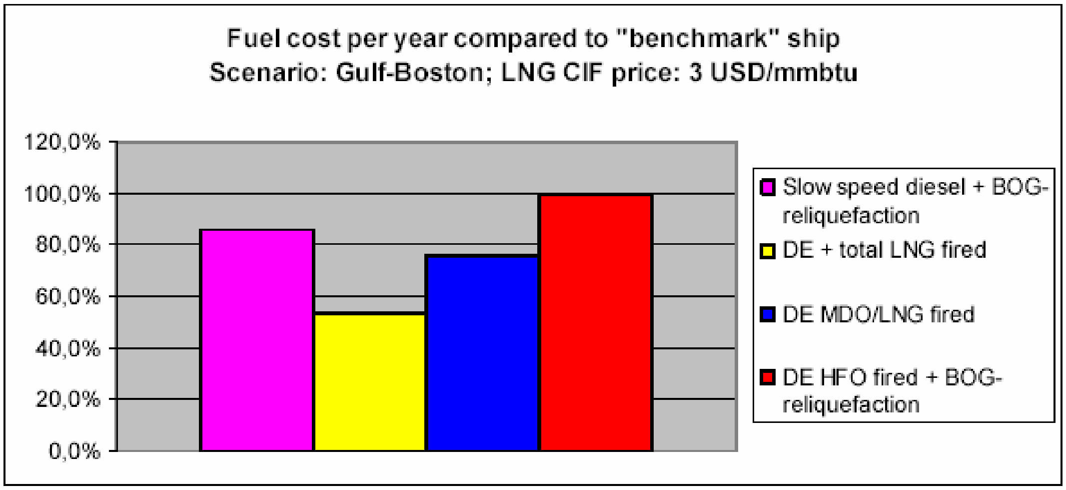


Figure 5: Fuel cost comparison

The net revenue in M USD/year for increasing LNG prices is shown in figures 6 to 8 for the different trade scenarios. The X-axis, or zero (0) revenue presents the benchmark ship. It is clear that all options achieve considerable revenue with increased benefits for rising LNG prices. Longer trades also allow higher savings. At current LNG and fuel prices the max. achievable annual revenue benefit for the Gulf to Boston trade totals abt. 2.8 MUSD for the slow speed diesel with BOG as well as for the diesel electric version utilising only LNG as fuel. One remarkable result is that the benefits can still be achieved with the diesel electric version firing HFO, considering the lower heat value & higher price of HFO as well as the additional investment and power consumption of the reliquefaction plant. This result demonstrates that a reliquefaction plant can be a viable option even for the diesel electric version, not only if HFO is the fuel, but also for dual fuel engines burning LNG, especially when involved in the spot cargo trade. The spot market will make it essential for vessels to be flexible and to operate efficiently at varying speeds which will be encountered on different routes.

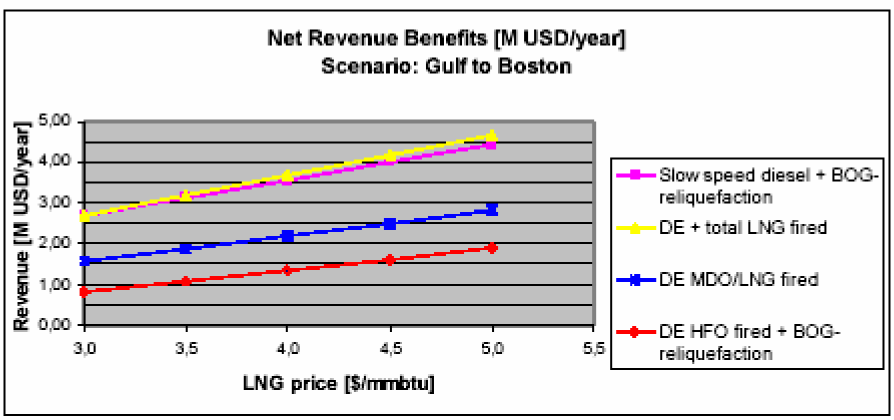


Figure 6: Net Revenue Benefits (Gulf to Boston)

