TUGNOLOGY '17

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Paper 7

Going Green while Staying Lean

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SYNOPSIS

The IMO and other regulatory bodies oblige ship owners to invest in environmentally-friendly engine and exhaust after-treatment technology to reduce SO_X and NO_X emissions, seemingly irrespective of the cost or operational complexity of the equipment concerned. With the entry into force of new rules still being phased in, and the technology to meet the restrictions still developing, Caterpillar believes that it is critical that tug owners consider alternative power plant combinations to ensure compliance at lower overall cost.

In this paper, Caterpillar offers a methodology to identify a route to compliance for tug owners and operators that dispenses with non-viable technologies and arrives at a solution which – over time – achieves the lowest total cost of ownership.

Caterpillar explores the technical options facing a prospective investor in two specific newbuild tug projects, assessing the propulsion plant for both vessel types in detail from the perspective of capital expenditure (capex) and operating expenditure (opex), based on compliance with IMO air emissions restrictions. After considering candidate power and propulsion solutions, it becomes clear that a 'bottom up' methodology based on operational requirements offers the best guidance for evaluating and comparing the different proposed solutions.

INTRODUCTION

Few of those active in shipping today need reminding that reconciling all of the drivers influencing investment choices can sometimes seem to be an impossibility. Almost a decade after the global financial crisis, maritime and offshore profitability is still under intense pressure, while owners and crews must deal with onboard equipment made increasingly complex to meet environmental and safety rules. The technical challenges include not only the complexity of the engines installed on vessels, but the fuels used to run them, their remote monitoring and maintenance, and their interface with onboard controls.

In particular though, the progress of SO_X and NO_X emissions rules, their regional application and uncertainty over global enforcement have created doubt over how, when and even whether to switch to less polluting marine fuel types, and on the most viable options in a shifting technical landscape.

In fact, there is a clear tension between financial, regulatory and technical considerations, but they represent today's market reality, the one upon which investment decisions are based. Given that, they cannot be avoided.

The challenge before us is how to make machinery selections in such a market, and optimise the balance between profitability and emissions regulations in terms of investment (capex) and operating expenditure (opex). If possible, we will seek to develop a methodology that is even-handed enough to recommend different technical solutions as required by specific operating profiles, even if these are superficially similar.

To meet IMO III regulations on NO_X emissions, for example, owners can opt for a diesel plant working in combination with either selective catalytic reduction or engines burning natural gas. Meanwhile, to meet existing and coming SO_x restrictions, ship owners in general may consider abatement technology (exhaust gas scrubbers) or prefer to switch fuels, possibly through investing in dual fuel (DF) engines that run on both diesel and gas.

But if dual fuel engines are the answer in general, are they the answer for tug operations in particular? More specifically, does a main engine that runs on either gas or diesel represent the most efficient choice for a vessel type which, whether working in a terminal or offshore, spends most of its time operating at low load? And, if a DF engine is favoured, how much gas consumption do we actually see in tug operations?

VESSEL ORDERING CONSIDERATIONS

Typically, owners with newbuilding in mind adopt two approaches when reaching the equipment specification stage. These can be loosely described as 'top down' (or solution-based) and 'bottom up' (or requirement-based) approaches.

In the top down scenario, the owner or their technical consultant chooses their preferred technical solution first and then thinks about design second. This is certainly decisive, and certainty on plant performance is advantageous when it comes to meeting current and future regulations.

If, for example, a ship owner opts for dual fuel technology at the outset, their understanding will be that they meet existing air emission rules, while future restrictions can be dealt with by switching more, if not all, of their vessel's operations to the gas-burning mode. Under this scenario, the owner may expect their decisiveness to be rewarded by operational simplicity, because their solution meets their responsibilities through a single technological commitment.

One shortcoming with such decisiveness might only become clear after the decision is made: others active in the market may share the same view and opt for DF in such numbers that our investor has difficulty in meeting their investment timetable. On a related theme, our owner's range of vendors as far as LNG engines is concerned is already very limited; deciding on an equipment strategy first might mean that they have no choice over the vendor at all, that the price is higher than anticipated, or that the available engines are actually too large for their requirement.

But, setting aside these potential practicalities, are there other shortcomings implicit to basing the choice, or seeming to, on technical considerations alone?

Let us look more closely at the top-down methodology by inserting a plausible combination, where a 6,000hp dual fuel powered vessel has a mechanical arrangement installed, connected to an azimuthing controlled pitch propeller.

We can see in *Figure 1* that the decisions over propulsion, and the power and conversion plant, have already been made in this case. To a large extent, this fixes or limits the owner's ability to influence 'downstream options', such as the maintenance regime and fuel costs, and ultimately places technical limits on the vessel's ability to respond to market conditions.

What is not so clear is that this methodology also risks sub-optimal financial returns. It takes no account of how closely the vessel's operating profile fits with the engine selected. While a vessel requiring 6,000hp of power is a reasonable proposition, there is no available 3,000hp DF engine on the market to make a twin DF engine installation. In fact, gaps in today's DF engine power bands (which are known and quantifiable) may commit an owner to an engine operating slightly off ideal spec throughout its lifetime, or operating sub-optimally most of the time.

In contrast, a requirement-based or 'bottom up' methodology *(Figure 2)* envisages defining the vessel's operational profile and then evaluating the different options that promise compliance with the rules, and making our comparison based on modelling the financial consequences. This approach also offers a logical path to compliance which, on the face of it, seems preferable. Its basis in a vessel's expected operating scenario is appealing because incoming regulatory and operational requirements are defined first, with equipment selection then based on the impact on Opex and Capex.

We could see an owner working their way logically through considerations that might include a speed of 12 knots, a given resistance profile and a preferred propulsion solution based on experience, and weighing up the engine/power combination in the light of these factors. Combined, these considerations would lead to conclusions on initial investments, fuel, operating and maintenance costs, and ultimately total cost of ownership (TCO).

