Old Men: Older Boats

Electric Drive, Power Storage and Power Generation in Commercial Fishing Vessels

A report for:

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Executive Summary

The majority of Australia's fishing fleet is outdated. That is, combustion engines are the typical form of power generation. As power generation technology has superseded traditional diesel engines in the last three decades, there is enormous room and requirement for improvement.

This report examines the prospect of building a modern fishing vessel using the latest technology of propulsion, power storage and power generation.

The author visited six countries on this study topic including The Netherlands, Iceland, Ireland, Florida (USA), Brussels and Norway, which was a major highlight. Here, the author experienced an electric fishing boat for a full day, met with ship designers, factory tank test hulls, and visited battery and fishing manufacturers.

A key outcome from the study is the evident significant barriers associated with regulations reducing uptake of newer technology.

Electric and hybrid power generation systems have been successfully utilised in Scandinavia and other parts of mainland Europe. Electric motors provide more power and vessels can utilise smaller engine units and conserve space for additional cargo, catch or crew

The added efficiencies associated with electric motors like thermal waste re-use, allow for further reductions in required power on board fishing vessels.

In addition, hull design enhances the efficiency of power conversion of electric motors and battery storage solutions are able to capitalise on commercial fishing conditions.

In summary, with new technology it is possible to reduce fuel costs by up to 80%, reduce maintenance costs by up to 50% and positively address occupational health and safety fatigue management and reduce the overall carbon footprint of the industry.

The now 'old' technology in fisheries needs to be supported with legislative framework to adopt today's available technology. Then, it will become appealing to the younger generations.

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Foreword

I come from a background in primary production. My father's family were cereal and sheep farmers on Eyre Peninsula, South Australia (SA).

My dad went fishing in the late 1960s as a crewman on a cray fishing boat and then bought a crayfish and shark licence working from Port Lincoln, SA. He proceeded to take up an experimental prawn permit in the mid-1970s working from Ceduna, SA.

I completed a motor mechanical apprenticeship in 1984 and purchased my first fishing licence, a marine scale licence, in 1985. This licence was handed in to receive a blue crab permit for the west coast of SA in 1986.

I married my wife Karen in 1987, who also has a cereal and wheat farming family background. Life has produced three children who, whilst able to pursue a career in seafood, are taking a different course and achieving tertiary education in other fields, thus coming to a seafood career will bring a much different perspective.

In 1989, we moved to Adelaide to take up an experimental crab permit in Gulf St Vincent.

Constant growth and purchases of additional licences and boats has occurred, and we now are the largest blue crab fishing company in Australia with a full vertical integration of pot to plate philosophy.

My mechanical background was supplemented with subsequent upgrading of my qualifications to include diesel mechanic endorsement, refrigeration knowledge, and Fishing Vessel Master Grade V and Marine Engine Driver Grade III certificates.

Further experience came as an owner of ten boats of various types, including catamarans, displacement, planning and semi displacement, with a large variety of diesel motors (most manufacturers) and a massive amount of engine hours – some 80,000 with propulsion motors and 140,000 with power generation.

My Nuffield studies comprised electric drives, power storage and power generation because of the cost of maintaining and repairing propulsion motors. The skill level of the mechanics and the hourly rate was severely negatively impacted by the mining boom because those mechanics had gone to work in the mines or were charging mining rates. Also, decreasing availability of parts because of cost cutting, added freight and resultant time out of production that was becoming unsustainable on a single vessel working over 330 days a year.

With high tech electronic management of drives, batteries and generators, most of these new components can report back to manufacturers with strings of data and trends. This can reduce maintenance costs by finding small faults before they get catastrophic and costly.

I believe the benefits it can have on our business are:

- Highly targeted maintenance and repairs – less tech hours.
- Very few moving parts to wear out.
- Far simpler drive lines i.e. no gear boxes or reduction.
- Elimination of hydraulics – no oil.
- Substantial reduction in greenhouse gasses.
- Electrical components which are plug and play.
- Estimates on my business is an 80% decrease in annual diesel fuel consumption from 200,000 litres to 40,000 litres.
- Reduction overall: One genset instead of four motors, where 1,500 litres of oil consumed per year would reduce to 200 litres per year.

My research started online. I then visited six countries on my personal studies including The Netherlands, Iceland, Ireland, Florida (USA), Brussels and the highlight which was Norway. I was able to experience an electric fishing boat for a full day, meet with ship designers, factory tank test hulls, and visit battery and fishing manufacturers.

A special thanks to Fisheries Research and Development Corporation (FRDC) for all the contacts provided, and Catherine Barret BIM Ireland for spending a week taking me around Ireland.

Acknowledgements

Firstly, I like to thank Nuffield Australia for believing in me and inviting me to experience this life changing journey. It has truly given me a world view of primary production (food) and helped me grow as a man, husband, father and an industry leader.

Thank you to FRDC who have invested in me.

The biggest thanks are to my family, especially my wife who prompted me to apply for this life changing experience for us all. Karen stepped up and managed the business and family while I travelled for 16 weeks to 19 countries, also the employees who all adjusted and thrived without me.

I truly worked out not everything hinges on me and hooray, “freedom for a new job” after this report is finished and presented.

Abbreviations

EMP – Eco Marine Power

FRDC - Fisheries Research and Development Corporation (FRDC)

FV – Fishing Vessel

IC – Internal combustion

kVA – Kilo volt x amps

kW – Kilowatt (a unit of electric power)

MDV - Masterplan Duurzame Visserij (from Dutch, Masterplan for Sustainable Fisheries)

MRE – Marine Renewable Energy

Nm – Newton-metre (a unit of torque)

PM – Permanent Magnet

RPM – Revolutions per minute

SME – Small or medium enterprise

SWATH - Small Waterplane Area Twin Hull

Objectives

To investigate the topic of moving to modern efficient, environmentally sustainable fishing boats. Specifically:

- Investigate the latest hull designs.
- Investigate electric drives.
- Investigate power storage options.
- Investigate power generation options.

Chapter 1: Introduction

The concept of commercial fishing - which is the supply of fish for commercial profit, typically from wild fisheries – has been in existence for centuries. From early settlement to the early 1960s commercial fishing existed. In the early part of the 1960s the commercial industry started to come under government management for the purpose of sustainability. This government management was introduced to manage the fisheries' stocks to meet international obligations. Initially this was a very basic authority to keep a watchful eye on the fishing community. Incidentally, fish was in fact the colony of South Australia's first export in 1836 (as referenced in For They Were Fishers by Evelyn Carter Wallace).

For a period between the early 1960s to mid-1990s the South Australian fishing industry evolved and developed exponentially due to the entrepreneurial nature of the fishing operators of this period. They operated under high physical duress, enduring many challenges around weather, boats and market forces with often high return. In this environment, new ideas were tested and adopted quickly, resulting generally in high benefits to the industry and community. (Innovation was the mother of necessity).

