Report Title:

Feasibility Study for Selected Vessel Categories

Vessel Feasibility Review and Consultation for the California Commercial Harbor Craft Regulation: Task 2

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Abstract

This report has been produced by the American Bureau of Shipping (ABS) for the California Air Resources Board (CARB) as part of CARB Agreement No. 21TTD005 – Vessel Feasibility Review and Consultation for the California Commercial Harbor Craft Regulation - **Task 2**, titled “Feasibility Study for Selected Vessel Categories”.

In this report four vessels (ATB[1]-Tug, ATB-Barge, Line Towing Vessel, Ferry) were selected and a feasibility study was conducted to study whether a retrofit could be performed within these vessels with engines meeting CARB’s new in-use performance standards for harbor craft. The study was done in two parts, first Tier 4 engines and their SCR/EGR systems were selected. Then DPFs were added to the configuration. Fitment, backpressure, stability, vessel modifications, and impacts were studied. The results of the feasibility study are provided in this report.

[1] ATB – Articulated Tug Barge

Executive Summary

Background

Commercial harbor craft in California needs to comply with CARB's new in-use performance standards as per CARB's CHC Regulation. In close coordination with CARB, ABS selected 4 vessels from three vessel sectors to assess the feasibility of Tier 4 engine and DPF retrofit to meet CARB's new in-use performance standards for harbor craft. EPA Tier 4 Category 1 engines plus DPF were evaluated for each selected vessel unless Category 2 engines were the only option (such as the ATB-Tug vessel), as required by the agreement between ABS and CARB. DPF evaluations required coordination with a third-party DPF vendor to determine DPF compatibility and sizing.

Methods

This feasibility study is primarily a technical feasibility analysis with some cost information provided "for reference purposes only".

Engines over 600 kW were repowered to Tier 4 engines, with an additional required selective catalytic reduction (SCR) system[2] and diesel particulate filter (DPF). Engines less than 600 kW were repowered to Tier 3 engines and fitted with an appropriate DPF. If engines were already Tier 3, no repower was performed and only a DPF was fitted. All possible Tier 4 engines were evaluated for feasibility study. This was done in two phases. First, only the engine repower was examined for feasibility. Then the DPF was added to see if feasibility could be maintained.

This technical feasibility goes over various aspects of the repower, however, as this is a feasibility study based on voluntary and confidential participation of owners/operators, there were some unknowns. Thus, to mitigate these unknowns some boundary conditions have been created and are clearly identified within the study. As far as practicable, factual data has been provided. In rare cases where data was unavailable or impractical to obtain, reasonable interpolations have been made and boundary conditions were set. These instances have been indicated as clearly as possible.

Results

As per the Agreement No. 21TTD005 with CARB for Task 2, feasibility studies were conducted for three vessel categories including the High-speed catamaran ferry 46 Code of Federal Regulations (CFR) Subchapter-T, Line towing vessel and Articulated Tug Barge (ATB). Repowering costs for the ATB-Barge, ATB-Tug, Line Towing Vessel and Passenger Ferry are to the tune of 21.68, 17.89, 13.46 and 4.19 million US dollars respectively. The repower timeline for the ATB-Barge is 13 months, ATB-Tug is 19 months, Line Towing Vessel is 16 months and Passenger Ferry is 12 months. A Lead time of about 20 months is expected for all vessels. For a detailed breakdown of the timelines, please refer to Figure 14. This lead time is due to engine manufacturers and shipyard backlogs resulting in longer waiting times for materials. At the time of writing, vendors have informed ABS of long wait times on tier 4 engines due to large backlogs and supply chain issues and a similar problem has occurred with shipyards resulting in an approximate lead time of 20 months. Though this lead time can vary depending on the engine and shipyard chosen, ABS has concluded that 20 months is a fair estimate based on industry knowledge and vendor feedback. Backpressures and preliminary stability calculations were also conducted as part of the feasibility study.

[2] Tier 4 engines evaluated are already EPA Marine Tier 4 certified with an OEM-integrated SCR system, except for the GE engines which use an Exhaust Gas Recirculation (EGR) system. CARB does not require exhaust aftertreatment SCR retrofits in the 2023 Amended CHC Reg. Order.

Conclusions

The results generated combined with preliminary stability calculations and holistic evaluation resulted in at least one feasible configuration for each vessel studied. However, certain vessels though technically feasible run into other difficulties which complicate repowering. Though outside of the scope of this study these issues are noted to fully frame all aspects of repowering.

Body of the Report

1 Introduction

This report has been produced by the American Bureau of Shipping (ABS) for the California Air Resources Board (CARB) as part of CARB Agreement No. 21TTD005 – Vessel Feasibility Review and Consultation for the California Commercial Harbor Craft Regulation - **Task 2**, titled “Feasibility Study for Selected Vessel Categories”.

Harbor craft includes a wide variety of vessels such as commercial fishing boats, tugs, ferries, patrol boats, workboats, dredges, pilot boats, and barges. These vessels may do a variety of jobs in and near a single port or region, such as assisting in maneuvering line vessels around the harbor, transporting crew and supplies to offshore facilities, moving cargo and people into and out of the port harbor area, and providing fuel to line vessels.

Historically, harbor craft have had Category 1 or 2 diesel engines (those with less than 30 liters per cylinder displacement). Today, newer harbor craft engines pollute significantly less than older models, and there are a variety of ways to upgrade older engines to reduce emissions[3].

This feasibility study report for selected vessels is the final deliverable for Task 2 of the overall project submitted electronically to CARB.

Cal Maritime has published a report for the California Air Resources Board titled “Evaluation of the Feasibility and Costs of Installing Tier 4 Engines and Retrofit Exhaust Aftertreatment on In-Use Commercial Harbor Craft”. This report presented the feasibility of repowering or retrofitting in-use harbor craft vessels with Tier 4 marine engines or retrofit aftertreatment and was published on September 30, 2019. This report, developed by ABS, is a feasibility study for selected California harbor craft not evaluated in the 2019 CMA Tier 4 feasibility study[4].

In developing this report, ABS engaged on a regular basis with CARB providing progress updates and seeking input on Task 2. This report includes and examines all details relating, but not limited to, backpressure calculations, stability considerations, and other technical concerns or considerations for determining the feasibility of California’s Commercial Harbor Craft Regulations, as detailed in this body of the report.

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[3] EPA Harbor Craft (HC) Best Practices to Improve Air Quality - https://www.epa.gov/ports-initiative/harbor-craft-hc-best-practices-improve-air-quality

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

Assumptions/Limitations of this Feasibility Study:

1. This feasibility study is not indicative of the entire fleet of vessels but has covered selected specific vessels which are a close representation of the fleet as suggested by CARB.
2. The vessels participating in this study are not automatically construed to be deemed feasible/infeasible based solely on this evaluation and this evaluation is not exhaustive of all aspects which need to be considered to judge feasibility. When the owner/operator submits a request for extension to CARB, an independent evaluation conducted by a naval architect based on the full body of evidence submitted by the owner/operator will be considered when determining actual feasibility.
3. Costs and timelines provided in this feasibility study are in a "business as usual" scenario. However, unexpected delays and unforeseen circumstances can elevate costs and extend timelines.
4. Rypos[5] was selected as the DPF provider in all instances, though it is understood that for Tier 4 engines, this is an academic evaluation as the system is not yet CARB verified for all engine Tier-level applications. This is so that all the elements in the feasibility study can be reasonably estimated and completed. Also, there are a few owners/operators who are concerned about the status of EIAPP certificates when DPF's are added to engines.
5. Longer vessels like barges may need to be relocated from the West Coast to the Gulf Coast or overseas for undergoing repower/retrofit, however determining where these repower/retrofits can ultimately be accomplished was difficult to ascertain with great accuracy and hence was not directly embedded in the analysis. For the ATB-Barge, some extra cost has been added to account for the repositioning but the Panama Canal passage fees etc. are not fully included.
6. Opportunity costs of taking the vessel out of service are not accounted for in retrofit or repower costs.
7. Labor rates, yard rates, equipment cost, material cost etc. all vary with geographic region and time (year the order was placed, and when engines/components/material are delivered). Reasonable assumptions have been made and clearly indicated. Inflation (time value of money) and salvage value have not been accounted for within this study. Cost of crew downtime, travel costs of maintenance crew, etc. are not accounted for, though these are real and practical costs.
8. The timeline for plan review, performed by ABS on behalf of the USCG[6], of repower and retrofit are estimated at a constant of 3 months. This provides for about 1 month review + 1 month revision/comments + 1 month second review, as is standard practice of classification societies. These reviews can also be conducted by the USCG but due to backlogs could be even longer which is why classification societies, such as ABS, have been authorized to act on behalf of flag states, reducing administrative processing times. However, it is important to note that Subchapter T vessels are exempt from this authorization. According to the coast guard these types of vessels "generally require a greater degree of interpretation of the regulations than do other types of vessels. This necessitates closer

[5] Rypos - https://www.rypos.com/
[6] USCG - NVIC 10-82

involvement of the OCMI throughout the plan review and inspection process. Accordingly, these vessel types are retained for plan review and inspection by the Coast Guard."

9. Yard capabilities can vary significantly and thus may affect timelines and costs.

10. The weight of piping, bellows, etc. for auxiliary components is minor compared to the extent of overall modifications done on the vessel and hence that weight is not separately considered in the evaluation.

11. Engine "Tiers" wherever used in this report, refer to United States (U.S.) EPA engine Tiers and not IMO engine Tiers, unless stated otherwise.

12. In some cases where space was limited, SCRs and DPFs were theoretically fitted over the engines to complete the calculations. This potentially creates some challenges for design and maintenance of those components but for the purposes of this analysis, those places were best suited to proceed with the analysis.

13. The primary reason 3D scans were created and are shown in the Appendix is to convey the idea that for vessels which do not have some or all drawings, 3D scans may be submitted to CARB instead of recreating 2D drawings. It is noted that some of the harbor craft are aged in the California fleet and due to the passage of time and potential change in ownership, some or all the drawings might be missing or inaccurate. The 3D point cloud scan technique provides an alternative approach of submitting drawings to CARB to be used in the feasibility analysis when real submissions are made. There are limitations for the 3D point clouds as they cannot show pipe thickness, weights etc. but can be used primarily to assess space available for new equipment. For the purposes of this study, though 2D drawings were available for all vessels, 3D point clouds were also created.

14. Using SCRs and DPFs in tandem have inherent challenges including the long-term effect of ammonia on the DPF catalyst and its potential to degrade and corrode the catalyst. This is a known issue which DPF manufacturers are currently working to solve and have had promising results in a test environment. Installation of DPFs and SCRs can also potentially result in an invalidation of the existing EPA certification and the changes to the design and engine operation would require new Engine International Air Pollution Prevention (EIAPP) certification.

15. Backpressure limits were provided by ABS to the DPF manufacturer and Rypos operated on some reasonable estimations to not exceed the manufacturer's backpressure limits when sizing those DPF. Backend calculations of how these backpressures were calculated could not be explicitly provided by the DPF manufacturer due to constraints on sharing information of proprietary nature for DPF design. It is important to note that DPF design and exhaust backpressures are closely interlinked and thus require close collaboration with the third-party DPF manufacturer during the design process. Sometimes silencers may need to be degraded to reduce their portion of the backpressure, but this is evaluated on a case-by-case basis. Also, some level of fire-extinguishing or suppression are recommended around the DPF.

16. Though a full stability and incline analysis and test is beyond the scope of this study, preliminary stability calculations were done in this study to provide a clear indication of when a full stability and

incline test is required. In this feasibility study, preliminary calculations were conducted, and these preliminary results are clearly shown. To provide some additional context, a full-fledged stability analysis and test is estimated to take a minimum of 150 engineering hours. In cases where lightship exceeds 2%, a full stability analysis and incline test might be required.

17. Due to internal policy or class regulations, when engines are repowered/retrofitted, some owners might choose to have a full stability and incline test done regardless of percentage lightship change. Those costs have been accounted for in the analysis. Sea trials might also take the vessel out of service and affect opportunity costs, but these are beyond the scope of the study.
18. Whenever possible detailed drawings and explanations are provided in this study. However, it is to be noted that due to privacy concerns, non-disclosure agreements and in the spirit of retaining true anonymity some of the backend engineering could not be embedded in this report. That said, all efforts have been made to do a thorough analysis and investigation.
19. A barge does not have any main engines. By definition, a barge is not self-propelled. However, for convenience and categorization, the two large engines on the barge have been grouped together with the main engines in this study.

Conclusions:

Table 1: Feasibility Table Legend

Infeasible	Conditional Feasibility[7]	Feasible
1	2	3

[7] This denotes a solution which can be technically accomplished but may come at a significant cost to the owner or require further investigation to confirm. At this time for the purpose of this report these will be considered feasible.

Table 2: Feasibility Table

Vessel	Mfr.	Engine Evaluated	DPF Model	Eng. Power Req.	Eng. Fit.	Eng. Stab.	DPF Fit.	DPF Back.	DPF Stab.	o/a[8] Feas.
ATB - Barge	MTU	12V-4000M05	ADPF-5-NS	3	3	3	3	3	3	3
ATB - Barge	Baud.		ADPF-4-NS	3	3	3	3	3	3	3
ATB - Barge	CAT.	3512E	ADPF-4-NS	3	3	3	3	3	3	3
ATB - Barge	Cum.	QSK38	ADPF-3-NS	3	3	3	3	3	3	3
ATB - Tug	CAT.	C280-12	ADPF-10-NS	3	1	3	3	3	2	1
ATB - Tug	GE	12V250MDC	ADPF-8-NS	3	3	3	3	3	3	3
Line-Towing	Cum.	QSK60	ADPF-6-NS	3	3	3	2	3	2	3
Line-Towing	MTU	16V-4000M05	ADPF-7-NS	3	3	3	2	3	2	3
Line-Towing	GE	6L250MDC	N/A[9]	1	1	1	1	1	1	1
Line-Towing	GE	8L250MDC	N/A[9]	1	1	1	1	1	1	1
Line-Towing	CAT.	3516E	ADPF-6ER-NS	3	1	3	2	3	2	1
Ferry	Baud.	6M-26.3	RH-408-XL	3	3	2	3	3	2	3
Ferry	CAT.	C32	RH-408-XL	3	1	2	3	3	2	1
Ferry	Yan-mar	6AYEM-GTWS	RH-410-XL	3	3	2	3	3	2	3
ATB - Barge	CAT.	C4.4	RH-304-M	3	3	3	3	3	3	3
Line	John Deere	4045AFM85	RH-404-M	3	3	3	3	3	3	3
ATB - Tug	John Deere	6090SFM85	RH-408-M	3	3	3	3	3	3	3
Ferry	North-ern Lights	M843NW3G	TBA[10]	3	3	3	3	3	3	3

[8] Overall Feasibility Determination
[9] Since this engine did not fit the power requirements for any of the vessels studied it was also excluded from DPF sizing.
[10] Does not currently have a model name.

Table 2 above shows the results of the feasibility study. It can be seen that every vessel type studied has at least one feasible configuration. This study reviewed repowers in two separate steps. The first was ensuring that a Tier 4 engine and its OEM SCR system could be installed in the vessel. Then the study proceeded by adding a DPF to that system. Each vessel type had some key findings that will be discussed here:

ATB-Barge:

The barge was the least difficult retrofit of the four vessels studied. Due to its large weight and size, it has plenty of space for retrofit and the added weights never approached 2% of the lightship so an additional stability study would not be needed for this vessel.

ATB-Tug:

The ATB-Tug had more challenges to reach feasibility. The space in the engine room was the first problem encountered. Potential engine replacements were limited due to some of the engines which though they fit the power requirements, were too large to fit in the footprint left behind. Also, The ATB-Tug has a unique profile which makes stability something that needs to be closely examined. ATB-tugs are short vessels compared to their height. This results in weight changes higher in the vessel having an increased impact on the overall stability of the vessel. It was determined in this study that the added weight of the DPF in the stack would be offset by the added weight in the engine room which is below the current center of gravity, and a rough calculation was performed to confirm this conclusion. Lastly, the engine options that fit the tug's power requirements all had lower backpressure limits. This could easily become an issue as the DPF system adds a significant backpressure load when it begins operation. Through discussions with the manufacturers, we were given increased backpressure limits which either accounted for a DPF system or used a solution developed by the manufacturer to increase the engine's base backpressure limit[11].

Line Towing Vessel:

For the Line Towing Vessel, the main issue arose when determining fitment for the DPF system. When analyzing the 3D scans of the ship it became apparent that the best space for installation would be in the stack of the vessel. However, the tug currently sits at 499 GT which places it outside of SOLAS requirements. The challenge is that to install the DPF in the stack an expansion will likely be necessary to allow for proper maintenance and heat dispersion, but this expansion would put this tug over the 500 GT limit bringing them into SOLAS requirements. This would require an expensive overhaul of many systems onboard the vessel and effectively change the current operating profile. For this reason, a conditional feasibility was given because technically the installation is not challenging and can be accomplished, but financially and logistically the retrofit is not viable.

[11] This option was available in GE systems and CAT systems.

Ferry:

The ferry ran into issues concerning the weight and space available for retrofit. The engines and DPFs systems were still able to fit within the space available in the ferry. Certain systems like Yanmar make this feasible through the integration of an SCR system within the engine itself. This consolidated footprint is crucial for this retrofit. The main issue is due to the ferry being so light, 2% of lightship is an easy threshold to cross and almost any retrofit taking place will likely have to go through additional stability studies. However, since the weights are all being added below the main deck and therefore below the center of gravity, they will likely not have an adverse effect on the stability of the vessel. Another issue is that this weight can be offset but it will likely be through a reduction in passenger and cargo capacity resulting in a large financial loss over the lifetime of the vessel.

1.1 Detailed Background

The Commercial Harbor Craft (CHC) Regulation, Section 93118.5, Title 17, Chapter 1, Subchapter 7.5 and Section 2299.5, Title 13, Division 3, Chapter 5.1[12] of the California Code of Regulations, was adopted in 2007 and amended in 2010 to reduce diesel particulate matter (PM) and criteria pollutant emissions from diesel powered engines on commercial harbor craft vessels.

The regulation applies to all commercial harbor craft vessels[13] including, but not limited to, ferries, excursion vessels, tugboats (including line tugs), towboats, push boats, crew and supply vessels, barge and dredge vessels, work boats, pilot vessels, commercial passenger fishing vessels, and commercial fishing boats.

On December 30, 2022, a new set of amendments was adopted to expand the applicability of the regulation to more vessel types as well as require cleaner upgrades and newer technology[14]. More information regarding the CHC amendments can be found at: https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft/chc-regulatory-documents.

The new in-use performance standards for diesel PM would require all CHC, except for the commercial fishing vessels[15], to meet the performance standard which is equivalent to the most stringent Tier 4 PM marine standard plus a DPF (in some specific cases Tier 3+DPF are allowed). However, there are challenges for some vessel categories to meet the proposed performance standards.

The new CHC amendments allow the vessel owners or operators to apply for compliance extensions. A summary list of CHC Extensions is listed in Table 6 for convenience. The new CHC Regulation[16] amendments entered into force on January 01, 2023, and depending on the vessel type and model year of the currently installed engine the date for compliance will vary. CARB has provided a fact sheet[17] for these compliance deadlines on their website. Operators may apply for extensions during the implementation of the amendments. For an E3 extension, technical feasibility assessment reports would need to be reviewed, and a determination would need to be made for the compliance extension applications. In addition, appropriate guidance[18] has been developed for stakeholders when submitting their feasibility analyses, and in other cases, providing analyses that can be used by applicants to support streamlined review of compliance extensions.

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[12] CHC Regulation: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2021/chc2021/chcfro.pdf
[13] Not all these vessel types had in-use requirements under the previous regulation, though all did have reporting requirements.
[14] CARB CHC, https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft
[15] Commercial Fishing Vessels have separate compliance requirements and their own compliance timeline.
[16] CHC Regulatory Documents, https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft/chc-regulatory-documents
[17] Commercial Harbor Craft 2022 Amendments Factsheet: Implementation Timeline (ca.gov)
[18] Guidance - Application Templates for CHC CARB, https://ww2.arFb.ca.gov/CHCapplicationtemplates-2023

1.2 Emissions Reductions

EPA Marine Compression Ignition Engines Exhaust Emission Standards can be found at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZP4H.pdf.

The emissions reductions will be based on the current engine vs the replaced engine EPA Tier. However, for the sake of convenience, EPA Tier 4 standards, EPA Engine Categories and current and replaced engines with their profile are shown in Table 3, Table 4 and Table 5.

Table 3: EPA Engine Categories (new marine engines) as per 40 CFR Part 1042*

Engine Category	Maximum Engine Power	Displacement (L/cyl) or application	Model Year
Category 1	kW < 75	disp.< 0.9	2009
Category 1	75 ≤ kW ≤ 3,700	disp.< 0.9	2012
Category 1	75 ≤ kW ≤ 3,700	0.9 ≤ disp. < 1.2	2013
Category 1	75 ≤ kW ≤ 3,700	1.2 ≤ disp. < 2.5	2014
Category 1	75 ≤ kW ≤ 3,700	2.5 ≤ disp. < 3.5	2013
Category 1	75 ≤ kW ≤ 3,700	3.5 ≤ disp. < 7.0	2012
Category 1	kW > 3,700	All	2014
Category 2	kW ≤ 3,700	7.0 ≤ disp. < 15.0	2013
Category 2	kW > 3,700	7.0 ≤ disp. < 15.0	2014
Category 2	All	15 ≤ disp. < 30	2014
Category 3	All	disp. ≥ 30	2011

* Note: For complete details see, https://www.ecfr.gov/current/title-40/chapter-I/subchapter-U/part-1042

Table 4: EPA Tier 4 Standards for Category 2 and Commercial Category 1 Engines at or above 600 kW as per 40 CFR Part 1042*

Maximum Engine Power	Displacement (L/cyl)	Model Year	PM (g/kW-hr)	NO_X (g/kW-hr)	HC (g/kW-hr)
600 ≤ kW < 1,400	all	2017+	0.04	1.8	0.19
1,400 ≤ kW < 2,000	all	2016+	0.04	1.8	0.19
2,000 ≤ kW ≤ 3,700[a]	all	2014+	0.04	1.8	0.19
kW > 3,700	disp. < 15.0	2014-2015	0.12	1.8	0.19
kW > 3,700	15.0 ≤ disp. < 30.0	2014-2015	0.25	1.8	0.19
kW > 3,700	all	2016+	0.06	1.8	0.19

Table 5: Replaced Main Engine Emission Profile

No.	Vessel Type	Current Engine Emission Profile	Repowered Main Engine Emission Profile
1	ATB-Tug	EPA Tier 2	EPA Tier 4
2	ATB-Barge	EPA Tier 2	EPA Tier 4
3	Line Towing Vessel	EPA Tier 3	EPA Tier 4
4	Subchapter T High Speed Catamaran Ferry	EPA Tier 3	EPA Tier 4

1.3 Purpose of Feasibility Study

As part of the Vessel Feasibility Review and Consultation for the California Commercial Harbor Craft Regulation project for CARB, ABS will provide technical support to CARB staff during the implementation of the amended CHC Regulation that has taken effect beginning on January 1, 2023.

In this report ABS has conducted a feasibility study of a representative vessel for selected vessel categories, based on currently available engines and DPFs.

The 2022 Amendments to the CHC Regulation provide several compliance extensions (Refer to Table 6) for various cases that may prevent regulated parties from demonstrating compliance with the applicable requirements. Parties must request extensions through a formal application process. Applications are subject to review and approval by the CARB Executive Officer.

Table 6: Summary of Extensions[19]

Extension Name	Type	Eligibility Criteria	Length of Extension	Application Due Date	Renewal Due Date
E1	Infrastructure Delays	Shore power, ZEAT infrastructure	1 year (Maximum of 2 years) [(b)]	At least 9 months prior to compliance dates	Accepted from 9 to 12 months before the expiration of the extension
E2	Technology Availability	Demonstration of lack of certified engines/DPFs[(c)]	2 years (Unlimited renewals)	No later than 9 months and no earlier than 12 months before the compliance date	Accepted from 9 to 12 months before the expiration of the extension
E3 (CPFV)	Technology Feasibility for CPFV with Tier 3 Or Better[(a)] Engines	Demonstration of Tier 3 or better by Dec. 31, 2024	10 years	By July 1, 2024	Nonrenewable
E3	Technology Feasibility and Financial Hardship for All Other Vessels	Demonstration of technical infeasibility to repower and financial difficulty	2 years (Maximum of 6 years, not beyond Dec. 31, 2034) [(d)]	No later than 18 months before the compliance date, or no later than nine months before the December 31, 2023, compliance date	Accepted from 9 to 12 months before the expiration of the extension
E4	Tier 4[(e)] with Limited Operating Hours	Tier 4 engine, limited operating hours[(f)], vessel replacement necessary for addition of DPF	2 Years (Unlimited renewals)	No later than 9 months and no earlier than 12 months prior to the compliance date	Accepted from 9 to 12 months before the expiration of the extension

[19] CHC Factsheet: Compliance Extensions, https://ww2.arb.ca.gov/resources/fact-sheets/chc-factsheet-compliance-extensions/printable/print, date accessed: 30-Nov-2023.

Extension Name	Type	Eligibility Criteria	Length of Extension	Application Due Date	Renewal Due Date
E5	Scheduling	Manufacturer or shipyard delays; conflicting compliance dates[(g)]	1 year (Unlimited)[(b)]	Prior to compliance date[(h)]	Accepted from 9 to 12 months before the expiration of the extension

Notes:

a. *Tier 3 or better means meeting Tier 3 or more stringent emissions standards.*

b. *Any combination of extensions cannot provide an extension for a single engine of more than 6 years, or for CPFV, Excursion Vessels, and Ferries, an extension of more than 8 years; also, no extensions may extend beyond December 31, 2034.*

c. *Engines certified to current Tier 3 or better emissions standards are available, but DPFs are not, applicants must repower the vessel with an available engine by applicable compliance dates to receive an extension for DPFs. The repower engine must be certified as the most stringent marine or Final Tier 4 off-road engine standard available for the power and duty cycle rating of their operation.*

d. *CPFVs, Excursion Vessels, and Ferries (except short run) can renew Extension E3 for a total of 8 years if they have compliance dates in 2024 or earlier; Workboats operating under Low-Use thresholds may receive an unlimited number of extensions.*

e. *For barge and barge mounted dredge vessels, all auxiliary engines must meet Tier 4 marine or Tier 4 Final off-road standards; main propulsion engines will not need to meet these standards. For all other regulated in-use vessel categories, all main propulsion engines must meet Tier 4 marine or Tier 4 Final off-road standards, and auxiliary engines will not need to meet these standards. If Tier 4 engines that are granted an E4 extension are operated beyond the applicable threshold hours in any calendar year, any compliance extensions granted will be terminated.*

f. *Up to 2600 annual hours or 1300 annual hours of operation in or within 2 miles of a DAC.*

g. *For multiple engines on multiple vessels with the same compliance dates, or for engines on a single vessel with different compliance dates.*

h. *While E5 applications may be submitted up to the applicable compliance deadlines specified in (e)(12) of the Final Regulation Order, CARB staff recommends that applicants allow 60 days for application review and consideration of approval. Engine operation beyond applicable (e)(12) compliance dates may be considered out of compliance.*

2 Materials and Methods

2.1 Methodology - Analysis

The engines listed in Table 7 and Table 8[20] have been used as a reference for repowering and matched with the selected vessels' existing engine horsepower to find replacements to accommodate similar power requirements. Once a list was compiled indicating which engines could potentially be used as replacements, a selection was made based on compatibility with engine power output and speed. For this study, an engine selection criterion was created that the engine's power must be greater than or equal to the original engine up to a 15% margin and operate at the same speed. Though the CHC regulation has no provision stating an engine would be infeasible regarding these criteria, ABS has added this boundary condition to limit the scope of this study. For the vessels analyzed suitable replacements were found rated for the same speed however, engines at various speeds can be utilized in a repower increasing the number of applicable engines. It should be noted, unavailability of engines at the same speed is not criteria to receive an E3 exemption. According to the regulation, vessels are still required to meet the cleanest engine requirements, meaning if an applicable, cleaner, engine is available then it must be used. Repowering with an engine rated for a different speed will require a look at both the vessel's current gearbox and propeller to ensure that they are compatible with the new speed. Often this is not the case and will result in a redesign of the gearbox, shaft, and propeller which are costly and time-intensive changes to implement. An installation like this will require the engineer to ensure the gearbox ratios are compatible, that the propellers' pitch and diameter are compatible with the new speed, and if the propeller is changed an adjustment is made to the shaft as well.

