144-Car Ferry LNG Fuel Conversion Feasibility Study

Life Cycle Cost Analysis

Prepared for
Washington State Ferries
Seattle, WA

File No. 11030.01
1 July 2011
Rev. -

THE GLOSTEN ASSOCIATES
Consulting Engineers Serving the Marine Community

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Revision History

Section	Rev	Description	Date	Approved
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References

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Executive Summary

Washington State Ferries (WSF) is investigating powering the new 144-Car Ferries with liquefied natural gas (LNG) fuel which has potential to reduce operational costs and air emissions when compared to diesel fuel. However, converting to LNG poses technical, regulatory, and economic challenges compared to diesel. The Glosten Associates (Glosten) was tasked to study both the technical and economic feasibility of such a conversion and to identify risks. This study finds that the conversion is both technically feasible and cost effective though technical and regulatory challenges remain. The basis for the cost analysis is the design described in the *144-Car Ferry LNG Fuel Conversion Feasibility Study Design Report* (Ref. 9) as well as cost information provided by WSF and equipment vendors.

There is a higher capital investment required for changing the design to LNG, when compared to diesel. However, the LNG option brings an operational costs savings of approximately $1M per year per vessel. As a result of the fuel cost savings the payback period of the additional capital cost is approximately 6 years.

Three propulsion system design options were evaluated and compared:

1. The existing diesel fueled design with equipment provided by EMD;
2. A dual fuel (LNG/Diesel) design with equipment provided by Wärtsilä;
3. A single fuel (LNG) design with equipment provided by Rolls Royce.

The capital, operational, and lifecycle costs were calculated for all three options. Because the study was for alternative options for main engines and fuel systems, only the costs directly associated with the three propulsion system options were included in the costs. All costs of common elements of the vessel design not related to or impacted by the propulsion system design were excluded. These excluded baseline costs should be considered by WSF in the total vessel capital, operational, and lifecycle costs but are not relevant for a comparison of propulsion system options.

The lifecycle costs, which include both capital and operational costs, were calculated over 30 years. The capital cost estimate includes the installed cost of main engines and gas system equipment as well as additional commissioning, testing, and regulatory approvals needed to accommodate the use of LNG fuel. The operational cost estimate includes the maintenance and repair of the engines and gas systems as well as the consumption of diesel oil, LNG, and lube oil. An inflation rate of 3% per year was used for the operational costs.

The calculated costs of the three options are presented in the following table.

Design Option	Capital Cost	30 Year Lifecycle Costs			Annual Operational Cost (First Year)
		Nominal Cost	Present Value Cost (3% Discount Rate)	Present Value Cost (5% Discount Rate)	
EMD (Diesel Fuel)	$2.45M	$130.00M	$ 80.54M	$ 61.22M	$ 2.68M
Rolls Royce (Gas Fuel)	$9.93M	$76.95M	$50.96M	$40.81M	$ 1.41M
Wärtsilä (Dual Fuel)	$8.52M	$ 93.05M	$ 60.27M	$ 47.47M	$ 1.78M

Section 1 Introduction

Washington State Ferries (WSF) is investigating powering the new 144-Car Ferries with liquefied natural gas (LNG) fuel. The new 144-Car Ferry class is a completed diesel powered vessel design that has not been built to date. Since the design has been carried to a production ready level, a conversion of the existing design is more desirable than a new and optimized design. The design conversion would allow new vessels to be built to utilize LNG as fuel, while maintaining the integrity of the current design.

Glosten was commissioned to study the feasibility of converting the existing diesel fuelled vessel design to LNG fuel. As part of the study, Glosten was tasked with conducting a life cycle cost analysis comparing the capital and lifecycle costs of the existing diesel fueled design and a LNG fuelled design.