Unfortunately, the evolution period stopped there. The operators of the early period of fishing never truly backed away from the industry. However, their operating plans changed after this period. Their initial risks resulted in high returns allowing them to operate businesses with high economical efficiencies for that period. This evolution period inflated the value of the commercial fishing industry exponentially increasing the value of fishing products, fishing gear and licenses. It corresponded with greater management scrutiny resulting in restrictions on catch, equipment and boats that became over time very prescriptive.

The management of the industry from the mid-1990s became increasingly and highly regulated with legal consequences, forcing the innovative nature of industry to halt. The impact of such management brought with it a reduced catch and effort. This becomes a cycle of reducing effort and corresponding reduced catch. This fisheries management means that reduced effort results in reduced catch whilst still using the same fishing equipment. This then means that the results are not any different and continue the circle of harsher management regimes to attempt to curb what they believe to be over fishing. This dramatic change stifled the evolutionary process as the rewards brought by the high risks were reduced due to catch limitations. The industrial evolution was never able to adapt to new changes as every reduction in fishing effort by the fishermen brought with it an increase in fisheries management to the fisherman as opposed to the management techniques evolving to aid the fishermen. As increasing restrictions were imposed upon the fishing industries, catches have decreased correspondingly with the effort decreasing (while catch effort per tonne remains the same or better), to which fisheries management conclude there is an ever-decreasing stock supply, further increasing regulations.

Particularly in South Australia, modern fisheries are still largely made up of the original fishing owners of the early 1960s using the equipment that was developed in the 1990s. The entire operation has aged and been unable to evolve resulting in fisheries that are both extremely expensive to enter and not cost effective to run. Coupled with ongoing uncertainty around access security for fishers and financers this has made the industry a very unappealing option to the younger entrepreneurial generation leaving the industry with old stubborn fishers.

The now old technology in fisheries needs to be supported with legislative framework to adopt today's available technology and then it will become appealing to the younger generation. They need to believe that the industry will be able to support them and reward them for what is a high-risk occupation. This means new technological evolutions to the industry must be made to make it appealing to younger generations. Chief of them is improving the efficiencies of the vessels and equipment. Most vessels in the majority of the fishing fleets are upwards of 30 years old with old propulsion and fishing technology. The use of old equipment incurs high carbon costs, high operating costs and high environmental costs. The knowledge and adoption of the technology proposed in this report will help to reduce operational and environmental costs and if managed in the correct way, improve public perception and availability of premium wild caught fish to the Australian community.

Wild caught fish are an intrinsic part of the food security in the world and needs to be viewed that way by all. Provided industry is supported and fostered to uptake technological options and opportunities, they will be part of the solution.

This report will outline an in-depth investigation into the use of electric propulsion in fishing vessels to reduce environmental and economic loads.

Chapter 2: Modern Motors for Modern Boats

Electric drives

All commercial fishing vessels (FVs) are driven by propellers. The propeller is a fan that converts rotational power (torque) into thrust. Thrust is described as forward or backwards movement. Drive systems come in a variety of configurations to suit different operational parameters. In electric fishing vessels, there are two categories of drive systems. Fully submerged pods, are an electric motor entirely submerged underwater in a casing with an attached propeller. Secondly, a more traditional arrangement might be adopted with an internal motor in an engine room with a shaft exiting the hull with a propeller attached to its end (Thornton, J. pers. comm. Jun. 2016).

In most commercial FVs, the rotational power is provided by an internal combustion (IC) engine, powered by diesel fuel only, while the propeller acts on the water to generate thrust. The internal combustion engine works by converting fuel energy into rotational energy. Internal combustion engines use air as the catalyst to burn the fuel to generate energy. IC engines convert fuel energy at a low rate relative to their input and can vary significantly across their operating range. The fuel conversion to energy function is known as efficiency. It is the ability to convert energy from one form to another. A varying efficiency poses two problems. Firstly, the engine will consume higher amounts of fuel at most operations. Secondly, due to a lower ability to convert energy most of the time, an IC engine will produce lower power at certain operations. A typical engine used in a FV will have a maximum efficiency of 35-40% with a minimum efficiency as low as 10% in some operations. Put in other words, for every 100 units of energy input, a typical vessel will output between 35-40 units and sometimes only 10 units.

Much of the wasted energy is lost as heat. In an IC engine, tiny controlled explosions act on moving metal components which rub against each other to turn the drive shaft, and then the propeller. The rubbing creates friction (even when oiled) and generates heat energy which is not converted into thrust. This contact between components does not occur in electric engines. The drive shaft is acted on by a magnetic field and there is an air gap between the engine and the driveshaft. As driveshafts are magnetically pushed, even running electrically, motors are generally cool to touch, and heat energy wastage is eliminated.

Commercial fishing operations require a dynamic range of thrust to achieve their objectives. Depending on the fishery, FVs might be required to operate for long periods of time and cover ocean at differing speeds. Therefore, the propeller in a fishing vessel will experience a large range of rotational speed. It will see operations at a very low rotational speed as well as very high rotational speed, and during this time the engine will be required to vary its output accordingly.

As a result of this varied efficiency, the IC engine has a narrow band at which it operates at its best ability. Operation outside of this band leads to low power and excessive fuel consumption by the engine.

In addition to the variable efficiency of engines, their ability to produce power also varies throughout the operation range. Whilst at lower engine speeds, peak power is also low and as the engine speed increases, power increases also, the rate at which power increases is non-linear. An FV will be underpowered until it reaches its peak operating range.

An IC engine's propeller efficiency varies with speed. Because of the non-linear relationship between efficiency and power production of IC engines, it is difficult to correctly match the propeller to the engine to achieve the most efficient thrust. The vessel needs to produce a certain amount of thrust at any point to overcome the drag of the water and propel the vessel forward. If the propeller exerts too little thrust, the vessel will stall. As a result, propellers must be matched to exert enough thrust to get the vessel moving at low speeds. As the propeller speed increases, the thrust also increases with it. Propeller design also impacts on thrust and efficiency of the engine (Van Wensen, F. pers. comm. Jun. 2016).

The propeller must be able to provide enough propulsion when the engine is operating at its lowest power and efficiencies. The design is a compromise between operation at low levels, and efficiency at high levels, which best harnesses the engine's top end power. Pictured below is the propeller power curve for a typical IC engine. Note that the thrust exerted by the propeller at the top end is a maximum of 85% of the power produced by the engine. Electric motors provide all their torque all of the time, unlike IC engines, which make peak torque within a narrow band of operation (Machak, L. pers. comm. Jan. 2016).