The applicable OEM SCR/EGR system was also included in the repower. Due to the limited number of available DPF vendors, particularly from the engine manufacturers themselves, a third-party DPF vendor has been used for all installations (Rypos). Though Rypos installations do not cover all use cases, for the purposes of the study, it was deemed the best available solution under the operating constraints.

Costs, impacts, modifications, emissions, schedule, and operational considerations were studied as part of the feasibility study. It is to be noted that although certain aspects of cost have been included in this study, financial hardship extension requests are not within the scope of ABS' evaluation of the overall project.

As part of this feasibility study, the subject vessels underwent a holistic examination for repower. Modification considerations in their structural components, tonnage capacity, internal equipment layout, piping, tanking, auxiliaries such as electrical power demand, generation and distribution cabling, cooling requirement and heat balance, etc. have been accounted for. As a result, some

[20] https://ww2.arb.ca.gov/sites/default/files/2023-10/FAB23-084%20-%20List%20of%20Tier%204%20Marine%20Engines.pdf

vessels may be technically rendered infeasible due to space, weight, and other constraints. Where applicable, ABS' holistic review at least included:

- Stability
- Structure
    - Dimensions and space availability
    - Strength of materials
- Performance
    - Speed-power characteristics
    - Maneuverability
    - Engines
    - DPFs
    - Urea Tanks
- Tonnage
- Heat Balance
    - Cooling requirement
- Fuel System
    - Fuel storage
    - Fuel supply system
    - Fuel availability
- Auxiliaries
    - Electrical power demand
    - Generation and distribution system
    - Heat exchangers
    - Piping
    - Hydraulic and pneumatic systems compatibility
    - Ventilation system
    - Cooling water pumps and sea chests
- Fire safety
    - Fuel type and flammability
    - Component and exhaust temperature
- Operational issues
    - Crew Safety
    - Physical maneuverability around the engine room and equipment
    - Maintenance of equipment
    - Vessel endurance due to reduced fuel storage to accommodate urea

Figure 1 below shows the process through which each configuration was evaluated. The feasibility analysis was broken down into two separate studies. The first looked solely at the feasibility of Tier

4 engine and SCR installation, and the second considered the addition of a DPF to that system. Finally, overall considerations for vessel modifications and their impacts from this retrofit were considered.

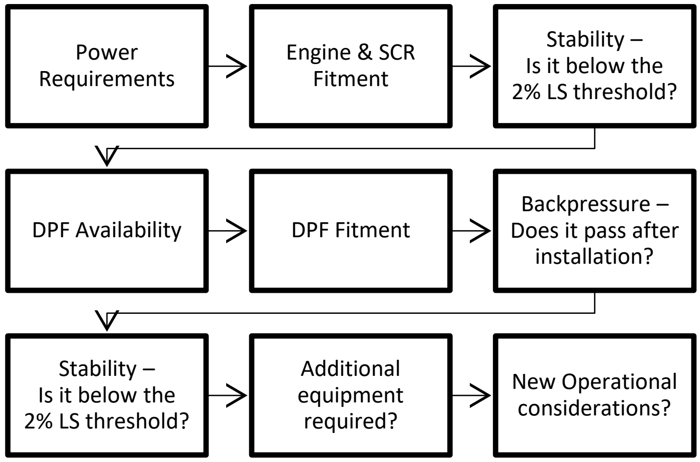

Figure 1: Methodology – Analysis

Table 7: List of Certified Tier 4 Marine Engines (as of 11 October 2023)

Manufacturer	Model	U.S. EPA Category	Power Range (kW)	RPM	Weight (kg)
Baudouin	6M-26.3	1	441 - 599	1,800-2,100	2,185
Baudouin	12M-26.3	1	883 - 1,214	1,800-2,300	3,615
Caterpillar	3512E	1	1,000 - 1,901	1,600-1,800	8,193
Caterpillar	3516E	1	1,865 - 2,525	1,600-1,800	9,620
Caterpillar	C32	1	746 - 1081	1,600-2,150	3,248
Caterpillar	C280-8	2	2,460 - 2,530	1,000	19,000
Caterpillar	C280-12	2	3,700 - 4,060	1,000	26,035
Cummins	QSK38	1	746 - 1,119	1,800	5,270
Cummins	QSK60	1	1,491 - 2,013	1,600-1,900	10,154
EMD 710 Series	8E 23	2	1,250	900	14,742
EMD 710 Series	12E 23	2	1491	900	19,414
EMD 710 Series	12E 23B	2	2237	900	23,133
EMD 710 Series	16E 23	2	2983	900	22,589
GE	6L250MDC	2	1,700-1,900	900-1,000	19,944
GE	8L250MDC	2	2,250-2,500	900-1,000	23,356
GE	12V250MDC	2	3,150-3,500	900-1,000	27,080
GE	16V250MDC	2	4,200-4,700	900-1,000	35,788
MAN Diesel	D2862LE428	1	749	1,300-1,900	2,270
Mitsubishi	S12R-Y4MPTAW	1	940	1,600	5,320
MTU	12V-4000M05	1	1,119-1,932	1,600-1,800	8,000
MTU	16V-4000M05	1	1,840-2,576	1,600-1,800	9,300
MTU	20V-4000M05	1	2,300-3,220	1,800	11,600
Yanmar	6AYEM-GTWS	1	670/749	1,938-2,000	2,418

Table 8: List of Marinized EPA Certified Tier 4 Final Non-Road Engines[21], as of 11 October 2023

Manufacturer	Model	U.S. EPA Category	Power Range (kW)	RPM	Engine Weight (kg)
M&H Engineering	M&H John Deere 4045MD	1	55 - 130	2,400	570
M&H Engineering	M&H John Deere 6068MD	1	169 - 224	2,400	750
M&H Engineering	M&H John Deere 6090MD	1	205 - 317	2,400	1,056

[21] Date Accessed: October 15, 2023 - https://ww2.arb.ca.gov/sites/default/files/2023-10/FAB23-084%20-%20List%20of%20Tier%204%20Marine%20Engines.pdf

2.2 Methodology - Itemized Cost

Initially a replacement engine was determined and the costs to repower with the tier 4 engine and CARB Verified Level-3 marine DPF retrofits were broken down into various categories deemed significant to the total costs shown in Table 9.

Table 9: Types of Itemized Costs

Engines and DPF	Costs for engines were quoted from multiple different distributors and were quoted for a complete repower of the ships and so they include any control systems needed to operate the new engine, its SCR, and a DPF. Engine costs are subject to an approximate 8% increase yearly as well as a lead time upon ordering, and as such will vary from the costs quoted in this report. DPF costs were sourced from a third-party vendor (Rypos).
Exhaust System & Engine Room Access	The exhaust system costs were calculated based on the labor cost. Experience has led ABS to use 10% of the cost of general labor as cost for exhaust changes that need to be made on the vessel to accommodate any increased ventilation needed. Engine room access was based on values seen from the Cal Maritime Report and value was added based on size of the vessel or complications in the process such as with the ferry where an aluminum build makes the ship harder for most shipyards to handle.
Shipyard Rates	Storage, labor and drydocking rates were all calculated using Northlake Shipyards rates[22], located in Seattle, Washington, as available on their website. Though it should be noted that these rates are subject to change and carry additional fees. Some rates were changed due to factors affecting the complexity of the project or services outside of the shipyard such as engineers. Northlake shipyard also imposes a regulatory rate which adds an additional 15% to the gross cost of service, although this is likely an uncommon fee, it might become more prevalent in the future for owners and shipyards. All costs for materials and subcontractors will incur an additional retail charge of 25% the cost (cost + 25%).
Engineering Rate	Engineering rate was based on 2019 rates published by HDR Engineering[23] and averaged to get an estimate of what an owner might see when seeking out design work. Engineering labor was assumed to be subcontracted out by the shipyard.

[22] Northlake Shipyard Rates, https://northlakeshipyard.com/rates/
[23] HDR Engineering Hourly Rates, https://www.rcgov.org/index.php?option=com_docman&view=download&alias=12794-pw011519-12-ex-c-2019-hdr-engineering-rate-sheet-pdf&category_slug=01-january-pw-3&Itemid=149

2.3 Emissions Compliance Options

The engines listed in Table 7 and Table 8 were the full list of evaluated replacements for the vessel's engines examined in this study. To meet CARB's Tier 3 + DPF or Tier 4 + DPF In-Use Performance Standards, engines are required to be equipped with a DPF system. These DPFs may either be CARB-Verified Level 3 DPFs or, in some cases, be integrated by the engine OEM which is able to meet CARB's applicable performance standard in subsection (e)(9) of the Commercial Harbor Craft Regulation. SCR/EGR systems, though not a CARB requirement, are typically installed by engine OEMs to meet EPA Tier 4 requirements. Since the EPA has not begun considering engines below 600 kW for Tier 4 compliance, it is to be noted that there exists fewer options for emissions compliance with engines of lesser horsepower.

In the future, when more low horsepower Tier 4 engines are available in the market, competition may result in lower prices, but this market is still nascent, and it needs to be closely monitored for new engine entrants.

There is also a developing market for Marinized EPA Certified Tier 4 Final Non-Road Engines which do have smaller engines, and this sector needs to be watched closely.

2.4 Vessel Particulars

The selected vessel particulars are listed in Table 10. These vessels were selected in coordination from CARB. The participants of this study (vessel owners, operators, designers) are not indicated in the report to retain anonymity. Part of the sample vessels' selection process was the degree of representativity and the owners' commitment to support ABS on this study. Certain details on the vessels' particulars (e.g. USCG Vessel Identification Number, IMO Number, etc.) have been purposefully excluded to retain anonymity.

Table 10: Generic Non-Identifying Particulars

Vessel Type	ATB-Tug	ATB-Barge	Line Towing Vessel	Subchapter T High-speed Catamaran Ferry
Description	46 CFR Subchapter M Towing Vessel, SOLAS	Oil and Chemical Tank Barge, Subchapter O & Subchapter D	Towing Vessel, Non-SOLAS	Catamaran, USCG Subchapter T, Coastwise
Vessel Construction Delivery (Year)	2006	2006	2007	2013
Design Deadweight (LT)	524.25	26,596.21	452.56	32.94
Estimated Gross Tonnage	950	13462	499	95
Estimated Net Tonnage	285	8791	149	76

Vessel Type	ATB-Tug	ATB-Barge	Line Towing Vessel	Subchapter T High-speed Catamaran Ferry
Length Overall (ft)	127.03	583.15	128.33	64.83
Breadth Molded (ft)	42.01	74.02	35	25
Depth Molded (ft)	21.94	40.01	17.50	6.75
Length Between Perpendiculars (ft)	127.03	583.15	119	60
Hull Type	Single Hull	Double Hull	Single Hull	Hydrofoil Supported Catamaran
Hull Material	Steel	Steel	Steel	Aluminum
Lightweight (LT)	917.67	6,198.17	544.51	32.94
Existing Engine Particulars	2 x Cat 3612B, 4,638 hp (3,411 kW) @ 900 rpm	2 x Cat 3512B, 1,435 hp (1,070 kW) @ 1,800 rpm	2 x MTU 16V4000 M64, 2,679 hp (1,970 kW) @ 1,800 rpm	2 x Cummins QSK 19-M, 800 bhp (597 kW) @ 1,800 rpm

2.5 Quality Assurance and Quality Control Procedures

The first two drafts of the reports were circulated among CARB and the voluntary participants of the feasibility study and comments were generated and addressed before the final release of this report.

3 Vessel Analysis for Installation of Tier 4 Engine

3.1 Repower/Retrofit Overview

An overview of the vessel engines being retrofitted are provided in Table 11 with the Tier 4 replacements selected shown in the right-hand columns.

These engines were selected based on their power requirements and rotational speeds. Engine sizing is a process which is accomplished through investigation of an engine's power curve to determine both power and rotational speeds which best match the operational ability of the engine being replaced. Designers would also need to consider various details such as gearbox changes, propeller and shaft variations, and electricity requirements. However, due to the number of engines and vessels being studied this process was simplified. Engines were chosen, which provided at least as much power as what was currently onboard and did not surpass 15% of the previous engines' power. Also, where possible, engines with similar rotational speeds were selected. The SCRs investigated were from the engine manufacturer for compatibility reasons[24]. There are currently no retrofit CARB-Verified Level 3 DPFs available from engine manufacturers and hence a CARB third-party vendor pursuing verification was selected.

Table 11: Overview of all the Assessed Tier 4 Main Engines

No.	Vessel Type	Current Main Engine	Evaluated Main Engines[25]
1	Articulated Tug Barge (ATB) - Tug	2 x Cat 3612B, 4,638 hp (3,411 kW) @ 900 rpm EPA Tier 2	(1) Cat C280-12 (2) GE 12V250MDC utilizing EGR instead of SCR
2	Articulated Tug Barge (ATB) - Barge	2 x Cat 3512B, 1,435 hp (1,070 kW) @ 1,800 rpm EPA Tier 2	(1) Cat 3512E (2) MTU 12V-4000M05 (3) Cummins QSK 38 (4) Baudouin 12M-26.3
3	Line Towing Vessel	2 x MTU 16V4000 M64, 2,679 hp (1,970 kW) @ 1,800 rpm IMO Tier 2/EPA Tier 3	(1) MTU 16V-4000 M05 (2) Cat Tier 4 3516E (3) Cummins QSK 60
4	Subchapter T High Speed Catamaran Ferry	2 x Cummins QSK 19-M 800 bhp (597 BkW) @ 1,800 rpm IMO Tier 2/EPA Tier 3	(1) Yanmar 6AYEM GTWS (2) Baudouin 6M-26.3 (3) Caterpillar C32

[24] EPA Tier 4 marine engines are certified with OEM-integrated SCR systems. It is to be noted that CARB is not requiring SCR retrofits for compliance.
[25] All engines listed are Tier 4 and include OEM SCR system unless otherwise noted.

Table 12: Overview of all the Assessed Auxiliary Engines

No.	Vessel Type	Current Auxiliary Engine	Evaluated Auxiliary Engines
1	Articulated Tug Barge (ATB) - Tug	2 x 250 kW, EPA Tier 3, John Deere model 6090SFM85	Not Needed as <600 kW and already EPA Tier 3
2	Articulated Tug Barge (ATB) - Barge	1 x CAT D-60 Tier 0 engine, rated at 95 bhp [70 kW] (model year 2004)	1 x Cat C4.4 75 kW, EPA Tier 3
3	Line Towing Vessel	John Deere 4045AFM85, 99 kW @1,800 rpm, EPA Tier 3	Not Needed as <600 kW and already EPA Tier 3
4	Subchapter T High Speed Catamaran Ferry	Northern Lights M843NW3G, 12 kW, EPA Tier 3	Not Needed as <600 kW and already EPA Tier 3

3.2 ATB-Tug

3.2.1 Fitment

Table 13: ATB-Tug Fitment Feasibility Summary

Engine	Dimensions (L"xW"xH")	Does it Fit?	Reasoning
Caterpillar C280-12	181.6 x 79.6 x 134	No	The SCR System must be installed vertically making fitment impossible in the available space.
GE 12V250MDC	205 x 107 x 143	Yes	Lack of SCR system and integrated EGR reduces engine footprint.

Fitment was a difficult challenge within the confines of the ATB-Tug. Due to its compact geometry and already tight walkways, the engine room has a lack of additional floor space to spare for a larger engine making fitment difficult for most Tier 4 engines which tend to be slightly larger.

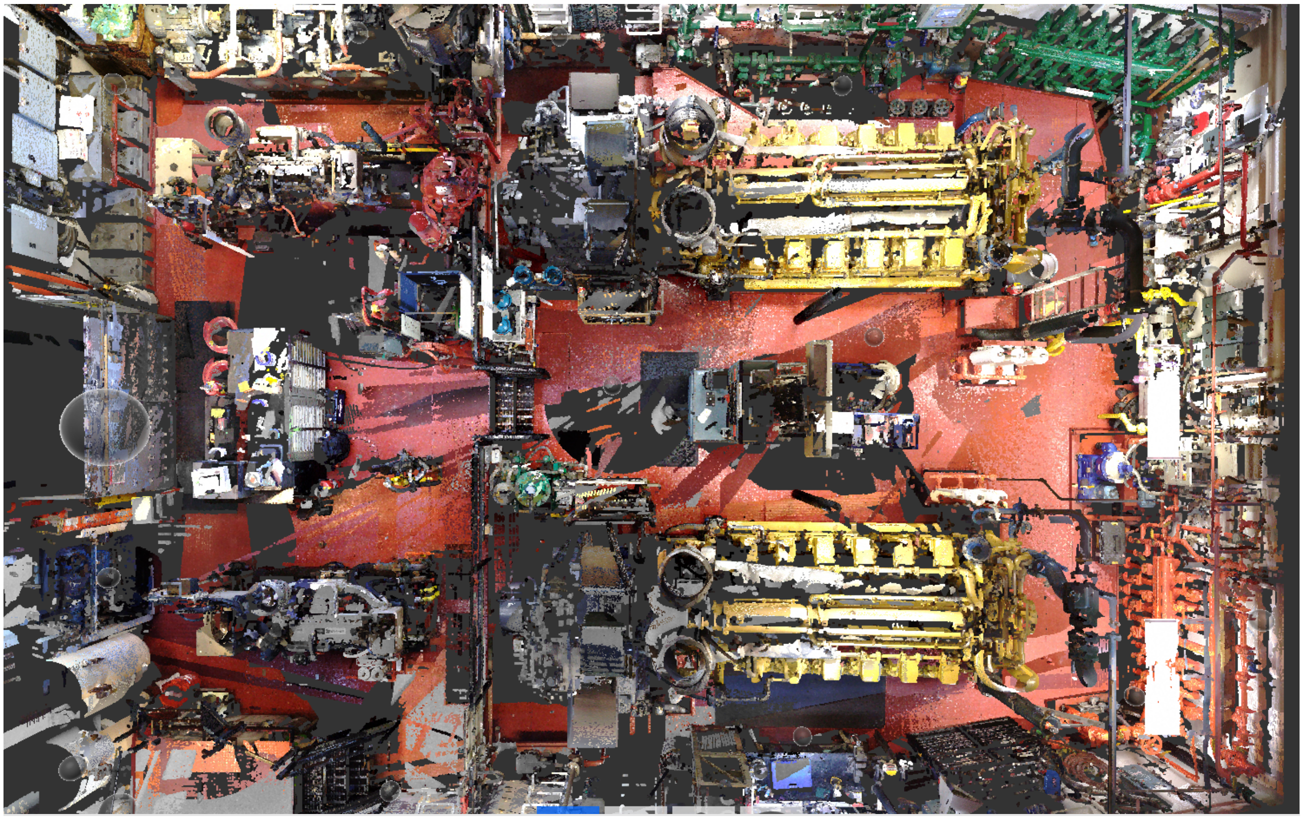

Figure 2: ATB-Tug Engine Room Above

Figure 2 above, shows the engine room configuration in the ATB-Tug. The existing engine has a footprint of 180" x 67" x 127" (LxWxH). Also, the distance between the engines is about 16' from center to center, along the outsides is about 5.5', and in front of the engine is around 7.25' of clearance.

The first engine to be examined for fitment is the Caterpillar C280-12. This engine's base footprint aligns closely with the existing engine at 181.6" x 79.6" x 134" easily fitting in the space. However, to keep EPA Tier 4 certification an SCR system must be included in the installation. Caterpillar does provide an OEM SCR called the Clean Emissions Module (CEM) to go with the C280-12, but it comes with significant drawbacks. This unit is 71.9" x 78.8" x 152.3" and must be installed vertically, because of this stipulation it cannot fit in the engine room and must be moved to the stack. Even if this unit replaces the silencer, Caterpillar claims it does have sound attenuation capabilities, it is much larger than the existing silencer and would require a significant change in the stack piping and likely a widening of the stack. Though this unit could potentially fit, it would leave fitment of a DPF next to impossible as the SCR system would likely take all available room in the stack.

The other engine analyzed was the Wabtec 12V250MDC. This engine, due to its integrated EGR system, removes the need for a SCR. This allows the engine to have a more compact footprint. This engine has dimensions of 205" x 107" x 143", slightly larger than the current engines, but will still fit within the space and provide enough remaining room for a walkway. It should be noted that even this configuration would require some further analysis of the current components onboard. There is a ladder which would be in the way of the new engine and a sewage tank which could be blocked. The location of the ladder in relation to the engine can be seen more clearly in Figure 3 below.

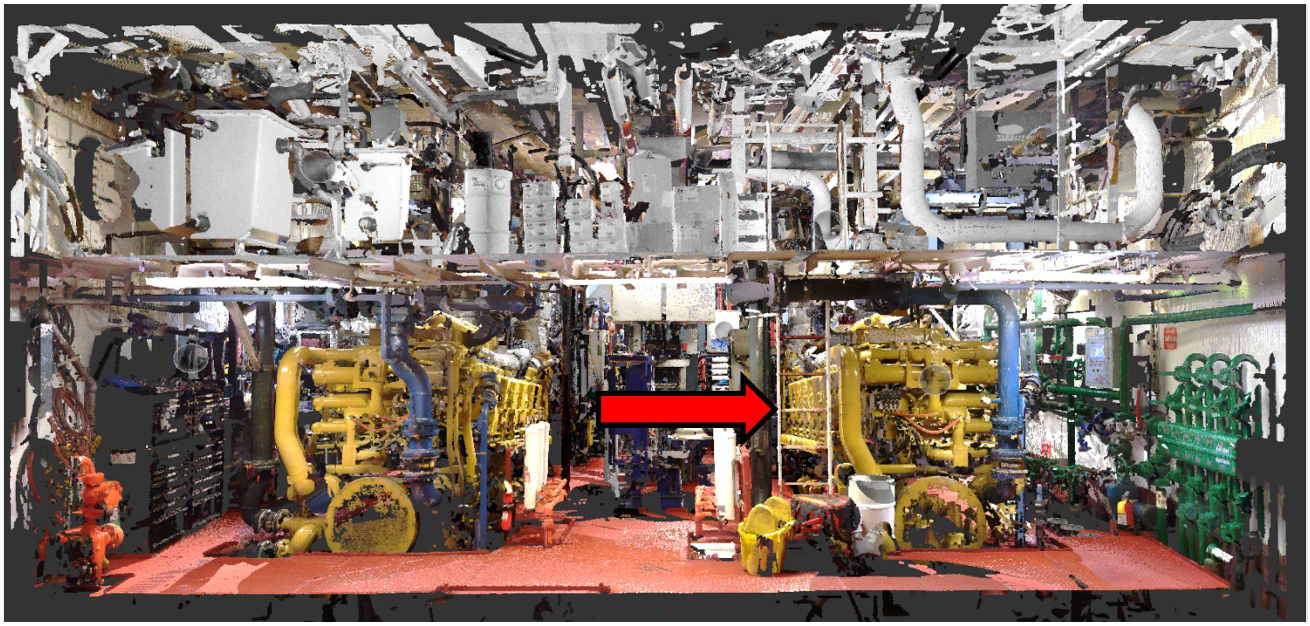

Figure 3: ATB-Tug Engine Room Looking Aft

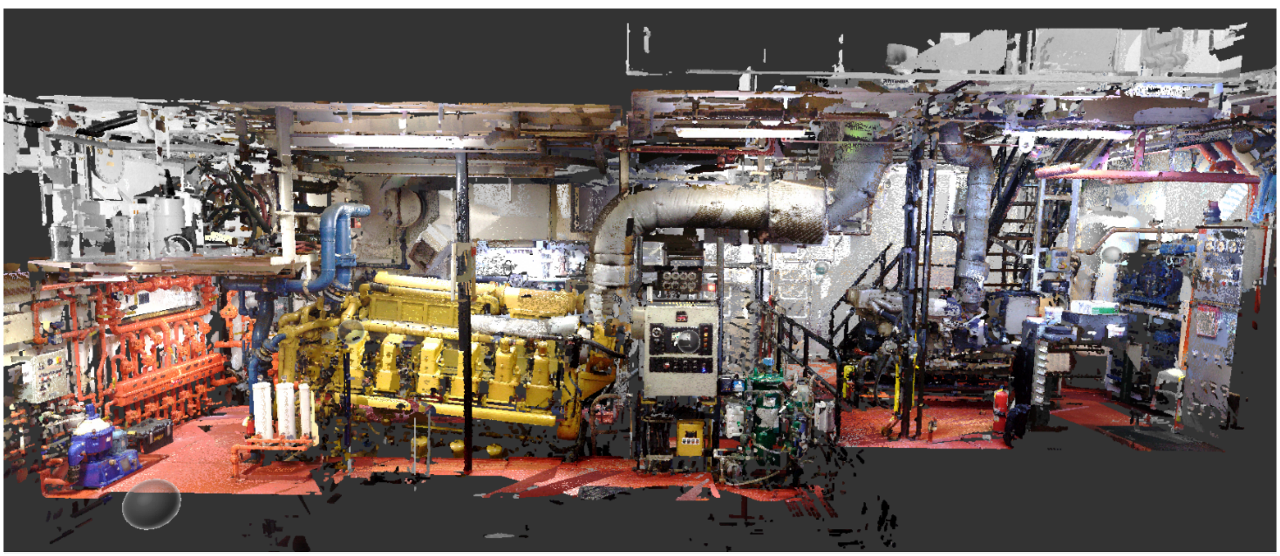

Figure 4: ATB-Tug Engine Room at Center Line Looking Starboard

3.2.2 Stability

Stability on the tug portion of an ATB can be easily affected due to its unique geometry. Typically, the length of these vessels' is short in comparison to their height and as such any weight placed above the current center of gravity can have a significant effect on the stability of the vessel as any changes in the vertical center of gravity will likely have a large negative effect on the stability, especially at larger angles of heel. This is not as great a concern for the Tier 4 repower of the vessel since these weights will be added below the main deck and likely below the current center of gravity, but this is an important consideration to keep in mind when preparing for a repower.

Table 14: ATB-Tug Stability Calculation for Caterpillar C280-12 Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	Caterpillar		Caterpillar	
Engine Name	3612B		C280-12	
Min Power	3,459	kW	3,700-4,060	kW
Length	180	in	182	in
Width	67	in	80	in
Height	127	in	134	in
Net Weight Dry	55,300	lbs	57,277	lbs
Removed Eng weight	49.38	LT		
Added Eng Weight			51.14	LT
20% Margin (conservative)			10.23	LT
Added Eng Weight w/ Margin			61.37	LT

SCR Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			19,600	lbs
Added SCR weight			17.50	LT
20% Margin			3.50	LT
SCR weight			21.00	LT

DPF Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
ADPF-8-NS			8.93	LT
20% Margin			1.79	LT
DPF Weight			10.71	LT

Urea Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			3.15	LT
Liquid Weight			33.21	LT
20% Margin			7.27	LT
Urea Weight			43.63	LT

Auxiliary Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	John Deere		John Deere	
Engine Name	6090SFM85		6090SFM85	
Net Weight Dry	2,323.2	lbs	2,323.2	lbs
Removed Eng weight	2.07	LT		
Added Eng Weight			2.07	LT
20% Margin			0.41	LT
Added Eng Weight			2.49	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Main engine weight			61.37	LT
SCR with 20% margin			21.00	LT
DPF			10.71	LT
Aux engine weight			2.49	LT
Urea			43.63	LT
Total Added weight (w/ DPF)			139.21	LT
Total Added weight (w/o DPF)			128.49	LT
2% of existing LS			18.283	LT
Aggregate Weight (w/ DPF)[26]			190.66	LT
Aggregate Weight (w/o DPF)[40]			179.94	LT
Aggregate Weight (w/ DPF)[27]			23.20	LT
Aggregate Weight (w/o DPF)[41]			21.42	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**YES**	**YES**
Exceed w/ DPF?			**YES**	**YES**

This engine fails the stability check when replacing the current Caterpillar 3612B engines with a Caterpillar C280-12. The added weight to accommodate the urea necessary to run the Caterpillar SCR system,

[26] If no weight certificates are available.
[27] If weight certificates are available.

Table 15: ATB-Tug Stability Calculation for GE (Wabtec) 12V250MDC Repower & DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	Caterpillar		GE (Wabtec)	
Engine Name	3612B		12V250MDC	
Min Power	3,459	kW	3,150-3,500	kW
Length	180	in	205	in
Width	67	in	107	in
Height	127	in	143	in
Net Weight Dry	55,300	lbs	63,067.4	lbs
Removed Eng weight	49.38	LT		
Added Eng Weight			56.31	LT
20% Margin (conservative)			11.26	LT
Added Eng Weight w/ Margin			67.57	LT

SCR [28] Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			0	lbs
Added SCR weight			0.00	LT
20% Margin			0.00	LT
SCR weight			0.00	LT

DPF Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
ADPF-8-NS			8.93	LT
20% Margin			1.79	LT
DPF Weight			10.71	LT

Urea[29] Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			0	LT
Liquid Weight			0.00	LT
20% Margin			0.00	LT
Urea Weight			0.00	LT

[28] Due to use of an EGR system, SCR weight is not applicable to this engine.
[29] Due to use of an EGR system, urea is not applicable to this engine.