The shortcoming appears to be that profound technical questions are left open until the last possible moment. This is about more than a lack of clarity: opting for the diesel + SCR or single gas options, as opposed to the dual fuel option, will have space implications and consequences for the behaviour of other equipment on board. Again, the viability of different technologies can

Figure 1: Top down approach

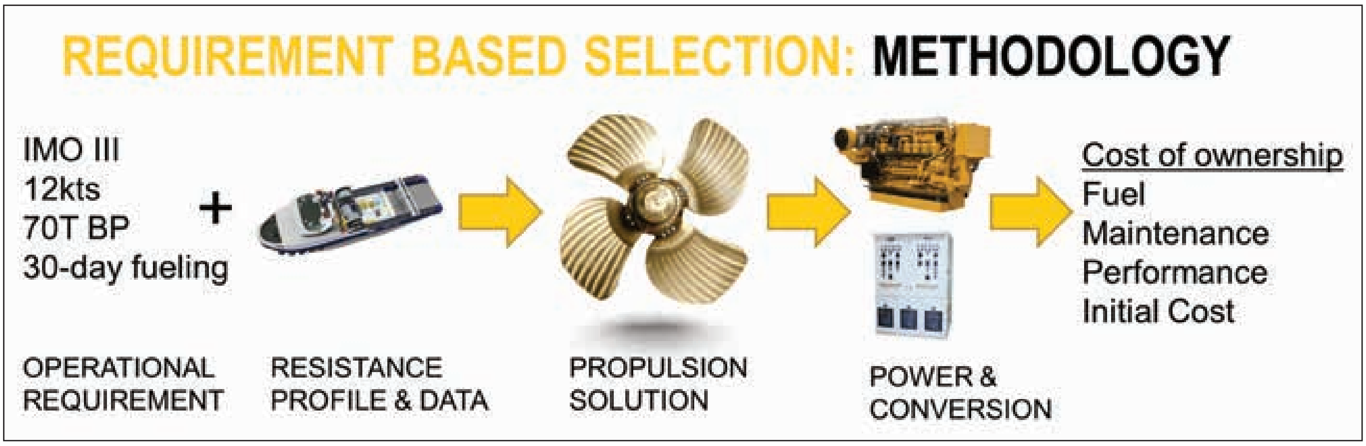

Figure 2: Bottom up/requirement-based approach

change with varying fuel prices, or indeed urea pricing and availability, which could make the owner's initial thinking redundant by the time the vessel enters service.

In the real world, an owner is likely to come to the table with preconceptions about different types of solution, and with knowledge of what they are expecting from their soon-to-be-ordered vessel. Rightly, they are likely to want to test all assumptions on current and future exhaust emissions compliance, vessel performance and vessel profitability in detail, before moving forward with their vessel specifications. It will therefore be helpful if we can look at some likely and realistic scenarios in the level of detail required to assist their decision-making, and to see whether a harmonised methodology can be developed that is nonetheless able to adjust to different operating scenarios.

TUG TEST CASES

Let us take two test case scenarios to get a good look at the decision-making process typically facing owners in 2017. For a general audience, the two vessel types may appear similarly dimensioned. For a shipping audience, however, the vessels concerned are significantly different in type and functionality.

One is a 45m long, 100-tonne bollard pull tug servicing an LNG terminal. Operating in the IMO III area, this tug will feature a 50m^3 capacity fuel tank, and is envisaged for the charter market. It is assumed that there is no issue related to the availability of LNG for bunkering purposes.

The second vessel is again a 100-tonne bollard pull tug and only 5m longer at 50m, but in this case it is designed as an offshore standby vessel. The DP2-capable vessel will also operate as part of the owner's 'green strategy'. In this case, for a vessel of this size it is assumed that an LNG tank size of 100m^3 is feasible, and that the vessel is operating on a 30-day bunkering interval.

A shipping audience will expect us, like our potential vessel buyer, to make some assumptions before we dig down into considering the propulsion equipment choices. The first of these is that textbook efficiencies apply when it comes to motors, generators and drives. The second, given for the purposes of argument, is that interest rates stand at 4 per cent and amortisation is carried out over 10 years. Based on market experience for this size of vessel, the third assumption is that electrical loads – hotel, winch and other electric consumers – are equivalent across all solution candidates.

In terms of translating the operational requirements – from speeds, thrust and weather conditions – we will be using a stock 45m and 50m hull profile as the baseline for calculating propeller rev/min, pitch and torque in relation to the capability of the engines at hand. This is facilitated by the Caterpillar tool for efficiency benchmarks known as 'Cat® Select', and helps with calculating the operational efficiency of any vessel based on operational requirements and hull parameters.

In our case, the prospective vessel owner has made three further 'best guesses', based on reasonable projections as of March 2017:

- MDO cost = €520/tonne;
- LNG bunkered cost = €11/GJ;
- Urea 32.5 concentration cost = €650/tonne.

We also suppose that our owner is highly technically literate and has knowledge of the comparative attributes of dual fuel engines and diesel engines. They are familiar with the efficiency trade-off in dual fuel engines between diesel and gas.

In this case, our owner knows that gas mode efficiency is more load dependent than diesel efficiency. They also know that the equivalent diesel engine has higher energy efficiency when compared to a DF engine running in diesel mode. Furthermore, our owner knows that, for reasons of safety, at low loads dual fuel engines revert to diesel mode because of restrictions in the air to fuel ratio. In addition, transient loads passing through very low loads are also subject to the risk of auto-reverting to diesel. Transition back to diesel is normally initiated by the user.

Given this level of knowledge, our owner's expectations of the performance of the diesel engine versus dual fuel engine in diesel mode versus DF engine in gas mode could be visualised in *Figures 3* and *4*.

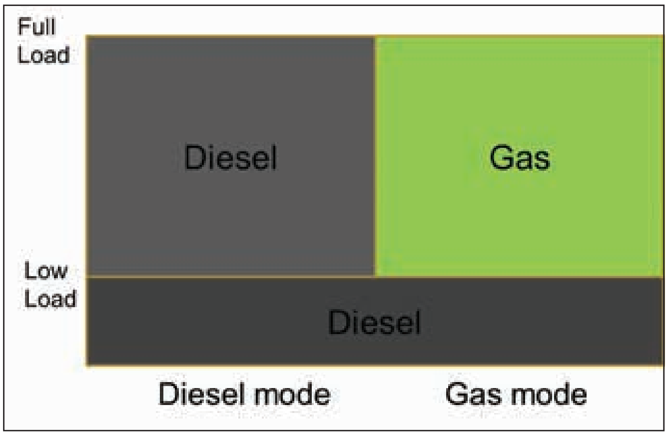

Figure 3: Dual fuel vs diesel engine – modes vs loads

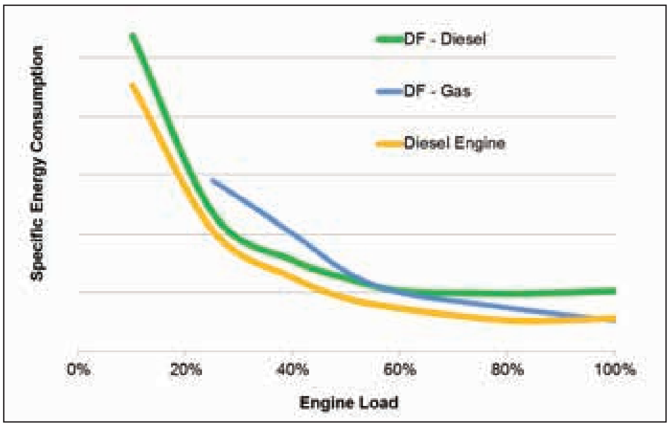

Figure 4: Dual fuel vs diesel engine – fuel efficiency vs load

With this knowledge, our owner is ready to apply their expectations to the two case studies we outlined. Here a range of options presents itself, into which we can slot specific machinery solutions.

