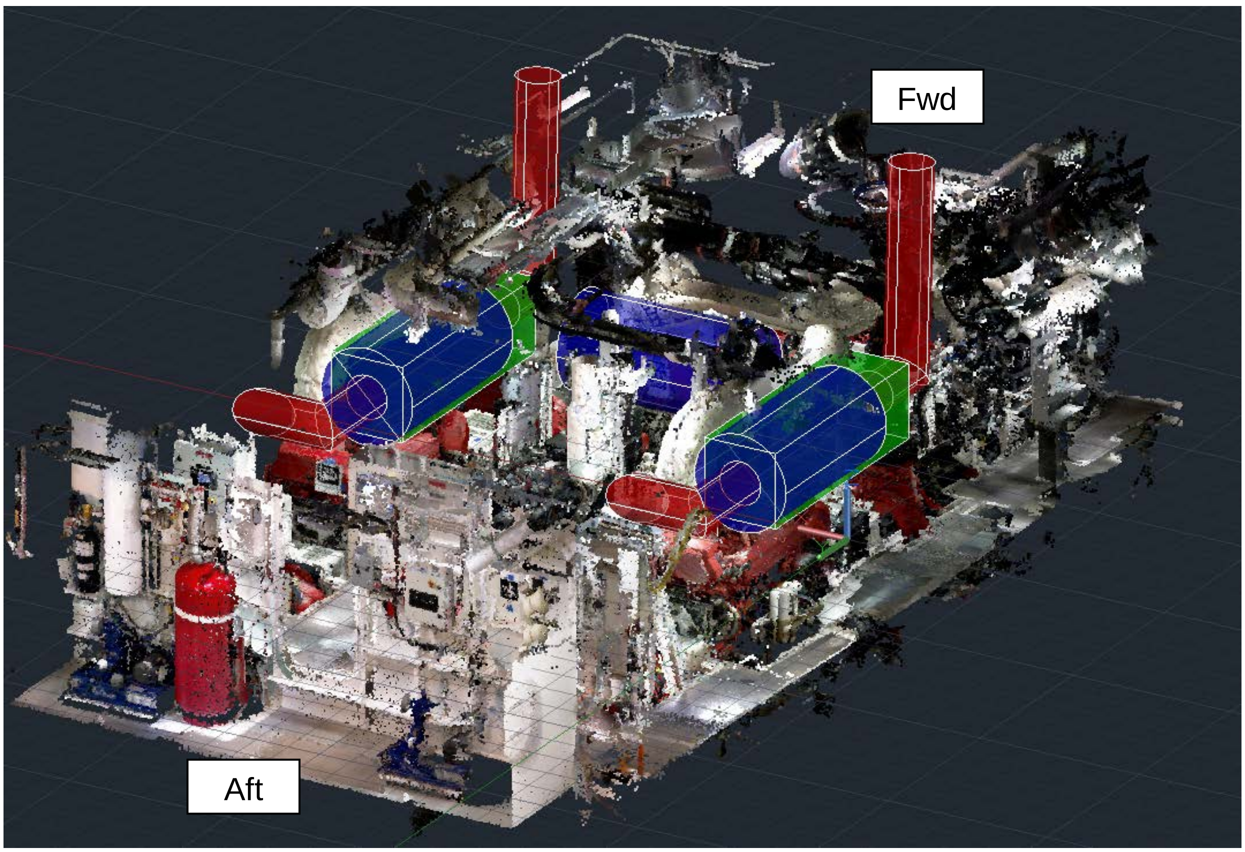

Figure 24. Special Use Vessel Retrofit Arrangement

2. Space Constraints – The water pumping piping system aboard this vessel generates the significant space constraints.

3. Existing Piping – This engine room has significant piping interferences as all engines are pump engines. The system aboard this vessel is designed so that the pumps can be run in parallel or serially. This increases the amount of piping junctions and valving that would not be typical in a standard engine room.