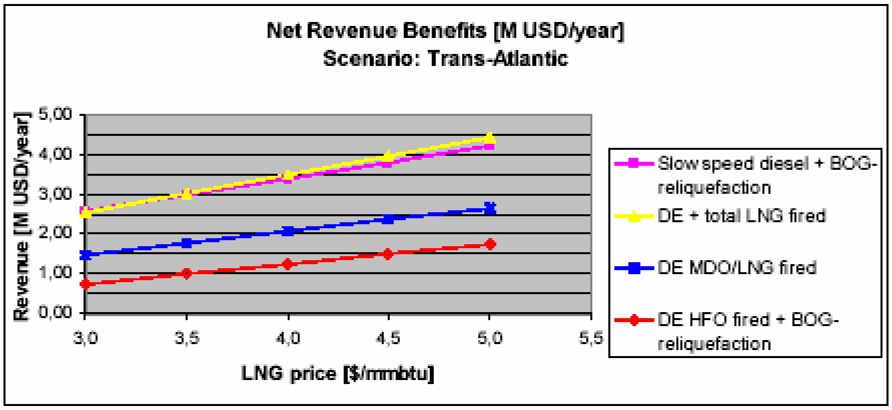


Figure 7: Net Revenue Benefits (Trans-Atlantic)

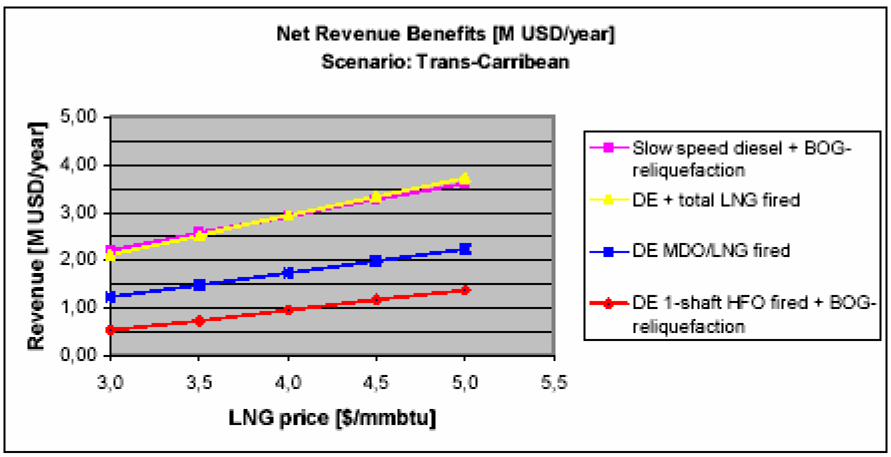


Figure 8: Net Revenue Benefits (Trans-Carribean)

Figure 9 gives an example for the viability of the reliquefaction system. The curve shows the LNG consumption for the diesel-electric version for the given speed. The boil-off-rate is more or less constant at 0.15% /day which are about 100mt/day for a 142,000 m³ ship. The shaded area above the curve indicates excessive boil off. If, for example, the ship was on a trade where it has to sail at only 18.0 knots, then 25 t of excessive boil off would be lost every day without a reliquefaction plant. The slower the sailing speed the more beneficial a reliquefaction plant can become. Additionally a reliquefaction plant makes the ship more flexible regarding the choice of fuel in the future in the case of non linear fuel price increases.