CASE STUDY 1: 45M LNG TERMINAL TUG

In the case of the 45m LNG terminal tug, for reasons of precise comparison, we are assuming that the vessel concerned operates using Twin X Cat MTA 834 controlled pitch azimuth propellers of 3,400mm diameter. The LNG terminal tug's operating conditions envisaged and its regulatory compliance could be achieved using different technical options.

Operating profile (Time%/mode):

18%	Transit 8 knots
12%	Transit 12 knots
30%	Offshore standby
18%	Towing 40 tonnes, 7 knots
9%	Assist 70 tonnes, 5 knots
3%	Bollard Pull
15%	Anchored

Candidate 1 *(see Figures 5 and 6)* is a diesel mechanical solution with SCR, where the preferred propulsion solution would be would be 2 x MaK 9M25E main engines (3,150kW @ 750 rev/min), working with 2 x C18 gen sets (340ekW).

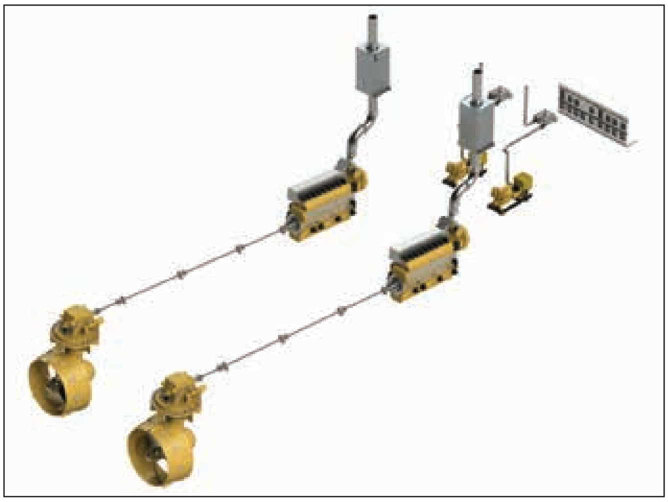

Figure 5: Candidate 1 – Diesel mechanical + SCR schema

In general, we can say that this selection conforms to a traditional vessel design, with engines operating in a straightforward manner of optimised efficiency across

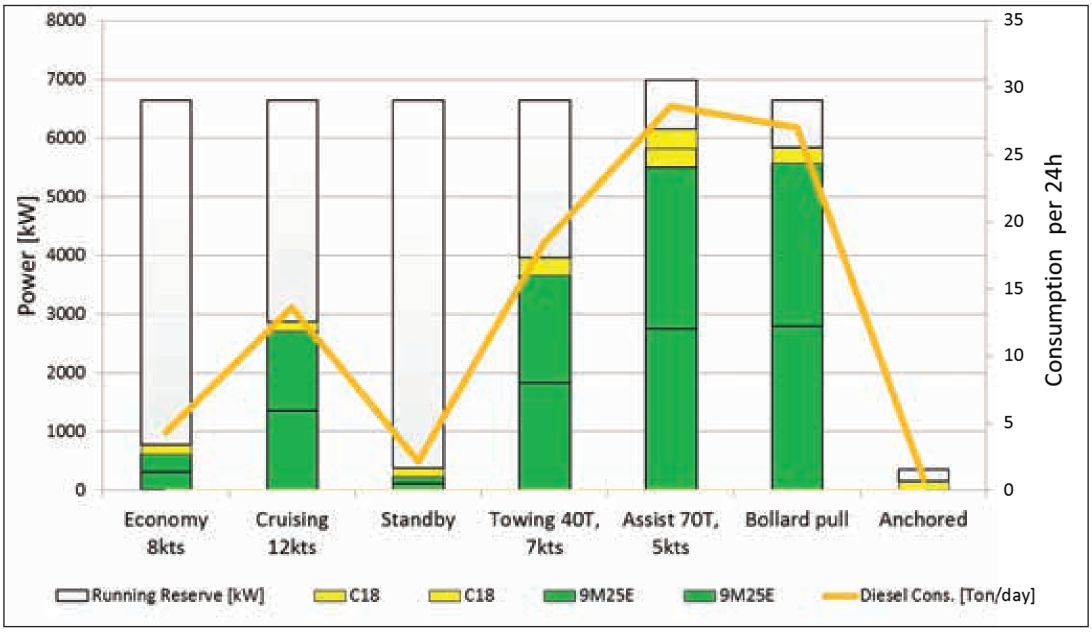

Figure 6: Candidate 1 – Power chart

the full load range and SCRs active across all engines in all modes.

The equivalent dual fuel solution is Candidate 2, shown in *Figures 7, 8 and 9*, which would see installation of 2 x MaK 6M34DF main engines (3,180kW @ 750 rev/min), working with 2 x Cat CG132-8 gas gen sets (400ekW) and featuring a 1 x 50m^3 fuel tank. It should be acknowledged that the size of the LNG fuel tank is an issue for this type of vessel, since space is a limited commodity.