An LNG design concept has been developed to retain as much of the existing design as possible while meeting the operational requirements of the ferry service as well as complying with regulatory requirements. The basis for the cost estimate is the design described in the Design Report (Reference 9) as well as cost information provided by WSF and equipment vendors. Three options were evaluated:

- The existing diesel fueled design (equipment provided by EMD)
- A dual fuel design, LNG/Diesel (equipment provided by Wärtsilä)
- A single fuel design, LNG only (equipment provided by Rolls Royce)

Section 2 Methodology

2.1 Capital Costs

Capital costs for main engines and gas storage and supply systems were determined as follows:

- Vendor supplied equipment costs were provided by Rolls Royce and Wärtsilä.
- Capital costs for the existing diesel engines were provided by WSF.
- Shipyard installation costs were estimated based on the design outlined in the Design Report (Reference 9).
- Slight differences in the scope of vendor provided equipment are discussed in this report and have been compensated for in the shipyard installation costs.
- Regulatory comments with a cost impact have been incorporated, where appropriate.

All capital costs were estimated in today's dollars (2011). Inflationary adjustments would be required if capital equipment and shipyard contracts are procured at a later date. As the existing detail design of the diesel powered vessel is nearing completion, additional engineering costs would be required to incorporate the required design modifications for operation on LNG. These engineering costs were not included in the capital costs, but are considered in this report.

2.1.1 Rolls Royce Scope of Supply

The Rolls Royce proposal included the following main components:

- 2 - Main engine (Bergen C26:33L9PG developing 2,190 kW (2,937 HP) at 900 RPM) with auxiliary equipment and exhaust silencer
- 1 - LNG bunkering system (no piping)
- 2 - Gas storage tanks (95 m^3 (25,096 gallon) tank skids)
- 2 - Gas vaporization and heating systems
- Gas supply equipment (no piping)
- Controls for the engine and gas systems
- Gas detection system
- No delivery
- Technical documentation
- 85 man-days of commissioning.

The proposed scope of supply and cost are included in Reference 14.

2.1.2 Wärtsilä Scope of Supply

The Wärtsilä proposal included the following main components:

- Main engines (Wärtsilä 6L34DF developing 2,300 kW (3,084 HP) at 750 RPM)
- 1 - LNG bunkering system and 65m (213 ft) piping
- Gas storage system (LNGPac 194) comprised of a single 194 m^3 (51,249 gallon) tank
- Gas vaporization and heating systems including glycol-water heating system

- Gas supply equipment (no piping)
- Controls for the engine and gas systems
- No gas detection system
- Delivery to Seattle, WA
- Technical documentation
- 60 man-days of commissioning and 3 man-days of sea trial participation

The proposed scope of supply and cost are included in Reference 15.

2.1.3 Shipyard Installation

It is assumed that installation of equipment that is not part of the existing diesel fuelled vessel design will increase the shipyard installation costs. These costs have been estimated. No installation cost changes are assumed where equipment in the existing diesel vessel design has been replaced with similar equipment in the gas fuelled vessel designs. For example, the existing design requires engine foundations and a similar but different foundation would be required for the gas design.

Shipyard supplied equipment and labor have been estimated with a burdened labor rate of $65/hr. Shipyard markups on capital costs have not been estimated. It is assumed that major capital equipment will be owner furnished. The shipyard installation costs are slightly different between the two gas vendors due to minor differences in scope of supply and gas system arrangement.

2.1.4 Design Engineering

As the existing diesel powered vessel design is nearly production ready, additional costs would be incurred to modify the design for operation on LNG fuel. These costs would be a onetime expense and are not significantly affected by the choice of gas supply and engine vendor.

The contract design effort for a gas fuelled vessel will involve selecting a vendor(s) for major equipment and developing the design to a level that can support an accurate shipyard bid. This effort assumes the following:

- Revision of arrangement drawings to include the selected major equipment vendor(s).
- System calculations and engineering necessary to determine secondary equipment requirements.
- System schematics and electrical diagrams for all systems revised as necessary to support the LNG design.
- Secondary support equipment is sized but specific vendors are not selected.
- Regulatory submittal of contract design for initial review prior to release for bid.