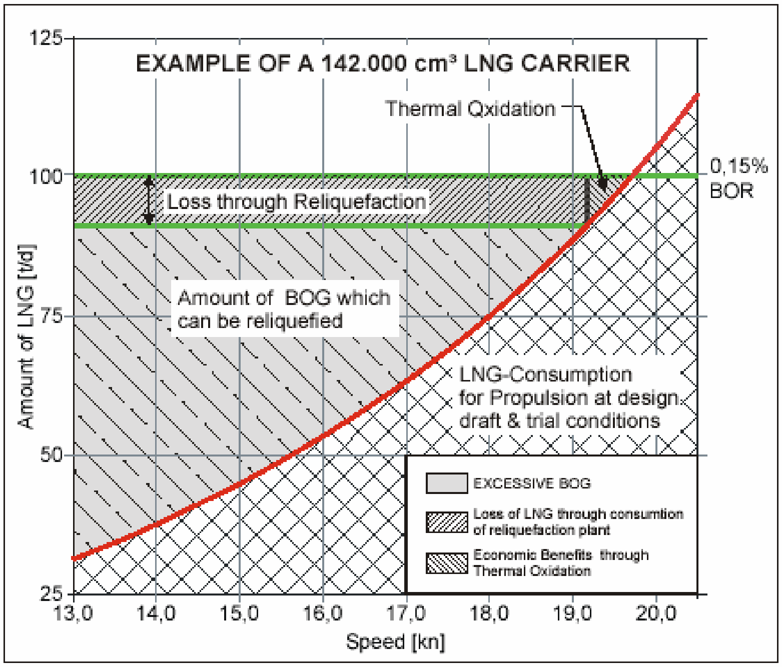


Figure 9: Example for BOG reliquefaction viability

10.4 CONCLUSIONS

Steam turbine installations have dominated LNG carrier propulsion and electric power generation for decades because no suitable alternatives were available. With the market introduction of low-pressure, four-stroke dualfuel engines came the chance to challenge the steam turbine dominance. Dual-fuel engines in combination with an electric drive have turned out to be the most attractive alternative to the traditional steam turbine installation, especially in terms of operating economy and environmental friendliness. The first dual-fuel-electric LNG carrier is about to enter commercial operation, a second vessel is on the building blocks, and a third ship is in the order book. More orders for dual-fuel-electric LNG carriers are imminent.

The evaluation has shown that there are clear arguments to move forward from steam propulsion for LNG ships. The slow speed diesel and the dual fuel diesel-electric are equivalent in terms of economic benefits. However the diesel-electric version allows a higher redundancy, increased flexibility as well as greater cargo capacity. A diesel-electric ship fitted with a reliquefaction plant seems to be the most promising solution for current and future demands to LNG carrier propulsion, especially considering the reduced emissions of NOx, SOx and CO2 and future trading and fuel choice flexibility.

10.5 Comparison

In order to show the true revenue making potential of gas turbine driven LNGC alternatives, they have to be compared with the current state-of-the-art conventional LNGC. First of all, on the basis of many contact with the LNG shipping community the most likely LNGC configuration was selected on the basis of technological merits.

Initially, calculations showed the gas turbine electric podded drive LNGC to have the best revenue making capacity, with its high cargo capacity and highly efficient propulsion system. However, in the light of recent events involving podded drive failures, it seems that the reliability of these systems does not yet comply with the requirements of the LNG shipping industry.

The next best alternative, the gas turbine mechanical drive LNGC offers unsurpassed thermal efficiency and high cargo capacity. However, the durability of the reduction gear, clutches and reversing gear for the FPP in commercial marine application is as yet unknown. Some owners have voiced objections to an alternative equipped with a CPP, citing its slightly lower propulsion efficiency.

The gas turbine electric drive LNGC combines excellent thermal efficiency and high cargo capacity, paired with the use of proven technology in the power train. Electric drive systems have gained some acceptance within the LNG shipping community, as illustrated by the order for one 74,000 cubic meter diesel-electric drive LNGC at Chantiers de l'Atlantique last year. Reliability, redundancy and revenue are the key words to this propulsion alternative.

To check the economic viability of the gas turbine electric drive LNGC, a cost calculation model has been designed using a range of input parameters to calculate long run economic performance under differing circumstances and on different trading routes. Three LNG trades are simulated; the short trade (Algeria - France), the medium trade (Trinidad - Spain) and the long trade (Qatar - Korea/Japan). Two different liquid fuel price levels, representing the extremes of the last ten years, have been used to check the survivability of the gas turbine drive alternatives in changing economic circumstances.

Six different aero-derivative gas turbines configuration have been selected to take part in the comparison, making this study the first full-scale performance comparison of all major aero-derivative gas turbine makes for commercial marine propulsion.

Voyage Parameters	Short	Medium	Long	Itinerary
Voyage Length	1,5	5,0	14,0	days
Maneuvering	0,125	days		
Loading Time	1,00	days		
Off-loading Time	1,00	days		
Non-workable Days Per Year	5	days		

Cargo Capacities LNGC Alternatives		
Gas Turbine Mechanical Drive LNGC	157 000	cubic meter
Gas Turbine Electric Drive LNGC	157 000	cubic meter
Gas Turbine Electric Podded Drive LNGC	160 000	cubic meter
Conventional Steam Turbine Driven LNGC	138 000	cubic meter

Technical Parameters		
Effective Capacity	98,5%	of the nominal cargo capacity
Boil Off Fraction when Loaded	0,15%	of cargo volume / 24 h
Boil Off Fraction when in Ballast	0,04%	of cargo volume / 24 h
Gas/Liquid ratio	618.1	
LNG Density	475	kg/m3
LNG LHV	48 422	kJ/kg
MGO LHV	42 700	kJ/kg
HFO LHV	41 200	kJ/kg
Propulsion Load when Loaded	26 000	kW
Propulsion Load in Ballast	23 500	kW
Maneuvering Load	5 000	kW
Sea Load	1 200	kWe
Harbor Load	1 500	kWe
Cargo Loading Load	2 400	kWe
Cargo Discharging Load	4 500	kWe