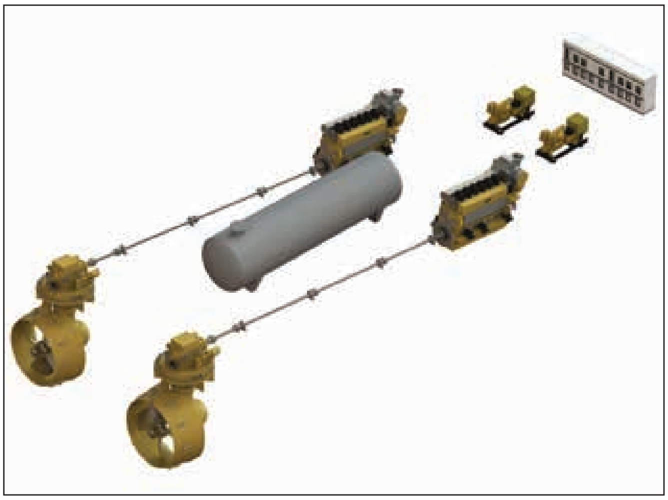

Figure 7: Candidate 2 – Dual fuel engines

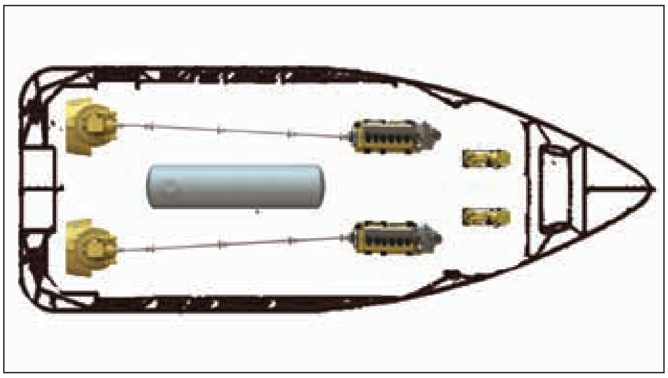

Figure 8: Candidate 2 – LNG tank placement

Looking at the operating results of this configuration, the assumption is that the engine will operate in gas mode wherever possible, only switching to diesel at very low loads – for example in standby mode. It is also known that system efficiency is slightly negatively affected overall in comparison to a conventional diesel engine, because the dual fuel engines' torque capacity is slightly lower, resulting in the propellers turning faster with lower pitch as a result.

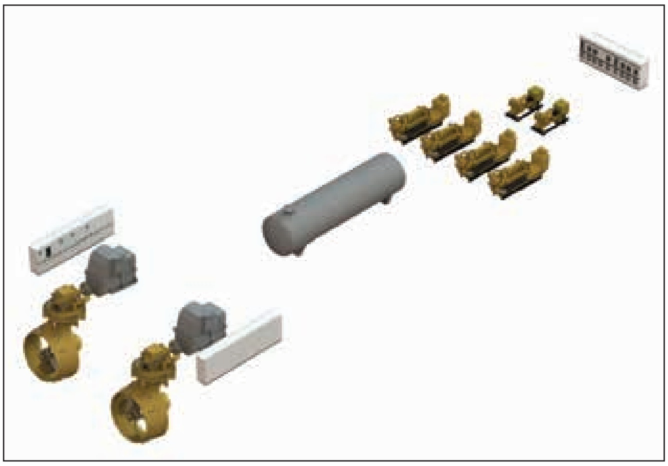

Figure 10: Candidate 3 – Gas electric engine

The gas electric equivalent, Candidate 3 *(Figures 10 and 11, overleaf),* would require 4 x Cat G3516C gas gen sets (1,550ekW), working with 2 x Cat CG132-8 gas gen sets (400ekW), and would again feature a 1x 50m^3 tank.

What's noticeable here is that Candidate 3's power chart demonstrates good propulsive efficiency for all modes and excellent torque characteristics in its electric motors. In the DF solution, it is fair to say that there are gaps in between the performances of different engines in the same range; the gas electric variant's use of CP azimuthing thrusters helps to bridge these gaps of lower load responsiveness in the gas gen sets. On the face of it, the gas electric solution is also appealing because it offers a simple single LNG fuel solution. However, the available engines in the market in the size range under

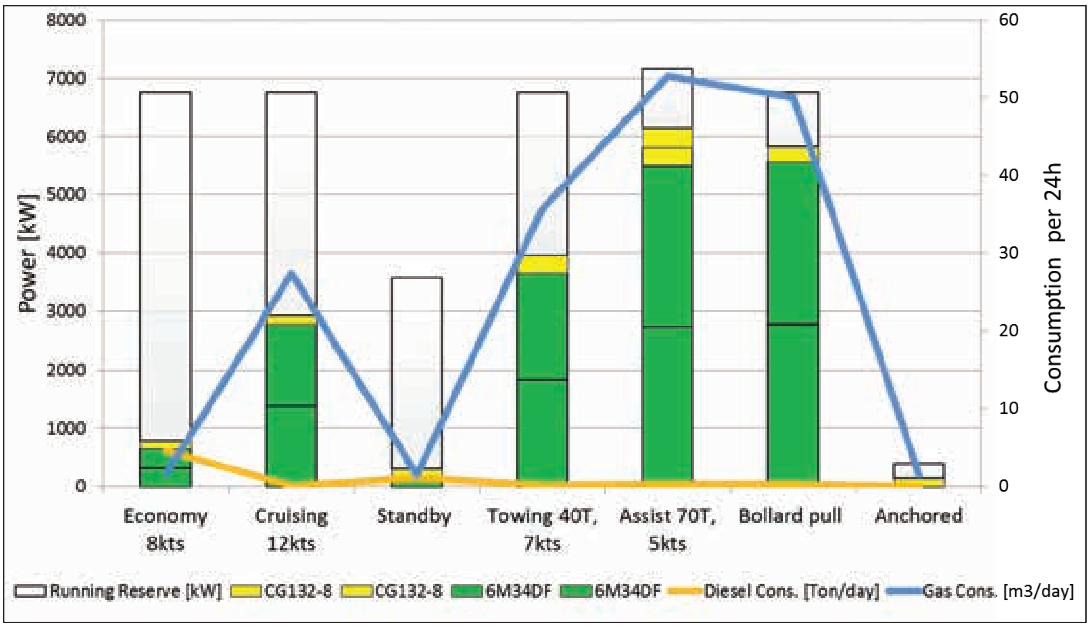

Figure 9: Candidate 2 – Dual fuel engine power chart

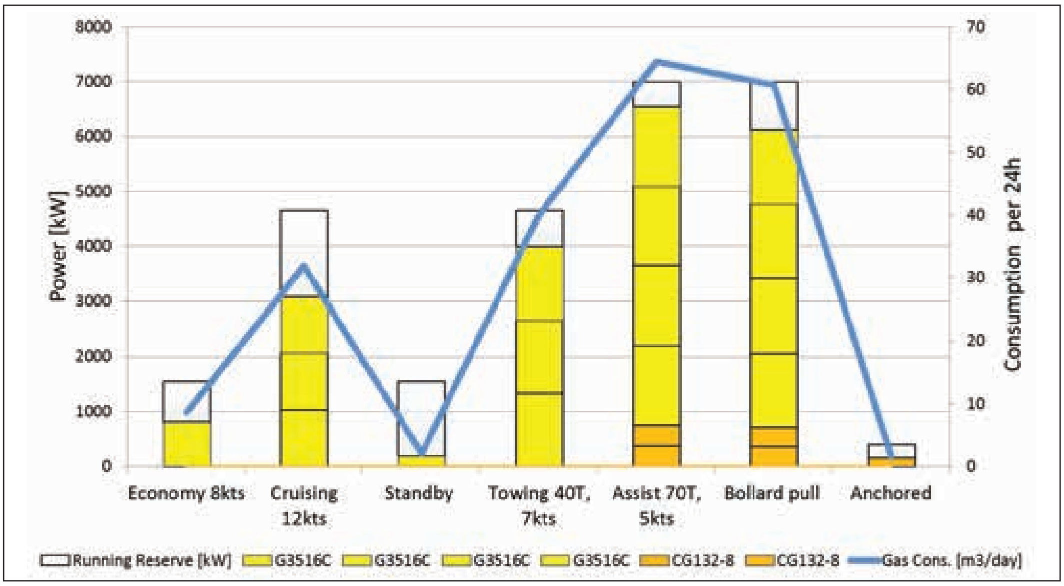

Figure 11: Candidate 3 – Gas electric engine power chart

consideration are limited, and the G3516C used in this example is a platform commonly chosen for land-based applications.