The preliminary design described in Reference 9 has been designed to meet the requirements of References 1 and 2, as well as the relevant USCG rules. The designed has been reviewed by both the USCG and Det Norske Veritas (DNV), the Norwegian classification agency with over 10 years of experience in classification of LNG fuelled ships. Written comments that clarify design requirements, and provide additional guidance that will be needed in the development of the contract and production designs have been received from both agencies (References 17 and 18).

While regulatory design review of a preliminary package is atypical, it was considered necessary and was encouraged by the regulators since the technology is just emerging in this country. WSF believes that early involvement of USCG will minimize schedule and cost risk. However, even with early involvement from regulators, an additional cost to WSF for regulatory approvals has been assumed to be approximately $350,000. Developing a contract and production design packages is assumed to add approximately $550,000.

2.1.5 Existing Equipment

WSF has already procured some of the major equipment for the propulsion system including the main diesel engines, reduction gears, propellers, and shafting for the first four vessels in the class. The capital costs for the previously procured equipment is not included in the capital cost changes for the new vessels. However, sunk costs associated with this equipment have been quantified for the first four vessels.

It is noted that six of the eight main diesel engines that were previously purchased have subsequently been used in the construction of the new 64-Car Ferries. The two remaining engines are of the same rotation direction which means that only one of the existing engines could be used in each of the first two new 144-Car Ferries, should they be fuelled by diesel. Four ship sets of the other propulsion equipment procured are still available for construction of the new vessels.

In order to compare capital costs equally, the cost of the main engines was included in the capital cost of the baseline (diesel) design. The engine cost was included as new engines would need to be purchased for all of the new vessels. However, as previously noted, one existing engine is available for each of the first two vessels. The cost of the existing engines was estimated by WSF to be $2,400,000 per ship set ($1,200,000 per engine). If the first two vessels were to be built with gas engines, an additional $1,200,000 cost for each of the two vessels would be incurred due to the sunk cost of the existing engines.

If the Wärtsilä engines are used, the existing reduction gears could not be used. This is because the Wärtsilä engines operate at 750 RPM and the existing reduction gears were designed for a 900 RPM input. The cost for the existing gears was estimated by WSF as $1,300,000 per ship set ($650,000 per reduction gear). If the first four vessels were to be built with Wärtsilä engines, an additional $1,300,000 cost for each of the four vessels would be incurred due to the sunk cost of the existing reduction gears.

2.1.6 Other Design Changes

The existing diesel fuelled vessel design, which is powered by EMD engines, was used as a baseline for the lifecycle cost. Only modifications required to accommodate the gas propulsion system were considered. It may be possible to realize some cost savings from additional optional design modification for a gas fuelled vessel. For example when switching to a gas system the required diesel storage capacity is drastically reduced. Removal or reduction of the existing double bottom diesel fuel tanks could provide cost savings. A review of the existing design with cost savings in mind is recommended to determine potential cost reductions in the gas fuelled vessel design.

2.2 Operational Costs

2.2.1 Route and Operating Profile

To simplify the calculation of operating costs, a representative average operating route was chosen, rather than a specific vessel route. The operating profile for the route is the same as was used for the 2003 WSF propulsion study, Reference 4. The engine power for transit, however, was updated to reflect the cruising power for the 144-Car Ferry. Table 1 shows the operating profile assumed in the analysis.

Table 1 Power Requirements and Annual Operating Profile Hours

Condition	Engine Power (kW)	No Engines	Total Power (kW)	Hours	Operating (kWh/year)
Transit	1,721	2	3,441	3,000	10,323,000
Maneuvering	391	2	781	1,000	781,000
Docked	379	1	379	2,000	758,000
Total				6,000	11,862,000

2.2.2 Fuel and Lube Oil Costs

The consumption of diesel fuel, gas fuel, and lube oil was calculated. The annual fuel consumption was calculated using the specific fuel consumption curves developed in Reference 9 and the annual operating hours at the various power levels. The lube oil consumption was calculated using the specific lube oil consumption given in the engine technical performance guides. The diesel fuel consumption for auxiliary generators is assumed to be the same for all three designs and therefore was not considered when comparing operating costs.