Fuel Gas Compressor Load when Loaded	1 500	kWe
Fuel Gas Compressor Load in Ballast	1 200	kWe
Gearbox Efficiency	98%	
Frequency Converter Efficiency	98%	
Electric Motor Efficiency	98%	
Shafting Efficiency	99%	
Boiler Efficiency	88%	
Steam Turbine Efficiency	35%	
HRSG in Fired Boiler Mode Efficiency	80%	
Steam Turbine Generator Efficiency	25%	
Podded Drive Propulsion Efficiency Increase	5%	

Financing Parameters		
Capital cost	12,00%	per year
Economic lifespan	20,0	years
Financing cost	10,00%	of contract value
Pre-delivery cost	3,50%	of contract value
Residual value	$15 000 000	

Bunker Price Level	**Low**	**High**	
HFO380	$70,00	$180,00	per ton
MGO	$150,00	$310,00	per ton

LNG Pricing	**Short**	**Medium**	**Long**	**Itinerary**
LNG FOB	$2,30	$2,30	$2,30	/MMBTU
LNG CIF	$2,80	$3,10	$3,65	/MMBTU

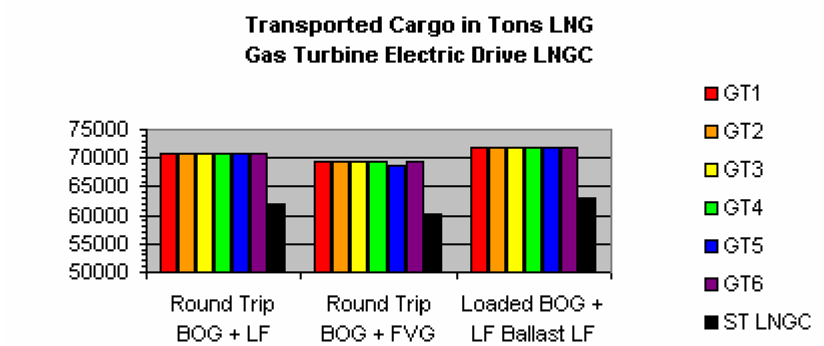
Operational Parameters		
Crew Cost	$13 000	per day
Harbour Dues	$100 000	per arrival
P&I	$1 500	per day
Miscellaneous	$1 000	per day

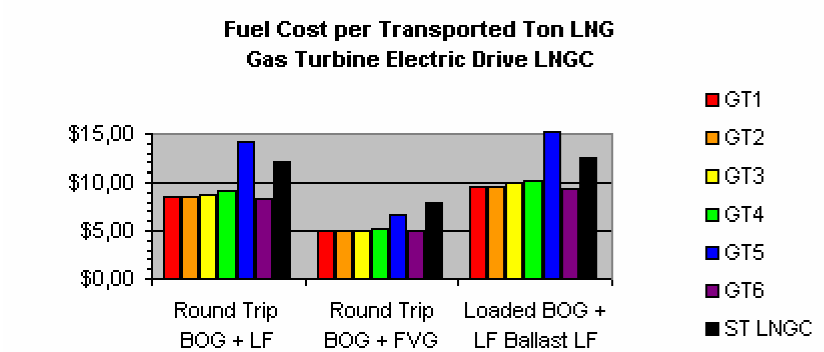
Maintenance Budget		
Conventional LNGC	$3 000	per day
Gas turbine maintenance surcharge		
GT1	$60	per fired hour
GT2	$60	per fired hour
GT3	$60	per fired hour
GT4	$80	per fired hour
GT5	$80	per fired hour
GT6	$60	per fired hour

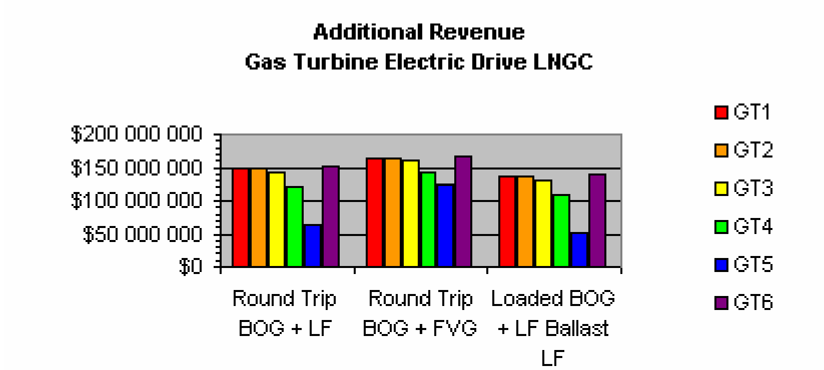
Three alternative fuel schedules have been used in this comparison:
Round Trip BOG + LF: the natural BOG is supplemented with liquid fuel on both the loaded and the ballast trip. The conventional LNGC burns BOG and HFO 380, while the gas turbine electric drive LNGC burns BOG and MGO;
Round trip BOG + FVG: on both the loaded voyage and the ballast voyage the full energy needs are covered by the available natural BOG, supplemented with Forced Vaporized Gas (FVG);
Loaded BOG + LF Ballast LF: on the loaded voyage the energy requirements are covered by the available BOG, supplemented with liquid fuel. On the ballast voyage only liquid fuel is used.