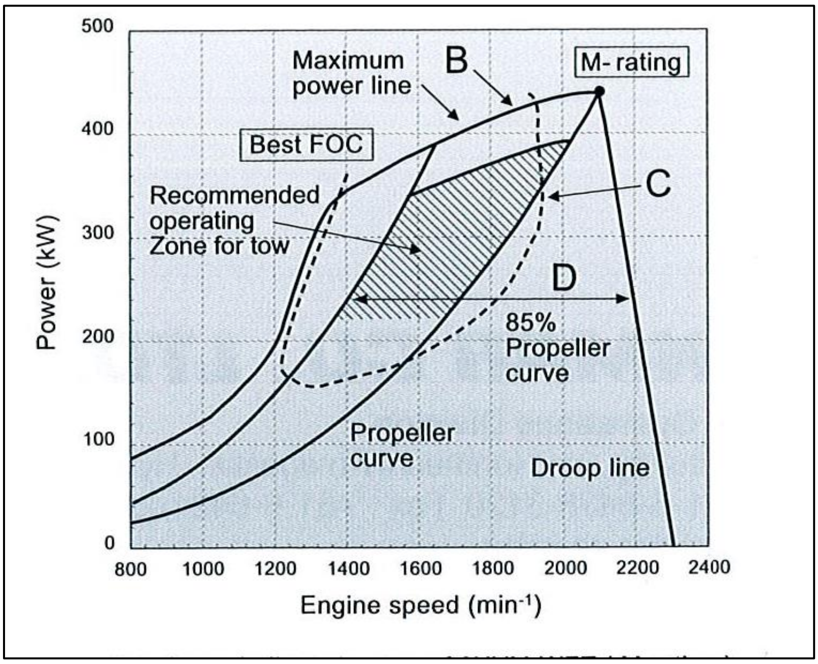


Figure 1: Yanmar Marine Diesel HYM-WET M-Rating Motor (fitted in FV Silver Spectre, Port Adelaide) Propeller curve

The later model European emission motors that are high temperature and high-performance motors compound all these problems (Lanssen, E. pers. comm. Jun. 2016). Motor manufacturers building in precautionary parameters are also compounding these existing issues and locking in the problems with a need to maintain warranty thus negating the benefits from a new engine.

Electric motors are also ‘self-feeding’. It is possible (especially in terrestrial vehicles) to implement regenerative braking, which recaptures forward momentum as battery charging (Nicholas, G. pers. comm. Jun. 2016).

Figure 2 below highlights the inefficiencies of a typical IC engine, like the unit powering the FV Silver Spectre. The second graph shows torque peak is where maximum efficiency is achieved. That is, where the engine is utilising the greatest amount of fuel and air to generate its maximum rotational force on the shaft. When the throttle is increased beyond that point, the limitations of the propeller shape and size lead to a reduced efficiency. This is highlighted by the third graph in Figure 2.

As the FV Silver Spectre operates in a variable load environment, an IC motor is comparatively inefficient option when electric engines are considered (Fuel Economy, Engine Efficiency & Power, Davis).

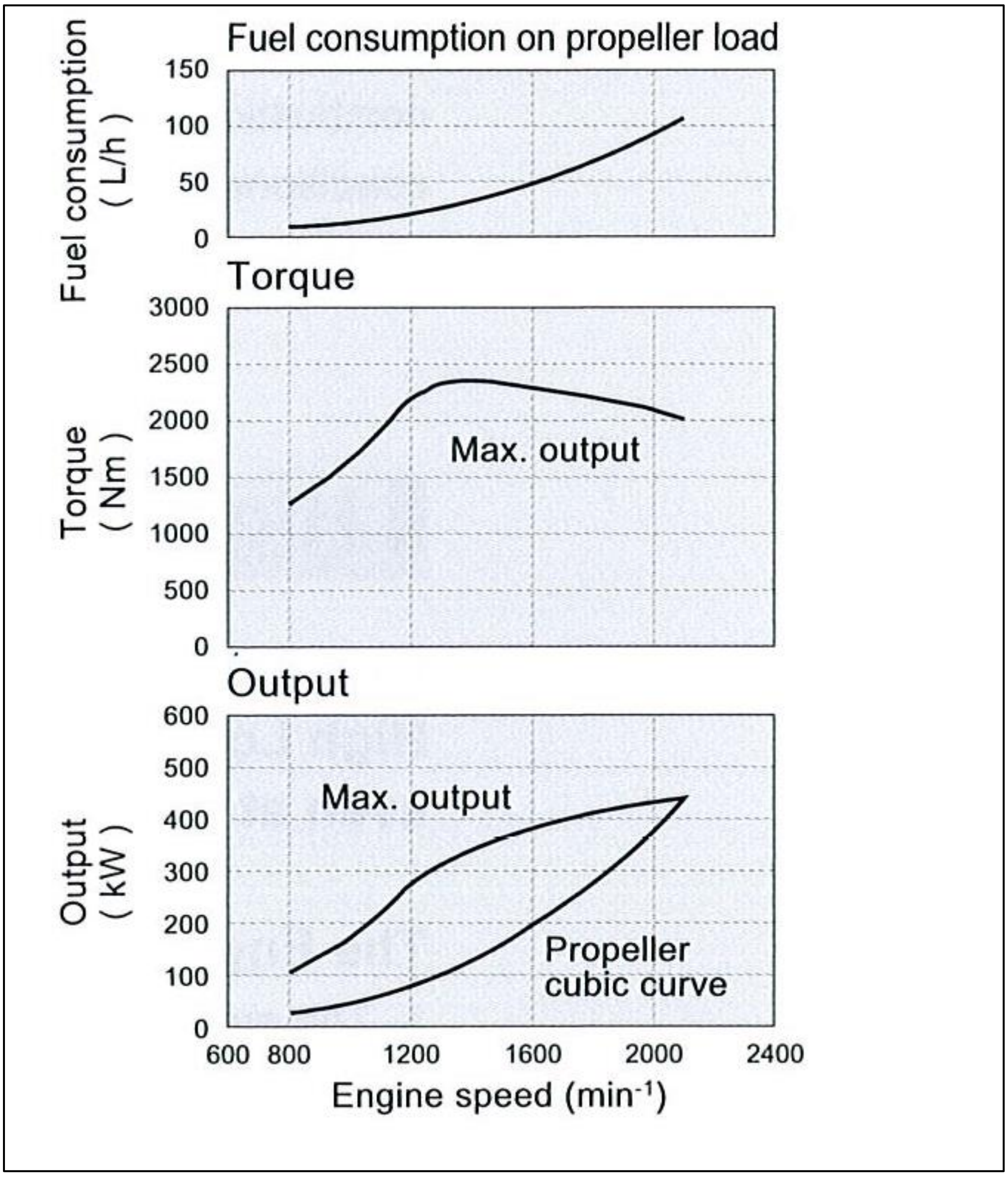


Figure 2: Fuel consumption, torque and output models of the FV Silver Spectre

Electric drives for propellers and equipment

The use of IC engines shows that a large amount of the time they are largely inefficient resulting in increased operation costs. The alternative method of providing rotational energy is with electric motors.