Auxiliary Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	John Deere		John Deere	
Engine Name	6090SFM85		6090SFM85	
Net Weight Dry	2,323.2	lbs	2,323.2	lbs
Removed Eng weight	2.07	LT		
Added Eng Weight			2.07	LT
20% Margin			0.41	LT
Added Eng Weight			2.49	LT

Stability Calculation (MTN 4-95) Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Main engine weight			67.57	LT
SCR with 20% margin			0.00	LT
DPF			10.71	LT
Aux engine weight			2.49	LT
Urea			0	LT
Total Added weight (w/ DPF)			80.78	LT
Total Added weight (w/o DPF)			70.06	LT
2% of existing LS			18.283	LT
Aggregate Weight (w/ DPF)[30]			132.22	LT
Aggregate Weight (w/o DPF)[38]			121.51	LT
Aggregate Weight (w/ DPF)[31]			13.46	LT
Aggregate Weight (w/o DPF)[39]			11.68	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**NO**	**YES**
Exceed w/ DPF?			**NO**	**YES**

The GE (Wabtec) 12V250MDC passes the 2% lightship check. This is mostly due to the lack of a urea tank despite the engine itself weighing more than its counterparts.

[30] If no weight certificates are available.
[31] If weight certificates are available.

3.2.3 Conclusions

The ATB-Tug has one Tier 4 engine which has reached a feasible conclusion, the GE Wabtec 12V250MDC. This engine was able to pass the power requirement, fitment, and stability tests. This is mainly due to the lack of an SCR and Urea tanks.

On fitment, the 12V250MDC was the only engine which passed. Due to the massive footprint of the Caterpillar SCR, it would not fit within the bounds of the engine room without significantly changing the vessel.

The GE (Wabtec) engines passed the stability tests. The GE (Wabtec) engine barely passed with a final aggregate weight of 17.79 LT passing the 2% lightship threshold of 18.283. However, the GE (Wabtec) engine was able to get a significantly lower aggregate weight of 14.55 LT. This engine uses an EGR system which minimizes formation of NOx during combustion instead of in the exhaust. This system alleviates the complications which normally must be made to the exhaust pipe route or find the space to fit the SCR system on the deck as it is integrated into the engine. Using the 2% lightship threshold, one of the main limiting factors is the weight added by the urea tank and the urea which are necessary to run the SCR system. Between a SCR system and EGR system alone the weights are extremely similar, however when the urea tanks are added this becomes a much larger margin.

3.3 ATB-Barge

3.3.1 Fitment

Table 16: ATB-Barge Fitment Feasibility Summary

Engine	Dimensions (L”xW”xH”)	Does it Fit?	Reasoning
Caterpillar 3512E	125.4 x 91.9 x 81.9	Yes	Engine room has sufficient clearance
MTU 12V-4000M05	108 x 71 x 81	Yes	Smaller than current engine
Cummins QSK 38	95 x 64 x 93	Yes	Smaller than current engine
Baudouin 12M-26.3	98.5 x 53.8 x 62.3	Yes	Smaller than current engine

Retrofitting these Tier 4 engines into the ATB-Barge does not pose as many challenges as with the other vessels. The current engine, the Caterpillar 3512B, has dimensions of 120.8 x 70.3 x 71.1. For most of the engines listed above this is significantly larger and therefore would not be a problem when these engines are being retrofit. The only engine that runs into issues is the Caterpillar 3512E. This engine is larger in all dimensions and includes a separate SCR system. However, due to the size of the barge this is not an issue. It can be seen best in Figure 7 that there is excess space around the engine which would easily fit the additional 5” needed. Looking at the drawing there was at least 5’ of clearance between the engine and the bulkhead. The hardest part would be locating the SCR system; however, the barge has a surplus of additional space where these systems can be utilized. The Caterpillar SCR for this engine also comes in a few different configurations which can ease fitment.

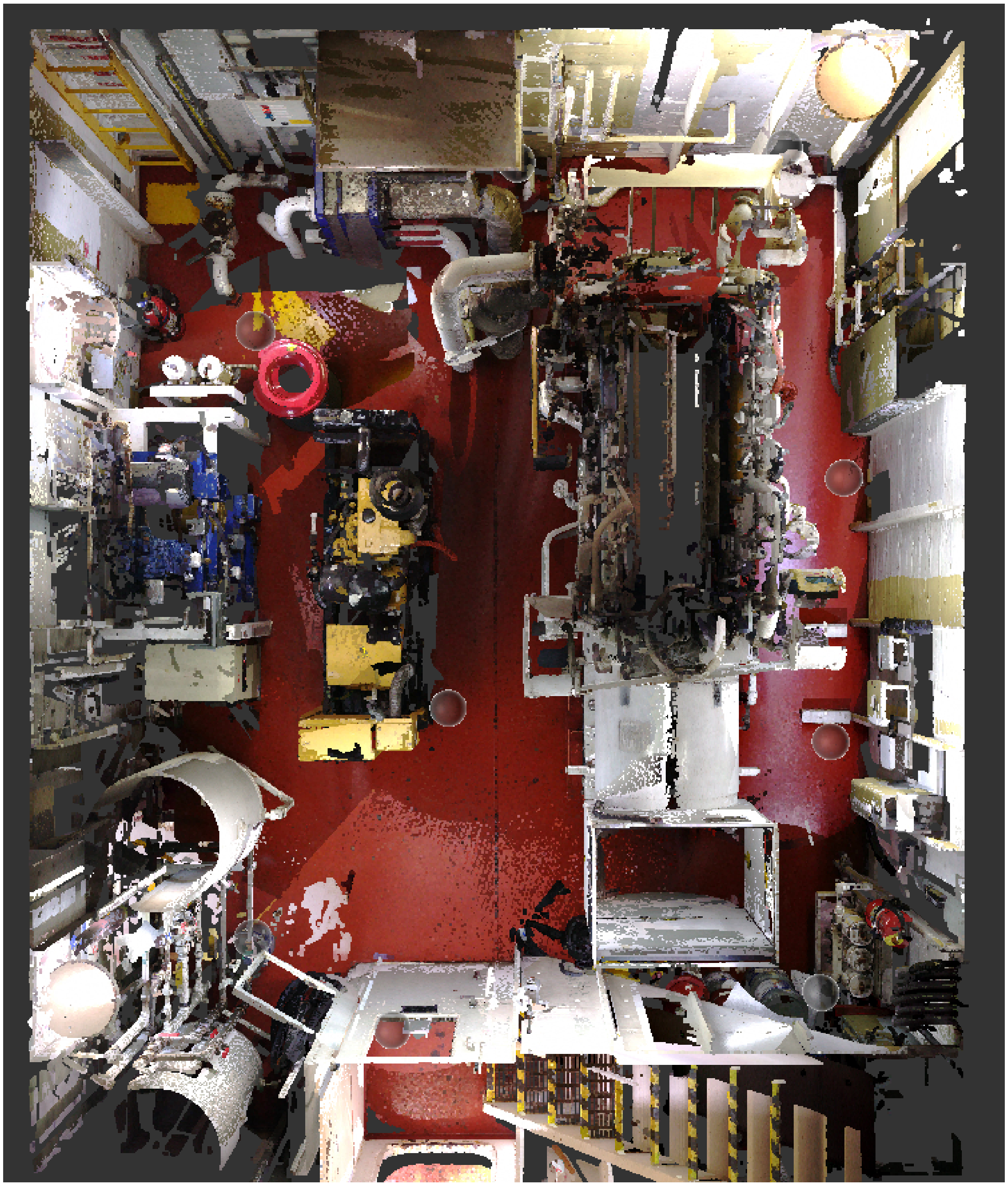

Figure 5: ATB-Barge Port Engine Room Above

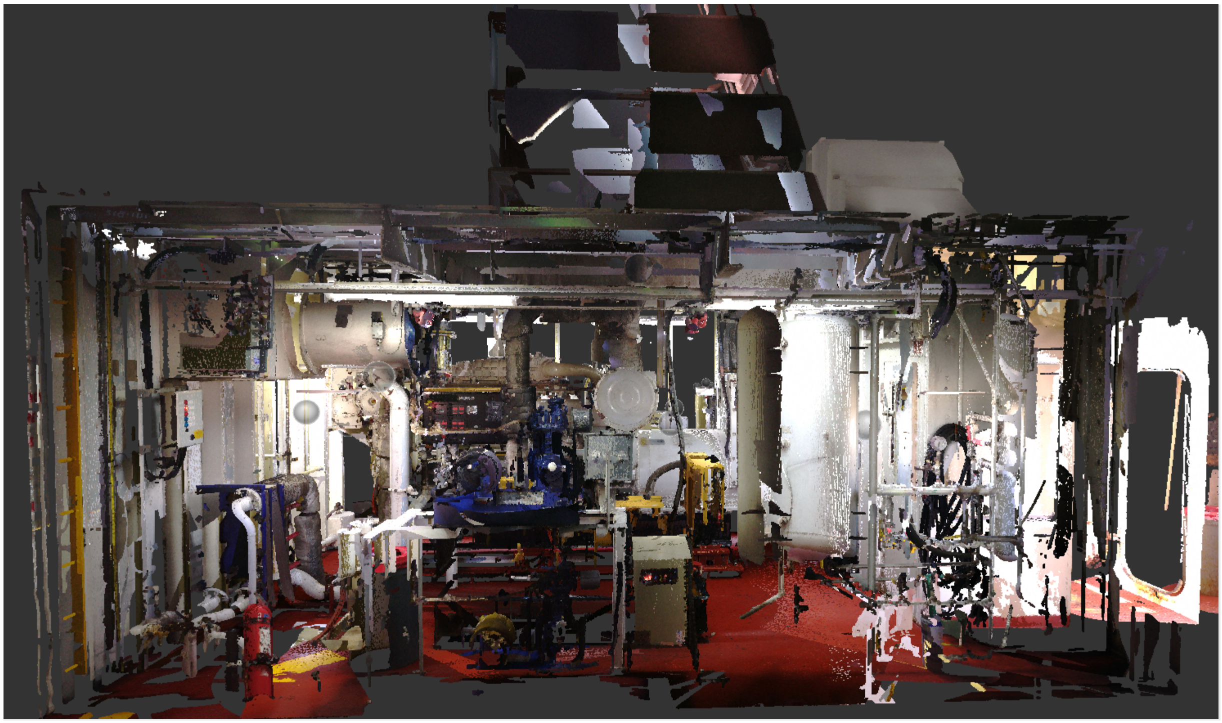

Figure 6: ATB-Barge Port Engine Room Looking Inboard

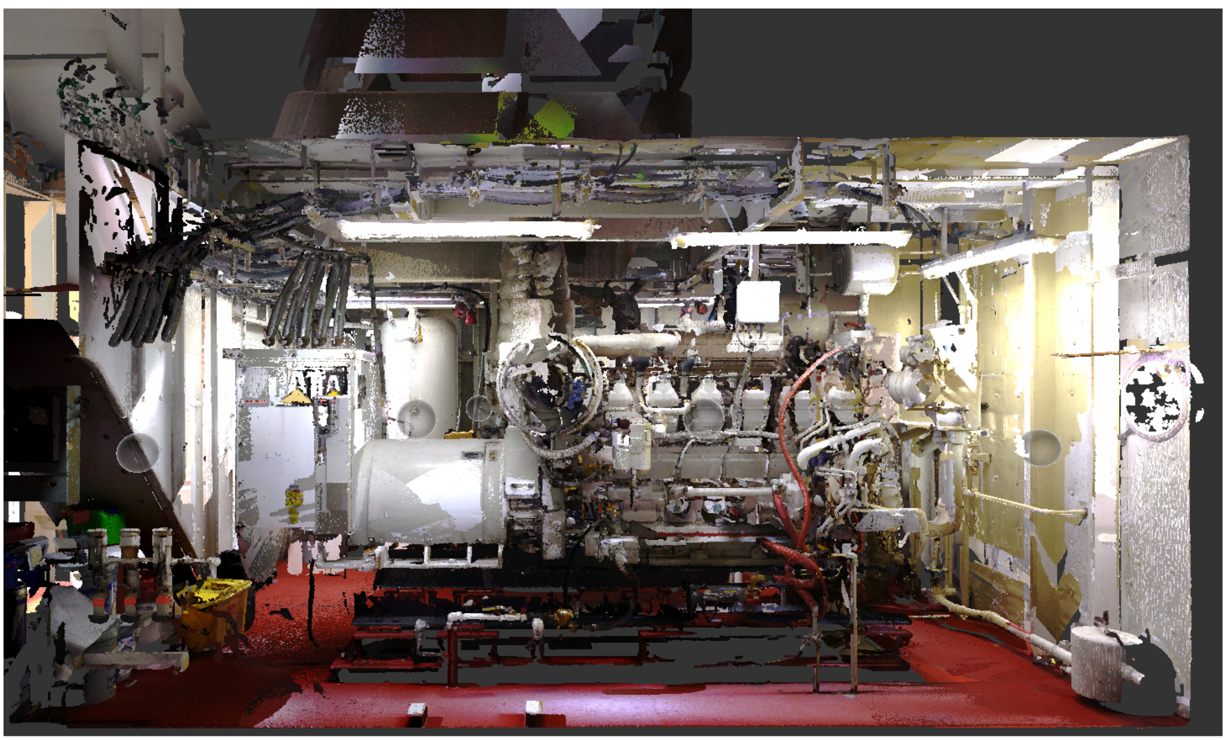

Figure 7: ATB-Barge Port Engine Looking Outboard

3.3.2 Stability

The ATB-Barge does not have significant stability issues. Due to its larger size, lightship, and the comparatively smaller engines which are being installed, its aggregate weight value never approaches 2% of the existing lightship.

Table 17. ATB-Barge Stability Calculation for Cummins QSK38 Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	Caterpillar		Cummins	
Engine Name	3512B		QSK38	
Min Power	1,070	kW	746-1,119	kW
Length	120.8	in	95	in
Width	70.3	in	64	in
Height	71.1	in	93	in
Net Weight Dry	13,400	lbs	11,594	lbs
Removed Eng weight	11.96	LT		
Added Eng Weight			10.35	LT
20% Margin (conservative)			2.07	LT
Added Eng Weight w/ Margin			12.42	LT

SCR Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			1,852	lbs
Added SCR weight			1.65	LT
20% Margin			0.33	LT
SCR weight			1.98	LT

DPF Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
ADPF-3-NS			3.75	LT
20% Margin			0.75	LT
DPF Weight			4.50	LT

Urea Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			0.88	LT
Liquid Weight			4.89	LT
20% Margin			1.15	LT
Urea Weight			6.92	LT

Auxiliary Engine Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Number of Engines	1		1	
	Caterpillar		Caterpillar	
Engine Name	D-60		C4.4	
Net Weight Dry	2,050	lbs	2,233	lbs
Removed Eng weight	0.92	LT		
Added Eng Weight			1.00	LT
20% Margin			0.20	LT
Added Eng Weight w/ Margin			1.20	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Main engine weight			12.42	LT
SCR with 20% margin			1.98	LT
DPF			4.50	LT
Aux engine weight			1.20	LT
Urea			6.92	LT
Total Added weight (w/ DPF)			27.03	LT
Total Added weight (w/o DPF)			22.53	LT
2% of existing LS			121.89	LT
Aggregate Weight (w/ DPF)[32]			39.91	LT
Aggregate Weight (w/o DPF)[32]			35.41	LT
Aggregate Weight (w/ DPF)[33]			4.50	LT
Aggregate Weight (w/o DPF)[33]			3.75	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**NO**	**NO**
Exceed w/ DPF?			**NO**	**NO**

The QSK 38 Tier 4 retrofit passes the 2% lightship test both with and without weight certificates.

[32] If no weight certificates are available.
[33] If weight certificates are available.

Table 18: ATB-Barge Stability Calculation for Caterpillar 3512E Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	Caterpillar		Caterpillar	
Engine Name	3512B		3512E	
Min Power	1,070	kW	1,000-1,901	kW
Length	120.8	in	123	in
Width	70.3	in	90.9	in
Height	71.1	in	104	in
Net Weight Dry	13,400	lbs	18,024.6	lbs
Removed Eng weight	11.96	LT		
Added Eng Weight			16.09	LT
20% Margin (conservative)			3.22	LT
Added Eng Weight w/ Margin			19.31	LT

SCR Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			7,783.30	lbs
Added SCR weight			6.95	LT
20% Margin			1.39	LT
SCR weight			8.34	LT

DPF Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
ADPF-4ER-NS			4.46	LT
20% Margin			0.89	LT
DPF Weight			5.36	LT

Urea Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			0.88	LT
Liquid Weight			4.89	LT
20% Margin			1.15	LT
Urea Weight			6.92	LT

Auxiliary Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	1		1	
Engine Manufacturer	Caterpillar		Caterpillar	
Engine Name	D-60		C4.4	
Net Weight Dry	2,050	lbs	2,233	lbs
Removed Eng weight	0.92	LT		
Added Eng Weight			1.00	LT
20% Margin			0.20	LT
Added Eng Weight w/ Margin			1.20	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Main engine weight			19.31	LT
SCR with 20% margin			8.34	LT
DPF			5.36	LT
Aux engine weight			1.20	LT
Urea			6.92	LT
Total Added weight (w/ DPF)			41.13	LT
Total Added weight (w/o DPF)			35.77	LT
2% of existing LS			121.89	LT
Aggregate Weight (w/ DPF)[34]			54.01	LT
Aggregate Weight (w/o DPF)[34]			48.65	LT
Aggregate Weight (w/ DPF)[35]			6.85	LT
Aggregate Weight (w/o DPF)[35]			5.96	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**NO**	**NO**
Exceed w/ DPF?			**NO**	**NO**

The Caterpillar 3512E Tier 4 retrofit passes the 2% lightship test both with and without weight certificates.

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[34] If no weight certificates are available.
[35] If weight certificates are available.

Table 19: ATB-Barge Stability Calculation for MTU 12V-4000M05 Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	Caterpillar		MTU	
Engine Name	3512B		12V-4000M05	
Min Power	1,070	kW	1,119-1,932	kW
Length	120.8	in	108	in
Width	70.3	in	71	in
Height	71.1	in	81	in
Net Weight Dry	13,400	lbs	17,600	lbs
Removed Eng weight	11.96	LT		
Added Eng Weight			15.71	LT
20% Margin (conservative)			3.14	LT
Added Eng Weight w/ Margin			18.86	LT

SCR Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			7783.30[36]	lbs
Added SCR weight			6.95	LT
20% Margin			1.39	LT
SCR weight			8.34	LT

DPF Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
ADPF-5-NS			3.93	LT
20% Margin			0.79	LT
DPF Weight			4.71	LT

Urea Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			0.88	LT
Liquid Weight			4.89	LT
20% Margin			1.15	LT
Urea Weight			6.92	LT

[36] Estimated from Caterpillar SCR weight as MTU SCR system specifics are not publicly available.

Auxiliary Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	1		1	
Engine Manufacturer	Caterpillar		Caterpillar	
Engine Name	D-60		C4.4	
Net Weight Dry	2,050	lbs	2,233	lbs
Removed Eng weight	0.92	LT		
Added Eng Weight			1.00	LT
20% Margin			0.20	LT
Added Eng Weight w/ Margin			1.20	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Main engine weight			18.86	LT
SCR with 20% margin			8.34	LT
DPF			4.71	LT
Aux engine weight			1.20	LT
Urea			6.92	LT
Total Added weight (w/ DPF)			40.03	LT
Total Added weight (w/o DPF)			35.32	LT
2% of existing LS			121.89	LT
Aggregate Weight (w/ DPF)[37]			52.91	LT
Aggregate Weight (w/o DPF)[36]			48.20	LT
Aggregate Weight (w/ DPF)[38]			6.67	LT
Aggregate Weight (w/o DPF)[37]			5.89	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**NO**	**NO**
Exceed w/ DPF?			**NO**	**NO**

The MTU 12V-4000M05 Tier 4 retrofit passes the 2% lightship test both with and without weight certificates.

[37] If no weight certificates are available.
[38] If weight certificates are available.

Table 20: ATB-Barge Stability Calculation for Baudouin 12M-26.3 Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	Caterpillar		Baudouin	
Engine Name	3512B		12M-26.3	
Min Power	1,070	kW	883-1,214	kW
Length	120.8	in	98.46	in
Width	70.3	in	53.82	in
Height	71.1	in	62.28	in
Net Weight Dry	13,400	lbs	7,260	lbs
Removed Eng weight	11.96	LT		
Added Eng Weight			6.48	LT
20% Margin (conservative)			1.30	LT
Added Eng Weight w/ Margin			7.78	LT

SCR Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			424.60	lbs
Added SCR weight			0.38	LT
20% Margin			0.08	LT
SCR weight			0.45	LT

DPF Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
ADPF-4-NS			3.04	LT
20% Margin			0.61	LT
DPF Weight			3.64	LT

Urea Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			0.88	LT
Liquid Weight			4.89	LT
20% Margin			1.15	LT
Urea Weight			6.92	LT

Auxiliary Engine Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Number of Engines	1		1	
Engine Manufacturer	Caterpillar		Caterpillar	
Engine Name	D-60		C4.4	
Net Weight Dry	2,050	lbs	2,233	lbs
Removed Eng weight	0.92	LT		
Added Eng Weight			1.00	LT
20% Margin			0.20	LT
Added Eng Weight w/ Margin			1.20	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Main engine weight			7.78	LT
SCR with 20% margin			0.45	LT
DPF			3.64	LT
Aux engine weight			1.20	LT
Urea			6.92	LT
Total Added weight (w/ DPF)			20.00	LT
Total Added weight (w/o DPF)			16.35	LT
2% of existing LS			121.89	LT
Aggregate Weight (w/ DPF)[39]			32.88	LT
Aggregate Weight (w/o DPF)[36]			29.23	LT
Aggregate Weight (w/ DPF)[40]			3.33	LT
Aggregate Weight (w/o DPF)[37]			2.73	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**NO**	**NO**
Exceed w/ DPF?			**NO**	**NO**

[39] If no weight certificates are available.
[40] If weight certificates are available.

3.3.3 Conclusion

The ATB-Barge's larger stature provides ample space for retrofit of the Tier 4 engines. This is increased further by the small engines which are installed relative to the size of the vessel as the barge is not self-propelled. This size also trivializes the potential stability changes which the installation of these engines might have. The 2% of existing lightship threshold is far greater than the aggregate weights which were calculated from installation of the Tier 4 engines.

3.4 Line Towing Vessel

3.4.1 Fitment

Table 21: Line Towing Vessel Fitment Feasibility Summary

Engine	Dimensions (L"xW"xH")	Does it Fit?	Reasoning
MTU 16V-4000M05	126 x 61 x 81	Yes	Additional length is within clearance necessary
Caterpillar 3516E	125.7 x 89.9 x 87.6	No	Additional length is within clearance, but SCR system cannot fit in space provided
Cummins QSK 60	132 x 70.1 x 85.5	Yes	Additional length is within clearance

Fitment of a Tier 4 engine within the line towing vessel is difficult due to the compact and cluttered space. The original engine, the MTU 16V 4000 M64, has a footprint of 122.4" x 66.5" x 81.3".

All the engines studied have a larger footprint than the original engine but the MTU and the Cummins Tier 4 engines both fall within acceptable bounds. Though the Cummins QSK 60 could pose issues and require some relocation of equipment within the engine room to properly install the engine. Looking at the drawings provided there is about 40" of empty space in both length and width that is available to accommodate these larger engines. Then looking at Figure 9 a substantial amount of empty space can be seen in the overhead. Also, since MTU and Cummins SCR systems can fit in different configurations including in the overhead space or with the MTU system as a box next to the engine. Cummins also claims that their SCR can replace most mufflers and silencers. Due to these attributes of the SCR systems and given the space available in the engine room, a feasible conclusion is made for the fitment of the Cummins QSK 60 and MTU 16V-4000M05.

The Caterpillar system, however, is much longer than the other two engines and as such would be a tough fit, especially on the port side of the vessel which has more machinery and a stairway in line of the engine which can best be seen in Figure 10 below. This issue would only be exacerbated once the SCR is installed. The Caterpillar SCR system is less flexible than the two listed above and must include a dosing cabinet as well which takes up a substantial amount of additional space in the engine room. For these reasons it has been deemed infeasible.