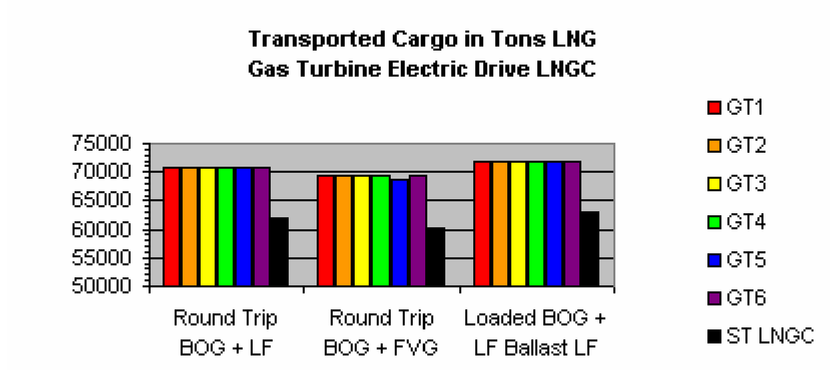
The results are presented in the diagrams below:

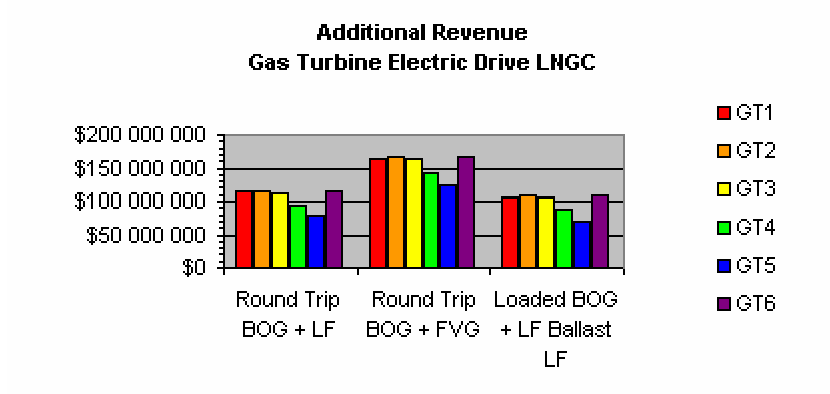
<u>Long itinerary: High (left) v/s Low (right) Liquid Fuel Prices</u>