Electric motors have evolved rapidly over the last decade. Electric motors have incredibly high torque production with efficiencies of up to 98%. The single biggest benefit of electric motors is the power development. While internal combustion engines rely on air and fuel to produce their power, electric motors use magnetic fields created by electricity to create rotational energy. Due to this, the amount of electricity and therefore the motor power, is incredibly linear across the engine's operating range, allowing the motor to have a far higher power level at low speeds. This has a benefit of allowing the propeller to be designed with far higher efficiencies as they can utilise greater amounts of power at lower speeds resulting in a high-power utilisation at higher speeds. Pictured below in Figures 3 and 4, is an example of a propeller curve for an electric motor. Note that the propeller is able to harness the entire 800kW of power at high shaft speeds. It is important to note that at part load the electric motor is still as high as 97% efficient. The efficiency drop of an electric motor is far less than that of an IC engine (Bachmann, T. pers. comm. Jun. 2016).

(Oswald PM synchronous motors) 'Tough-Fantastic' series water-cooled (this is fitted in FV Immanuel)

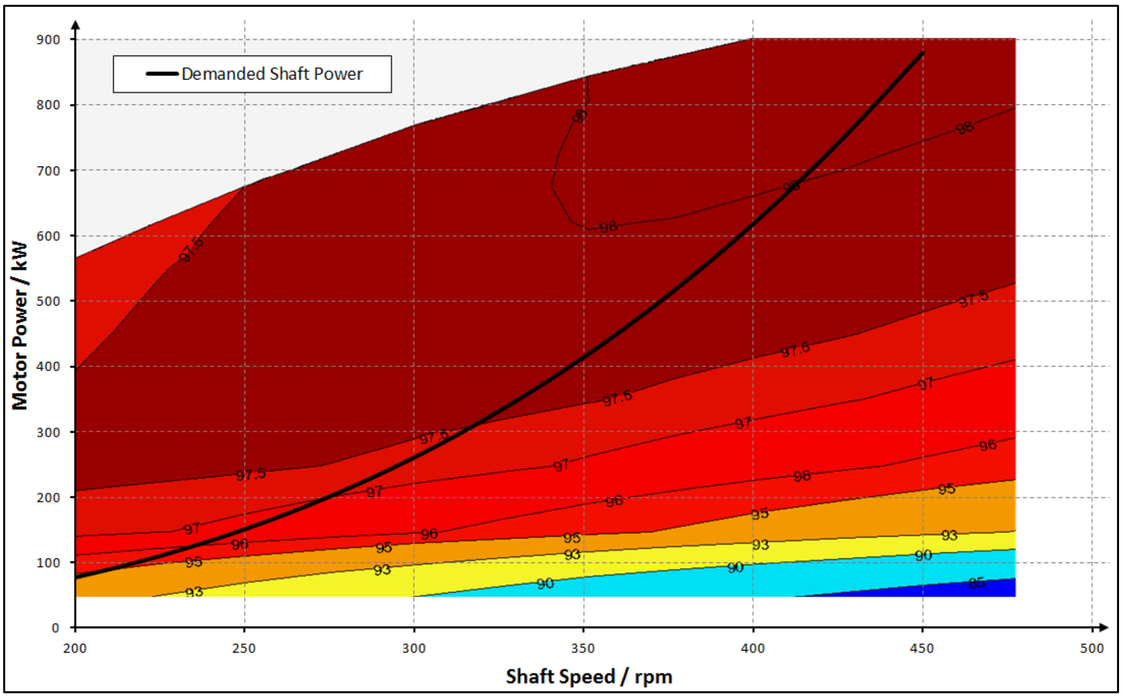
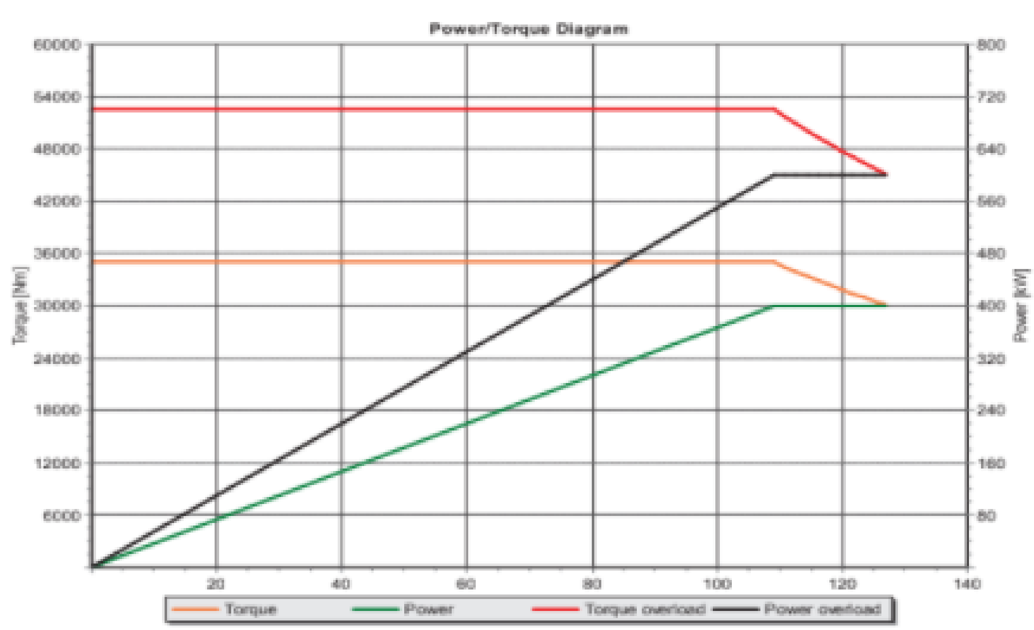


Figure 3: Propeller demands shaft power according to shown curve



Driving Data

			Rated				Overload			
			P_{red}	P	Fw $P_{con.}$	Fw $P_{red.}$	P_{red}	P	Fw $P_{con.}$	Fw $P_{red.}$
Voltage	U	[V]		370	370			390	390	
Power mech.	P	[kW]		400	400			600	600	
Current	I	[A]		730				1150		
Frequency	f	[Hz]		36,3	42,3			36,3	42,3	
Speed	n	[min^{-1}]		109,0	127,0			109,0	127,0	
Torque	T	[Nm]		35045	30077			52570	45115	
Power factor	cos φ	[-]		0,90				0,84		
Efficiency	η	[%]		95,0				93,0		