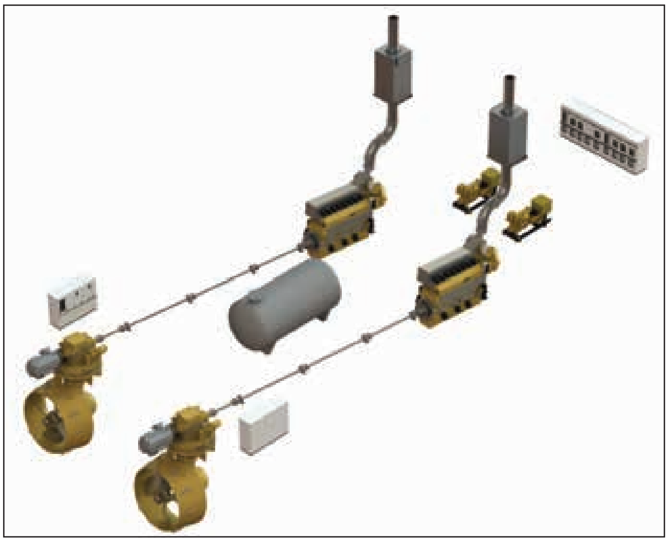

Figure 12: Candidate 4 – Diesel mechanical/gas electric hybrid with SCRs

Finally, let us consider a diesel mechanical/gas electric hybrid with SCRs, Candidate 4 *(Figures 12 and 13)*, which for the sake of equivalence in this configuration would feature 2 x MaK 8M25E engines (2,800kW @ 750 rev/min), 2 x CG132-12 gas gen sets at 600ekW, and 1 x 25m^3 fuel tank.

The system is a mix of two fuel technologies, and therefore the technical solution will be different depending on the load requirement. At lower speeds, the configuration runs on its gen sets in pure gas mode for its propulsion power (electricity) generation. In the case to hand, this is the preferred solution for speeds up to 8-10 knots, depending on the motor selection. At higher speeds, the main engine, working in combination with the SCR and the gen sets, drives the electrical loads in a 'mixed' fuel operation, making it a dual fuel vessel.

It needs to be acknowledged that the efficiency of this solution is dependent on how easy it is to switch between modes, and that this could mean a slight adjustment in the bridge solution, where a one-touch automatic mode selection may be required.

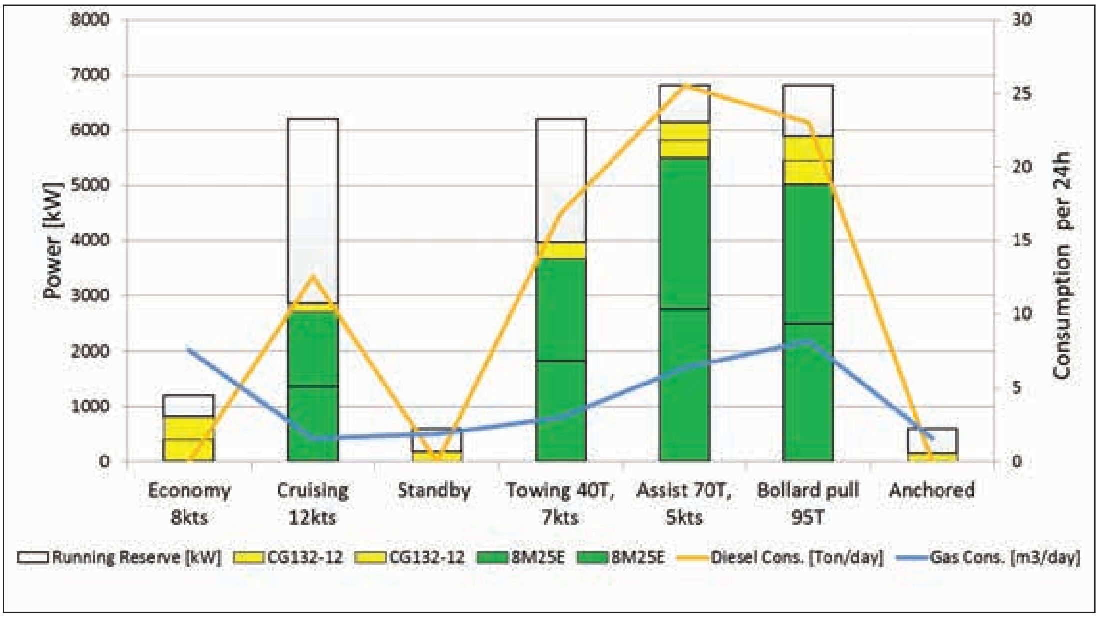

Figure 13: Candidate 4 – Diesel mechanical/gas electric hybrid with SCR power chart

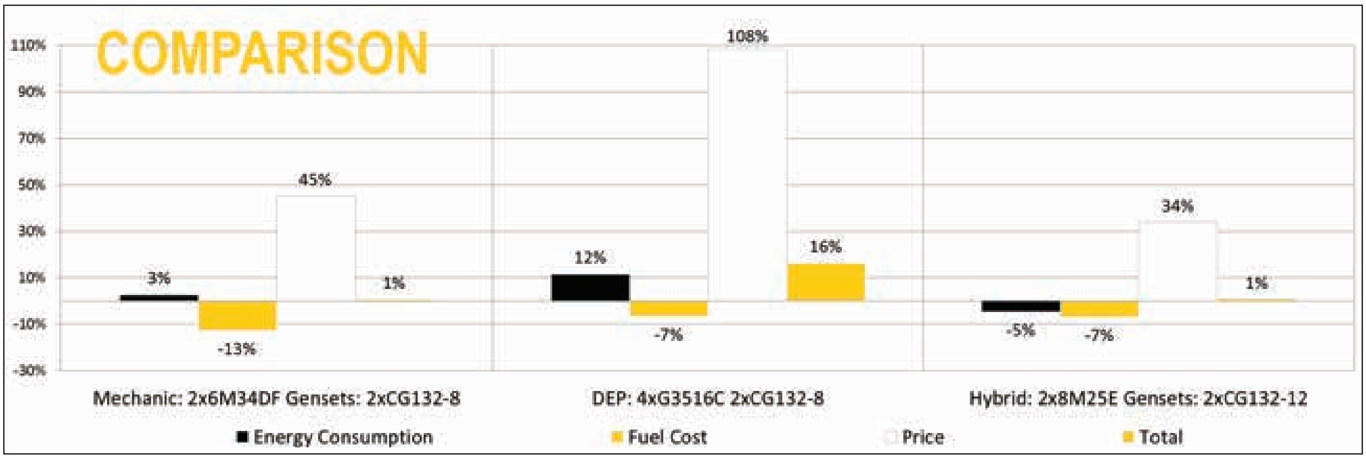

Figure 14: Comparison of candidates using diesel mechanical with SCR as reference – 45m LNG terminal tug