4. Electrical System – This vessel is equipped with two 100kW gensets. The generator engines were sized for additional hydraulic pumps and not for electrical load, therefore the generator engines are oversized. Additionally generators can be paralleled. There is no restriction by the electrical system for the after-treatment system.

5. Stability – The weight of the added Tier 4 or aftertreatment equipment and exhaust modifications will not have a significant impact on vessel stability. Added weight to vessel is approximately 1-6.2 LT.

13.3. Installation

1. Engine Room Access Repower – Given the amount of overhead piping in the engine room, the easiest path for new engine installation may be by cutting a section out of the side shell and entering from the port or starboard side of the vessel.

2. Engine Room Access Retrofit – There is a sizeable entry into the engine room for personnel. It may be possible to use this to install retrofit aftertreatment equipment.

3. DEF Tankage – Tankage for the vessel was estimated based on the refueling interval and not total fuel onboard. Tankage to be located in the auxiliary machinery space aft of the engine room. Exterior location of DEF piping for fill will have to be determined. It is estimated that there needs to be 600 gallons of DEF.

4. Electrical – Minimal modifications to the main switchboard will be required. Modifications will vary based on type of retrofit aftertreatment system. Additional equipment may be required to prevent no more than one DPF regeneration at a time.

5. Mechanical – The existing air compressor system will need to be integrated with the aftertreatment system if required. The repower option does not require an air compressor. Due to the unique configuration of the propulsion engines as pumps, additional cost and analysis will be required to fit the new engines.

Pump piping will need to be modified to accommodate the change in dimension of the engines.

6. Fuel System – The combined DPF/SCR systems with active DPF regeneration will require a fuel based system for regeneration. Additional fuel piping and filters will be required for installation of system.

7. Exhaust System – In the case of the repower or the retrofit aftertreatment system, current piping for main engines will need to be removed. All exhaust piping exists the machinery space at the sides of the engine room via a two stacks to the upper decks of the vessel. New piping and hangers will be installed. In addition, new custom lagging will be required to be installed on all exposed metal in the exhaust system. This vessel is used in emergency operations. Due to the vocation of this vessel, an aftertreatment exhaust bypass may be required to ensure full operational availability in the event of an aftertreatment system failure. The installation of a bypass is likely to be approved on a case by case basis and monitored by CARB.

13.4. Costs

Table 97 highlights the insured vessel replacement value as well as the current annual vessel fuel cost. For this application, there were both repower and retrofit options available.

Table *98* highlights the average fuel savings when repowering a Tier 3 engine with a Tier 4 engine as well as the additional maintenance and DEF operating costs associated with repowering. Table *99* highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the available repower technologies shown in Table 102. Table *100* highlights the estimated additional retrofit operating diesel fuel cost incurred from regenerating the DPF and DEF for the SCR. As no maintenance information was provided by the retrofit companies for each of their respective technologies, those costs were not included.

Table 101 highlights the cost ranges for the capital and labor/installation costs with the categorical breakdown costs to install the retrofit technologies shown in Table 103.

Table 97. Special Use Vessel Cost Information

Insured Vessel Replacement	$15,000,000
Current Vessel Fuel Cost @ $3/gal ($/yr)	$21,600

Table 98. Special Use Vessel Annual Operational Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Main Engine Fuel Cost (Tier 3 to Tier 4 only) per year	-$432	-$1,296	-$864
Maint. Cost of Tier 4 SCR (Main Engine) per year	$6,804	$13,276	$10,040
DEF @ $1.75/gal			$1,890
Total Repower Operational Cost Impact			$11,066

Table 99. Special Use Vessel Summary of Capital/Installation Costs for Main Engine Repower and SCR

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs	$550,000	$600,000	$575,000
Labor + Installation Costs			$294,000
Total Capital + Installation Costs			$869,000