Poles	40	
Connection	Star	
Duty	S1	
Allowed inverter frequency ≥	3	**kHz**
Allowed pulse rise time ≥	0,3	**µs**

Equivalent circuit (each phase to phase values)

R1 u-v	17,0	**mΩ**
Lges u-v	0,85	**mH**
U_0 u-v	3046	**V/1000rpm**

Resistance R at room temperature (20°C/68°F).
Conversion to operation temp.: R_{hot} = $R_{20°C/68°F}$ x 1,3

Protection:

Temperature sensors

3 x PT100 (Winding)
3 x PT100 (Winding reserve)
2 x PT100 (Bearing)

Protection IP	54	
Insulation class	F	
Winding insul. max.	1,56	**kV peak**

Figure 4: FV Immanuel Power torque diagram

Efficient electric propulsion has been utilised on two international fishing vessels FV Immanuel (Netherlands) and FV Karoline (Norway).

Several other vessels in Europe, including the Immanuel and the Karoline have utilised electric propulsion and realised the enormous benefits associated when compared to their IC predecessors.

These vessels' motors are brushless electric motors. Brushless motors replace a commutator and brushes with an electronic controller[1] (Collins, 2016). Now the permanent magnets act as the rotor and rotate around on the inside while the stator is made up of the fixed electromagnetic coils now on the outside. The controller powers each coil according to what charge it needs to attract the permanent magnet. In addition to moving the charge around electronically, the controller can also provide a same charge to oppose the permanent magnet. Since like charges oppose each other, this pushes the permanent magnet. Now the rotor is moving thanks to a pull and a push.

Brushless motors are intrinsically simple. There are only two wear points in the motor - front and rear roller bearings. The only maintenance required is to lubricate their points as part of general boat maintenance which does not require specialist technical qualification (Campbell, C. pers. comm. Jun. 2016). Electric motors do not require consumables of oil and filters. They run smoothly with no reciprocal movements, removing all combustion motor noise and vibration (Campbell, C. pers. comm. Jun. 2016).

The two examples of torque data sheets (Figure 4) demonstrate the newton metres of torque between electric and diesel to the order of 14.5:1 in favour of the electric motor, and consequently a bigger propeller can be used for proportionally increased thrust.

The Immanuel replaced a 3516 V16 Caterpillar at 1450kw for a maximum of 5000 Nm of torque. The new Immanuel has a 400kw electric motor with 34000 Nm of torque (Bachmann, T. pers. comm. Jun. 2016). The replacement of the old IC engine did not sacrifice any of the power specifications it previously had. The cost to purchase the two different sources of torque to propeller is comparable at about AU$500,000. A major cost saving of the electric motor is the dispensing of a gearbox/reduction unit which can also cost approximately AU$500,000 to purchase.

Both vessels were able to reduce their propulsion power while still reaching the necessary targets. The Immanuel is a 31-meter vessel with a 400kW electric motor connected to a fixed speed generator. This system uses 60 litres per hour as opposed to the vessel it replaced which was a 38-meter vessel with a 1450kW diesel engine consuming 300 litres per hour (Bachmann, T. pers. comm. Jun. 2016).

Meanwhile, the Karoline (Figure 5) is a 12-metre vessel with an 80kW electric motor (Figure 6) that consumes 100 litres per fishing day, replacing a 12-metre vessel with a diesel engine that consumed 300 litres per fishing day (Bachmann, T. pers. comm. Jun. 2016). Both vessels saw dramatically reduced fuel and power consumption while maintaining vessel performance.

[1] Commutators are used in direct current (DC) machines. Commutation is the process of switching the field in the armature windings to produce constant torque in one direction. By reversing the current direction in the rotating windings each half turn, torque is produced.

Figure 5: FV Karoline

Figure 6: Electric motor on FV Karoline

An added benefit of the electric motors is a high reduction in maintenance costs of electric drive when compared to a vessel using internal combustion propulsion as there are far less moving parts and less heat damage.

The two biggest benefits were kW reduction and reduced fuel for effectively the same performance. As can be seen in the above examples, there is a dramatic reduction in operating costs and as a result the capital costs of an electric vessel can be paid off, in some cases, in as little as five years.

Maintenance comparison

Electrical propulsion motors generate purely rotational energy. This differs from IC motors in that they are not reciprocating motors that have to turn vertical energy into rotational energy. This process generates friction and wear between all of the moving parts.

Electric motors, on the other hand only require two bearings, one each end of the drive shaft. Therefore, they require less gear, equipment and moving parts to maintain. Contactless systems containing magnetic fields, rather than interconnecting systems means that the engine componentry is subject to less wear.

In addition, electric motors do not require motor oil. Typically, a bearing check is only needed every 30,000 hours and a full dismantle and service is required after 50,000 hours. It has been documented that electric motors can sustain 100,000 hours of use before a full dismantle is required (De Blaeij, D. pers. comm. Jun. 2016).

The FV Silver Spectre was built in 2010 in South Australia. It is a commercial blue crab fishing vessel that operates with two diesel IC engines. In its lifetime it has seen approximately 24,000 hours of operation per motor.

Maintenance Category (entire working life)	**FV Silver Spectre (IC Engine)**	**Comparable Electric Motor**
Service frequency	48,000 hours	100,000 hours
Fuel consumption	1.5 million litres	300,000 litres
Engine oil changes	48/motor	Nil
Fuel and oil filter changes	192 filters	Nil

Table 1: Comparison in maintenance costs between FV Silver Spectre and an electric motor of comparable output

Table 1 above summarises the comparison in maintenance costs between the FV Silver Spectre and an electric motor of comparable output. Coolant is also required to operate the engines and the FV Silver Spectre requires approximately 50 litres in each needing replacement every 5,000 hours.

In addition to fuels and oils, the FV Silver Spectre has undergone repairs to its fuel injectors 16 times and requires frequent valve and fuel system repairs.

Whilst electric motors are not mainstream due to their high installation costs, their low maintenance enables business to save costs during their working life.

It is estimated that hybrid diesel-electric boats will probably burn between one third and one fifth of the amount of the diesel that a traditional diesel IC vessel would.

In addition to the savings on maintenance costs, vessels can be kept in the water longer. One cod boat from Vannvåg Island, Norway documented 20% more time in the water due to reduced crew fatigue.

Chapter 3: Electric Power Generation

Power generation

Traditional power generation on fishing vessels is a fixed speed diesel generator (Figure 7) with all the same inherent issues of diesel propulsion. This means they never run on maximum thermal efficiency (Chapter 1). Inefficiencies extend to generating electricity along with the inefficiencies of the drive motor. The net result is energy in is not converted efficiently in fixed speed generators (approximately 25% thermal efficiency on the majority of fixed speed generators).