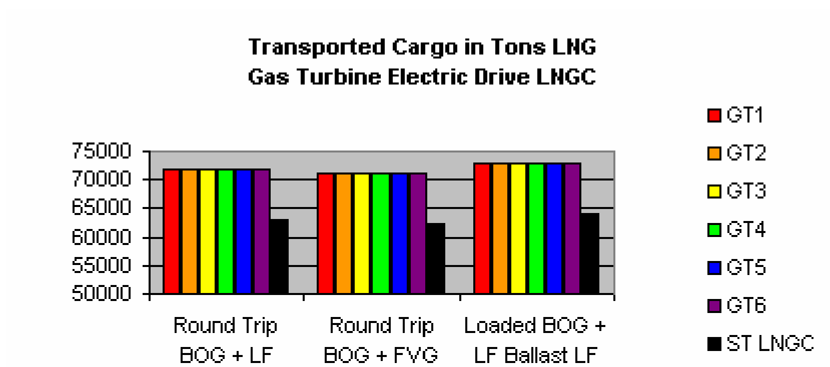


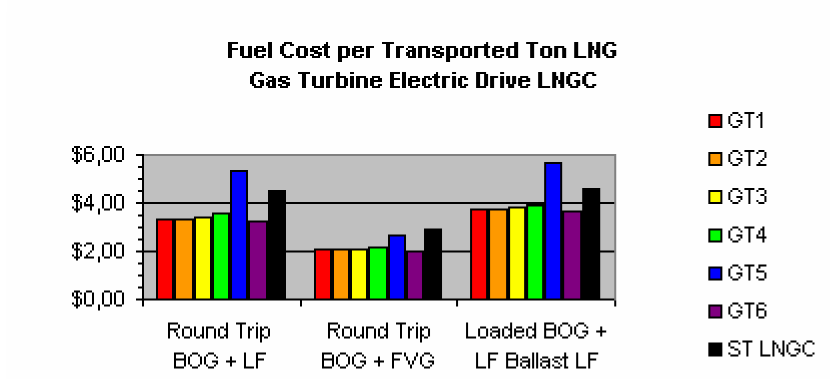


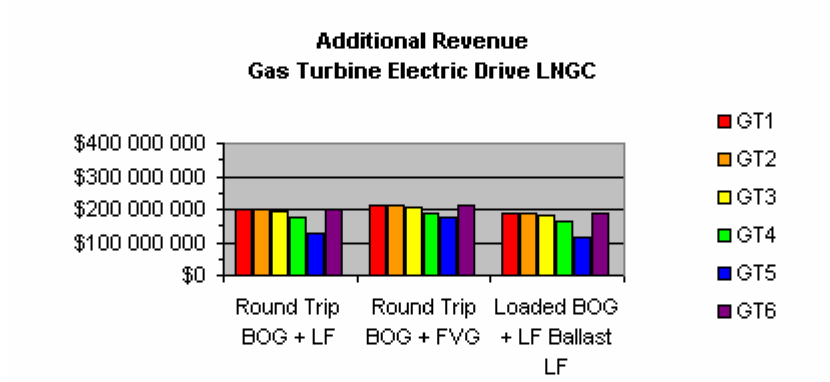


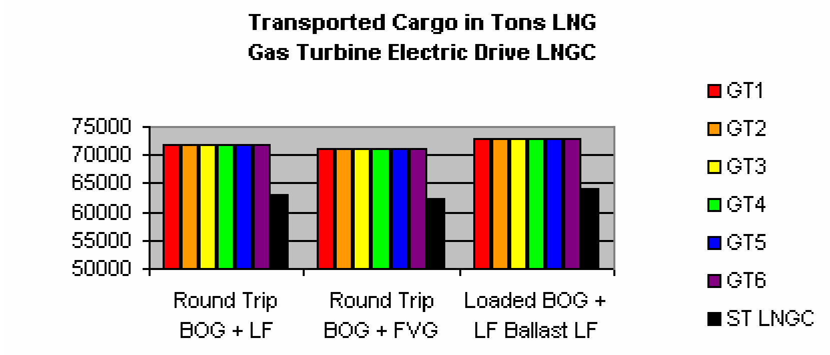


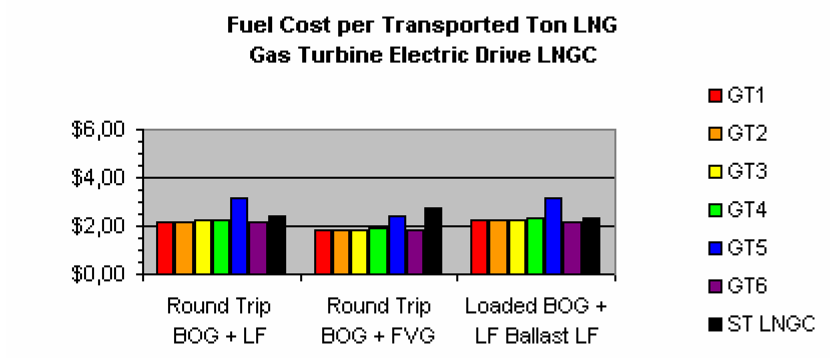
Medium Itinerary: High (left) v/s Low (right) Liquid Fuel Prices