Table 2 Consumables

Operating Condition	Specific Fuel Gas (kJ/kWh)	Total Fuel Gas (gal/yr)	Specific Fuel Oil (g/kWh)	Total Fuel Oil (gal/yr)	Specific Lube Oil (g/kWh)	Total Lube Oil (gal/yr)
Rolls Royce						
Transit	7,619	1,022,334	0	0	0.4	1,246
Maneuvering	8,667	88,037	0	0	0.4	94
Docked	8,683	85,500	0	0	0.4	91
Wärtsilä						
Transit	8,253	1,107,424	2.92	8,958	0.4	1,246
Maneuvering	11,473	116,530	10.59	2,457	0.4	94
Docked	11,517	113,399	10.70	2,407	0.4	91
EMD						
Transit	0	0	194.84	597,070	0.206 gal/hr	1,236
Maneuvering	0	0	215.10	49,895	0.206 gal/hr	412
Docked	0	0	215.25	48,404	0.206 gal/hr	412

The prices used for fuel were based on recent fuel price prices received from WSF. The price of marine diesel oil (MDO) was assumed to be $3.65 per gallon. The price of LNG was assumed to be $1.05 per gallon. The MDO was assumed to have a density of 3.37 kg/gal and lube oil was assumed to have a density of 3.31 kg/gal. The LNG was assumed to have an energy content of 76.94 mJ/gal. A 3% annual inflation rate was assumed for all consumables. No fuel oil price escalation rate was assumed.

2.2.3 Maintenance and Repair Costs

The maintenance and repair (M&R) costs were calculated for both the main engines and the gas system. Estimated M&R parts costs for the main engines were provided by all three engine vendors. Estimated M&R labor hours were provided for the EMD engines and the Rolls Royce engines. The M&R labor hours were not provided for the Wärtsilä engines and were therefore estimated to be the average annual M&R labor hours from the other two engines. A 3% annual inflation rate was assumed for all maintenance and repair costs.

The M&R costs were also estimated for the gas systems. An annual, 6,000 hour, maintenance interval was assumed for routine maintenance of valves, operators, heat exchangers, and pumps. It was also assumed that all the tanks, gasification equipment, and gas supply units will undergo an overhaul every 30,000 hours (5 years). No vendor maintenance information was supplied and labor and materials costs were estimated for all gas system M&R events.

2.3 Present Value of Cost

All lifecycle and capital costs were calculated in nominal dollars and then discounted to a present value. Because no discount rate was specified by WSF, the present values were calculated for discount rates of both 3% and 5%. These discount rates were assumed to bracket the cost of capital if the project were to be funded with state issued bonds.

The cost of capital was assumed to be the same as the discount rate such that the cost of capital and the discount rate cancel each other out for initial capital expenditures. Therefore the nominal capital cost and the present value capital cost are the same.

Section 3 Results

The costs presented in this report are considered Rough Order of Magnitude (ROM) estimates intended to capture the magnitude of the overall costs. The accuracy of a ROM cost is expected to be +/- 30% because the design that forms the basis for the enclosed estimates is preliminary. Typically, project costs are refined as a design is developed to a higher level of detail. These costs are intended to assist WSF in the decision to invest in the LNG propulsion system and give an estimate for expected capital outlays and payback time.

Vessel operating costs are estimated based on fuel costs available at the time the report was written. Significant changes in the 30 year projected costs can be seen with slight variations in fuel costs. For this report it is assumed that both diesel and gas fuel increase at a 3% inflation rate over the 30 year projection. Actual fuel costs are often volatile and unpredictable. If gas prices increase at a faster rate than diesel prices the projected cost differences will be reduced. If diesel prices increase faster than gas prices the projected cost differences will be increased.