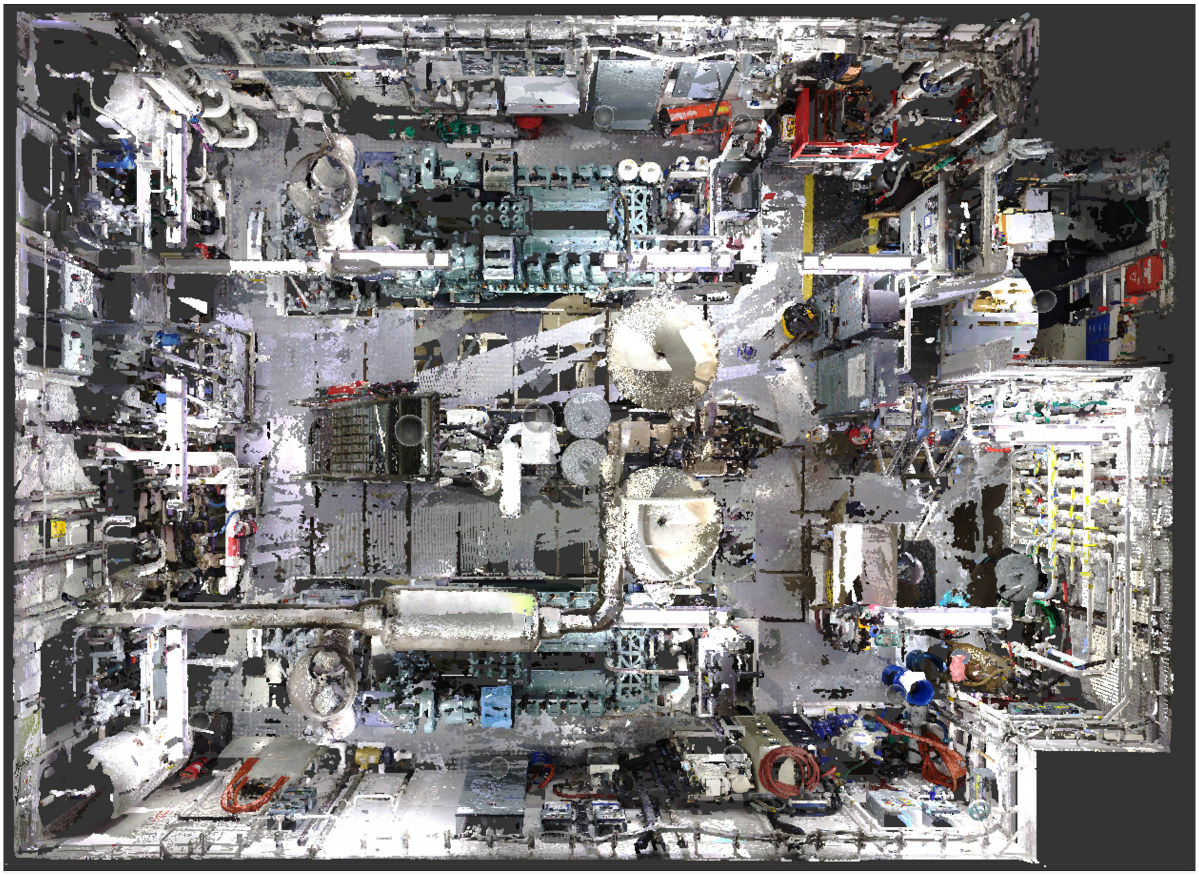

Figure 8: Line Towing Vessel Engine Room Above

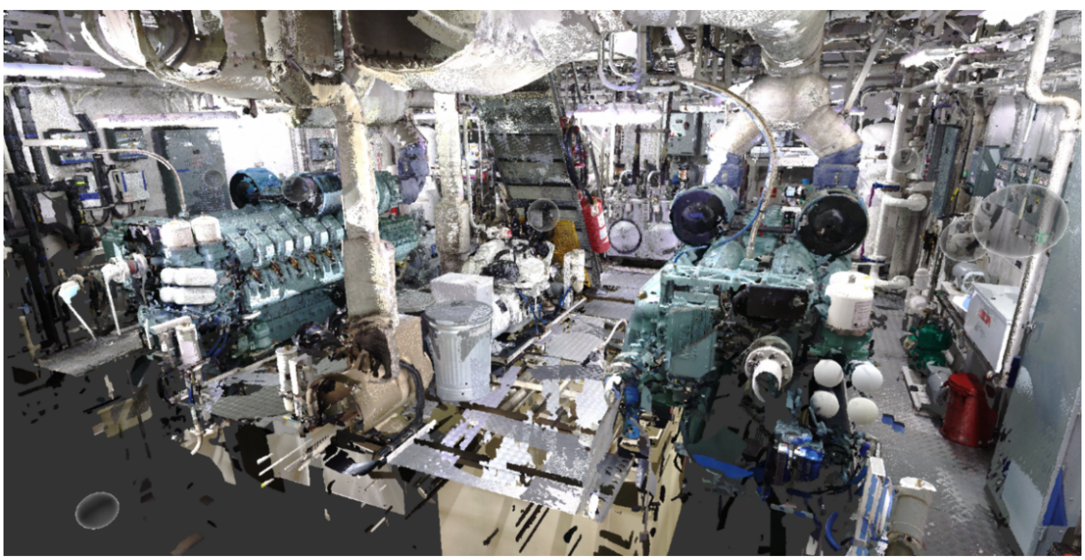

Figure 9: Line Towing Vessel Engine Room Looking Aft

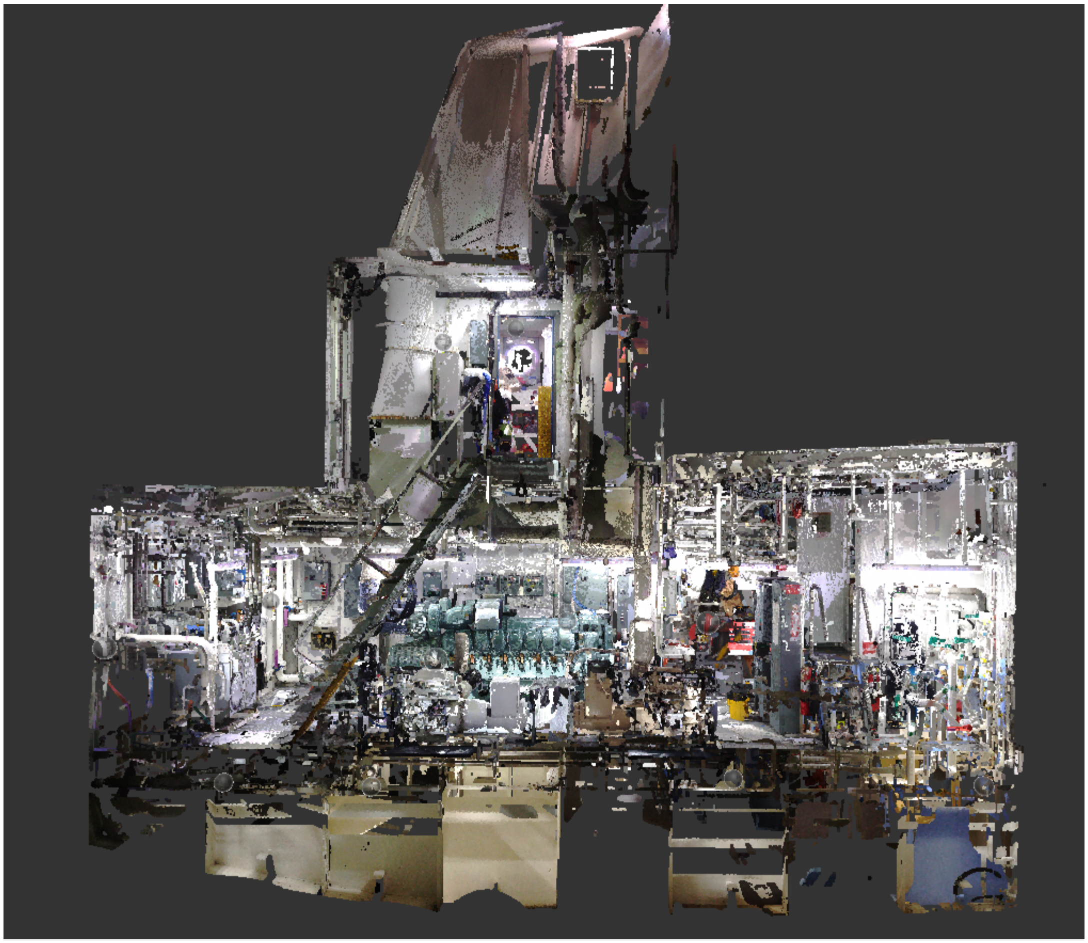

Figure 10: Line Towing Vessel Center Line Looking Port

3.4.2 Stability

Stability is not as much of an issue on the Line Towing Vessel for a Tier 4 repower. It is not as light as some of the other vessels studied and its hull shape is not as limiting as the ATB-Tug's to create large stability concerns. Due to these factors the Line Towing Vessel showed strong stability outcomes when performing a repower to Tier 4.

Table 22: Line Towing Vessel Stability Calculation for Cummins QSK60 Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	MTU		Cummins	
Engine Name	16V-4000M64		QSK60	
Min Power	1,998	kW	1,491-2,013	kW
Length	122.4	in	132	in
Width	66.5	in	70.12	in
Height	81.3	in	85.47	in
Net Weight Dry	19,996	lbs	22,338.8	lbs
Removed Eng weight	17.85	LT		
Added Eng Weight			19.95	LT
20% Margin (conservative)			3.99	LT
Added Eng Weight w/ Margin			23.93	LT

SCR Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			6,160	lbs
Added SCR weight			2.75	LT
20% Margin			0.55	LT
SCR weight			3.30	LT

DPF Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
ADPF-6-NS			4.11	LT
20% Margin			0.82	LT
DPF Weight			4.94	LT

Urea Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			2.78	LT
Liquid Weight			27.58	LT
20% Margin			6.07	LT
Urea Weight			36.44	LT

Auxiliary Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturers	John Deere		John Deere	
Engine Name	4045AFM85		4045AFM85	
Net Weight Dry	1,271.6	lbs	1,271.6	lbs
Removed Eng weight	1.14	LT		
Added Eng Weight			1.14	LT
20% Margin (conservative)			0.23	LT
Added Eng Weight			1.36	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Main engine weight			23.93	LT
SCR with 20% margin			3.30	LT
DPF			4.94	LT
Aux engine weight			1.36	LT
Urea			36.44	LT
Total Added weight (w/ DPF)			69.97	LT
Total Added weight (w/o DPF)			65.03	LT
2% of existing LS			10.89	LT
Aggregate Weight (w/ DPF)[41]			88.96	LT
Aggregate Weight (w/o DPF)[42]			84.02	LT
Aggregate Weight (w/ DPF)[42]			11.66	LT
Aggregate Weight (w/o DPF)[43]			10.84	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**NO**	**YES**
Exceed w/ DPF?			**YES**	**YES**

The retrofit of the Cummins QSK 60 Tier 4 engine and SCR system does pass the 2% lightship test.

[41] If no weight certificates are available.
[42] If weight certificates are available.

Table 23: Line Towing Vessel Stability Calculation for Caterpillar 3516E Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	MTU		Caterpillar	
Engine Name	16V-4000M64		3516E	
Min Power	1,998	kW	1,865-2,525	kW
Length	122.4	in	125.6	in
Width	66.5	in	89.9	in
Height	81.3	in	86.6	in
Net Weight Dry	19,,996	lbs	21,164	lbs
Removed Eng weight	17.85	LT		
Added Eng Weight			18.90	LT
20% Margin (conservative)			3.78	LT
Added Eng Weight w/ Margin			22.68	LT

SCR Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			6,128	lbs
Added SCR weight			2.74	LT
20% Margin			0.55	LT
SCR weight			3.28	LT

DPF Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
ADPF-6ER-NS			5.08	LT
20% Margin			1.02	LT
DPF Weight			6.10	LT

Urea Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			2.78	LT
Liquid Weight			27.58	LT
20% Margin			6.07	LT
Urea Weight			36.44	LT

Auxiliary Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
	John Deere		John Deere	
Engine Name	4045AFM85		4045AFM85	
Net Weight Dry	1,271.6	lbs	1,271.6	lbs
Removed Eng weight	1.14	LT		
Added Eng Weight			1.14	LT
20% Margin (conservative)			0.23	LT
Added Eng Weight			1.36	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Main engine weight			22.68	LT
SCR with 20% margin			3.28	LT
DPF			6.10	LT
Aux engine weight			1.36	LT
Urea			36.44	LT
Total Added weight (w/ DPF)			69.85	LT
Total Added weight (w/o DPF)			63.76	LT
2% of existing LS			10.89	LT
Aggregate Weight (w/ DPF)[43]			88.84	LT
Aggregate Weight (w/o DPF)[44]			82.75	LT
Aggregate Weight (w/ DPF)[44]			11.64	LT
Aggregate Weight (w/o DPF)[45]			10.63	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**NO**	**YES**
Exceed w/ DPF?			**YES**	**YES**

The retrofit of the Caterpillar 3516E Tier 4 engine and SCR system does pass the 2% lightship test.

[43] If no weight certificates are available.
[44] If weight certificates are available.

Table 24: Line Towing Vessel Stability Calculation for MTU 16V-4000M05 Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	MTU		MTU	
Engine Name	16V-4000M64		16V-4000M05	
Min Power	1,998	kW	1,840-2,576	kW
Length	122.4	in	126	in
Width	66.5	in	61	in
Height	81.3	in	81	in
Net Weight Dry	19,996	lbs	20,460	lbs
Removed Eng weight	17.85	LT		
Added Eng Weight			18.27	LT
20% Margin (conservative)			3.65	LT
Added Eng Weight w/ Margin			21.92	LT

SCR Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			7,000	lbs
Added SCR weight			3.13	LT
20% Margin			0.63	LT
SCR weight			3.75	LT

DPF Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
ADPF-7-NS			6.70	LT
20% Margin			1.34	LT
DPF Weight			8.04	LT

Urea Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			2.78	LT
Liquid Weight			27.58	LT
20% Margin			6.07	LT
Urea Weight			36.44	LT

Auxiliary Engine Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
	John Deere		John Deere	
Engine Name	4045AFM85		4045AFM85	
Net Weight Dry	1,271.6	lbs	1,271.6	lbs
Removed Eng weight	1.14	LT		
Added Eng Weight			1.14	LT
20% Margin (conservative)			0.23	LT
Added Eng Weight			1.36	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Main engine weight			21.92	LT
SCR with 20% margin			3.75	LT
DPF			8.04	LT
Aux engine weight			1.36	LT
Urea			36.44	LT
Total Added weight (w/ DPF)			71.51	LT
Total Added weight (w/o DPF)			63.47	LT
2% of existing LS			10.89	LT
Aggregate Weight (w/ DPF)[45]			90.49	LT
Aggregate Weight (w/o DPF)[46]			82.46	LT
Aggregate Weight (w/ DPF)[46]			11.92	LT
Aggregate Weight (w/o DPF)[47]			10.58	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**NO**	**YES**
Exceed w/ DPF?			**YES**	**YES**

The retrofit of the MTU 16V-4000M05 Tier 4 engine and SCR system does pass the 2% lightship test.

3.4.3 Conclusion

The Line Towing Vessel is likely feasible to repower with Tier 4 engines. Regarding fitment, it had three out of three engines pass which gives multiple options for a potential Tier 4 retrofit. Though the larger Cummins engine might require some minor additional vessel modifications, especially on the port side due to a stairwell in way of the engine it could likely be made to fit within the space. However, this study does not investigate specific vessel modifications.

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45 If no weight certificates are available.
46 If weight certificates are available.

For stability, all engines passed the 2% lightship test. This indicates that these retrofits would likely not have significant impacts on stability.

3.5 Subchapter T High Speed Catamaran Ferry

3.5.1 Fitment

Table 25: Ferry Fitment Feasibility Summary

Engine	Dimensions (L”xW”xH”)	Does it Fit?	Reasoning
Yanmar 6AYEM GTWS	84.8 x 51.4 x 62.9	Yes	Engine fits within space available
Baudouin 6M-26.3	82.8 x 46.1 x 47.1	Yes	Engine fits within space available
Caterpillar C32	89.8 x 63.5 x 57.3	No	Engine is too tall with SCR installed

The ferry is a small vessel in comparison to the other harbor craft studied, and so there is not much additional space for a larger engine to fit. The original engine, a Cummins QSK -19 M, has dimensions of 79.1 x 42.8 x 69.5. This is a small footprint and so when considering a replacement, it is crucial that an engine of similar size is chosen. Within the engine room, there is around 80” of additional clearance in length around the currently installed and about 70” total clearance for the height of the engine.

The first two engines pass the fitment test. Although larger, they are within the bounds of the engine room. The Yanmar dimensions contain their built-in SCR system and so these dimensions encompass the total footprint which this engine would cover.

The Baudouin engine with the SCR system comes in at 98.5 x 53.8 x 62.3. This easily fits within the clearances of the engine room.

The Caterpillar C32, due to the additional height of the SCR system, would not fit within the bounds of the engine room. The C32 is already much taller than the other engines studied and when an additional 23.5” is needed to install the SCR system above the engine putting the total installed height at a minimum of 80.8” which falls outside the clearance of 70”. Also looking at Figure 12 below, the clearance for the width of the engine is limited. This is another limitation for installation of the C32 since it is over 20” greater in width when compared to the current engine.

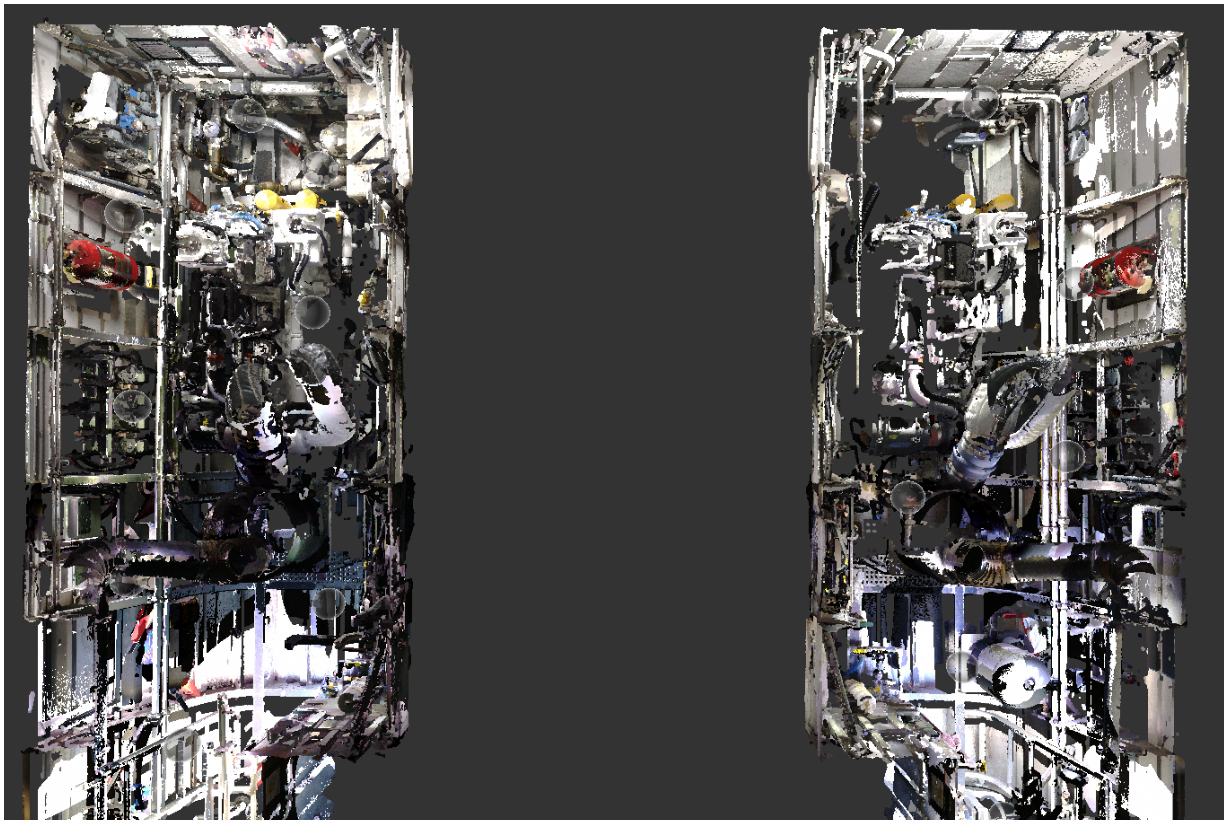

Figure 11: Ferry Engine Room Above[47]

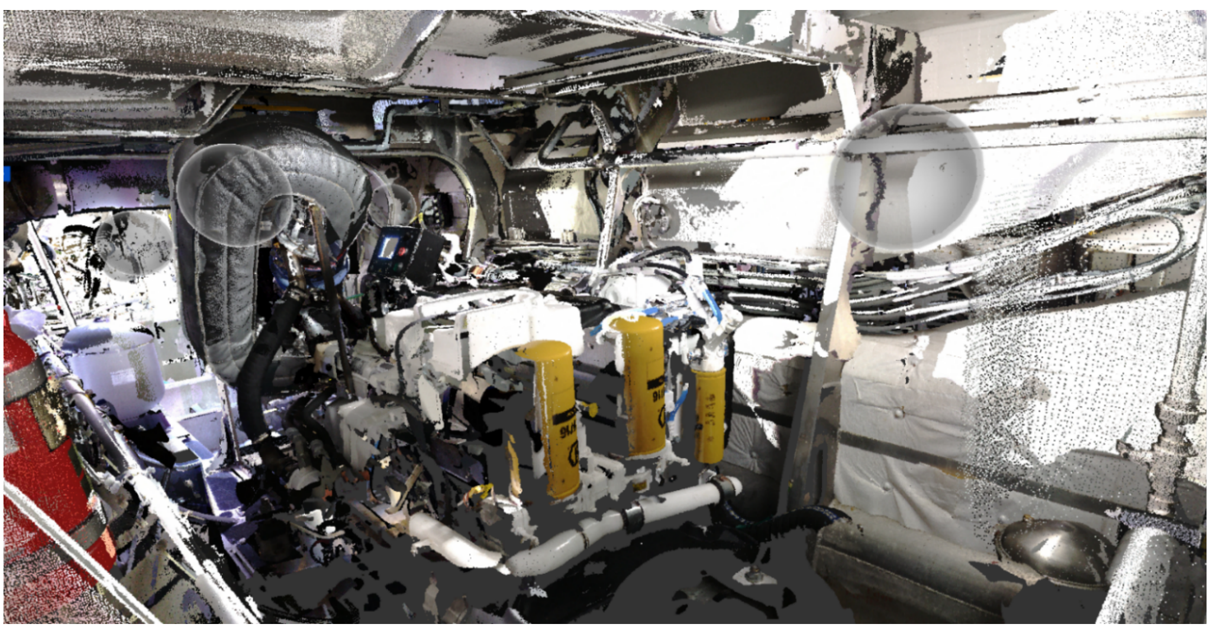

Figure 12: Ferry Starboard Engine Room Looking Aft

[47] This figure was edited together from two separate scans of the port and starboard catamaran engine rooms.

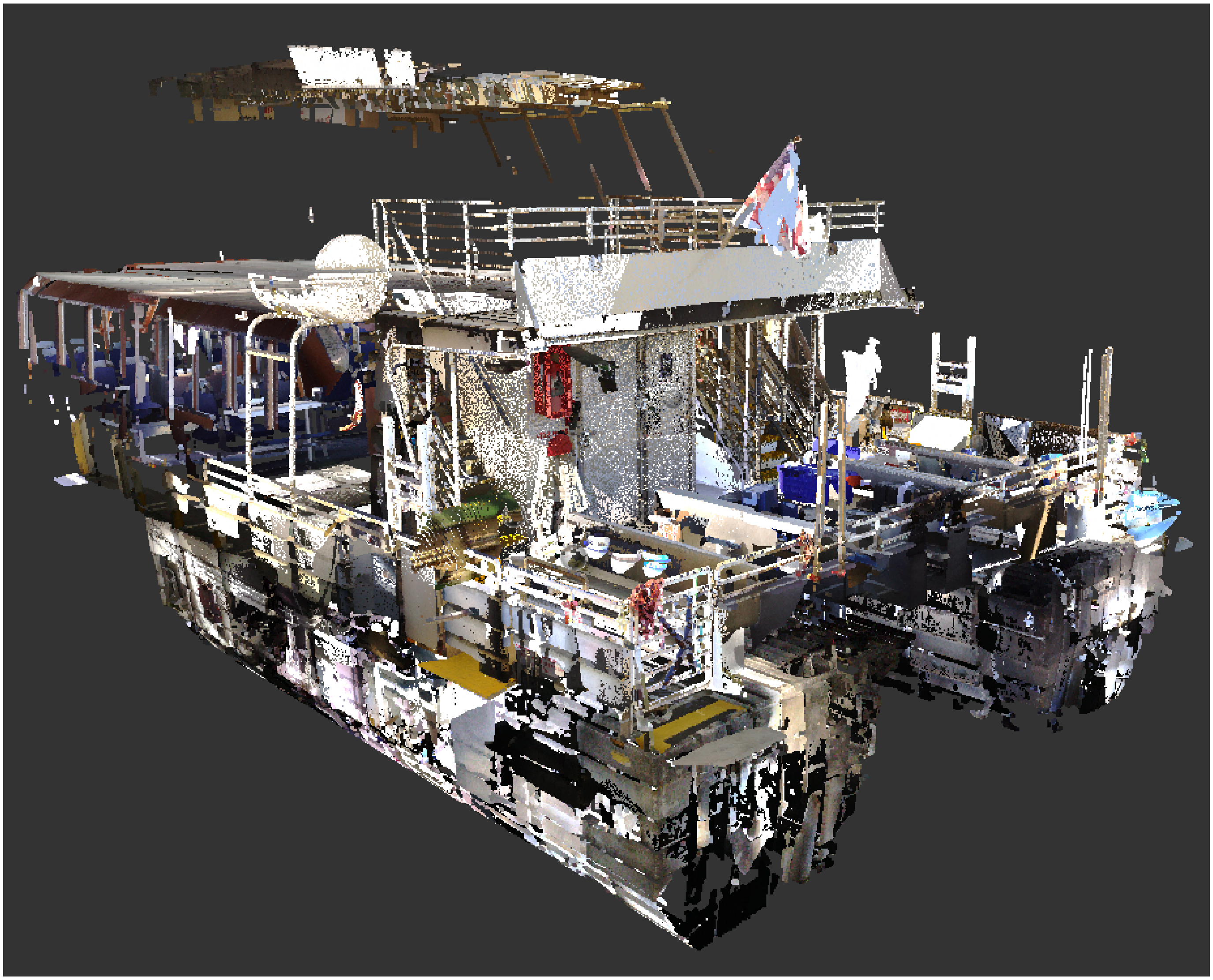

Figure 13: Ferry Outboard View Looking Forward and Starboard

3.5.2 Stability

The ferry as the smallest and lightest vessel has the most chance to have its stability impacted by these installations. Even small changes in weight push past the 2% lightship threshold on this vessel and so it is likely that a full stability test and incline will need to be performed for this vessel post-repower. However, due to the ferry's ability to shed passenger capacity and that these weights will be installed below the center of gravity in this vessel, the negative impact on the vessel will be mitigated.

Table 26: Ferry Stability Calculation for Baudouin 6M-26.3 Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	Cummins		Baudouin	
Engine Name	QSK 19-M		6M-26.3	
Min Power	800	kW	441-599	kW
Length	79.12	in	82.8	in
Width	42.82	in	46.14	in
Height	69.47	in	47.09	in
Net Weight Dry	4,826	lbs	4,367	lbs
Removed Eng weight	4.31	LT		
Added Eng Weight			3.90	LT
20% Margin (conservative)			0.78	LT
Added Eng Weight w/ Margin			4.68	LT

SCR Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			5,786	lbs
Added SCR weight			2.58	LT
20% Margin			0.52	LT
SCR weight			3.10	LT

DPF Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
RH-408-XL			0.56	LT
20% Margin			0.11	LT
DPF Weight			0.67	LT

Urea Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			0.11	LT
Liquid Weight			0.21	LT
20% Margin			0.06	LT
Urea Weight			0.37	LT

Auxiliary Engine Calculation				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
	Northern Lights		Northern Lights	
Engine Name	M843NW3G		M843NW3G	
Net Weight Dry	741.4	lbs	741.4	lbs
Removed Eng weight	0.66	LT		
Added Eng Weight			0.66	LT
20% Margin (conservative)			0.13	LT
Added Eng Weight			0.79	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info.**	**Units**	**Replacement Info.**	**Units**
Main engine weight			4.68	LT
SCR with 20% margin			3.10	LT
DPF			1.07	LT
Aux engine weight			0.79	LT
Urea			0.37	LT
Total Added weight (w/ DPF)			10.02	LT
Total Added weight (w/o DPF)			8.95	LT
2% of existing LS			0.30	LT
Aggregate Weight (w/ DPF)[48]			14.99	LT
Aggregate Weight (w/o DPF)[48]			13.92	LT
Aggregate Weight (w/ DPF)[49]			1.67	LT
Aggregate Weight (w/o DPF)[49]			1.49	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**YES**	**YES**
Exceed w/ DPF?			**YES**	**YES**

The repower of the Baudouin 6M-26.3 Tier 4 engine and SCR system do not pass the 2% lightship test.

[48] If no weight certificates are available.
[49] If weight certificates are available.

Table 27: Ferry Stability Calculation for Yanmar 6AYEM-GTWS Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	Cummins		Yanmar	
Engine Name	QSK 19-M		6AYEM-GTWS	
Min Power	800	kW	670/749	kW
Length	79.12	in	78.7	in
Width	42.82	in	51.4	in
Height	69.47	in	56.3	in
Net Weight Dry	4,826	lbs	5,319.6	lbs
Removed Eng weight	4.31	LT		
Added Eng Weight			4.75	LT
20% Margin (conservative)			0.95	LT
Added Eng Weight w/ Margin			5.70	LT

SCR[50] Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			0	lbs
Added SCR weight			0.00	LT
20% Margin			0.00	LT
SCR weight			0.00	LT

DPF Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
RH-410-XL			1.15	LT
20% Margin			0.23	LT
DPF Weight			1.38	LT

Urea Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			0.11	LT
Liquid Weight			0.21	LT
20% Margin			0.06	LT
Urea Weight			0.37	LT

50 SCR weight included in the engine.

Auxiliary Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
	Northern Lights		Northern Lights	
Engine Name	M843NW3G		M843NW3G	
Net Weight Dry	741.4	lbs	741.4	lbs
Removed Eng weight	0.66	LT		
Added Eng Weight			0.66	LT
20% Margin (conservative)			0.13	LT
Added Eng Weight			0.79	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Main engine weight			5.70	LT
SCR with 20% margin			0.00	LT
DPF			1.38	LT
Aux engine weight			0.79	LT
Urea			0.37	LT
Total Added weight (w/ DPF)			8.24	LT
Total Added weight (w/o DPF)			6.87	LT
2% of existing LS			0.30	LT
Aggregate Weight (w/ DPF)[51]			13.22	LT
Aggregate Weight (w/o DPF)[50]			11.84	LT
Aggregate Weight (w/ DPF)[52]			1.37	LT
Aggregate Weight (w/o DPF)[51]			1.14	LT

Does it exceed 2% Lightship?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**YES**	**YES**
Exceed w/ DPF?			**YES**	**YES**

The retrofit of the Yanmar 6AYEM - GTWS Tier 4 engine and SCR system does not pass the 2% lightship test.

[51] If no weight certificates are available.
[52] If weight certificates are available.