It is legitimate to ask why more time has been spent in outlining the operation of the diesel/gas hybrid solution. The answer lies in the operating profile of the LNG terminal tug under consideration. It is estimated that a vessel of this type would spend 63 per cent of its time either operating at speeds of 8 knots or lower in standby mode, or at anchor.

While it is not expected that more than 25 per cent of the vessel's energy would be generated by burning LNG, it is nonetheless the case that, for nearly two thirds of its time in service, the most efficient solution is to operate in gas mode without SCRs. We might also note that the hybrid's all-gas operation gen set is a significantly more straightforward technology than its dual fuel counterpart. This is reflected in the fact that the single fuel gas gen sets operate at low pressure, making the overall gas system less complex and allowing for operation on boil of gas, for example. This solution also allows for fitting a smaller LNG tank, mitigating the difficulty of finding space for the tank.

Boiling down our comments to a direct comparison will help decision-making. *Figure 14* uses the diesel + SCR as its reference point for comparison with and between the other candidates. However, the figurative comparison includes some base assumptions that need to be made explicit, in order that our owner can take their decisions based on their priorities.

What's striking at first sight is the very unappealing price tag (capex) attached to the gas electric solution (Candidate 3), and the fact that the energy consumption of this option is also inferior to the other two candidates due to the higher electrical losses. This candidate does come with simpler gas installation due to single fuel gas gen sets, but overall seems to be 16 per cent more expensive, on a year to year basis, than the diesel mechanical solution, despite a projected lower cost in bunkered LNG fuel.

Therefore, while the gas electric solution promises to be the most environmentally-friendly candidate in terms of emissions overall, it appears to be the least palatable on grounds of cost. The other two candidates appear to be more or less neutral in terms of TCO when compared to the conventional diesel plant. None of the options involving LNG as a fuel present any significant reduction in total cost of ownership compared to a diesel + SCR vessel over 10 years, if the price of LNG is 90 per cent that of diesel. If the price difference is 80 per cent, the dual fuel mechanical vessel has the lowest TCO and would be the preferred option in the case under consideration.

The methodology has enabled us to make a choice, but overall the result of the comparison is rather unsatisfying because it has not proved clear-cut. Nevertheless, we can make some observations based on our comparison.

- Candidate 3, the gas electric solution, does not offer promise as a viable commercial choice;
- The dual fuel alternative has approximately the same energy efficiency as a diesel alternative, but benefits from a lower fuel cost and from not having to pay for urea (because it would operate in gas mode in IMO III areas);
- The diesel/gas hybrid solution benefits from flexibility and a lower capex, but represents a solution that could be considered overly novel in today's market.

In these circumstances, it appears worthwhile examining whether our proposed decision-making model is robust, or whether it will be so subject to qualifications as to be of little further use. Where possible, we want our methodology to give our owner confidence that they are choosing the environmentally-responsible option which is also the most efficient in terms of fuel consumed vs power used.

CASE STUDY 2: 50M OFFSHORE TUG, 100T BOLLARD PULL

Greater insight is offered using our second vessel type – the 50m offshore tug, featuring 100 tonnes of bollard pull.

As before, we include some fixed equipment selections to make any comparison realistic. Here, the main propulsion remains the same, twin Cat MTA 834 controllable pitch azimuth propellers with 3,400mm

diameter. The vessel is stretched 5m to allow for a 100m³ LNG tank. For DP2 compliance, a pair of Cat MTT 114 controllable pitch bow thrusters is added, as well as shaft alternators on the front of the main engines. The operating profile is taken from what is considered an FPSO support vessel commonly known as an infield support vessel or offtake support vessel. Vessel operation is assumed to be year-round for a long term operational charter contract *(Figure 15)*.

Operating profile (Time%/mode):

6%	Transit 7-13 knots (40/40/20 over 7/12/13 knots)
55%	Offshore standby
16%	DP2 low environment load
7%	DP2 high environment load
7%	Towing 40 tonnes, 7 knots
5%	Assist 70 tonnes, 5 knots
4%	Anchored/Port

The diesel mechanical engine with SCR candidate comprises two medium speed main engines (MaK 9M25E, 3,150kW@750 rev/min) driving thrusters (Cat MTA 834 CP) with high speed gen sets (Cat C18, 340ekW) for electrical power. The SCR deals with NO_X emissions in order that the diesel combustion outputs comply with IMO III/EPA4.

Tugs working offshore spend long periods in the standby mode, when they are required to be close to the operational area, but not in active DP mode. Furthermore, the diesel main engines are designed to work most efficiently at higher loads, meaning that long periods of idling or working at low speeds are suboptimal in terms of fuel consumption. Clearly, however, Candidate 1 does not include an LNG fuel tank, and so there is no endurance-related issue regarding gas fuel storage as well as a significant capex reduction, considering the cost of today's LNG tanks.

The dual fuel mechanical solution, or Candidate 2, *(Figure 16)* features DF main engines (MaK 6M34DF, 3,180kW@750 rev/min) driving thrusters working in combination with high speed single fuel gas gen sets (Cat CG132-8, 400ekW). Once more, the fact that the vessel is working predominantly at low loads has consequences for the power train, because modes with low varying loads will auto-revert to diesel. This creates