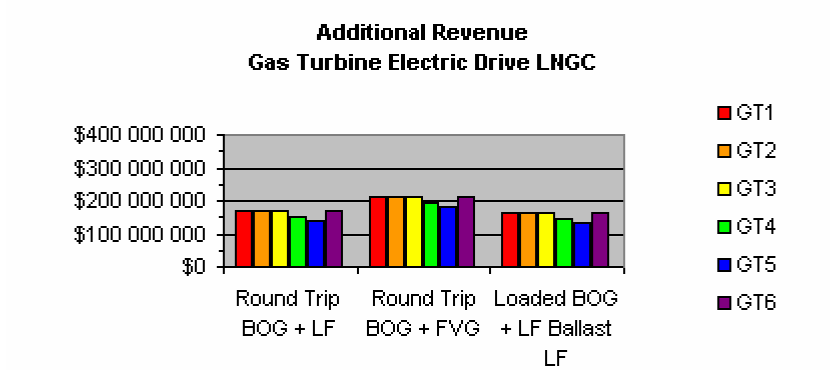




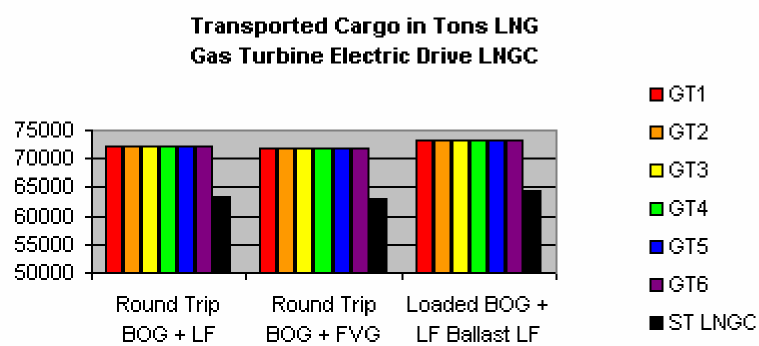

Additional Revenue
Gas Turbine Electric Drive LNGC
$400 000 000
$300 000 000
$200 000 000
$100 000 000
$0
Round Trip BOG + LF
Round Trip BOG + FVG
Loaded BOG + LF Ballast LF
GT1
GT2
GT3
GT4
GT5
GT6

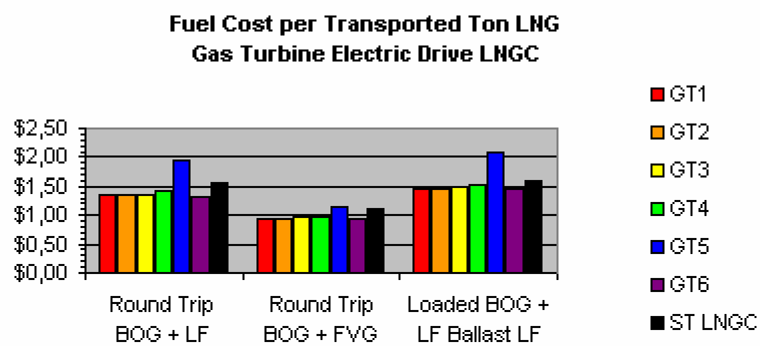

Transported Cargo in Tons LNG
Gas Turbine Electric Drive LNGC
75000
70000
65000
60000
55000
50000
Round Trip BOG + LF
Round Trip BOG + FVG
Loaded BOG + LF Ballast LF
GT1
GT2
GT3
GT4
GT5
GT6
ST LNGC

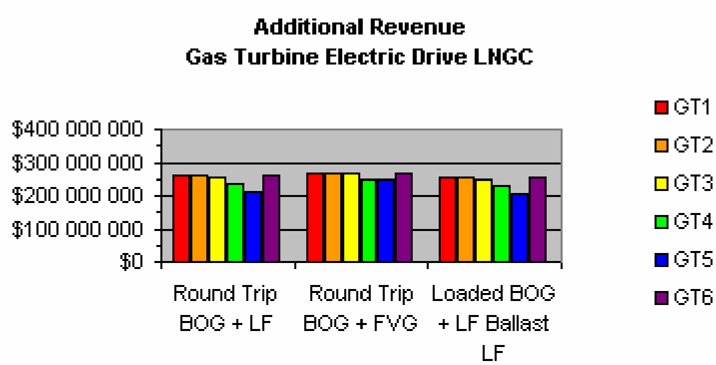

Fuel Cost per Transported Ton LNG
Gas Turbine Electric Drive LNGC
$6,00
$4,00
$2,00
$0,00
Round Trip BOG + LF
Round Trip BOG + FVG
Loaded BOG + LF Ballast LF
GT1
GT2
GT3
GT4
GT5
GT6
ST LNGC