Table 28: Ferry Stability Calculation for Caterpillar C32 Repower and DPF Retrofit

Main Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
Engine Manufacturer	Cummins		Caterpillar	
Engine Name	QSK 19-M		C32	
Min Power	800	kW	746	kW
Length	79.12	in	89.8	in
Width	42.82	in	57.3	in
Height	69.47	in	63.5	in
Net Weight Dry	4,826	lbs	7,145.6	lbs
Removed Eng weight	4.31	LT		
Added Eng Weight			6.38	LT
20% Margin (conservative)			1.28	LT
Added Eng Weight w/ Margin			7.66	LT

SCR Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Net Weight Dry			2,910	lbs
Added SCR weight			1.30	LT
20% Margin			0.26	LT
SCR weight			1.56	LT

DPF Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
RH-408-XL			0.89	LT
20% Margin			0.18	LT
DPF Weight			1.07	LT

Urea Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Urea Tank Weight			0.11	LT
Liquid Weight			0.21	LT
20% Margin			0.06	LT
Urea Weight			0.37	LT

Auxiliary Engine Calculation				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Number of Engines	2		2	
	Northern Lights		Northern Lights	
Engine Name	M843NW3G		M843NW3G	
Net Weight Dry	741.4	lbs	741.4	lbs
Removed Eng weight	0.66	LT		
Added Eng Weight			0.66	LT
20% Margin (conservative)			0.13	LT
Added Eng Weight			0.79	LT

Stability Calculation (MTN 4-95)				
Parameter	**Existing Info**	**Units**	**Replacement Info.**	**Units**
Main engine weight			7.66	LT
SCR with 20% margin			1.56	LT
DPF			1.07	LT
Aux engine weight			0.79	LT
Urea			0.37	LT
Total Added weight (w/ DPF)			11.45	LT
Total Added weight (w/o DPF)			10.38	LT
2% of existing LS			0.30	LT
Aggregate Weight (w/ DPF)[53]			16.43	LT
Aggregate Weight (w/o DPF)[52]			15.35	LT
Aggregate Weight (w/ DPF)[54]			1.91	LT
Aggregate Weight (w/o DPF)[53]			1.73	LT

Does it exceed 2% LS?			**W/ Weight Certificates**	**W/o Weight Certificates**
Exceed w/o DPF?			**YES**	**YES**
Exceed w/ DPF?			**YES**	**YES**

The retrofit of the Caterpillar C32 Tier 4 engine and SCR system does not pass the 2% lightship test.

3.5.3 Conclusion

The ferry, as the smallest vessel studied, can be largely impacted by this retrofit. The engine room did fit 2 out of the 3 engines studied along with their SCR systems so fitment of the retrofit is feasible, but stability needs further analysis to understand the full effects of this retrofit. However, these systems would be installed below the Vertical center of gravity for the vessel and as such would likely have less of a negative impact on the overall stability. For this reason, the ferry is still considered feasible but would likely have to reduce their passenger limit to keep their design draft.

[53] If no weight certificates are available.
[54] If weight certificates are available.

4 Feasibility of DPF Installation

An overview of the engine DPFs being retrofitted are provided in Table 30.

These DPFs were selected with help from Rypos. The DPF sizing is based on various technical specifications of the engine such as exhaust flow, exhaust temperature, and maximum backpressure. These technical specifications were sourced either directly from vendors when available or online to provide Rypos with the most accurate values. However, it should be noted that DPF models may vary and for most accurate quotes Rypos should be directly contacted. At this point there are no CARB-Verified Level 3 DPF systems, and models below are based on calculations performed by Rypos to approximate specifications needed. To accurately size a DPF system, Rypos requires the engines echaust flow rate, exhaust temperature, and maximum backpressure. However, for engines with backpressure limits of 10 inches of water or less, it is currently impossible for Rypos to fit with a DPF. This is due to the inherent increase in backpressure that the DPF systems induces during operation exceeding the base backpressure limit of the engine.

Backpressure calculation results were achieved by analyzing the current pipe run in the vessel using the technical specifications of the new engine and adding a backpressure of 10 – 15 in. H_2O, a value given by Rypos, which is induced on the system when the DPF is running to calculate if the engines backpressure limit would be exceeded.

4.1 DPF Retrofit Overview

Table 29: Overview of DPFs Assessed

Vessel Type	Engine	Backpressure Limit (in. of water)	Rypos DPF Model	DPF Weight (lbs)	DPF Dimensions (L"xB"xD")	DPF Price (USD)
ATB-Barge	Caterpillar 3512E	27	ADPF-4NS	5,000	83x98x43	157,500-182,500
ATB-Barge	MTU 12V-4000M05	34	ADPF-5-NS	4,400	98x84x64	212,500-237,500
ATB-Barge	Cummins QSK38	40.8	ADPF-3-NS	4,200	98x84x48	144,500-169,500
ATB-Barge	Baudouin 12M-26.3	24	ADPF-4-NS	5,000	83x98x43	157,500-182,500
ATB-Barge	Auxiliary: Caterpillar 4.4	60.2	RH-304-M	150	L = 50 D = 20.75	27,500-42,500
ATB-Tug	Caterpillar C280-12	36	ADPF-10NS	7,500	102x104x84	371,500-386,500
ATB-Tug	GE (Wabtec) 12V250MDC	24	ADPF-8-NS	7,500	92x106x78	324,085-337,085
ATB-Tug	Auxiliary: John Deere 6090SFM85	30	RH408-M	290	L = 62 D = 20.75	44,500-69,500

Vessel Type	Engine	Backpressure Limit (in. of water)	Rypos DPF Model	DPF Weight (lbs)	DPF Dimensions (L”xB”xD”)	DPF Price (USD)
Line Towing Vessel	Caterpillar 3516E	28.1	ADPF-6ER-NS	5,690	98x102x64	262,500-287,500
Line Towing Vessel	Cummins QSK60	40.8	ADPF-6-NS	4,608	98x84x64	236,000-261,000
Line Towing Vessel	MTU 16V-4000M05	34	ADPF-7-NS	7,500	98x84x80	279,000-304,500
Line Towing Vessel	Auxiliary: John Deere 4045AFM85	30	RH404-M	200	L = 50” D = 20.75”	34,000-59,000
Subchapter T High Speed Catamaran Ferry	Baudouin 6M-26.3	24	RH-408-XL	1,000	L = 83” D = 38”	97,500-122,500
Subchapter T High Speed Catamaran Ferry	Yanmar 6AYEM-GTWS	76.4	RH-410-XL	1,285	L = 90” D = 38”	111,500-136,500
Subchapter T High Speed Catamaran Ferry	Caterpillar C32	26.9	RH-408-XL	1,000	L = 83” D = 38”	97,500-122,500
Subchapter T High Speed Catamaran Ferry	Auxiliary: Northern Lights M843NW3G	48	TBA	45	L = 36” D = 6”	4,250-16,750

Notes:

- DPF weights are approximate within a 10% margin
- Prices are approximate, for exact pricing please contact Rypos
- DPF Models listed as N/A are due to inability to size a DPF based on low backpressure limits
- TBA indicates that Rypos is currently working on a solution for this engine

4.2 ATB-Tug

4.2.1 DPF Fitment

It was determined looking at the 3D scans and drawings given that the most applicable space for the DPF was in the stack of the vessel. Here there is additional space to install the DPF where it is not available directly above the engine. This is attributed to the fact that most SCR systems are designed to be installed directly above the engine occupying that space which could house the DPF. Figure 3 & Figure 4 shown previously clearly identify the lack of available space directly above the engine for installation of a DPF.

4.2.2 Backpressure Calculation Results

Table 30: Backpressure Calculation Results for ATB-Tug

Manufacturer	Model	Exhaust Flow Rate (cfm)	Exhaust Temperature (ºC)	Engine Backpressure limit (in. H_2O)	Calculated Backpressure [55]	Total Backpressure After DPF Installation
GE (Wabtec)	12V250MDC	19,105	360	24	9.43	19.43-24.43
Caterpillar	C280-12	25,876	523	36[56]	13.76	23.76-28.76

On the topic of backpressure, two of the engines could be evaluated. The third, due to the constraints of DPF technology at this time, could not be fit with a DPF. Engines that are sensitive to increases in backpressure and have limits equal to 10 in H_2O and below such as the EMD models are too difficult design a DPF for. Rypos does not currently have the ability to accommodate these engines and thus they automatically fail the backpressure test for this reason.

The GE (Wabtec) 12V250MDC is a unique case. The base model of this engine has a similar backpressure limit to the other engine models studied, but Wabtec has designed an intake boost air eductor modification which raises this limit to 24" H_2O. This provides just enough backpressure for a DPF to be sized for the engine and for a calculation to be performed. It can be seen in Table 31 above that the engine passes after retrofit with the current pipe runs on the vessel. Then an additional 10 – 15 in H20 is added to account for the backpressure applied when the DPF is in operation. With this added backpressure, it can be seen that the engine fails at the highest end of the potential backpressure increase from DPF operation. With minor optimization of the pipe runs, this could be reduced further and so this was considered technically feasible within this study.

The Caterpillar C280-12 showed the best performance in its calculated backpressure. Though the engine itself has a backpressure limit of 10 in H_2O, it was explained after talks with Caterpillar that when considering the whole system, SCR & DPF, the limit is raised to 36 in H_2O. With this new limit the engine that had initially failed, showed the highest margin between the limit and the total

[55] Backpressure for engines is equivalent as both have the same pipe run.
[56] Maximum allowable system backpressure.

backpressure after installation. Though it is recommended to perform further study to confirm the performance of the C280-12 under these higher backpressures, as it stands a feasible conclusion was reached.

4.2.3 Stability Considerations

Table 31: Stability Results for ATB-Tug

Manufacturer	Model	DPF Model	2% of Lightship	Aggregate Weight (w/ weight certs.)	Aggregate Weight (w/o weight certs.)	Passes?
GE (Wabtec)	12V250MDC	ADPF-8-NS	18.283	13.46	132.22	Yes
Caterpillar	C280-12	ADPF-10-NS	18.283	19.70	169.66	No

As was discussed in Section 3.2.2, the ATB-Tug's stability can be significantly impacted by minor changes due to its unique geometry. This is exacerbated by the fact that the DPF installation location is high in the vessel above main deck and the current VCG causing a need to look closely at the stability impacts.

Table 14 and Table 16 in section 3.2.2, show that with the installation of a DPF, the 2% lightship threshold is exceeded. This shows that this would have a significant impact on stability and again due to the location of the DPF in the stack this would likely have a negative effect on the overall stability of the vessel. This results in a conclusion of infeasible for the metric of stability for these two engines

In Table 15, however, the GE (Wabtec) engine passes the 2% lightship test. This would usually be enough to be deemed feasible but as was discussed before the ATB-Tug can be impacted greatly by small weight changes and so a rough center of gravity calculation was performed to test the general impact this installation would have on stability. It was seen that even using maximum values for the distance between the vessel's center of gravity and placement of the DPF that a change in VCG of about 0.4" could be seen. When looking at the ATB-Tug's stability charts, this is far below the maximum allowable VCG and so the installation of a DPF on the ATB-Tug was concluded feasible.

4.3 ATB-Barge

4.3.1 DPF Fitment

The barge, as was stated in section 3.3, is a large vessel with an excess of space to accommodate the modifications needed, if any, to house the DPF.

4.3.2 Backpressure Calculation Results

Table 32: Backpressure Calculation Results for ATB-Barge

Manufacturer	Model	Exhaust Flow Rate (cfm)	Exhaust Temperature (ºC)	Engine Backpressure limit (in. H_2O)	Calculated Backpressure[57]	Total Backpressure After DPF Installation
Baudouin	12M-26.3	8,933	550	24	3.05	13.05-18.05
Caterpillar	3512E	10,797.8	524	27	4.60	14.60-19.60
Cummins	QSK38	7,745	464	40.8	2.56	12.56-17.56
MTU	12V-4000M05	11,442	430	34	5.85	15.85-20.85

All the engines examined passed after installation of a DPF with plenty of margin to spare. Using the existing pipe routes in the vessel

4.3.3 Stability Considerations

Table 33: Stability Results for ATB-Barge

Manufacturer	Model	DPF Model	2% of Lightship	Aggregate Weight (w/ weight certs.)	Aggregate Weight (w/o weight certs.)	Passes?
Cummins	QSK-38	ADPF-3-NS	121.87	4.5	39.91	Yes
Caterpillar	3512E	ADPF-4-NS	121.87	6.85	54.01	Yes
MTU	12V-4000M05	ADPF-5-NS	121.87	6.67	52.91	Yes
Baudouin	12M-26.3	ADPF-4-NS	121.87	3.33	32.88	Yes

The ATB-barge does not have special stability considerations for these installations. The DPF is with the heaviest DPF still only 0.04% of the existing lightship. This change in weight would have a negligible impact on overall stability and therefore is not a concern for the ATB-Barge.

4.4 Line Towing Vessel

4.4.1 DPF Fitment

A DPF system could not fit in the Line towing vessel without significantly modifying or expanding the stack, which is where the DPF system would most likely be installed. This expansion would increase the internal volume of the vessel and therefore result in an increase in tonnage. This is a major issue for the Line Towing vessel as it is already registered at 499 GT and vessels exceeding 500 GT must abide by SOLAS. This change would fundamentally alter the operation of the vessel and add a new set of factors the owner must consider to successfully repower the vessel. Therefore, a conclusion of “technically feasible but financially unviable” was reached since this change can be accomplished as it is not impossible to expand the stack, but this would result in

[57] Backpressure for engines is equivalent as both have the same pipe run.

the owner incurring several different operational difficulties which makes this solution difficult to implement from and operational and financial perspective.

4.4.2 Backpressure Calculation Results

Table 34: Backpressure Calculation Results for Line Towing Vessel

Manufacturer	Model	Exhaust Flow Rate (cfm)	Exhaust Temperature (ºC)	Engine Backpressure limit (in. H_2O)	Calculated Backpressure[58]	Total Backpressure After DPF Installation
Caterpillar	3516E	15,563	483.3	65.6	17.10	27.10-32.10
Cummins	QSK60	13,324	623	40.8	4.93	14.93-19.93
MTU	16V-4000M05	16,103	465	34	8.74	18.74-23.74

All engines pass the backpressure test on the Line towing vessel resulting in a feasible conclusion. This means that little to no modifications will have to be made to the current piping system to accommodate the DPF installation.

4.4.3 Stability Considerations

Table 35: Stability Results for Line Towing Vessel

Manufacturer	Model	DPF Model	2% of Lightship	Aggregate Weight (w/ weight certs.)	Aggregate Weight (w/o weight certs.)	Passes?
Cummins	QSK-60	ADPF-6-NS	10.96	11.66	88.96	No
Caterpillar	3516E	ADPF-6ER-NS	10.96	11.64	88.84	No
MTU	16V-4000M05	ADPF-7-NS	10.96	11.92	90.49	No

The line tug is another case that is very close to passing the 2% lightship test for all engines. This requires further investigation into the potential impacts the installation of the DPF could have on the system. However, when considering that the added weights will be installed lower than the current center of gravity. Only the DPF system which is planned to be installed in the stack will be higher than the current center of gravity. Given the low overall weight of the DPF in relation to the rest of the systems, it is offset by the engine and SCR system which will be installed below the vertical center of gravity and therefore should not have a negative impact on stability.

4.5 Subchapter T High Speed Catamaran Ferry

4.5.1 DPF Fitment

Analyzing the drawings provided it was determined that fitment is possible for all DPF models within the ferry. There is a long run of the exhaust where the DPF could be installed in the vessel. However, the exhaust pipe would likely need to be lowered to fit the DPF system.

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[58] Backpressure for engines is equivalent as both have the same pipe run.

4.5.2 Backpressure Calculation Results

Table 36: Backpressure Calculation Results for Ferry

Manufacturer	Model	Exhaust Flow Rate (cfm)	Exhaust Temperature (ºC)	Engine Backpressure limit (in. H_2O)	Calculated Backpressure[59]	Total Backpressure After DPF Installation
Baudouin	6M-26.3	4,273	600	24	3.90	13.90-18.90
Yanmar	6AYEM-GTWS	5,644	491	76.4	7.77	17.77-22.77
Caterpillar	C32	4,785.1	323.3	40	7.16	17.16-22.16

All the calculated backpressures caused from the installation of a DPF system are within the backpressure limits for each engine. This means that little to no modifications will have to be made to the current piping system to accommodate the DPF installation.

4.5.3 Stability Considerations

Table 37: Stability Results for Ferry

Manufacturer	Model	DPF Model	2% of Lightship	Aggregate Weight (w/ weight certs.)	Aggregate Weight (w/o weight certs.)	Passes?
Baudouin	6M-26.3	ADPF-3-NS	0.67	1.49	14.99	No
Yanmar	6AYEM-GTWS	ADPF-4-NS	0.67	1.37	13.22	No
Caterpillar	C32	ADPF-5-NS	0.67	1.91	16.43	No

None of the engines listed above pass the initial 2% lightship check and so require a further look into the impacts that a DPF installation would have on the vessel will be required. However, it is possible that the ferry could make up this difference in the weights by reducing its maximum carrying capacity. This will adversely affect the operating conditions and revenue of the vessel but could account for the difference in weight produced by the DPF system installation. Also, the increase in weight below the center of gravity by the installation of a Tier 4 engine and SCR system, will more than offset the additional weight of a DPF system.

5 Vessel Modifications Required

- All engines will be repowered and placed in the exact locations where the current engines are located.
- The SCR and DPF locations will be at the aft end of the engine for the ferry and within the stack for the Line Towing vessel and the ATB-Tug. For the barge, as there is enough space, the SCR and DPFs will be located next to the engine which is located on the main deck. For the other vessels, feasible locations have been chosen after careful consideration.

[59] Engines have different pipe runs, only run with highest backpressure is shown.

- There are some major considerations when installing the SCR and DPF systems on these vessels. The first is that there must be sufficient space around the SCRs for the removal and replacement of the catalyst elements. These elements can potentially weigh up to 50 lbs. each, so an easily serviceable location is important.
- Though a thermal analysis was outside the scope of this study, both SCR and DPF systems are known to add large heat loads to the vessel. For this reason, ABS recommends both the SCR and DPFs to have sufficient space to allow air flow past them so that heat loads can be removed from the engine rooms. This should also allow for safe and regular maintenance. Vessels will still have to abide by all current USCG regulations regarding heat management and crew safety therefore, a detailed heat load analysis might be required to determine the level of ventilation necessary and if a fixed fire suppression system is required. If no fixed fire extinguishing system is required, then portable fire extinguishing systems are to be put in place.
- Also, the DPF and SCR equipment must be plumbed in series with large diameter plumbing, fittings, and thermal expansion joints which take up substantial additional space.
- Another item is dealing with low frequency noise/vibration to combat crew fatigue on long voyages. There are claims that DPFs or SCR systems could replace silencers, but this issue currently has not been proven with SCR and DPF data, so out of caution, it is recommended to continue use of mufflers.
- For most Tier 4 engines a large urea tank will be necessary to supply the DEF fluid for the Tier 4 engine's SCR system. This tank usually has a capacity of about 5% of the fuel oil on the ship. This is a large tank holding a dense liquid which will have to be fit in the vessel preferably near the engine room. For this reason, it seems a primary solution is repurposing the fuel oil tank to hold the urea, but urea storage cannot be touching fuel storage and requires a void space between. This means that the vessel will be losing more than 5% of its current fuel oil stores and therefore over 5% of its endurance. However, to alleviate this issue CHC vessels on regular fixed operating routes have instead utilized smaller polymer day tanks for urea. These smaller tanks are easier to fit in the vessel and could be free-standing rather than needing to repurpose fuel stores. Since vessels operating on known routes can plan ahead for urea refills, they do not need excess stores giving vessels with this operating profile an option which will not complicate existing tank structures or have as large an impact on stability.

5.1 Impacts to Vessel due to Modifications

As with any modification, there are certain impacts to the vessels' outfitting and systems. Pipe routing will have to be modified in almost all cases, but this does not significantly impact weight.

DPF system energy use is about 13 kW per DPF installation. The power available in the ATB-Barge, ATB-Tug, and line towing vessels are sufficient to meet the additional electrical loads imposed by the SCR and DPFs, but on the ferry an additional generator will likely have to be installed to meet the additional energy requirements. However, even on the larger vessels studied they are very close to the electrical load limits and in some cases like the Line towing vessel, the operator chooses to run with full redundancy capability and therefore is likely to install another generator. Redundancy of essential systems is required per USCG Subchapter M requirements. However, not all systems are essential systems and thus the full redundancy is an option the operator is exercising, so an additional generator was not added to the line towing vessel. Secondly, none of the vessels studied within this report needed vessel elongation to meet the Tier 4 repowers.

Generally, the larger the vessel, the lesser engine repower impacts stability. When engine repowers or other vessel modifications are performed, a lightship test described in MTN 4-95 is conducted to determine the extent of the changes being made. Depending on the percentage change in the lightship, a new inclining test, stability test and stability analysis can be required for these vessels. Tier 4 engines generally have a larger footprint and are heavier than the engines they are replacing. This combined with the SCR and DPF system have the potential to create stability issues especially for smaller harbor craft. This is exacerbated by the urea tanks which are required for the SCR systems. The best practice for the industry has shown that about 5% of current fuel stores worth of urea is adequate to continue operation as normal with the new SCR system. However, it can be seen in the stability calculations that using this standard, urea will take up about 60% of the added weight to the vessel. The placement of such a large weight will assuredly have an impact on the stability of the vessel and will need to be studied further to ensure stability remains in safe bounds. For this reason, the EGR subsystem which is integrated into the engines for GE-Wabtec engines might be a prime solution. Usage of EGRs eliminates the need for urea and associated urea tanks effectively eliminating about 50% of the potential added weight during the repower. Though the engine itself is larger and heavier than its counterparts, the benefits to weight and space seem to outweigh these downsides.

Additional Items for consideration during modifications:

1. The SCRs and DPFs must have sufficient space around them for air flow. Generous air flow past the SCRs and DPFs is necessary to remove their heat loads from the engine room.
2. Maintenance space around SCRs and DPFs is necessary for safe and regular maintenance. Specifically, access to the Diesel Exhaust Fluid (DEF) reaction chamber is to be given special attention.
3. Dealing with low frequency noise/vibration is important to combat crew fatigue on long voyages. SCR or DPF abilities to deal with these frequencies is to be considered. Mufflers may need to be plumbed in series with the SCR and DPF.
4. A detailed Electrical Load Analysis - includes DPF units, SCR units, urea dosing pumps, extra ventilation fans, and if the urea tank is located adjacent to another space besides the engine room, that space also must have forced air-ventilation according to class society rules.

The line towing vessel carries 130,000 gallons of fuel. At the projected burn rate of 5%, it necessitates a urea tank of approximately 6,500 gallons to continue normal operations. Considering the relatively small size of this vessel, this is a significant structural modification which cannot be accomplished without rearranging a significant portion of the auxiliary equipment in the engine room or, if it is decided to repurpose existing tanks must have voids to separate them from diesel tank as per class society rules, leading to a loss in fuel capacity of greater than 6,500 gallons.

A unique constraint for the line towing vessel arises from tonnage. The stack and fiddley have limited room to fit two SCRs and two DPFs plus the existing equipment. If these were fitted, then some structural changes would have to be implemented. This would result in an expansion of the stack and fiddley which would raise the tonnage. This tonnage change would also raise other technical & economic challenges as the vessel is already at 499 GT ITC and moving to 500 GT ITC puts the vessel in SOLAS category. Other locations for the SCR's and DPF's are not possible for the line towing vessel due to its space constraints.

For the ferry, there are concerns with stability and passenger capacity when repowering the vessel. The inclusion of an SCR, urea tank, DPF, and Tier 4 engine add a significant amount of weight to the ferry and push it over the 2% threshold in almost all situations. This will require further inquiry into the stability of the vessel and will affect the number of passengers that can be carried. Any increase in weight will inherently reduce the current maximum carrying capacity of the ferry and it should be noted that a passenger capacity reduction of 25% will result in the modifications being considered not feasible. However, this must be paired with documentation which shows that reducing the passenger capacity will operationally result in increased emissions[60].

Key stability calculations for all vessel types were shown in tabular format in the previous sections. These calculations are not all encompassing when determining intact stability and damage stability but provide a basic understanding of the underlying basis. As a reminder, MTN 4-95 is to be followed.

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[60] CHC Factsheet: Attachment: Compliance Extensions | California Air Resources Board

5.2 Additional Mitigation of Impacts

Other potential impacts of repowering were also considered. Vibrations might decrease with a repowered higher Tier engine rendering the existing damping material redundant. Therefore, there may be a slight decrease in weight, but this has not been accounted for within the study as real installations and verifications need to be done before removing any damping accessories.

There is no observable impact to crew accommodations on the vessels. However, the ferry would lose about 20 - 25% of its passenger capacity, decreasing revenue. Extensions based on financial evaluations are not part of this study.

While fully insulated to meet applicable USCG surface temperature requirements, both the SCR and DPF add large heat loads to the engine room and will likely require extra forced-air ventilation. Operational safety and design standards for CHCs or their crews would need to be according to USCG requirements. It is to be noted that all USCG design and safety standards apply. To meet these requirements, an increase in the ventilation rate and air changes per hour can be implemented. It is important to note, however, that an engine room which is uncomfortable to work in will affect an operator’s ability to retain a good crew and likely not receive adequate supervision or maintenance. It is therefore crucial to consider the health and safety of crew members when designing these systems.

5.3 USCG Certification

The United States Coast Guard review is an independent process and falls under the Marine Safety Center (MSC). All the below listed USCG guidelines are to be followed when making modifications to the vessels, as applicable:

- Marine Safety Center Technical Notes (MTN)
- Plan Review Guidelines
- Tonnage Guides

Particular attention is to be paid to the MTN 4-95, Lightship Change Determination to understand when weight changes to a vessel are significant enough to warrant a new deadweight survey or a full stability test (deadweight survey and inclining). Compliance with all applicable stability criteria must be demonstrated to the satisfaction of the Marine Safety Center (MSC), regardless of the magnitude of lightship weight change.

All modifications are to be in compliance with USCG Plan Review Guidelines. Some vessels are eligible to have compliance verified by a classification society under either the Alternate Compliance Program (ACP) or the Navigation and Vessel Inspection Circulars (NVIC).

6 Operational Considerations

There are a multitude of operational considerations which need to be evaluated during a repower/retrofit. The major considerations include facilities, manning, vessel operation, maintenance, crew licensing, certification and training, passenger capacity reduction for passenger vessels, and regulatory compliance. These have been detailed in this subsection.

6.1 Facilities

There are over 60 repair shipyards and facilities in the United States capable of performing engine repowering. However, upon a preliminary inquiry on availability from the participants of the study, most of these yards' capacity is full for the foreseeable future thus restricting availability unless planned far in advance (multiple years). The proposed schedule is given in Section 7.4.

6.2 Manning

Crew manning for the selected vessels is shown in _Ref152284560.

Table 38: Manning on Selected Vessels

Vessel Type	Crew
ATB-Tug	ATB-Tug = 10-person crew Main Deck: 1 Chief 01 Deck: (3 x 2-man) + (2 x 1-man) + (1 x Captain)
ATB-Barge	Barge = 0 crew, unmanned
Line Towing Vessel	9 berths total Main Deck: 3 x 1-man 01 Deck: 2 x 1-man Below Deck: 2 x 2-man
Ferry	149 passengers + 3 crew = Total 152 persons

6.3 Vessel Operation

Due to the repower/retrofit there are impacts for vessel operation such as vessel endurance and operating distance on most of the fleet and particularly the ATBs. Reduced endurance is an important concern as the operating distances between ports are fixed and if fuel capacity is reduced, then the vessel cannot operate between these fixed ports. Protocols for filling urea tanks, when added, need to be developed. Some additional duties may be imposed with newer engines and some level of training might be needed but these can be easily covered by the existing crew.

6.4 Maintenance

There are increased maintenance requirements with the added SCR and DPF equipment. It will be an additional responsibility of the crew to learn the maintenance procedures necessary to keep these systems in good working order. Detailed maintenance procedures will have to be developed so that maintenance is performed on a regular basis. It is vital for these systems to be kept in good condition to optimize engine performance and reduce any potential impacts on fuel consumption. SCR systems key maintenance tasks include regular visual inspections, monitoring of urea levels and quality, catalyst cleaning, and sensor calibration to ensure accurate dosing of urea. Using the

Yanmar SCR system[61] as an example, the catalyst within the SCR system needs cleaning around every 2 years. DPF filters should be cleaned about once per year or about every 1000 hours of engine operation[62]. Maintenance must be performed to clean the ash buildup in the filter to keep efficient operation of the engine as well as prevent backpressure buildup within the system. Also, for the equipment placed high up in a stack, access, maneuvering, and heat is an issue. These systems require regular maintenance and as such easy access is a must if the systems are to be checked often. This access must also be combined with good ventilation to provide both safe and comfortable conditions for the crew who will perform the maintenance on this machinery.

6.5 Crew Licensing, Certification and Training

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), sets qualification standards for personnel on seagoing ships. These requirements have been incorporated into U.S. Regulation and Policy for certain personnel. STCW Training is standard practice within the industry and repower does not significantly impact crew licensing, certification, and training. However, the crew will have to learn to maintain the new DPF and SCR systems onboard the vessel.