3.1 Capital Cost

3.1.1 Equipment Costs

Table 3 summarizes the additional capital costs per vessel for the main engines and gas storage and supply systems for each of the three options. Details of the vendors' scope of supply are included in References 13, 14, and 15. Details of the shipyard costs are included in Reference 13. Not included in these totals are the additional sunk costs incurred for the first four vessels that have pre-purchased equipment and the non-recurring design costs for converting the design to LNG fuel. Both of these costs are addressed separately.

Table 3 Capital Cost Summary (Per Vessel)

Description	Wärtsilä	Rolls Royce	EMD
Total Capital Cost	$ 8,520,971	$ 9,930,108	$ 2,452,000

3.1.2 Design Costs

There are design costs associated with the modification of the existing diesel fuelled vessel for operation on LNG. However, these costs will only be incurred in the development of the first vessel and will not recur with subsequent vessel in the class. Because these costs are non-recurring, they were not included in the capital cost of the vessel, but should still be considered in the overall cost of the 144-Car Ferry program. The non-recurring design costs are summarized in Table 4.

The EMD design is the current diesel powered design and would not require additional design work. The Wärtsilä contract and production design costs are slightly higher as new reduction gears would be required and gear foundation modifications are likely required. The Rolls Royce design would require an additional enclosure to be designed around the gas supply unit.

Table 4 Non-recurring Design Cost Summary

Description	Wärtsilä	Rolls Royce	EMD
Contract Design	$ 260,000	$ 250,000	$ -
Regulatory Liaison & Submittal	$ 100,000	$ 100,000	$ -
Design Classification Review	$ 250,000	$ 250,000	$ -
Production Design	$ 320,000	$ 310,000	$ -
Total Design Costs	$ 830,000	$ 810,000	$ -

Operational Cost

Table 5 summarizes the first year per vessel operational costs for each of the three options. Details of the operational costs are included in Reference 13.

Table 5 First Year Operational Cost Summary (Per Vessel)

Description	Wärtsilä	Rolls Royce	EMD
Main Engine & Gas System			
Fuel Oil Cost	$ 50,451	$ -	$ 2,538,101
Fuel Gas Cost	$ 1,404,220	$ 1,255,664	$ -
Lube Oil Cost	$ 7,157	$ 7,157	$ 10,300
M&R Cost	$ 301,408	$ 124,843	$ 132,620
Gas Storage and Vaporization			
M&R Cost	$ 13,580	$ 21,060	$ -
Projected Cost (Nominal $)	$1,776,816	$ 1,408,725	$ 2,681,021
Present Value Cost (3% Discount Rate)	$1,725,064	$ 1,367,694	$ 2,602,933
Present Value Cost (5% Discount Rate)	$1,692,205	$ 1,341,642	$ 2,553,354

Table 6 summarizes the total per vessel operational costs over 30 year for each of the three options. Details of the operational costs are included in Reference 13.

Table 6 30 Year Operational Cost Summary (Per Vessel)

Description	Wärtsilä	Rolls Royce	EMD
Main Engine & Gas System			
Fuel Oil Cost	$ 2,400,216	$ -	$ 120,751,219
Fuel Gas Cost	$ 66,806,331	$59,738,750	$ -
Lube Oil Cost	$ 340,514	$ 340,514	$ 490,027
M&R Cost	$ 14,339,611	$ 5,939,453	$6,309,452
Gas Storage and Vaporization			
M&R Cost	$ 646,074	$ 1,001,938	$ -
Projected Cost (Nominal $)	$ 84,532,746	$ 67,020,656	$130,002,698
Present Value Cost (3% Discount Rate)	$ 51,751,914	$ 41,030,812	$80,539,996
Present Value Cost (5% Discount Rate)	$ 38,946,575	$ 30,878,270	$61,218,135

3.2 30 Year Lifecycle Cost

Table 7 summarizes the total 30 year per vessel lifecycle cost with and without a discount rate. The total lifecycle costs are the sum of the capital costs (Table 3) and 30 year operational costs (Table 6). Not included in lifecycle costs are the additional sunk costs incurred for the first four vessels that have pre-purchased equipment (Table 9) nor additional non-recurring design costs (Table 4).