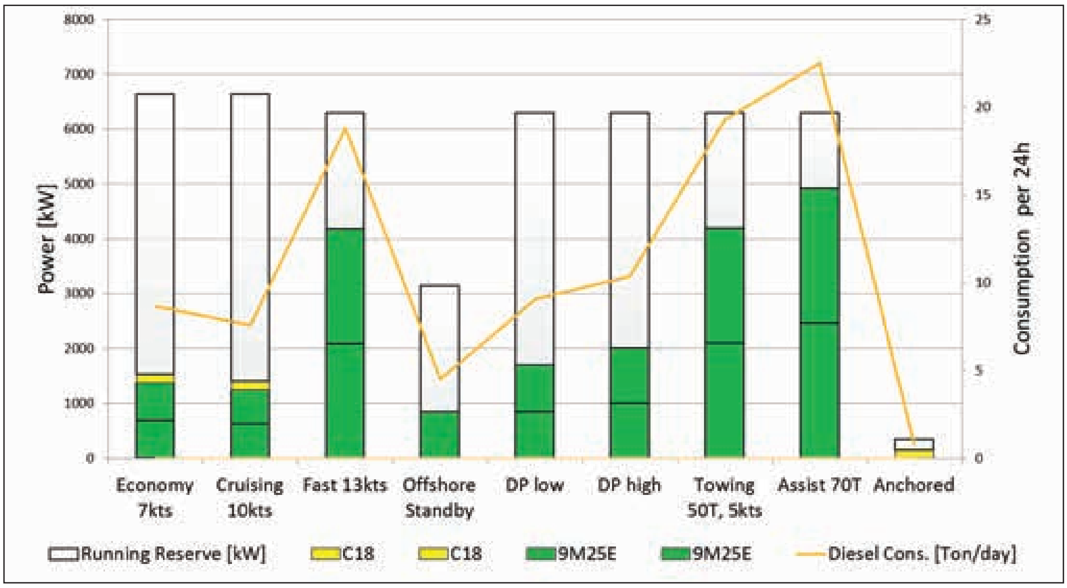

Figure 15: Candidate 1 – 50m offshore tug diesel + SCR power chart

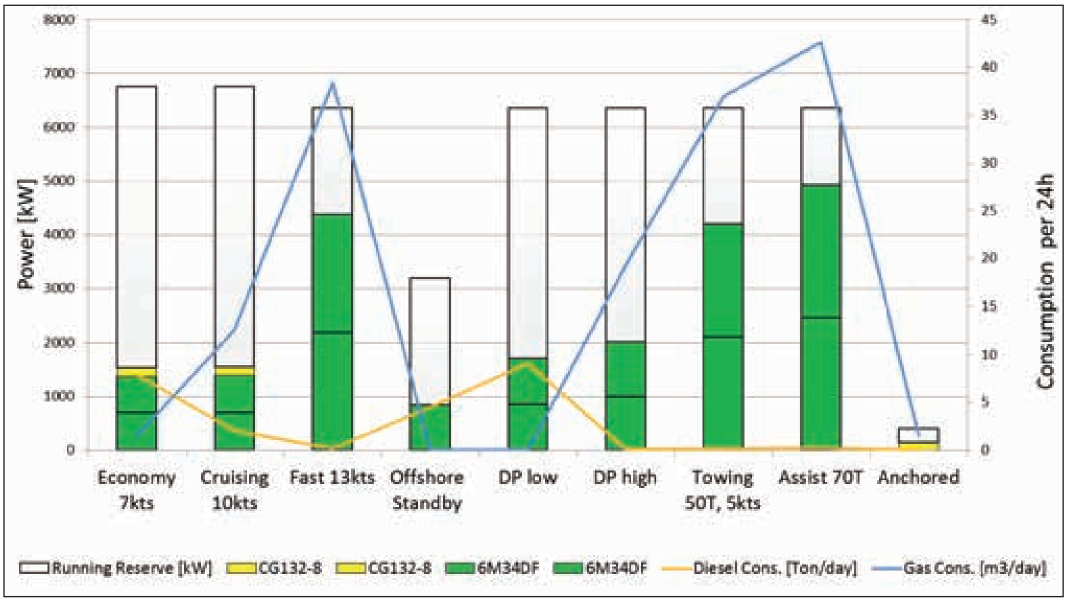

Figure 16: Candidate 2 – Dual fuel + single gas gen sets power chart

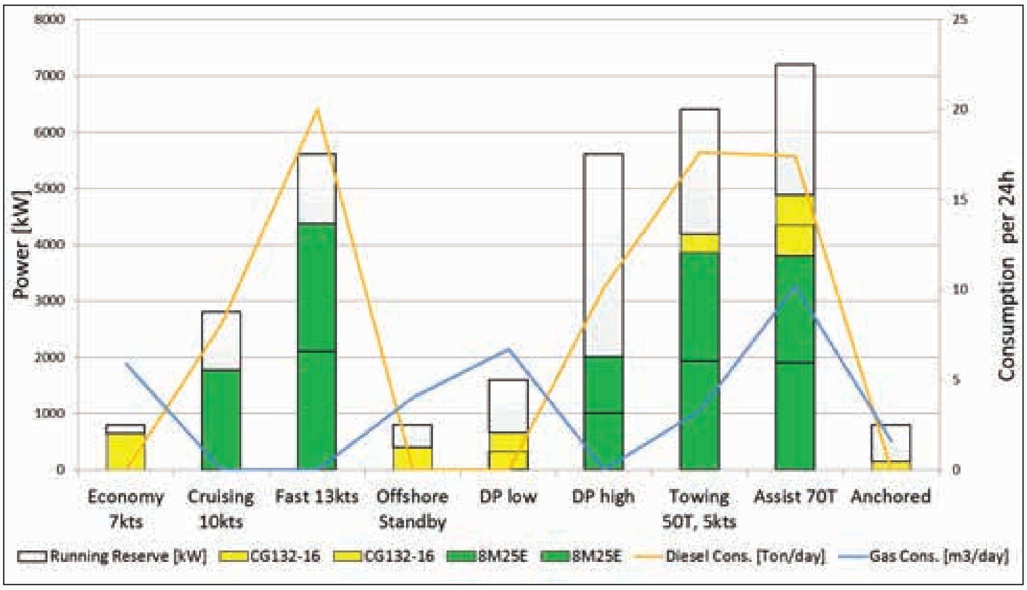

Figure 17: Candidate 3 – diesel mechanical/gas electric combination working with SCRs – power chart

a potential 'urea-bunkering' headache because the diesel mode requires SCR operation to achieve IMO III compliance. Furthermore, the 100m^3 LNG fuel tank in combination with operating profile described only supports a 14-day endurance.

The other way to address this would be lengthening the vessel and fitting a larger tank. A simple geometric comparison indicates that extending the vessel by 5m would add ~75m^2 of LNG storage, and the above-mentioned vessel would thus need up to a 10m extension to fit the tank required. This is feasible, but puts additional stress on the capex for this candidate.

The experienced market watcher may rightly wonder why no mention of an electric dual fuel variant has so far been included in this analysis. Compared to Candidate 2, going for a DF electric combination would increase the efficiency in low power modes by allowing propellers to turn at lower, more optimal speeds because the torque curve mechanic engines do not limit the electric motors. Splitting the power plant across more engines also allows for operation in gas mode in more of the lower power modes, since engine load factor increases.