6.6 Regulatory Compliance

Regulatory compliance with US CFRs and, in some scenarios, classification societies need to be closely adhered to. Since most of the engine repower options in the CARB approved list are already classification society type approved, this decreases the burden on regulatory compliance. However, newer engines added to the list, such as the M&H marinized engines, will have to undergo rigorous inspection and verification by class societies, although certain vessel types, such as subchapter T vessels, do not require type-classed engines to receive a USCG certificate of inspection. All other vessels included in this study require type-classed equipment.

7 Itemized Cost

Total installation and capital costs for each of the retrofits/repowers are listed in this sub-section and provided for reference purposes as required by CARB. This section also includes shipyard fabrication work costs such as drydocking cost, fabrication work/labor, materials of fabrication, OEM engines, OEM aftertreatment devices, OEM retrofit aftertreatment DPFs, third-party DPF's etc. For the full list of fabrication work costs, please see the detailed tables for cost in Appendix G – Prices.

Costs have been itemized to the lowest extent possible for this project. Margins have been added to account for price variations. Engine costs are in the same range and go by per kilowatt for most instances, so every type of engine based on kilowatts was evaluated for pricing. Costs have been estimated based on available data to a reasonable extent when real information was not readily

[61] scr_system_en.pdf (yanmar.com)
[62] Operator's Manual (rypos.com)

available. Due to the nature of engines being back-order, costs may fluctuate with time. There might also be discounts for engines and components, but these have not been accounted for. Though every attempt was made to pin down real costs, these costs need to be viewed as a representative cost and not the actual repower/retrofit costs.

7.1 Passenger Ferry

The selected vessel is a passenger ferry capable of holding 149 passengers and does carry overnight equipment. However, due to the vessel's size, there are some key considerations that were considered when calculating the cost of repower. The limited space complicates the engineering required to fit the DPF and SCR systems needed to achieve CARB's in-use performance standards. It is likely that this problem would require additional engineering compared to other repowers and the hours quoted reflect this. A smaller vessel needs additional equipment to run these systems, including a larger auxiliary generator and an air compressor. A cost breakdown for the repower of the Passenger Ferry is shown in Table 39.

Table 39: Cost Breakdown – Passenger Ferry

Category	Itemized List	Cost ($USD)	# of Units	TOTALS
Materials	Engine*	$625,000.00	2	$1,562,500.00
Materials	DPF (Rypos)*	$78,000.00	2	$195,937.50
Materials	Aux. Engine DPF (Rypos)	$10,449.00	1	$13,061.25
Materials	Auxiliary generator	$25,000.00	1	$31,250.00
Materials	Air compressor	$5,000.00	1	$6,250.00
Materials	Urea Tank	$5,000.00	1	$4,211.25
Materials	Exhaust System Costs	$44,160.00	1	$55,200.00
Materials	Engine Room Access	$35,000.00	1	$43,750.00
Materials	Storage (per ft^2 per month)	$2.00	6000	$12,000.00
Labor and Instl.	General Labor (per hour)	$92.00	4800	$441,600.00
Labor and Instl.	Crane Labor (per hour)	$317.00	20	$6,340.00
Labor and Instl.	Forklift Labor (per hour)	$152.00	20	$3,040.00
Labor and Instl.	Engineer Labor (per hour)	$200.00	480	$120,000.00
Stab. & Incline	Naval Architect Labor (per hour)	$150.00	80	$15,000.00
Stab. & Incline	Surveyor Labor (per hour)	$160.00	20	$4,000.00
Stab. & Incline	Eco-Block Rental (per block)	$75.00	4	$375.00
Stab. & Incline	General Labor (per hour)	$84.00	600	$50,400.00
Stab. & Incline	Tug Rental (per hour)	$4,216.00	8	$42,160.00
Stab. & Incline	Crane Labor (per hour)	$317.00	20	$6,340.00
Misc. Fees	Drydocking (per Foot Day)	$10.00	3328	$33,280.00
Misc. Fees	Periodic Maintenance Costs	$45,917.00	2	$91,834.00
Misc. Fees	Annual Loss in Revenue (person @ 185 lbs)	$36.75.00	14976	$550,368.00
Misc. Fees	Regulatory Fees (15%)	15%	1	$493,334.55
Misc. Fees	Margin (+/-10%)	10%	1	$378,223.16
TOTALS	TOTAL (Raw)	-	-	$3,288,897.00
TOTALS	TOTAL (Including Regulatory Fee)	-	-	$3,782,231.55
TOTALS	TOTAL (+ Negative Margin)	-	-	$3,404,008.40
TOTALS	TOTAL (+ Positive Margin)	-	-	$4,160,454.71

* Reasonable estimates based on available information

Note: The grey color highlighted cells incur an additional retail charge of 25% the cost (cost + 25%)

7.2 ATB

Cost breakdown for the repower of the ATB is shown in Table 41 (ATB-Barge) and Table 42 (ATB-Tug).

Table 40: Cost Breakdown – ATB-Barge

Category	Itemized List	Cost ($USD)	# of Units	TOTALS
Materials	Barge Main Engine*	$2,221,000.00	2	$5,552,500.00
Materials	Aux. Engine (Barge)*	$235,273.03	1	$294,091.00
Materials	DPF (Rypos)*	$170,000.00	2	$425,000.00
Materials	Barge Aux. Engine DPF (Rypos)*	$40,000.00	1	$50,000.00
Materials	Urea Tank (Barge)	$32,647.00	1	$40,809.00
Materials	Exhaust System Costs	$80,640.00	1	$100,800.00
Materials	Engine Room Access	$75,000.00	1	$93,750.00
Materials	Storage (per ft^2 per month)	$2.00	15000	$30,000.00
Labor and Instl.	General Labor (per hour)	$84.00	9600	$806,400.00
Labor and Instl.	Crane Labor (per hour)	$309.00	80	$24,720.00
Labor and Instl.	Forklift Labor (per hour)	$144.00	80	$11,520.00
Labor and Instl.	Engineer Labor (per hour)	$200.00	320	$80,000.00
Stab. & Incline	Naval Architect Labor (per hour)	$150.00	100	$15,000.00
Stab. & Incline	Surveyor Labor (per hour)	$160.00	40	$8,000.00
Stab. & Incline	Eco-Block Rental (per block)	$75.00	16	$1,500.00
Stab. & Incline	General Labor (per hour)	$84.00	1000	$84,000.00
Stab. & Incline	Tug Rental (per hour)	$4,216.00	12	$63,240.00
Stab. & Incline	Crane Labor (per hour)	$317.00	40	$12,680.00
Misc. Fees	Towing Cost	$150,000.00	1	$187,500.00
Misc. Fees	Drydocking of barge (per Foot Day)	$10.00	38766.75	$387,668.00
Misc. Fees	Periodic Maintenance Costs	$35,000.00	4	$140,000.00
Misc. Fees	Regulatory Fees (15%)	15%	1	$1,261,377.00
Misc. Fees	Margin (10%)	10%	1	$840,918.00
TOTALS	TOTAL (Raw)	-	-	$8,409,178.00
TOTALS	TOTAL (Including Regulatory Fee)	-	-	$9,670,554.00
TOTALS	TOTAL (+ Negative Margin)	-	-	$8,829,636.00
TOTALS	TOTAL (+ Positive Margin)	-	-	$10,511,471.92

* Reasonable estimates based on available information

Note: The grey color highlighted cells incur an additional retail charge of 25% the cost (cost + 25%)

Table 41: Cost Breakdown – ATB-Tug

Categories	Itemized List	Cost ($USD)	# of Units	TOTALS
Materials	Tug Main Engine*	$3,877,553.82	2	$9,693,885.00
Materials	DPF (Rypos)*	$380,000.00	2	$950,000.00
Materials	Tug Aux. Engine DPF (Rypos)*	$60,000.00	2	$150,000.00
Materials	Urea Tank (Tug)	$139,903.00	1	$174,879.00
Materials	Exhaust System Costs	$80,640.00	1	$100,800.00
Materials	Engine Room Access	$75,000.00	1	$93,750.00
Materials	Storage (per ft^2 per month)	$2.00	15000	$30,000.00
Labor and Instl.	General Labor (per hour)	$84.00	9600	$806,400.00
Labor and Instl.	Crane Labor (per hour)	$309.00	80	$24,720.00
Labor and Instl.	Forklift Labor (per hour)	$144.00	80	$11,520.00
Labor and Instl.	Engineer Labor (per hour)	$200.00	960	$240,000.00
Stab. & Incline	Naval Architect Labor (per hour)	$150.00	100	$15,000.00
Stab. & Incline	Surveyor Labor (per hour)	$160.00	40	$8,000.00
Stab. & Incline	Eco-Block Rental (per block)	$75.00	16	$1,500.00
Stab. & Incline	General Labor (per hour)	$84.00	1000	$84,000.00
Stab. & Incline	Tug Rental (per hour)	$4,216.00	12	$63,240.00
Stab. & Incline	Crane Labor (per hour)	$317.00	40	$12,680.00
Misc. Fees	Drydocking of tug (per Foot Day)	$10.00	8382	$83,820.00
Misc. Fees	Periodic Maintenance Costs	$35,000.00	4	$140,000.00
Misc. Fees	Regulatory Fees (15%)	15%	1	$1,902,629.00
Misc. Fees	Margin (10%)	10%	1	$1,268,419.00
TOTALS	TOTAL (Raw)	-	-	$12,684,193.00
TOTALS	TOTAL (Including Regulatory Fee)	-	-	$14,586,822.00
TOTALS	TOTAL (+ Negative Margin)	-	-	$13,318,403.00
TOTALS	TOTAL (+ Positive Margin)	-	-	$15,855,241.63

* Reasonable estimates based on available information

Note: The grey color highlighted cells incur an additional retail charge of 25% the cost (cost + 25%)

7.3 Line Towing Vessel

Cost breakdown for the repower of the Line Towing Vessel is shown in Table 43.

Table 42: Cost Breakdown – Line Towing Vessel

Categories	Itemized List	Cost ($USD)	# of Units	TOTALS
Materials	Engine (MTU)*	$3,156,834.71	2	$7,892,087.00
Materials	DPF (Rypos)*	$225,000.00	2	$562,500.00
Materials	Aux. Engine DPF (Rypos)*	$45,000.00	2	$112,500.00
Materials	Urea Tank	$121,128.00	1	$151,410.00
Materials	Exhaust System Costs	$53,760.00	1	$67,200.00
Labor and Instl.	Engine Room Access	$65,000.00	1	$81,250.00
Labor and Instl.	Storage (per ft^2 per month)	$2.00	8000	$16,000.00
Labor and Instl.	General Labor (per hour)	$84.00	6400	$537,600.00
Labor and Instl.	Crane Labor (per hour)	$309.00	30	$9,270.00
Labor and Instl.	Forklift Labor (per hour)	$144.00	30	$4,320.00
Labor and Instl.	Engineer Labor (per hour)	$200.00	960	$240,000.00
Stab. & Incline	Naval Architect Labor (per hour)	$150.00	80	$12,000.00
Stab. & Incline	Surveyor Labor (per hour)	$160.00	20	$4,000.00
Stab. & Incline	Eco-Block Rental (per block)	$75.00	8	$750.00
Stab. & Incline	General Labor (per hour)	$84.00	800	$67,200.00
Stab. & Incline	Tug Rental (per hour)	$4,216.00	8	$42,160.00
Misc. Fees	Crane Labor (per hour)	$317.00	30	$9,510.00
Misc. Fees	Drydocking (per Foot Day)	$10.00	5646.52	$56,465.00
Misc. Fees	Periodic Maintenance Costs (per engine)	$45,850.00	2	$91,700.00
Misc. Fees	Regulatory Fees (15%)	15%	1	$1,493,688.00
Misc. Fees	Margin (10%)	10%	1	$995,792.00
TOTALS	TOTAL (Raw)	-	-	$9,957,922.00
TOTALS	TOTAL (Including Regulatory Fee)	-	-	$11,451,610.00
TOTALS	TOTAL (+ Negative Margin)	-	-	$10,455,818.00
TOTALS	TOTAL (+ Positive Margin)	-	-	$12,447,402.00

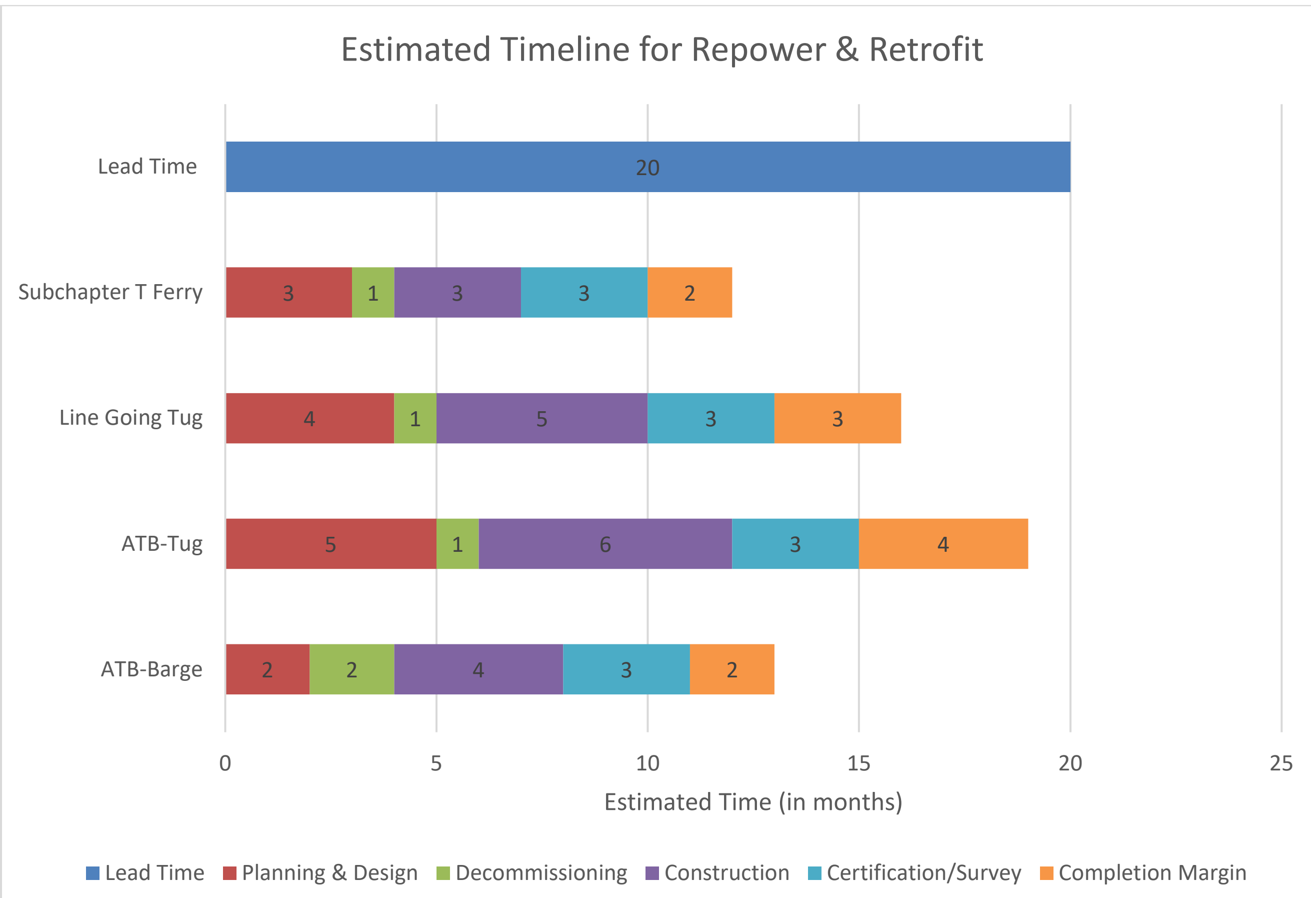
* Reasonable estimates based on available information

Note: The grey color highlighted cells incur an additional retail charge of 25% the cost (cost + 25%)

7.4 Schedule

Figure 14 shows the schedule for repowering and retrofitting the vessels based on experience and the extent of repower. The ATB-Barge schedule is estimated at 13 months, while the ATB-Tug is estimated at 19 months. The line towing vessel is estimated at 16 months and the ferry is estimated at 12 months. The ferry must also account for some complicated cutouts to complete the new installation which were included in the time estimates. The barge would be the simplest repower of all the vessels with adequate space for performing the repower. The lead time for all vessels is estimated at 20 months and includes engine manufacturer backlogs which have been reported by vendors. This lead time is not shown on the timeline below as it can vary widely depending on the engine manufacturer and the shipyard. At the time of writing, a 20-month lead time is reasonable.

Figure 14: Repower & Retrofit Timeline



Note: Lead time refers to the waiting time for the owner to conduct a feasibility analysis for the retrofit and procure the equipment required to complete the retrofit. This lead time should be considered in planning but will likely overlap with other periods in the timeline.

8 Summary and Conclusions

The feasibility study was conducted to upgrade vessels to CARB's new In-Use Performance Standards for harbor craft on 4 vessels across 3 vessel categories. Table 43 shows the summary results in tabular format.

Table 43: Summary of Repower & Retrofit Costs, Timeline and Technical Feasibility

Vessel Type	Estimated Repower Costs in USD (with positive margin)	Estimated Repower Timeline[63]	Technical Feasibility (Tier 4)	Technical Feasibility (Tier 4 + DPF)	Primary Reason for Feasibility Determination
ATB-Barge	$21,688,804.52	13 months	**Feasible**	**Feasible**	Though some modifications are required to accommodate repower of all 3 engines (2 main+1 auxiliary), it is able to accommodate them. The urea tank and DPFs on the large sized barge are not an issue.
ATB-Tug	$17,893,771.94	19 months	**Feasible**	**Feasible**	Limited space to accommodate urea tanks, SCRs and DPFs. Significant structural modifications are required. Vessel endurance is affected as fuel tank capacity is decreased.
Line Towing Vessel	$13,461,975.00	16 months	**Feasible**	**Feasible**[64]	The vessel goes over 500 GT and would need to comply with SOLAS negating harbor craft purpose, as SOLAS requires extensive modifications to the vessel including structural fire protection.
Passenger Ferry	$4,197,965.61	12 months	**Feasible**	**Feasible**	Though space is limited, passenger space is expended to accommodate repower. Most likely an issue for financial feasibility which is not part of the study.

The outcome of this study is that all vessels can reach at least one feasible conclusion for the installation of a Tier 4 engine and DPF. However, each vessel type, excluding the ATB-barge, had unique challenges which needed to be overcome to reach this conclusion and will be described in more detail below.

[63] Lead time of about 20 months runs parallelly for all vessels and is not included below

[64] Technically feasible, but financially unviable.

Key conclusions from the feasibility study are listed here:

1. **Substantial Engineering Work:**
   Feasibility Study for Selected Vessel Categories of ATB, Towing Vessel and Ferry have been conducted on representative vessels to replace the existing engines with suitable higher Tier engines. The amount of engineering work required for each repower is substantial but this is a known issue well understood by the harbor craft community.

2. **Fitment (Line Tug & Ferry):**
   The limited amount of space for retrofit on these vessels became increasingly apparent in the cases of the Line Tug and the Ferry. For the tug repower will require modifications likely increasing the size of the stack to allow for safe and efficient maintenance on the DPF system, but as the tug is already at 499 GT, any minor modification will automatically take it over 500 GT at which point SOLAS becomes applicable. This will require a signficant redesign of the vessel as the vessel is not built for SOLAS compliance. This will limit the vessel's profitability over its lifetime and drastically increase the cost of repower. This has resulted in the conclusion of "technically feasible but financially unviable" listed above.

   The ferry repower will require some innovative thinking and engineering but is mostly limited by the higher costs relative to the ferry itself. Also, many of the changes will likely lower both the cargo carrying capacity as well as the passenger carrying capacity due to the addition of heavier engines, urea tanks, etc.. Again these changes will affect the lifetime profitability of the vessel as the number of passengers will be permanently reduced.

3. **Stability – Lightship (All vessels):**
   Whenever the aggregate added weight exceeds 2% lightship, a significant investment might become necessary for redoing the stability booklet, stability tests and incline tests. Though full stability tests are beyond the scope of this feasibility study, MTN 4-95 can be used to determine if significant changes are being made to the lightship and whether those changes need to be further investigated. It is in the best interest of those conducting the repower to have certified weights of new engines, SCRs and DPFs to aid in engineering analysis. Certified weight are any weights measured in presence of surveyor or supported by manufacturer specification (for this particular unit/component). Not having certified weights significantly affects the lightship change in the vessel and in most cases requires a new stability test and stability analysis, significantly increasing the complexity and costs. It is ideal to have certified weights of the new engine(s), SCR(s), DPF(s) and old engine(s). Where the 2% lightship was exceeded, a rough calculation was performed based on the given stability booklet and estimated center of gravities of the newly installed machinery to determine whether a negative impact could be seen.

It should be noted that, according to the U.S. Coast Guard if the aggregate weight change is within 2-10% only a lightweight survey will be needed, but if 10% is exceeded then a full stability test is required. However, an important caveat is that if a lightweight survey is selected and the result show that the actual lightship changed more than 1% from the original, then they will also require a full stability test. For this reason a full stability test might be recommended to avoid having to perform both tests.

4. **DPF Backpressure:**
   There is also active work being done by third-party manufacturers to miniaturize the DPF sizes (to about 80% reduction in size and weight) which will further aid in the repower/retrofits in the future. One of the most important and limiting factors in this study is engine OEM backpressure limits and the available DPF options on the market. Backpressure is a restrictive part of the design phase for these retrofits and is affected heavily by pipe runs, so all DPF integration should be done in coordination with the DPF manufacturer and engine manufacturer. These backpressure calculations were done and the details are listed in an appendix. This is not as much of a problem for smaller engines which tend to have higher backpressure limits but does become a problem for larger engines with backpressure limits falling within 10 – 30 in of H_2O. Most DPF manufacturers on the market right now will struggle to meet these limits as it can be expected that the DPF system itself will add around 10 – 15 in of H_2O of backpressure. We have seen some engine OEMs provide configurations or solutions which effectively raise the original backpressure limit of their engine and expect to see similar solutions throughout the market in the future.

5. **EGR Benefits:**
   EGR technologies do not require urea and associated tanks further decreasing the size and weight constraints. Some engine manufacturers like GE-Wabtec[65] are using the EGR technology and embedding this within the engine module. Though these engines tend to be larger than their competitors, the space and weight savings from the removal of the need for urea and the corresponding urea tank is significant. In the study it was our assumption that to keep their current operational profile vessels would need urea equivalent to about 5% of their current fuel stores. Using this assumption urea stores would account for about 60% of the total weight of retrofit and these large tanks would have to be fit somewhere on the vessel. In many cases it was determined that repurposing fuel oil tanks would likely be the solution but this cuts the vessel's endurance and since void tanks are required to be installed between urea and fuel oil, even more than the initial 5% of fuel will be lost. This makes EGR technology an enticing option for those who can fit the larger engine.

[65] GE Wabtec, Section 2, EGR Technology – how it works? - https://www.wabteccorp.com/EPA-T4-IMO-III-emissions-compliance-without-urea-after-treatment.pdf?inline

6. **Economic Challenges:**
   The most significant constraint to any repower/retrofit is costs. As is common knowledge, feasibility of retrofitting/repowering harbor craft mostly boils down to economics - a sentiment echoed throughout most of the harbor craft community. Some of the technical challenges can be overcome through careful engineering and design, as shown through this feasibility study. However, some challenges become insurmountable when payback periods are calculated or when vessels not originally designed for SOLAS cross into SOLAS categorization. For instance, structural fire protection requirements, fire detection, fixed fire extinguishing systems, life saving appliances, portable extinguishers would all come into force if a vessel is categorized as SOLAS.

9 References

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10 List of inventions reported, and copyrighted materials produced

None.

No new inventions have been reported, or publications or pending publications have been produced as a result of the project. Therefore, the titles,authors, journals or magazines, and identifying numbers that will assist in locating such information have not been included in this section.

That said, the following copyrighted material and drawings have been "reproduced" from other sources with permissions. A list of these reproduced materials is listed below.

1. Appendix B – 3D Point Cloud Scans of Selected Vessels
    a. B.1 ATB-Barge
        i. Figure 15: ATB-Barge Port Engine Room Above
        ii. Figure 16: ATB-Barge Port Engine Room Looking Inboard
        iii. Figure 17: ATB-Barge Port Engine Looking Outboard
    b. B.2 ATB-Tug
        i. Figure 18: ATB-Tug Engine Room Above
        ii. Figure 19: ATB-Tug Engine Room Looking Aft
        iii. Figure 20: ATB-Tug Engine Room at Center Line Looking Starboard
    c. B.3 Line Towing Vessel
        i. Figure 21: Line Towing Vessel Engine Room Above
        ii. Figure 22: Line Towing Vessel Engine Room Looking Aft
        iii. Figure 23: Line Towing Vessel Center Line Looking Port
    d. B.4 Ferry
        i. Figure 24: Ferry Engine Room Above
        ii. Figure 25: Ferry Starboard Engine Room Looking Aft
        iii. Figure 26: Ferry Outboard View Looking Forward and Starboard
2. Appendix C – Ferry General Arrangement
    a. Figure 27: Ferry General Arrangement
3. Appendix D – Line Towing Vessel General Arrangement
    a. Figure 28: Line Towing Vessel Outboard Profile
    b. Figure 29: Line Towing Vessel General Arrangement

11 Glossary of Terms, Abbreviations, and Symbols

3D	Three Dimensional
ABS	American Bureau of Shipping
ACP	Alternate Compliance Program
ADPF	Active Diesel Particulate Filter
ATB	Articulated Tug Barge
Aux	Auxiliary
Back.	Backpressure
Baud.	Baudouin
CA	California
CARB	California Air Resources Board
Cat	Caterpillar
cfm	Cubic Feet per minute
CFR	Code of Federal Regulations
CHC	Commercial Harbor Craft
Cumm.	Cummins
DEF	Diesel Exhaust Fluid
DPF	Diesel Particulate Filter
EGR	Exhaust Gas Recirculation
EIAPP	Engine International Air Pollution Prevention
EPA	United States Environmental Protection Agency
Feas.	Feasibility
Fit.	Fitment
IMO	International Maritime Organization
in	Inches
Info.	Information
in H_2O	Inches of Water
Instl.	Installation
kPa	Kilopascals
kW	Kilowatts
lbs	Pounds
LS	Lightship
LT	Long tons
m	Meters
Mfr.	Manufacturer
min	Minute
Misc.	Miscellaneous
MTN	Marine Safety Center Technical Notes
NVIC	Navigation and Vessel Inspection Circulars
OEM	Original Equipment Manufacturer
PM	Particulate Matter
Req.	Requirement
SCR	Selective Catalytic Reduction
SOLAS	International Convention for the Safety of Life at Sea
Stab.	Stability
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
U.S.	United States
USA	United States of America
USCG	United States Coast Guard
ZEAT	Zero Emission & Advanced Technology

Appendices

Appendix A – Diesel Particulate Filters[66]

The combustion of diesel fuel in a diesel engine results in the generation of particulate matter (PM) from incomplete combustion (soot) and impurities suspended in the diesel fuel. The PM emitted from a diesel engine can range in size from ultrafine particles (respirable, 0.1 micron in size and smaller), $PM_{2.5}$ (respirable, 2.5 microns and smaller), PM_{10} (10 microns and smaller) to larger visible PM emissions. A particulate filter acts to capture this material on the filter's surface.

DPFs can be of the partial or flow-through filter design or wall-flow design. Partial or flow- through filters pass exhaust gases in essentially a straight line through the filter and rely on material adhering to the filter surface area as the gases pass through. Surfaces in this type of filter are rough at a microscopic level and PM impinges on this rough surface area adhering to those surfaces. Partial or flow-through filters may or may not utilize a catalyst material to increase capture efficiency and surface regeneration efficiency. The higher efficiency wall-flow filters are designed to change the direction of the exhaust gases as they pass through the filter which causes entrained PM to impart its energy on filter surfaces making the PM more likely to drop out of suspension in the exhaust gas stream and adhere to the filter surface and drop.

DPFs must be durable and continue to perform in a high temperature, dirty atmosphere for long periods and heavy engine use. Much like a catalytic converter, DPFs utilize a honeycomb design to allow gases to pass through and provide ample surface area for the PM to adhere to. Material used to construct DPFs can include ceramic material (cordierite) which is relatively affordable, ceramic fibers which are woven together to provides porosity, silicon carbide which has a high melting point (melting point of almost 5,000 °F), woven metal fibers which allow for an electric current for surface area regeneration and paper which is affordable and disposable. Capture needs and affordability are often the deciding factors in determining the appropriate filter for a certain application.