Table 7 Total 30 Lifecycle Cost Summary (Per Vessel)

Description	Wärtsilä	Rolls Royce	EMD
Projected Cost (Nominal $)	$ 93,053,716	$ 76,950,764	$ 130,002,698
Present Value Cost (3% Discount Rate)	$ 60,272,884	$ 50,960,920	$ 80,539,996
Present Value Cost (5% Discount Rate)	$ 47,467,545	$ 40,808,378	$ 61,218,135

3.3 Existing Equipment

The first four planned vessels in the 144-Car Ferry class have some equipment pre-purchased. The pre-purchased equipment is listed in Table 8. The majority of this equipment has been incorporated into the gas powered design. The exceptions are the two EMD diesel engines (one for each of the first two vessels) and the reduction gears, if a Wärtsilä design is chosen.

Table 8 Pre-Purchased Equipment

Vessel	Engines (1)	Gears	CPP Propellers	Propeller Shafting	Combining Shafting
1	1	2	2	2	1
2	1	2	2	2	1
3	0	2	2	2	1
4	0	2	2	2	1
5 +	0	0	0	0	0

(1) Two opposite handed engines required

The pre-purchased equipment that would not be able to be used is a sunk cost that must be added to the capital cost of vessels one through four. Table 9 summarizes the sunk cost per vessel for the first four vessels in the 144-Car Ferry class. Any salvage value of the existing equipment has not been included.

Table 9 Sunk Cost per Vessel for Initial Vessels in Class

Vessels	Wärtsilä	Rolls Royce	EMD
1 & 2			
Engines	$1,200,000	$1,200,000	$ -
Gears	$1,300,000	$ -	$ -
Total	$2,500,000	$1,200,000	$ -
3&4			
Engines	$ -	$ -	$ -
Gears	$1,300,000	$ -	$ -
Total	$1,300,000	$ -	$ -
5+	$ -	$ -	$ -

For vessels built after the first four vessels in the 144-Car Ferry class, there are no sunk costs and the capital costs shown in Table 3 and the 30 year lifecycle costs shown in Table 7 are applicable.

Section 4 Discussion

Modifying the existing design for gas operation will result in substantial operational costs savings. Based on the analysis conducted for this study, both gas fuelled vessel designs have the potential of achieve an annual reduction in operating costs of over $1 million per vessel when compared to the baseline diesel fuelled vessel design. The modification of the vessel design for LNG fuel will result in a higher capital cost of the vessel. However, the operational cost savings offset the increased capital cost, and a payback period of approximately 6 years is anticipated for the gas fuelled vessel designs. It should be noted that the payback period will be longer for the first vessels in the class due to sunk costs.

While difference in 30 year lifecycle cost between the diesel fuelled vessel design and the gas fuelled vessel designs is clear, the differences in lifecycle costs between the two gas fueled design are smaller. Over the 30 year lifecycle the Rolls Royce design has lower costs.

Capital costs in this report only consider modifications to the propulsion system. Costs for the construction of the balance of the vessel are not considered in this report. Existing cost estimates and bids must be combined with these costs to develop overall vessel costs.

The capital costs vary widely between the three vessel designs. The existing EMD design has the least capital costs as the design matches the existing design. The Wärtsilä platform has a lower upfront cost than the Rolls Royce option. The difference in capital costs between Wärtsilä and Rolls Royce is reduced for the first four vessels because additional sunk costs are incurred for the Wärtsilä option. However, taking the added sunk costs into account, the capital outlay for a Wärtsilä system is still slightly lower than Rolls Royce.

The operational cost for the Wärtsilä system is higher than for the Rolls Royce design due to the higher specific fuel consumption of the Wärtsilä engines. Therefore, over the 30 year period the Rolls Royce system has the lowest lifecycle cost.