Disadvantages of using fixed speed power generation include:

- At only one point through the kilowatt range do motors run at maximum thermal efficiency. The balance of the time the engine is using the fuel but not able to reach the full energy output of the fuel.
- A genset must be set for maximum power requirements, when in reality, 100% power is only required opportunistically (refrigeration requires more power (an extra 40%) to reach optimum temperature then drops to sustain).
- All the maintenance requirements of underutilised engines.

Advantages of using fixed speed power generation include:

- Effective when able to be operated at a constant 100% load (boats are not in this category).
- Cost effective to purchase and manage the electrical output for constant frequency.

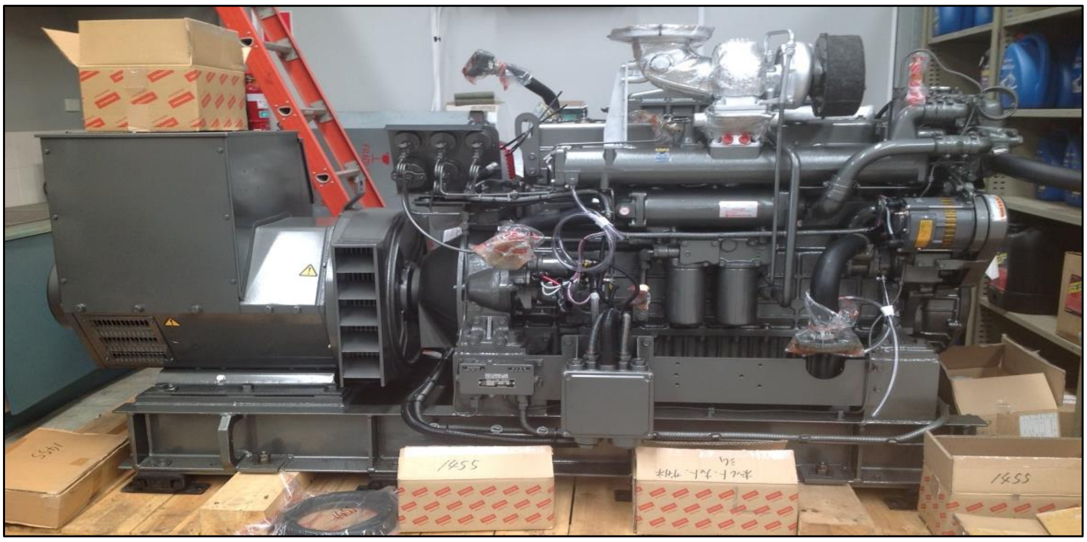


Figure 7: Yanmar 100KVA fixed speed generator (fitted in the FV Silver Spectre)

Variable speed diesel generators (Figure 8) are recently (in the last three-to-five years) available and operate in a wide speed range to generate the power demanded while fully optimising thermal efficiency.

Disadvantage of variable speed include:

- Higher cost to purchase (at least double) because of management of the frequency of electricity (50hz).
- A diesel motor with maintenance requirements.

Advantages of variable speed include:

- Smaller capacity motors required to produce the kilowatts needed.
- Up to 40% fuel reduction.
- Service intervals mean up to 75% more time between oil changes.
- Less overall hydrocarbons used in the life of the unit (Erussard, V. pers. comm. Jun. 2016).
- Increased low load times mean less overall noise (Magne Gjerde, P. pers. comm. Jun. 2016).

Figure 8: Variable Speed Generator. Fischer Panda 45 KVA

Micro turbine generators

Micro turbine generators (Figure 9) are small combustion turbines approximately one third the size of equivalent diesel engines with outputs ranging from 5kW-500kW. Micro turbines can be run using different fuel types such as hydrogen, LPG, alcohol, bio oil and diesel.

Advantages of micro turbines:

- Small number of moving parts.
- Compact size with potential to be located for size limitations.
- Lightweight.

- Capability of utilizing waste heat (i.e. exhaust) ratio of 30kW micro turbine from 150kW heat from exhaust.
- Low carbon emissions with multi fuel capability.

Disadvantages of micro turbines include:

- Cost.
- Management of electricity produced.
- Not currently mainstream.

This can be a combined system with a micro turbine which you also harvest the waste thermal power from the exhaust. For example, a turbine producing 30kW electricity will produce 150kW thermal power. This can be used for domestic requirements.

Figure 9: A micro turbine with waste thermal power unit attached

Solar

Solar panels convert sunlight energy into electricity using photovoltaics (PVs).

Solar panels are a widely adopted form of auxiliary power generation for use in many households. Some households use solar generation to offset electricity bills, while others use them to entirely remove electricity bills.

Solar panels also see use industrially for the same reasons above. The use of solar generation of marine vessels is used largely to maintain the charge of DC batteries for engine starting and lighting. These are often very small-scale systems used largely on pleasure vessels. The use of solar in commercial fishing environments is uncommon.

This is largely because their power generation cannot match the power requirements of a commercial vessel. Largely because the energy efficiency is still quite low, and the surface area required to produce the necessary amounts of energy will not fit on a commercial boat.

The thermal characteristics of solar panels vary greatly. Some panels of lower quality will lose their efficiency as the ambient air temperature increases, which results in less energy harnessed from the greater heat, reducing their effectiveness. High quality solar panels do not have this issue and are far better suited.

While solar panels are unsuitable for power production on their own, they can be incorporated into the power generation mix on a commercial vessel, offsetting the power required by the main power source. To do this effectively there must be a battery bank for the solar power to be stored in (Warnock, B. pers. comm. Aug. 2016).

As a brief example, if a boat uses 40kWh of energy per day, solar can put 15-20kWh back into the system most days, leaving a draw of around 25kw/hour in daylight operations to be taken up by the main power generation system (Warnock, B. pers. comm. Aug. 2016). Solar power is a good method to offset power production reducing overall fuel loads.

Wind

Investment into modern wind powered ships is ironic, as many of the first commercial cargo and fishing boats were powered under sail before steam powered ships became preferred and prevalent. In the 1970s and 1980s there were several ships fitted with rigid sails of various types with the aim of reducing fuel consumption. The rigid sail concept has also been applied to a range of smaller vessels, but it has not gained widespread acceptance to date on either large ships or smaller vessels (Atkinson, G. pers. comm. Jun. 2016).

The Eco Marine Power (EMP) Aquarius Marine Renewable Energy (MRE) System is an innovative wind and solar MRE solution and is designed so that the practical limitations of using rigid sails and solar panels on ships are overcome (Worsley, P. 2016).