As the filter's available surface area is used, it is necessary to periodically regenerate it. This is accomplished by oxidizing (burning) the soot that has accumulated on the filter surfaces. Soot burns at temperatures greater than 500 °F. Soot burning can be accomplished passively by using the heat of the engine's exhaust gas. This process may include adding a catalyst to the filter to increase the rate at which the soot can be combusted. Active strategies to regenerate filter surface areas include alternative methods to heat the engine's exhaust gases to temperatures that ignite the soot and combustible material captured by the filter. These active methods can include microwave energy, electric (resistive) heating coils, increasing exhaust gas temperatures through engine tuning (late fuel injection or fuel injection during the exhaust stroke), introducing a catalyst into the fuel which will react with soot to lower soot combustion temperatures, post turbo fuel burners and catalytic oxidizers to name a few.

Basic Reactions[67]:

$$C\ (soot) + O_2 \rightarrow CO_2$$
$$CO + \tfrac{1}{2}\,O_2 \rightarrow CO_2$$
$$C_xH_y + O_2 \rightarrow CO_2 + H_2O$$

[66] Air Emissions from Marine Vessels, January 2020, Maine Department of Environmental Protection, Appendix B. Diesel Particulate Filters, https://www.barharbormaine.gov/DocumentCenter/View/4878/Marine-Vessels-Air-Emissions-1-2020

[67] MARINE-X® Diesel Particulate Filters, https://dcl-inc.com/pdf/brochures-product-specification-sheets/MARINE-X-Diesel-Particulate-Filter.pdf

Appendix B – Ferry General Arrangement

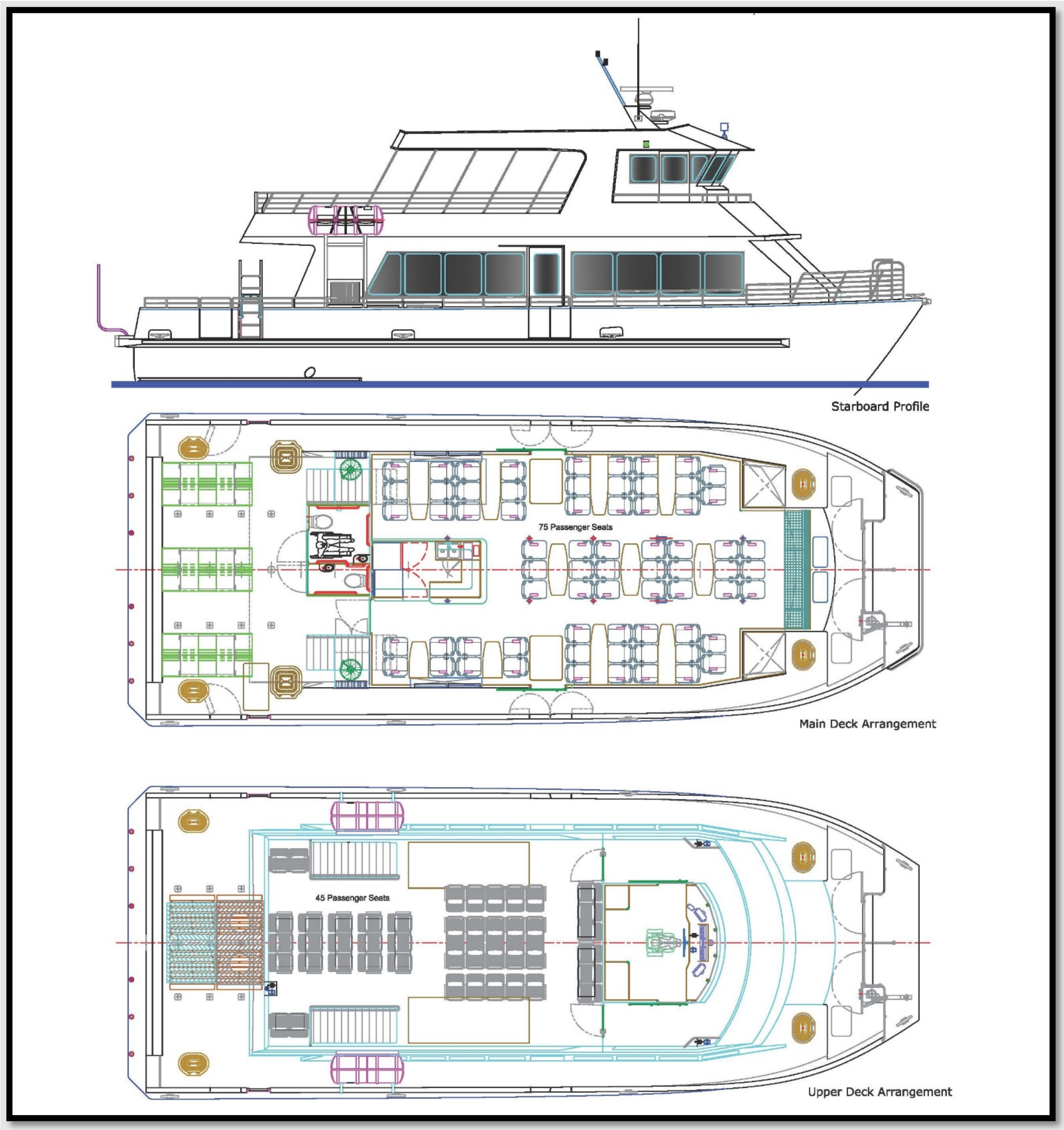


Figure 15: Ferry General Arrangement

Appendix C – Line Towing Vessel General Arrangement

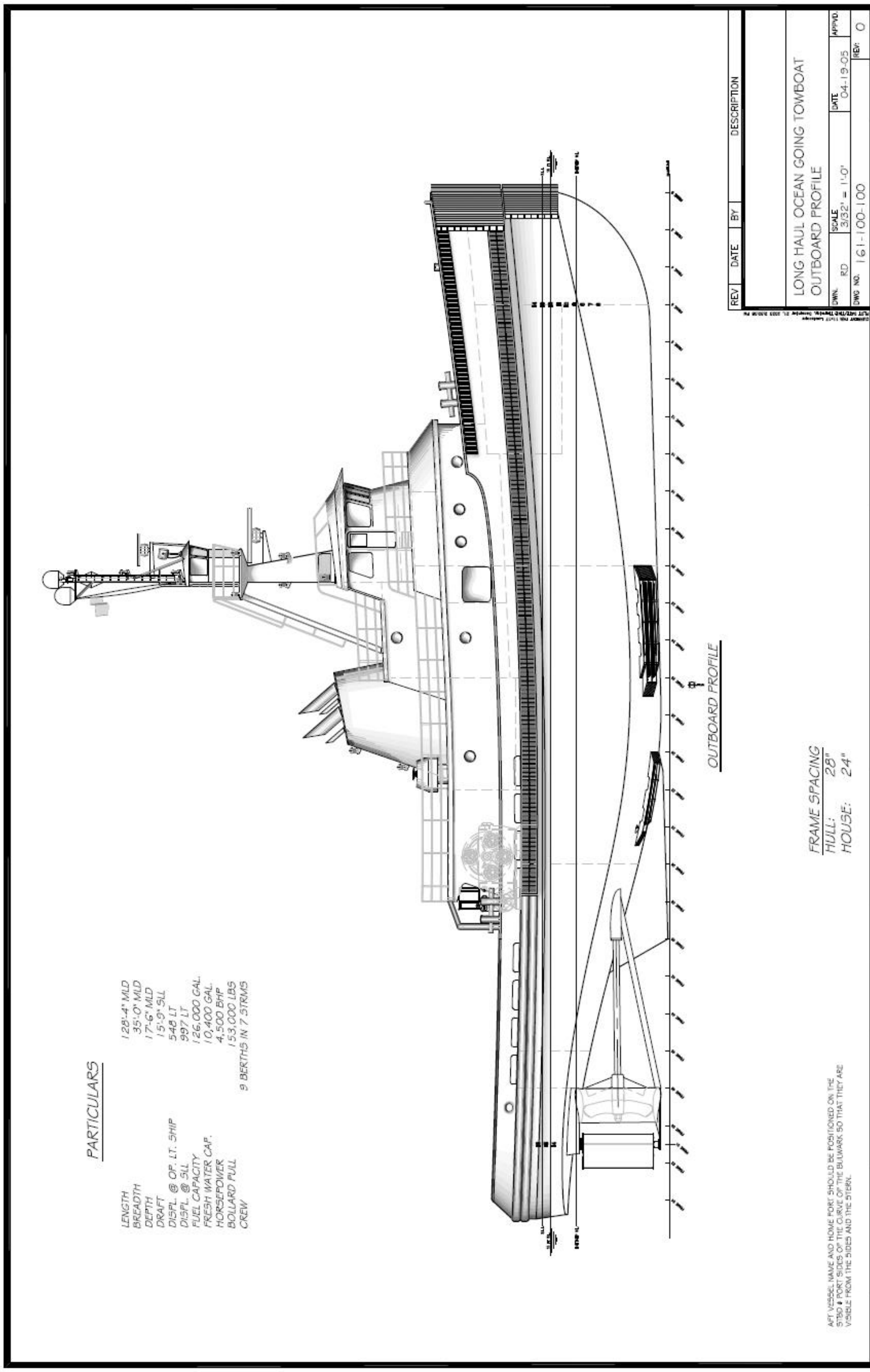


Figure 16: Line Towing Vessel Outboard Profile

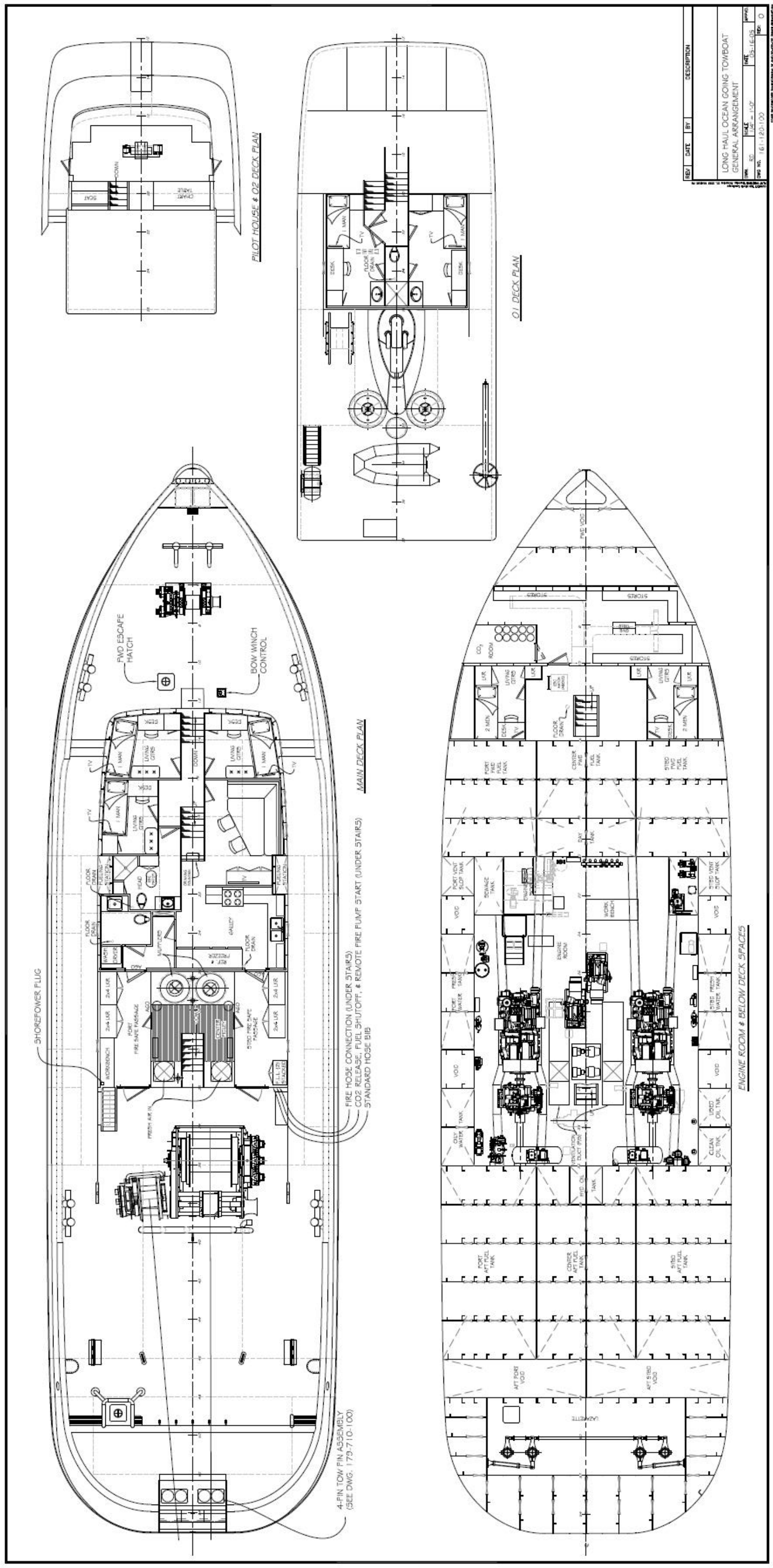


Figure 17: Line Towing Vessel General Arrangement

Appendix D – Weights[68]

All units of weight in this appendix are in lbs.

ATB Barge Weight				
Component	**Original**	**Weight (lb)**	**Replacement**	**Weight (lb)**
Main Engine	2x Cat 3512B	26800	2x CAT 3512E	36050
Auxiliary Engine(s)	2x CAT 3512B	26800	2x CAT 3512C	33016
	1x Cat D-60	2054	1x CAT C4.4	2338
SCR System			CAT SCR System	2783.3
DPF (Main)			2x ADPF-4NS	6800[69]
DPF (Aux. 3512C)			2x ADPF-4NS	6800.00
DPF (Aux. C4.4)			1x RH-304-M	150.00
Urea Tank			N/A	10957.2[70]

ATB Tug Weight				
Component	**Original**	**Weight (lb)**	**Replacement**	**Weight (lb)**
Main Engine	2x Cat 3612	55300	CAT C280-12	57276
Auxiliary Engine(s)	2x John Deere Model 6090SFM85	4656	N/A	N/A
SCR System			CAT SCR System	9800
DPF (Main)			2x ADPF-10NS	15000[69]
DPF (Aux.)			2x RH408-M	290.00
Urea Tank			-	74401.32[70]

Line Towing Vessel Weight				
Component	**Original**	**Weight (lb)**	**Replacement**	**Weight (lb)**
Main Engine	2x MTU 16V 4000 M64	39992	2x MTU 16V 4000 M05	41000
Auxiliary Engine(s)	2x John Deere Model 4045AFM85	1274	N/A	N/A
SCR System			MTU SCR System	11760[71]
DPF (Main)			2x ADPF-6-NS	8600[69]
DPF (Aux.)			2x RH404-M	200.00
Urea Tank			-	61778[70]

68 Weights shown in this Appendix are in pounds (lbs.)
69 Included 10% Margin
70 9.2 lbs. per gallon, https://semlerindustries.com/def-faq#:~:text=as%20a%20fertilizer.-,Q.,to%209.2%20pounds%20per%20gallon.
71 Reasonable estimation made as public data was unavailable.

Ferry Weight				
Component	**Original**	**Weight (lb)**	**Replacement**	**Weight (lb)**
Main Engine	2x QSK 19-M	4826	Yanmar 6AYEM-GTWS	2418
Auxiliary Engine(s)	Northern Lights M843NW3G	743	N/A	N/A
SCR System			Yanmar Included SCR	N/A
DPF (Main)			2x RH-410-L	1250[69]
DPF (Aux.)			1x TBA	45.00
Urea Tank			-	460[70]

Appendix E – Dimensions

ATB Barge Dimensions				
Component	**Original**	**Dimensions (L"xW"xH")**	**Replacement**	**Dimensions (L"xW"xH")**
Main Engine	2x Cat 3512B	120.8x70.3x71.1	2x CAT 3512E	104.2 x 91.9 x 81.9
Auxiliary Engine(s)	2x CAT 3512B	120.8x70.3x71.1	2x CAT 3512C	104.2 x 87.5 x 80.2
	1x Cat D-60	77.2x43.3x48	1x CAT C4.4	68.9 x 47.8 x 39.4
SCR System			CAT SCR System	135.97 x 64.06 x 39.86
DPF (Main)			2x ADPF-4NS	78-83 x 98-104 x 38-43
DPF (Aux. 3512C)			2x ADPF-4NS	78-83 x 98-104 x 38-44
DPF (Aux. C4.4)			1x RH-304-M	L = 50" x D = 20.75"
Urea Tank			N/A	65.04 x 65.04 x 65.04

ATB Tug Dimensions				
Component	**Original**	**Dimensions (L"xW"xH")**	**Replacement**	**Dimensions (L"xW"xH")**
Main Engine	2x Cat 3612	180x67x127	CAT C280-12	182 x 80 x 134
Auxiliary Engine(s)	2x John Deere Model 6090SFM85	67.4x55.7x38.7	N/A	N/A
SCR System			CAT SCR System	71.9 x 78.8 x 152.3
DPF (Main)			2x ADPF-10NS	98-102 x 98-104 x 78-84
DPF (Aux.)			2x RH408-M	L = 50" x D = 20.75"
Urea Tank			N/A	123.12 x 123.12 x 123.12

Line Towing Vessel Dimensions				
Component	**Original**	**Dimensions (L"xW"xH")**	**Replacement**	**Dimensions (L"xW"xH")**
Main Engine	2x MTU 16V 4000 M64	122.4x66.5x81.3	2x MTU 16V 4000 M05	126 x 61 x 81
Auxiliary Engine(s)	2x John Deere Model 4045AFM85	43.5x35x37.9	N/A	N/A
SCR System			MTU SCR System	91.14 x 47.24 x 32.68 63 x 63 x 32.68
DPF (Main)			2x ADPF-6-NS	78-83 x 98-104 x 49-54
DPF (Aux.)			2x RH404-M	L = 50" x D = 20.75"
Urea Tank			N/A	115.8 x 115.8 x 115.8

Ferry Dimensions				
Component	**Original**	**Dimensions (L"xW"xH")**	**Replacement**	**Dimensions (L"xW"xH")**
Main Engine	2x QSK 19-M	79.12x47.25x42.82	Yanmar 6AYEM-GTWS	84.84 x 24.09 x 31.69
Auxiliary Engine(s)	Northern Lights M843NW3G	38.5x19.0x25.3	N/A	N/A
SCR System			Yanmar Included SCR	N/A
DPF (Main)			2x RH-410-L	81 x 14 x 28
DPF (Aux.)			1x TBA	L = 36" x D = 6"
Urea Tank			N/A	22.56 x 22.56 x 22.56

Appendix F – Prices[72]

ATB Barge Price				
Component	**Original**	**Price**	**Replacement**	**Price**
Main Engine	2x Cat 3512B	$3,356,561.94	2x CAT 3512E	$4,441,954.86
Auxiliary Engine(s)	2x CAT 3512B	$2,517,421.45	2x CAT 3512C	$3,331,466.15
	1x Cat D-60	$219,588.16[73]	1x CAT C4.4	$235,273.03[73]
SCR System			CAT SCR System	Included in engine
DPF (Main)			2x ADPF-4NS	$345,000.00[74]
DPF (Aux. 3512C)			2x ADPF-4NS	$345,000.00
DPF (Aux. C4.4)			1x RH-304-M	$45,000.00
Urea Tank			N/A	$7,146.00[75]

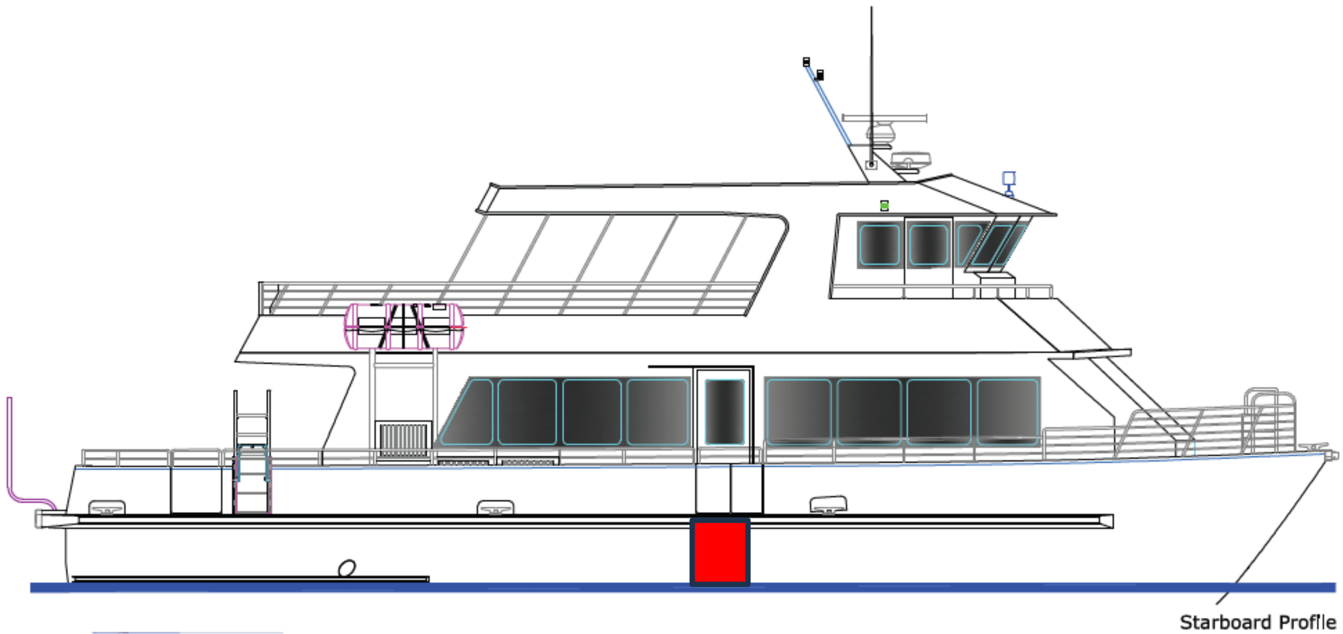
ATB Tug Price				
Component	**Original**	**Price**	**Replacement**	**Price**
Main Engine	2x Cat 3612	$3,156,834.71	CAT C280-12	$7,755,107.64
Auxiliary Engine(s)	2x John Deere Model 6090SFM85	$518,389.55[73]	N/A	N/A
SCR System			CAT SCR System	included in engine
DPF (Main)			2x ADPF-10NS	$760,000.00[74]
DPF (Aux.)			2x RH408-M	$120,000.00
Urea Tank			N/A	$48,522.00

Line Towing Vessel Price				
Component	**Original**	**Price**	**Replacement**	**Price**
Main Engine	2x MTU 16V 4000 M64	$2,449,733.15	2x MTU 16V 4000 M05	$3,156,834.71
Auxiliary Engine(s)	2x John Deere Model 4045AFM85	$171,567.10[73]	N/A	N/A
SCR System			MTU SCR System	Included in engine
DPF (Main)			2x ADPF-6-NS	$450,000.00[74]
DPF (Aux.)			2x RH404-M	$95,000.00
Urea Tank			N/A	$40,290.00

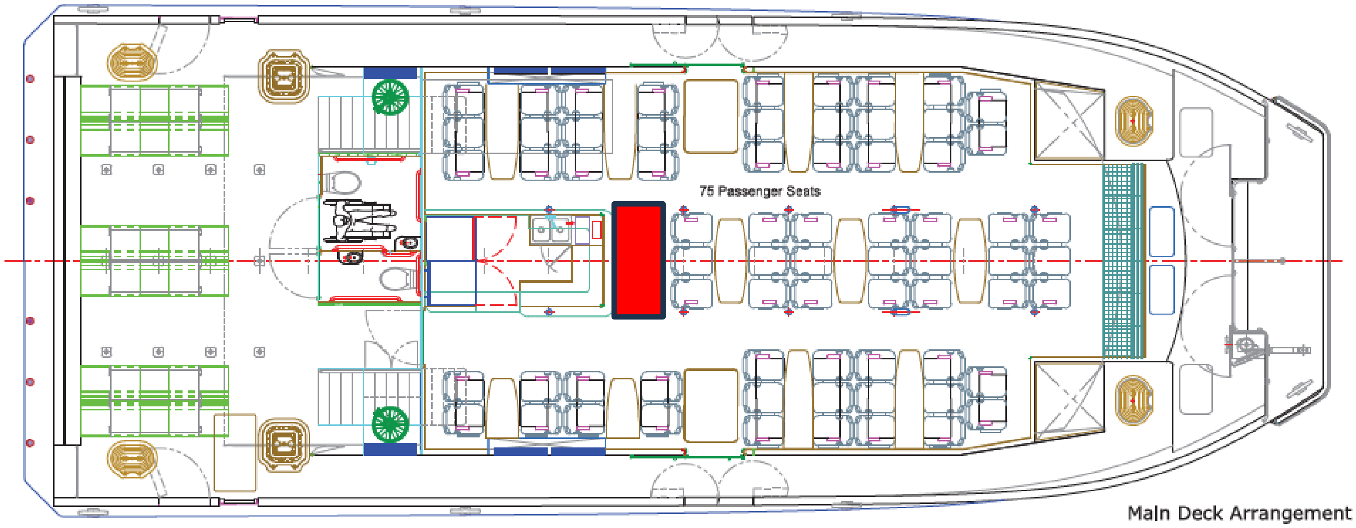
72 Prices in this Appendix are in United States Dollars (USD)
73 Reasonable approximation, extrapolated from available main engine price by kW sizing.
74 Includes 15% allowance for system bypass @ customer request.
75 Assumed to be $6/gal, which is the cost to fill urea tank and not to construct.

Ferry Price				
Component	**Original**	**Price**	**Replacement**	**Price**
Main Engine	2x QSK 19-M	$1,000,000.00	2x Yanmar 6AYEM-GTWS	$1,250,000.00
Auxiliary Engine(s)	Northern Lights M843NW3G	$22,091.31[73]	N/A	N/A
SCR System			Yanmar Included SCR	Included in engine
DPF (Main)			2x RH-410-L	$160,000.00[74]
DPF (Aux.)			1x TBA	$10,000.00
Urea Tank			N/A	$300.00

Appendix G – Estimated Urea Tank Location for Passenger Ferry[76]

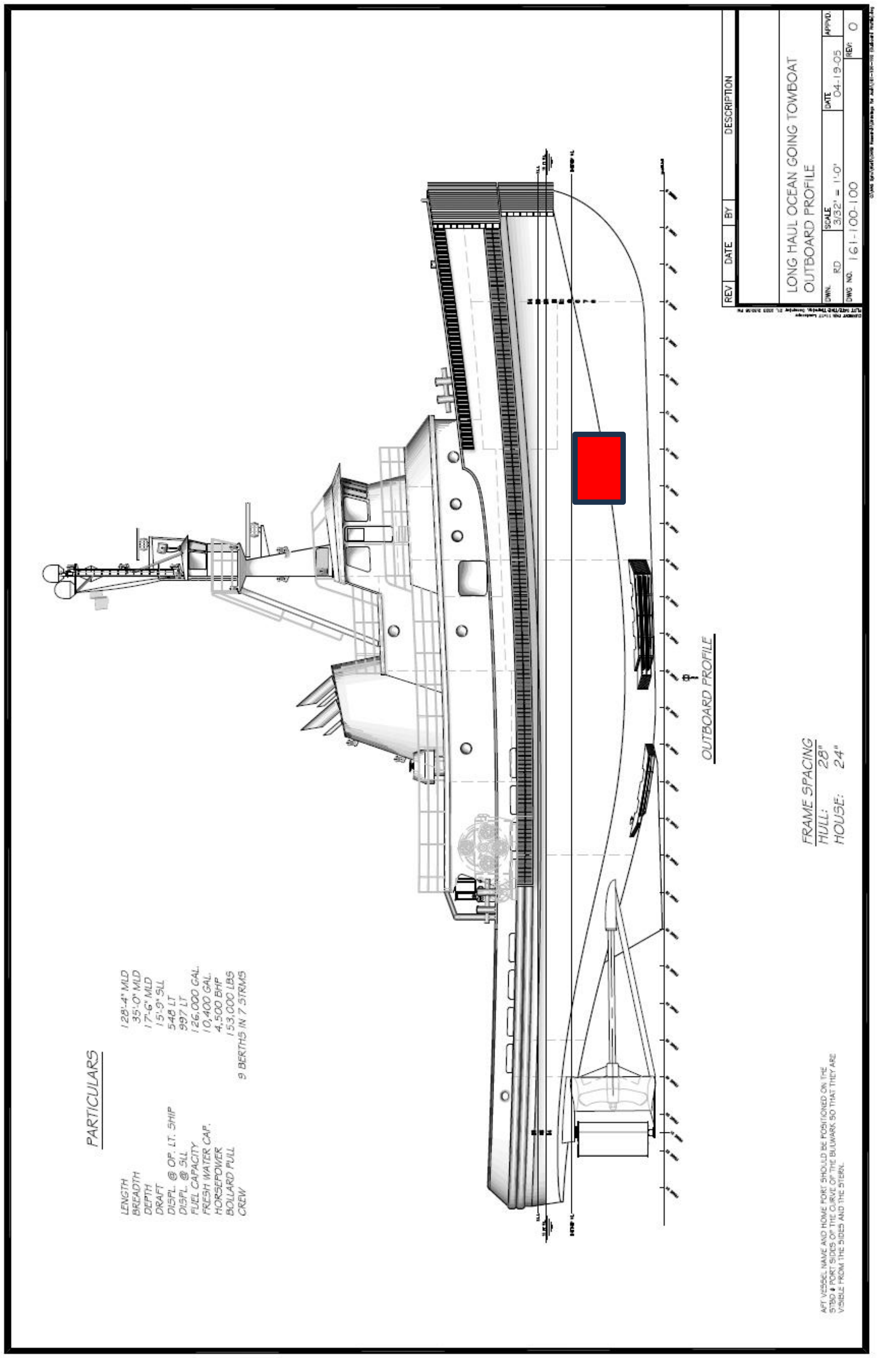


[76] Tanks are shown in red. Dimensions and location shown here are not exactly to scale but a close approximation.