Table 100. Special Use Vessel Annual Operational Costs for Retrofit DPF+SCR

	Low Estimated Cost	High Estimated Cost	Average Cost per Year
Maint. Cost of SCR per year	Not Provided	Not Provided	Not Provided
DEF @ $1.75/gal			$1,890
Regen Fuel Cost	$4,526	$14,208	$9,367
Total Retrofit Operational Cost Impact			$11,257

Table 101*. Special Use Vessel Summary of Capital and Installation Retrofit DPF+SCR*

	Low Estimated Cost	High Estimated Cost	Average Cost
Capital Costs SCR + DPF	$185,000	$218,000	$201,500
Capital Costs DPF ONLY	$112,000	$120,000	$116,000
Labor + Installation Costs			$240,000
Total Capital + Installation Costs SCR + DPF			$441,500
Total Capital + Installation Costs DPF ONLY			$356,000

Table 102. Special Use Vessel Detailed Installation Costs for Main Engine Repower

	Estimated Cost
Structural	$36,000
Mechanical	$66,000
Engine Room Access	$65,000
Testing & Commissioning	$36,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$294,000

Table 103. Special Use Vessel Detailed Installation Costs for Retrofit

	Estimated Cost
Structural	$18,000
Mechanical	$42,000
Engine Room Access	$65,000
Testing & Commissioning	$24,000
Haulout/Shipyard Cost	$91,000
Total Installation Cost	$240,000

Appendix

A1. Sample Vessel Added Weight Calculation

Aftertreatment				
	DPF+SCR		DPF	
	System A	System B	System C	System D
Model	xxxxx	xxxxx	xxxxx	xxxxx
Weight (lbs)	2000	1000	750	900
Dos. Cab	200	200		
Qty.	2	2	2	2
Aftertreatment Weight (lbs)	4400	2400	1500	1800
DEF and Tankage				
Total Onboard				
15%	0	0		
-OR-				
Fuel per interval	2000	2000		
15%	300	300		
Lbs/Gallon	9	9		
Tank Weight	400	400		
Weight DEF + Tanks	2,700	2,700	-	-
Additional Weight				
Structural	1000	1000	1000	1000
Exhaust Mods+ Insulation	300	300	300	300
Qty.	2	2	2	2
Total	1600	1600	1600	1600
Total				
Lbs	8700	6700	3100	3400
LT	4	3	1	2
Total w/10% Margin				
Lbs	9570	7370	3410	3740
LT	4.3	3.3	1.5	1.7

Repower	System F
Model	
New Engine Weight (lbs)	4000
Dos. Cab	200
SCR Weight	400
Qty.	2
Old Engine Weight (lbs)	3500
Change in Weight Due to Aftertreatment and Engine(lbs)	2200
DEF and Tankage	
Total Onboard	
15%	0
-OR-	
Fuel per interval	2000
15%	300
Lbs/Gallon	9
Tank Weight	400
Weight DEF + Tanks	2,700
Additional Weight	
Structural	1000
Exhaust Mods+ Insulation	300
Qty.	2
Total	1600
Total	
Lbs	6500
LT	3
Total w/10% Margin	
Lbs	7150
LT	3.2

A2. Vessel Regulations

46 CFR Subchapter D – Tank Vessels

46 CFR Subchapter F – Marine Engineering

46 CFR Subchapter G – Measurement of Vessels

46 CFR Subchapter H – Passenger Vessels

46 CFR Subchapter I – Cargo and Miscellaneous Vessels

46 CFR Subchapter J – Electrical Engineering

46 CFR Subchapter K – Small Passenger Vessels Carrying More Than 150 Passengers or With Overnight Accommodations For More Than 49 Passengers

46 CFR Subchapter M – Towing Vessels

46 CFR Subchapter O – Certain Bulk Dangerous Cargoes

46 CFR Subchapter S – Subdivision and Stability

46 CFR Subchapter T – Small Passenger Vessels (Under 100 Gross Tons)

ABS Steel Vessels under 90 Meters in Length

MTN 04-95

NVIC 02-89