A ship fitted with the Aquarius MRE System such as a bulk carrier, oil tanker or cargo ship (Figure 11) will be partly a solar powered ship and partly a sail powered ship (along with the ship's main engines). These ships will be able to use wind and solar power together as a source of energy and propulsion in order to reduce harmful emissions and lower fuel consumption. On a large ship, 1,000 tonnes or more of bunker fuel could be saved a year by using the Aquarius MRE System.

Figure 10: JAMDA - A computer controlled, sail assisted merchant ship

Chapter 4: Effect of Hull Design on Power Efficiency

Hull types

As mentioned in chapter one, electric propulsion characteristics are vastly different to that of diesel propulsion. The power development curve of a diesel engine is much steeper than an electric motor. They produce peak power for a limited window and prior to this window their performance and efficiency is reduced. In comparison, electric motors have a very broad and flat window of power, increasing their overall efficiency of power conversion.

Current hull designs of fishing vessels are tailored for use to suit the fishing operation they are undertaking. Applicable regulations are also considered. Some regulations have resulted in the development of hull designs that can compromise safety (in order to hold sufficient catch), but still comply with manning requirements for traditional diesel propulsion. Hull size and shape are currently restricted by the selection of a diesel engine, often requiring vastly overpowered engines to accommodate acceptable hull performance.

Hulls designed for use with electric propulsion, should be designed to ensure that the benefits of electric propulsion can be maximised.

There are several hull styles that have been investigated for use with electric propulsion. This report investigates the most appropriate styles of hull for electric propulsion.

Displacement hulls

The displacement hull (Figure 13) provides floatation through water displacement. They use the shape of the hull to displace the required volume of water in order to maintain buoyancy. In order to displace the huge amount of water required to maintain a vessel's buoyancy, these hulls are large, bulky designs which require a lot of material to construct, increasing the weight of the vessel significantly. Displacement hulls are a simple and cost-effective hull style.

Figure 11: FV Peter Crombie, built as a displacement hull in 1971

Displacement hulls are a very effective hull option for high volume fisheries such as trawling. This is due to displacement hulls providing buoyancy based largely on the volume of water displaced as opposed to the weight of the vessel.

The speed of the displacement hull is limited by the waterline to length ratio. This ratio is an empirical calculation used to determine the maximum speed of a hull. This calculation is:

$$V_{hull} \cong 2.43 * \sqrt{L_{WL}}$$

- where V_{Hull} is the hull speed in knots; and
- L_{WL} is the length of the waterline in meters (Downer, M. pers. comm. Jun. 2016).

This equation shows that as the waterline length increases, the hull speed of the vessel increases, however, at a slowed rate. The length of the waterline is defined as the total length of the vessel that sits on the waterline. This means the waterline length is a function of both the vessel length and the vessel width. This means that the narrower a hull design the faster the hull speed, however, given the boat is narrower, this sacrifices stability for speed.

Many fishing vessels are broad boxy style hulls allowing high fishing loads and stability, however, this decreases the speed of the hull and ultimately increases the amount of fuel consumed.

It is worth noting that well-designed displacement hulls are highly efficient and quite fast for the applied horsepower (Bergero, R. pers. comm. Jun. 2016).

Planing hulls

A planing hull design (Figure 14) allows the hull to rise out of the water once the required power is reached, allowing the vessel to exceed the traditional hull speed. Where a displacement hull utilises buoyancy to provide floatation, a planing hull utilises lift provided by the hull to raise the vessel further out of the water. This has the effect of reducing the vessel’s displacement and as a result reducing the friction/drag loss of the hull, allowing the vessel to exceed the traditional hull speed.

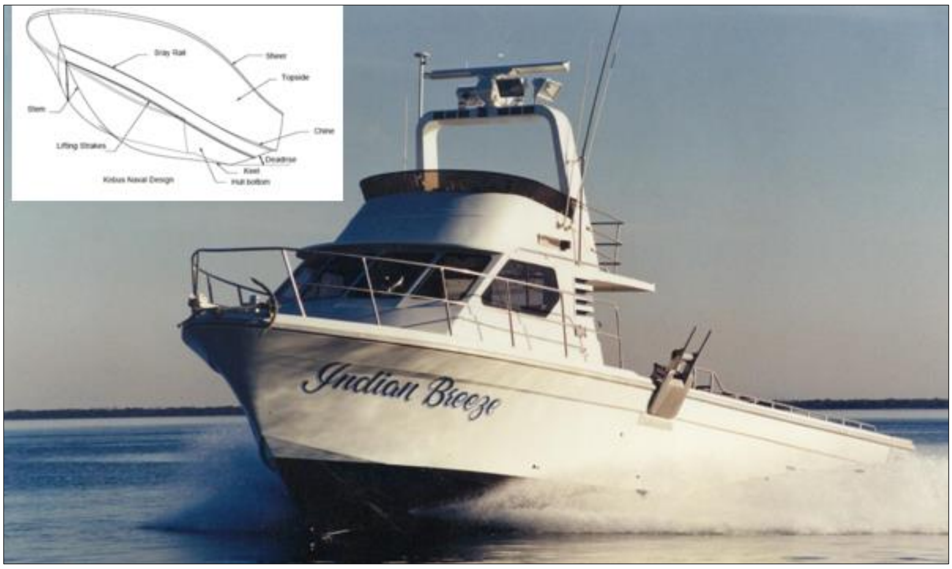


Figure 12: FV Indian Breeze, built 1985 a planing hull and a Kobus Naval Design diagram, inset

The planing hull comprises of several hull designs in one. The top layer is the typical displacement hull allowing the boat to float when not in motion. The middle section provides the lift - this section is used at low speeds to enable the hull to rise out of the water. The final section is the planning section which is designed to have as limited surface area as possible and uses vessel speed to maintain buoyancy (Potgeiter, 2006).

The disadvantage to the planing hull design is the weight carrying capacity of the hull is significantly reduced to within 20% of the vessel's work trim weight. This is because the hull must provide the initial lift to raise out of the water. This initial lift requires a significantly higher level of power to raise the hull out of the water than when planing due to the hull combatting high levels of water drag. Once the vessel has lifted from the water to a planing stage, the power required to maintain vessel speed is significantly reduced. If the vessel's weight is increased too much, the power required to lift the vessel would exceed the power that can be provided by the vessel's propulsion, resulting in high fuel consumption.

Due to the low power consumption required at a planing level, these vessels often have a lower fuel consumption compared to other hull designs. However, due to the large engines required to plane, these vessels have a high fuel consumption per operation time.

As a result, it is believed that planing hulls will benefit greatly from the flat power production of electric motors.

Semi planing hulls

Displacement hulls and planning hulls both have compromises in their design to achieve operational efficiency. The semi planning hull borrows elements from both displacement and planning hulls to allow them to have a reasonable carrying capacity whilst being able to achieve higher speeds than a traditional displacement hull. This style is still a compromise and will never match the carrying capacity of the displacement hull or the speed of the planing hull, however it is a more flexible design.