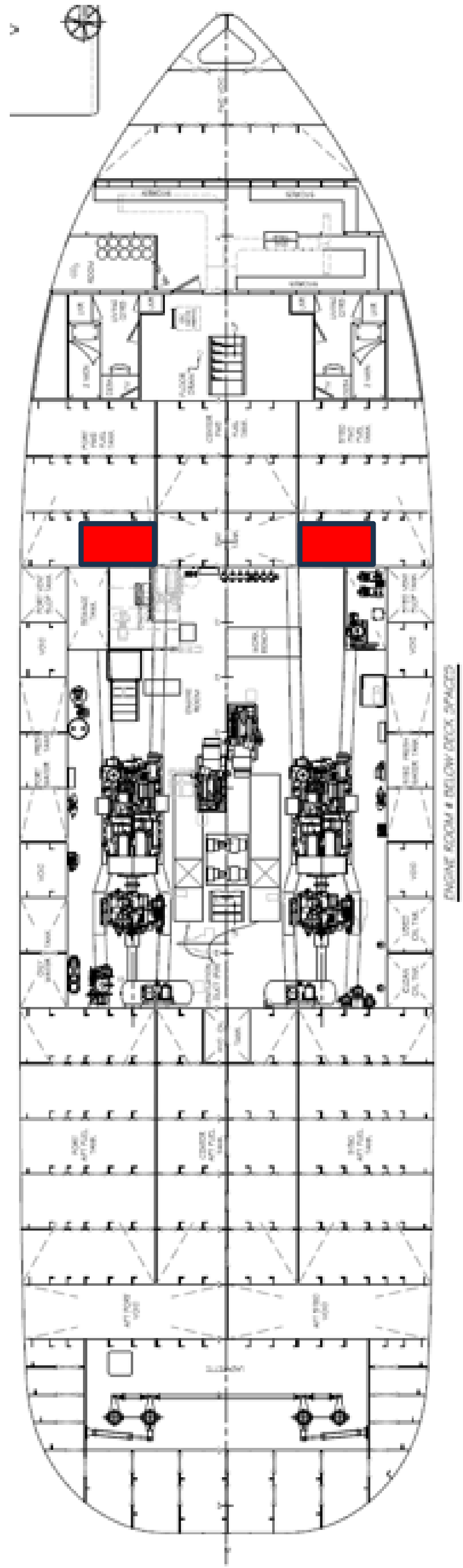

75 Passenger Seats
Main Deck Arrangement

Appendix H – Estimated Urea Tank Location for Line Towing Vessel[77]

Note: Urea tanks cannot be located right next to fuel tanks, so a void is also added to the area around the urea tanks (not shown in the picture in this appendix).



[77] Tanks are shown in red. Dimensions and location shown here are not exactly to scale but a close approximation.


ENGINE ROOM & BELOW DECK SPACES

Appendix I – Backpressure Calculations

Table 44: Summary of Backpressure Calculations

Vessel Type	Engine Type	Manufacturer	Model	Backpressure Limit (inches of water)	Calculated Backpressure (Engine 1) (inches of water)	Calculated Backpressure (Engine 2) (inches of water)
Ferry	Main	Baudouin	6M-26.3	24	3.27	3.90
Ferry	Main	Yanmar	6AYEM-GTWS	76.4	6.52	7.77
Ferry	Main	Caterpillar	C32	26.9	6.01	7.16
Ferry	Aux.	Northern Lights	M843NW3G	48	6.83	N/A
ATB-Tug	Main	GE (Wabtec)	12V250MDC	40.8	9.43	9.43
ATB-Tug	Main	Caterpillar	C280-12	27	13.76	13.76
ATB-Tug	Aux.	John Deere	6090SFM85	30	3.3	N/A
ATB-Barge	Main	Caterpillar	3512E	34	4.60	4.60
ATB-Barge	Main	Cummins	QSK38	28.1	2.56	2.56
ATB-Barge	Main	MTU	12V-4000M05	40.8	5.85	5.85
ATB-Barge	Aux.	Caterpillar	C4.4	60.2	1.69	N/A
Line Towing Vessel	Main.	Caterpillar	3516E	34	17.11	17.11
Line Towing Vessel	Main	Cummins	QSK60	10	4.93	4.93
Line Towing Vessel	Main	MTU	16V-4000M05	10	8.74	8.74
Line Towing Vessel	Aux.	John Deere	4045AFM85	30	1.66	N/A

Equations Used:

Gas volume and Resistance:

$$\boldsymbol{v} = \frac{\left[{}^{\boldsymbol{VE}}\!\Big/\!\left(\boldsymbol{\pi D^2}/_{\boldsymbol{4}}\right)\right]}{\boldsymbol{60}}$$

Straight Pipe Resistance:

$$\Delta \boldsymbol{P} = \frac{\boldsymbol{\lambda} * \left({}^{\boldsymbol{L}}/_{\boldsymbol{D}}\right) * \left(\boldsymbol{\gamma} * \boldsymbol{v}^2\right)}{\boldsymbol{2000}}$$

Elbow Resistance:

$$\Delta \boldsymbol{P}' = \frac{\boldsymbol{\zeta} * \boldsymbol{\gamma} * \boldsymbol{v}^2}{\boldsymbol{2000}}$$

Total Resistance:

$$\boldsymbol{P} = \Delta \boldsymbol{P} * \boldsymbol{L} + \Delta \boldsymbol{P}' * \boldsymbol{N} + \boldsymbol{PM}$$

K.1 Ferry

K.1.1 Engine 1 - 6M-26.3

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	120.9979001	m^3/min
D (Internal diameter of Exhaust Pipe)	0.254	m
v (Gas Speed)	39.79873498	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.254	m
y (Specific Gravity of Gas at 673 K)	0.399965636	kg/m^3
v (Gas Speed)	39.79873498	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.037412675	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.51	m
y	0.399965636	kg/m^3
v	39.79873498	m/s
ΔP' (Elbow Resistance per elbow)	0.161547929	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.037412675	kPa/m
L	8.813522987	m
ΔP'	0.161547929	kPa/m
N (Number of Elbows)	3	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	0.814381257	kPa
P	3.27299827	in of water

K.1.2 Engine 1 - 6AYEM-GTWS

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	159.8203014	m^3/min
D (Internal diameter of Exhaust Pipe)	0.254	m
v (Gas Speed)	52.56823315	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.254	m
y (Specific Gravity of Gas at 673 K)	0.457028796	kg/m^3
v (Gas Speed)	52.56823315	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.074584377	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.51	m
y	0.457028796	kg/m^3
v	52.56823315	m/s
ΔP' (Elbow Resistance per elbow)	0.322055341	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.074584377	kPa/m
L	8.813522987	m
ΔP'	0.322055341	kPa/m
N (Number of Elbows)	3	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	1.623517145	kPa
P	6.524915405	in of water

K.1.3 Engine 1 - C32

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	135.4989589	m^3/min
D (Internal diameter of Exhaust Pipe)	0.254	m
v (Gas Speed)	44.56843594	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.254	m
y (Specific Gravity of Gas at 673 K)	0.585560959	kg/m^3
v (Gas Speed)	44.56843594	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.068688565	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.51	m
y	0.585560959	kg/m^3
v	44.56843594	m/s
ΔP' (Elbow Resistance per elbow)	0.296597223	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.068688565	kPa/m
L	8.813522987	m
ΔP'	0.296597223	kPa/m
N (Number of Elbows)	3	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	1.495179916	kPa
P	6.009128081	in of water

K.1.4 Engine 2 - 6M-26.3

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	120.9979	m^3/min
D (Internal diameter of Exhaust Pipe)	0.254	m
v (Gas Speed)	39.79873	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.254	m
y (Specific Gravity of Gas at 673 K)	0.399966	kg/m^3
v (Gas Speed)	39.79873	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.037413	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.51	m
y	0.399966	kg/m^3
v	39.79873	m/s
ΔP' (Elbow Resistance per elbow)	0.161548	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.037413	kPa/m
L	8.650945	m
ΔP'	0.161548	kPa/m
N (Number of Elbows)	4	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	0.969847	kPa
P	3.897814	in of water

K.1.5 Engine 2 - 6AYEM-GTWS

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	159.8203	m^3/min
D (Internal diameter of Exhaust Pipe)	0.254	m
v (Gas Speed)	52.56823	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.254	m
y (Specific Gravity of Gas at 673 K)	0.457029	kg/m^3
v (Gas Speed)	52.56823	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.074584	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.51	m
y	0.457029	kg/m^3
v	52.56823	m/s
ΔP' (Elbow Resistance per elbow)	0.322055	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.074584	kPa/m
L	8.650945	m
ΔP'	0.322055	kPa/m
N (Number of Elbows)	4	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	1.933447	kPa
P	7.770522	in of water

K.1.6 Engine 2 – C32

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	135.499	m^3/min
D (Internal diameter of Exhaust Pipe)	0.254	m
v (Gas Speed)	44.56844	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.254	m
y (Specific Gravity of Gas at 673 K)	0.585561	kg/m^3
v (Gas Speed)	44.56844	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.068689	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.51	m
y	0.585561	kg/m^3
v	44.56844	m/s
ΔP' (Elbow Resistance per elbow)	0.296597	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.068689	kPa/m
L	8.650945	m
ΔP'	0.296597	kPa/m
N (Number of Elbows)	4	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	1.78061	kPa
P	7.156271	in of water

K.1.7 Auxiliary Engine – M843NW

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	159.82	m^3/min
D (Internal diameter of Exhaust Pipe)	0.254	m
v (Gas Speed)	52.56813	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.254	m
y (Specific Gravity of Gas at 673 K)	0.696	kg/m^3
v (Gas Speed)	52.56813	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.113583	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.51	m
y	0.696	kg/m^3
v	52.56813	m/s
ΔP' (Elbow Resistance per elbow)	0.49045	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.113583	kPa/m
L	2.001016	m
ΔP'	0.49045	kPa/m
N (Number of Elbows)	3	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	1.69863	kPa
P	6.826794	in of water

K.2 ATB-Tug

K.2.1 Engine 1 – C280-12

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	732.7268	m^3/min
D (Internal diameter of Exhaust Pipe)	0.4064	m
v (Gas Speed)	94.1442	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.4064	m
y (Specific Gravity of Gas at 673 K)	0.438656	kg/m^3
v (Gas Speed)	94.1442	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.143499	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.438656	kg/m^3
v	94.1442	m/s
ΔP' (Elbow Resistance per elbow)	0.699815	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.143499	kPa/m
L	9.215258	m
ΔP'	0.699815	kPa/m
N (Number of Elbows)	3	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	3.421825	kPa
P	13.75232	in of water

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	732.7268	m^3/min
D (Internal diameter of Exhaust Pipe)	1.22	m
v (Gas Speed)	10.44675	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	1.22	m
y (Specific Gravity of Gas at 673 K)	0.438656	kg/m^3
v (Gas Speed)	10.44675	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.000589	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.438656	kg/m^3
v	10.44675	m/s
ΔP' (Elbow Resistance per elbow)	0.008617	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.000589	kPa/m
L	3.375413	m
ΔP'	0.008617	kPa/m
N	0	
PM	0	
P	0.001987	kPa
P_{total}	3.423812	kPa
P	0.007985	in of water
P_{total}	13.7603	in of water

K.2.2 Engine 1 – 12V250MDC

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	540.9934	m^3/min
D (Internal diameter of Exhaust Pipe)	0.4064	m
v (Gas Speed)	69.50939	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.4064	m
y (Specific Gravity of Gas at 673 K)	0.551611	kg/m^3
v (Gas Speed)	69.50939	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.098369	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.551611	kg/m^3
v	69.50939	m/s
ΔP' (Elbow Resistance per elbow)	0.479725	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.098369	kPa/m
L	9.215258	m
ΔP'	0.479725	kPa/m
N (Number of Elbows)	3	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	2.34567	kPa
P	9.427249	in of water

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	540.9934	m^3/min
D (Internal diameter of Exhaust Pipe)	1.22	m
v (Gas Speed)	7.71314	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	1.22	m
y (Specific Gravity of Gas at 673 K)	0.551611	kg/m^3
v (Gas Speed)	7.71314	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.000403	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.551611	kg/m^3
v	7.71314	m/s
ΔP' (Elbow Resistance per elbow)	0.005907	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.000403	kPa/m
L	3.375413	m
ΔP'	0.005907	kPa/m
N	0	
PM	0	
P	0.001362	kPa
P_{total}	2.347032	kPa
P	0.005474	in of water
P_{total}	9.432723	in of water

K.2.3 Auxiliary Engine – 6090SFM85

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	43.80617	m^3/min
D (Internal diameter of Exhaust Pipe)	0.165862	m
v (Gas Speed)	33.79081	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.165862	m
y (Specific Gravity of Gas at 673 K)	0.529768	kg/m^3
v (Gas Speed)	33.79081	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.054705	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.529768	kg/m^3
v	33.79081	m/s
ΔP' (Elbow Resistance per elbow)	0.108882	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.054705	kPa/m
L	11.04013	m
ΔP'	0.108882	kPa/m
N (Number of Elbows)	2	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	0.821713	kPa
P	3.302465	in of water

K.3 ATB-Barge

K.3.1 Engine 1 – 3512E

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	305.7597	m^3/min
D (Internal diameter of Exhaust Pipe)	0.323851	m
v (Gas Speed)	61.86565	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.323851	m
y (Specific Gravity of Gas at 673 K)	0.438105	kg/m^3
v (Gas Speed)	61.86565	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.077665	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.438105	kg/m^3
v	61.86565	m/s
ΔP' (Elbow Resistance per elbow)	0.301822	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.077665	kPa/m
L	2.991455	m
ΔP'	0.301822	kPa/m
N (Number of Elbows)	3	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	1.137795	kPa
P	4.572799	in of water

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	305.7597	m^3/min
D (Internal diameter of Exhaust Pipe)	0.609601	m
v (Gas Speed)	17.46013	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.609601	m
y (Specific Gravity of Gas at 673 K)	0.438105	kg/m^3
v (Gas Speed)	17.46013	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.003286	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.438105	kg/m^3
v	17.46013	m/s
ΔP' (Elbow Resistance per elbow)	0.024041	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.003286	kPa/m
L	1.915672	m
ΔP'	0.024041	kPa/m
N	0	
PM	0	
P	0.006296	kPa
P_{total}	1.144091	kPa
P	0.025302	in of water
P_{total}	4.598102	in of water

K.3.2 Engine 1 – QSK38

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	219.314	m^3/min
D (Internal diameter of Exhaust Pipe)	0.323851	m
v (Gas Speed)	44.37473	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.323851	m
y (Specific Gravity of Gas at 673 K)	0.473772	kg/m^3
v (Gas Speed)	44.37473	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.04321	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.473772	kg/m^3
v	44.37473	m/s
ΔP' (Elbow Resistance per elbow)	0.167924	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.04321	kPa/m
L	2.991455	m
ΔP'	0.167924	kPa/m
N (Number of Elbows)	3	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	0.633034	kPa
P	2.544165	in of water

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	219.314	m^3/min
D (Internal diameter of Exhaust Pipe)	0.609601	m
v (Gas Speed)	12.52373	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.609601	m
y (Specific Gravity of Gas at 673 K)	0.473772	kg/m^3
v (Gas Speed)	12.52373	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.001828	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.473772	kg/m^3
v	12.52373	m/s
ΔP' (Elbow Resistance per elbow)	0.013375	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.001828	kPa/m
L	1.915672	m
ΔP'	0.013375	kPa/m
N	0	
PM	0	
P	0.003503	kPa
P_{total}	0.636537	kPa
P	0.014077	in of water
P_{total}	2.558242	in of water

K.3.3 Engine 1 – 12V-4000M05

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	324.0014	m^3/min
D (Internal diameter of Exhaust Pipe)	0.323851	m
v (Gas Speed)	65.55657	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.323851	m
y (Specific Gravity of Gas at 673 K)	0.496686	kg/m^3
v (Gas Speed)	65.55657	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.098869	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.496686	kg/m^3
v	65.55657	m/s
ΔP' (Elbow Resistance per elbow)	0.384226	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.098869	kPa/m
L	2.991455	m
ΔP'	0.384226	kPa/m
N (Number of Elbows)	3	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	1.44844	kPa
P	5.82128	in of water

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	324.0014	m^3/min
D (Internal diameter of Exhaust Pipe)	0.609601	m
v (Gas Speed)	18.5018	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.609601	m
y (Specific Gravity of Gas at 673 K)	0.496686	kg/m^3
v (Gas Speed)	18.5018	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.004184	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.496686	kg/m^3
v	18.5018	m/s
ΔP' (Elbow Resistance per elbow)	0.030604	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.004184	kPa/m
L	1.915672	m
ΔP'	0.030604	kPa/m
N	0	
PM	0	
P	0.008014	kPa
P_{total}	1.456454	kPa
P	0.03221	in of water
P_{total}	5.85349	in of water

K.3.4 Engine 1 – 12M-26.3

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	252.9544	m^3/min
D (Internal diameter of Exhaust Pipe)	0.323851	m
v (Gas Speed)	51.18133	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.323851	m
y (Specific Gravity of Gas at 673 K)	0.424265	kg/m^3
v (Gas Speed)	51.18133	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.051476	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.424265	kg/m^3
v	51.18133	m/s
ΔP' (Elbow Resistance per elbow)	0.200047	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.051476	kPa/m
L	2.991455	m
ΔP'	0.200047	kPa/m
N (Number of Elbows)	3	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	0.754131	kPa
P	3.030852	in of water

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	252.9544	m^3/min
D (Internal diameter of Exhaust Pipe)	0.609601	m
v (Gas Speed)	14.44473	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.609601	m
y (Specific Gravity of Gas at 673 K)	0.424265	kg/m^3
v (Gas Speed)	14.44473	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.002178	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.424265	kg/m^3
v	14.44473	m/s
ΔP' (Elbow Resistance per elbow)	0.015934	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.002178	kPa/m
L	1.915672	m
ΔP'	0.015934	kPa/m
N	0	
PM	0	
P	0.004173	kPa
P_{total}	0.758304	kPa
P	0.01677	in of water
P_{total}	3.047622	in of water

K.3.4 Auxiliary Engine – C4.4

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	14.49823	m^3/min
D (Internal diameter of Exhaust Pipe)	0.113792	m
v (Gas Speed)	23.76012	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.113792	m
y (Specific Gravity of Gas at 673 K)	0.380816	kg/m^3
v (Gas Speed)	23.76012	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.028339	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.380816	kg/m^3
v	23.76012	m/s
ΔP' (Elbow Resistance per elbow)	0.038698	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.028339	kPa/m
L	6.610109	m
ΔP'	0.038698	kPa/m
N (Number of Elbows)	6	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	0.419512	kPa
P	1.686021	in of water

K.4 Line Towing Vessel

K.4.1 Engine 1 – 3516E

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	645.7997	m^3/min
D (Internal diameter of Exhaust Pipe)	0.406401	m
v (Gas Speed)	82.97507	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.406401	m
y (Specific Gravity of Gas at 673 K)	0.461682	kg/m^3
v (Gas Speed)	82.97507	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.117321	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.461682	kg/m^3
v	82.97507	m/s
ΔP' (Elbow Resistance per elbow)	0.572151	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.117321	kPa/m
L	11.87376	m
ΔP'	0.572151	kPa/m
N (Number of Elbows)	5	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	4.253792	kPa
P	17.09599	in of water

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	645.7997	m^3/min
D (Internal diameter of Exhaust Pipe)	1.068834	m
v (Gas Speed)	11.99599	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	1.068834	m
y (Specific Gravity of Gas at 673 K)	0.461682	kg/m^3
v (Gas Speed)	11.99599	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.000932	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.461682	kg/m^3
v	11.99599	m/s
ΔP' (Elbow Resistance per elbow)	0.011959	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.000932	kPa/m
L	3.320041	m
ΔP'	0.011959	kPa/m
N	0	
PM	0	
P	0.003096	kPa
P_{total}	4.256888	kPa
P	0.012441	in of water
P_{total}	17.10843	in of water

K.4.2 Engine 1 – QSK60

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	377.2937	m^3/min
D (Internal diameter of Exhaust Pipe)	0.406401	m
v (Gas Speed)	48.47628	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.406401	m
y (Specific Gravity of Gas at 673 K)	0.389699	kg/m^3
v (Gas Speed)	48.47628	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.033801	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.389699	kg/m^3
v	48.47628	m/s
ΔP' (Elbow Resistance per elbow)	0.164839	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.033801	kPa/m
L	11.87376	m
ΔP'	0.164839	kPa/m
N (Number of Elbows)	5	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	1.225535	kPa
P	4.925426	in of water

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	377.2937	m^3/min
D (Internal diameter of Exhaust Pipe)	1.068834	m
v (Gas Speed)	7.008383	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	1.068834	m
y (Specific Gravity of Gas at 673 K)	0.389699	kg/m^3
v (Gas Speed)	7.008383	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.000269	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.389699	kg/m^3
v	7.008383	m/s
ΔP' (Elbow Resistance per elbow)	0.003445	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.000269	kPa/m
L	3.320041	m
ΔP'	0.003445	kPa/m
N	0	
PM	0	
P	0.000892	kPa
P_{total}	1.226427	kPa
P	0.003584	in of water
P_{total}	4.92901	in of water

K.4.3 Engine 1 – 16V-4000M05

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	455.9862	m^3/min
D (Internal diameter of Exhaust Pipe)	0.406401	m
v (Gas Speed)	58.58703	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.406401	m
y (Specific Gravity of Gas at 673 K)	0.47313	kg/m^3
v (Gas Speed)	58.58703	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.05994	kPa/m

Elbow Resistance		
	Value	**Units**
ζ	0.36	m
y	0.47313	kg/m^3
v	58.58703	m/s
ΔP' (Elbow Resistance per elbow)	0.292318	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.05994	kPa/m
L	11.87376	m
ΔP'	0.292318	kPa/m
N (Number of Elbows)	5	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	2.17331	kPa
P	8.734535	in of water

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	455.9862	m^3/min
D (Internal diameter of Exhaust Pipe)	1.068834	m
v (Gas Speed)	8.470128	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	1.068834	m
y (Specific Gravity of Gas at 673 K)	0.47313	kg/m^3
v (Gas Speed)	8.470128	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.000476	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.47313	kg/m^3
v	8.470128	m/s
ΔP' (Elbow Resistance per elbow)	0.00611	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.000476	kPa/m
L	3.320041	m
ΔP'	0.00611	kPa/m
N	0	
PM	0	
P	0.001582	kPa
P_{total}	2.174892	kPa
P	0.006356	in of water
P_{total}	8.740891	in of water

K.4.4 Auxiliary Engine – 4045AFM85

Gas Volume and Speed		
Parameter	**Value**	**Units**
VE (Gas Volume)	19.39704	m^3/min
D (Internal diameter of Exhaust Pipe)	0.127	m
v (Gas Speed)	25.52027	m/s

Straight Pipe Resistance		
Parameter	**Value**	**Units**
L (Pipe Length)	1	m
D (Inside diameter of pipe)	0.406401	m
y (Specific Gravity of Gas at 673 K)	0.493876	kg/m^3
v (Gas Speed)	25.52027	m/s
λ (Friction Coefficient)	0.03	
ΔP (Straight Pipe Resistance)	0.011872	kPa/m

Elbow Resistance		
Parameter	**Value**	**Units**
ζ	0.36	m
y	0.493876	kg/m^3
v	25.52027	m/s
ΔP' (Elbow Resistance per elbow)	0.057898	kPa/m

Total Resistance		
Parameter	**Value**	**Units**
ΔP	0.011872	kPa/m
L	10.43866	m
ΔP'	0.057898	kPa/m
N (Number of Elbows)	5	
PM (Resistance of Mufflers)	0	
P (Total Resistance)	0.413416	kPa
P	1.661518	in of water

Appendix J – Repower-Retrofit-Feasibility Supplemental Reading

A selected list of supplemental reading is listed below for enhancing the understanding of repowers, retrofits and feasibility studies. However, information provided in this appendix is only for reference and has no bearing on this study.

1. NYC Ferry Fuel & Propulsion Feasibility Study Final Report
2. Feasibility study of diesel engine replacement on passenger ships: a system dynamics approach
3. Emission Reduction Strategies Findings Report for The New York/New Jersey Harbor Navigation Project
4. Guemes Island Ferry Propulsion & Power Study
5. M/V Guemes CY2019 Lifecycle Valuation and Propulsion Study
6. M/V Guemes O.N. 601686, Ferry Replacement Plan
7. Dann Marine Towing Tug Gulf Coast Repower Project
8. Small Vessel with Inboard Engine Retrofitting Concepts; Real Boat Tests, Laboratory Hybrid Drive Tests and Theoretical Studies
9. Yanmar Repower Guide
10. U.S.C.G Sector San Francisco – Re-Power Checklist
11. Costs of Emission Reduction Technologies for Category 3 Marine Engines
12. Jennifer G – Marine Diesel Engine Replacement
13. Emission Benefits from Repowering the MV Daniel W. Wise
14. Wabtec EPA T4 / IMO III emissions compliance without urea after-treatment
15. Evaluation of the Feasibility and Costs of Installing Tier 4 Engines and Retrofit Exhaust Aftertreatment on In-Use Commercial Harbor Craft
16. Vessel Electrification Feasibility Study for the New York State Canals
17. Feasibility Study of Replacing the R/V Robert Gordon Sproul with a Hybrid Vessel Employing Zero-emission Propulsion Technology
18. Feasibility Study of Hydrogen as Fuel for PSV Applications
19. Evaluating the Use of Liquefied Natural Gas in Washington State Ferries
20. 144-Car Ferry LNG Fuel Conversion Feasibility Study, Design Report

Appendix K – Report Approval & Release Status and Revision History

Title:	Feasibility Study for Selected Vessel Categories – Vessel Feasibility Review and Consultation for the California Commercial Harbor Craft Regulation: Task 2
Version / Status / Purpose:	Rev 4, 31-Jul-2024, Update report based on comments received for Rev 3
Distribution / Confidentiality:	Privileged and Confidential - Proprietary Information (See Notice on Page 2)
Project Lead / Primary Author:	Robert Fernandez
Keywords:	Harbor Craft, California Air Resources Board (CARB), Feasibility Study
Supervisor:	Shankar Vaidhyanathan
Management Lead:	Kirk H. Waltz
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ABS Project Number:	4871420

Revision History

Revision	Date	Description
1	30-Nov-2023	Initial preliminary release for feedback/comments
2	01-Feb-2024	Second Draft for feedback and comments. Taken into consideration all comments received on Rev 1 and addressed all comments accordingly.
3	30-Apr-2024	Third revision addressing all comments from Rev. 2.
4	31-Jun-2024	Fourth revision addressing all comments from Rev. 3 Final submission to CARB for Task 2.