However, a severe obstacle for the DE solution is set by the current endurance limitation for dual fuel, which means it will still require either SCRs and extensive diesel operation or a significantly larger (longer) vessel. Furthermore, the DF-DE solution will consist of smaller bore engines which traditionally have lower efficiency as well as electrical losses of ~15 per cent. A more fatal drawback of the dual fuel, diesel-electric solution in the case under consideration would be its capital cost. The DF electric solution faces the same challenges as its DF mechanical counterpart, but in capex terms costs around 30 per cent more than the duel fuel mechanic due to the increased number of engines and the electrical package required.

In this case study, the gas electric solution we earmarked as Candidate 3 remains broadly undefined, although we do know that the main engines will be working in combination with gas gen sets.

Therefore, we will not be considering Candidate 3 from our previous analysis as a viable option, and will instead jump straight to a 'new' Candidate 3 *(Figure 17)* a diesel mechanical/gas electric hybrid working with SCRs, featuring medium speed main engines (MaK 8M25E, 2,800kW@750 rev/min) with SCRs driving the thrusters and high speed single fuel gas gen sets (Cat CG132-16, 800ekW). In the first case study, we identified this configuration as Candidate 4.

Once more, we are going to test the diesel mechanical main engine/gas gen set hybrid against the operating conditions that vessels encounter while in operation.

As noted, for much of the time, offshore tugs are either on standby or operating in low DP mode. This is to say, they can operate for a substantial part of the time in 'electric mode', running on their gen sets alone. In this case, the gen sets operate on a single fuel – environmentally friendly LNG – which not only brings them within IMO III NO_X compliance, but will address any SO_X emissions restrictions in place or envisaged globally after 2020.

Superficially, this option uses the available machinery in the most efficient way while also complying with exhaust emissions regulations, and thus represents the optimal investment choice. Running on gas without using the main engines for a large part of the time means that green operation also appears to be distinguishing itself as the most efficient in terms of energy consumption. In transit mode too, the vessel can operate at lower speeds, where its electrical propulsion power can again come from the gas gen sets. This could be the case for speeds of up to 8-10 knots, depending on the motor/VFD selection.

Only in the towing, fast transit and assist modes is it necessary to engage the main diesel engines. In this scenario, the main engines will be working at high

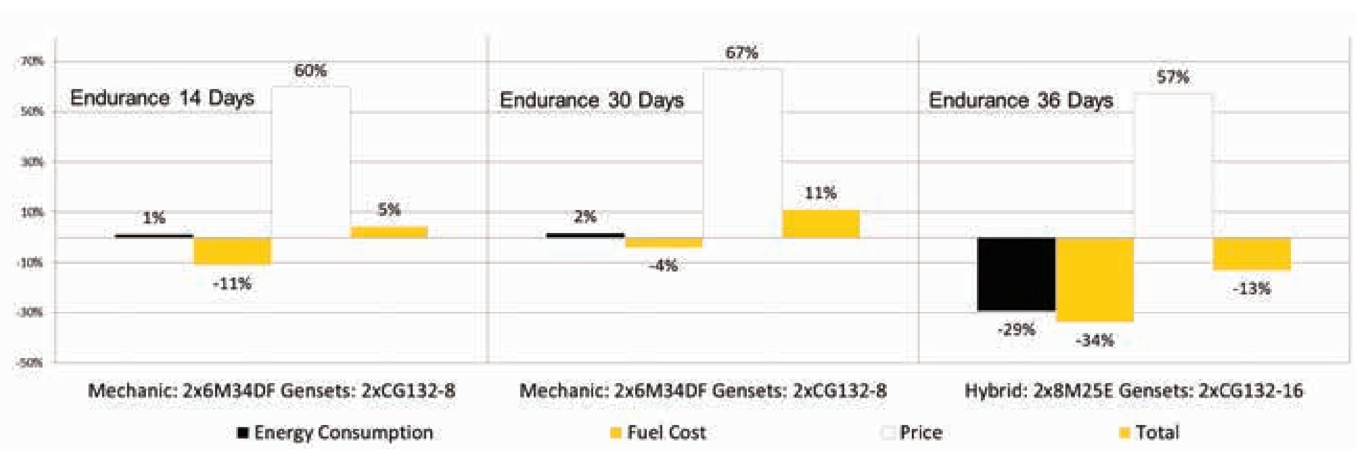

Figure 18: Comparison of dual fuel main engines/gen set vs hybrid diesel main engine/gas gen set

and healthy loads, and therefore operating at optimal efficiency. Again, in this mixed diesel and gas mode for higher power modes, we can say that main propulsion is running in variable speed, optimising power in relation to fuel consumption.

Shown in figurative terms, our comparison of the Candidate 2 and new Candidate 3 variants is made against the baseline model, Candidate 1 – the diesel mechanical + SCR solution (not shown). Two variations are offered for Candidate 2, our dual fuel + single gas gen sets combination. The first shows its relative performance with the original 14-day endurance and with the operating profile outlined and a 100m^3 tank, noting that this solution is not compliant with the operating requirements. The second, in the centre of *Figure 18*, shows the performance of the same solution with added SCRs to main engines and operating 16 days of the 30-day endurance on diesel + SCRs.

For our 50m offshore tug, we can see that while all of the alternatives offered achieve the same operational requirements, the hybrid solution's performance is superior when the endurance period is even less restricted – at 36 days. This can translate into a significant 13 per cent reduction in the TCO compared to the base model, where the alternative mechanical combination is more expensive over both 14- and 30-day endurance periods.

The margin of superiority is wholly the result of far lower energy consumption and an even greater (34 per cent) cut in fuel consumption while, as the endurance increases, the hybrid solution secures its position as the best option to meet air emissions restrictions at the best available Capex.

CONCLUSION

Having explored the technical options facing a prospective investor in two specific newbuild tug projects that comply with new and envisaged air emissions restrictions, Caterpillar assessed both vessels in detail from the perspective of Capex and Opex.

Caterpillar has concluded that owners can take a smarter approach when it comes to achieving both lean and green objectives, by working through a 'bottom up' methodology to establish compliance at optimal cost for their vessels. In the cases given here, for example, the dual fuel solution that appears to be the best choice for an LNG terminal tug does not seem to work at all for an offshore tug, where hybrid propulsion appears more favourable.

In detail, Caterpillar finds that for two not uncommon but specific tug types, its methodology is flexible enough to arrive at contrasting propulsion solutions for vessels which are not markedly dissimilar in design, but whose operating profiles are different. In one tug case, the methodology leads to the selection of a mechanical dual fuel arrangement, albeit with qualification. In the second case, its model points towards a diesel/gas hybrid as the most energy efficient option, offering the fewest endurance restrictions and the lowest requirement to run in diesel mode for extended periods of time.