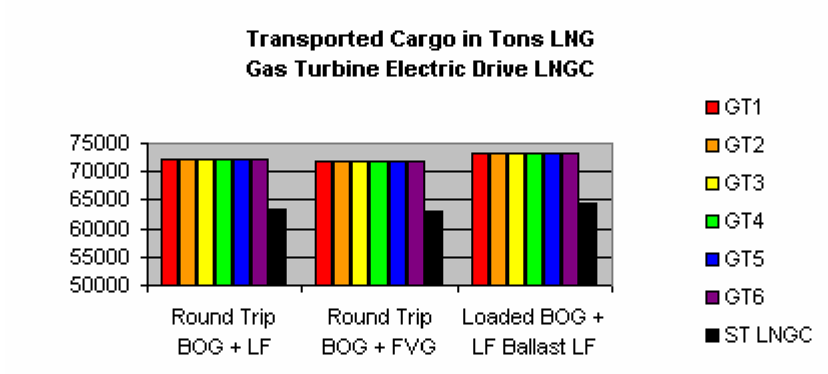

Additional Revenue
Gas Turbine Electric Drive LNGC
$400 000 000
$300 000 000
$200 000 000
$100 000 000
$0
Round Trip BOG + LF
Round Trip BOG + FVG
Loaded BOG + LF Ballast LF
GT1
GT2
GT3
GT4
GT5
GT6

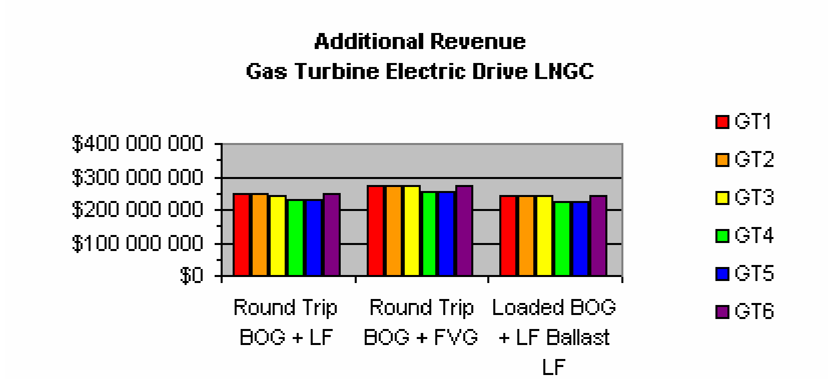
Short Itinerary:High (left) v/s Low (right) Liquid Fuel Prices











<u>There are a number of preliminary conclusion to be drawn:</u>

First of all, the cargo quantities delivered by all gas turbine driven LNGCs are substantially higher than that of the conventional LNGC, which translates in additional income;
Quite surprisingly, high liquid fuel prices are actually favourable for the gas turbine propulsion system. The explanation is that the thermal efficiency of the gas turbine based propulsion plants is so high that the effects of high liquid fuel prices on the total operating cost are much less than for the steam turbine powered conventional LNGC. On the loaded voyage, the gas turbine driven LNGC hardly needs any liquid fuel, while the conventional LNGC relies on liquid fuel for about 40% of its total energy requirements;
On shorters trades, the effects of an increase in cargo capacity are more pronounced than on longer trades. On the short trade, a gas turbine electric driven LNGC transports the equivalent of 9.6 conventional LNGC cargoes extra per year, against 1.7 extra cargoes on the long trade. The additional revenue from this additional cargo improves return on investment significantly, which in turn makes it easier to finance such a newbuilding project;
Even on long trades, with low liquid fuel prices, the gas turbine driven LNGC still generates over USD. 110M in additional revenue over a 20 year period, even whenthe ballast voyage has to be made on liquid fuel only. This worst case scenario clearly illustrates that gas turbine driven LNGCs provide a safe and steady stream of additional revenue even under the "worst" of circumstances;
Gas turbine powered LNGCs are flexible and profitable under all circumstances. Switching between long and short charters does influence the overall rate of

return on investment, but it will always be substantially higher than the ROI of conventional LNGCs. Fuel costs for long ballast voyages on liquid fuel only are indeed higher than those of conventional LNGCs, but much lower fuel cost for the loaded voyage more than compensate this disadvantage. This makes the gas turbine powered LNGC also suitable for the carriage of spot cargoes, which sometimes requires longer ballast voyages without heel;
The gas turbines GT1, GT2, GT3 and GT6 show almost identical performance, which brings increased competition to LNGC propulsion market, currently dominated by two Japanese steam turbine manufacturers. The resulting effect on the general price level for LNGC newbuildings can be very beneficial for owners considering fleet extentions or renewal.

Additional calculations show that, under certain circumstances, it is economically feasible to re-engine a conventional LNGC with a gas turbine electric drive power plant incorporating gas turbine types GT1, GT2, GT3 or GT6, even if the cargo capacity is not increased. However, the conversion should take place early in the charter for the conversion to be profitable and the vessel will not have the same flexibility and high ROI as LNGCs especially designed to exploit the benefits of gas turbine propulsion to the maximum.

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