Multi hull

The multi hull is a style of hull that has more than one hull. This is generally twin or tri hulled. These hulls can be a displacement, planing or a combination of the two. These vessels are very broad. However, due to having multiple hulls, their effective length of waterline is far greater than that of a standard single hull design. This means that the speed of a displacement multi hull is far greater than a single hull. Similarly, a planing hull will be faster, and have a higher carrying capacity than a single hull.

Due to the vessel having two smaller hulls, the carrying volume is far lower than that of a single hull design. Meaning for use in the fishing industry, they could compromise the carrying capacity of large volume fisheries.

Catamaran (two hull)

Catamarans (Figure 15) can be both planing or displacement hulls. They are the most common style of multi hull vessel. They enjoy the typical advantages and disadvantages of the multi hull style mentioned previously.

Figure 13: FV Grey Ghost, built 2005, Catamaran

Tri-hull

Tri-hull vessels (Figure 16) are exclusively planing vessels. They consist of three hulls - a main centre hull which acts like a displacement single hull vessel, allowing high carrying volume and capacity at low speeds; and two outer hulls that act as planing hulls. The design lifts the displacement hull out of the water and enables high speeds at the same time. For their size and speed, they are considered to have very high carrying capacities.

Figure 14: Futuristic version of a Tri-hull

SWATH Hulls

SWATH hulls (Figure 17) are a small water plane area twin hull. These hulls have the majority of their surface area submerged below the water level. This minimises the effect of waves on the hull. It provides a very stable platform with a high carrying capacity. However, due to the deep submerged hull they have a large amount of drag and very deep draft.

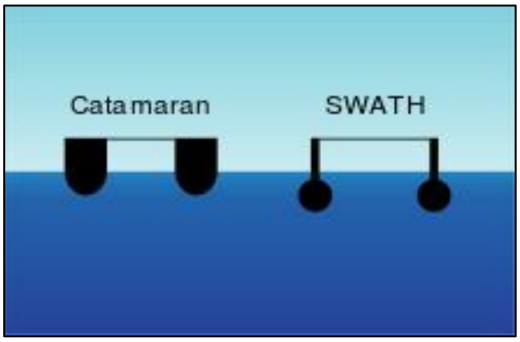


Figure 15: Swath Hulls

Fishing industry hull preference

For the fishing industry, the catamaran hull is most suitable. The catamaran has a large deck with fine easy to push hulls. Generally, they are burdened with light to moderate loads, with minimal impact on performance.

Chapter 5: Power Storage Solutions

Battery storage

Battery storage is imperative to the modernisation of fishing fleets. Currently, evolution of the power storage modules (batteries) is rapid in both capacity and cost reduction. In the last 18 months of my investigation, battery costs have reduced by approximately 30% and capacity has increased by 10% per kilogram weight (Dyrseth, M. pers. comm. Jun. 2016). Life span has doubled and there are far more compositions and greater placement options (Young, R. pers. comm. Jan. 2016).

The greenfield of battery development has enormous potential for application in the fishing industry. It is expected that with the adoption of electric drive propulsion, there will be a substantial uptake of battery storage when the technologies reach manufacture.

Some of the more unique and exciting composition options include:

- Aluminium air batteries – air and sacrificial aluminium plates to store energy.
- Sodium batteries – liquid salt to store the energy.
- Dual carbon batteries – dry cell with positive and negative carbon rods which store the energy. Five times the capacity and 20 times quicker to charge than current lithium.

At the time of publication of this report, tiny metallic-gold particles are being used to convert sunlight into fuel (Radford, 2017). The technology is being developed in South Australia to store solar energy as an alternative to battery storage. This demonstrates the rapid advancement of energy capture and storage.

Lithium batteries were developed in the 1970s. There are many manufacturers of lithium-based battery packs with fully integrated management of individual cells and the ability to configure modules to fit both area and capacity (Hauso, H. pers. comm. Jun. 2016). Some systems reach 4.16MWh and one currently in development will supply the world's largest electric ferry, carrying 1.7 million passengers and 1.9 million vehicles for zero emissions (Parkinson, N. pers. comm. Jun. 2016).

Lithium has a series of chemical compositions, including:

- Lithium Nickel Cobalt (G-NMC):
    - High energy density: 0.59kWh/kg.
    - Long life span: approximately 8,000 cycles at 80% discharge.

- Lithium Nickel Cobalt Aluminium Oxide (NCA/LTO):
    - Long life cycles.
    - Fast charge and fast discharge.

All lithium systems are modular. The industry average is 6.5kWh per module and they are stacked together to create the kWh required. All run a high voltage bus system (i.e. 400V-1,000V, then inverts to drive systems 415V or 240V) (Janda, J. pers. comm. Jun. 2016).

The disadvantages of lithium include:

- It is relatively heavy weight for total kilowatt hours. The research for this report investigated a system for the 24 metre FV Silver Spectre which would need a 500kWh battery pack and would weigh approximately five tonnes.
- Battery packs pose a fire risk, being caused by a thermal runway.
- The global supply of lithium is limited and inaccessible (Leni, 2017).
- Lithium is hard to recycle and dispose.

Conclusion

The majority of Australia’s fishing fleet is outdated. That is, combustion engines are the typical form of power generation. As power generation technology has superseded traditional diesel engines in the last three decades, there is enormous room and requirement for improvement.

Electric motors provide more power. Vessels can utilise smaller engine units and conserve space for additional cargo, catch or crew. They operate at efficient power conversion points and provide all their torque on the propeller, all of the time, rather than plateau like a traditional diesel IC engine.

Electric and hybrid power generation systems have been successfully utilised in Scandinavia and other parts of mainland Europe. The costs of these systems might be cost prohibitive on face value, however green energy schemes can be put in place to assist fishing SME’s access to them. Savings on fuel and repairs, as well as the allowance of extra fishing effort due to reduced fatigue will enable business to repay initial associated costs with their installation.

The added efficiencies associated with electric motors, like thermal waste re-use, allow for further reductions in required power on board fishing vessels. There is often sundry equipment on board fishing vessels, including but not limited to chilling, packing or navigation. Systems like thermal waste convertors can assist in making vessels self-sustaining and highly efficient.

Hull design enhances the efficiency of power conversion of electric motors. Constructing new vessels to replace the aging fleet is an opportunity to couple electric motors with clever hull design. A holistic approach to clean, green boat design is a concept that should not be neglected when establishing new vessels.

Battery storage solutions are able to capitalise on commercial fishing conditions. As boats spend long periods of time in sunny and windy locations, battery life can be extended by solar and wind power generation options. In fact, it could be said that the fishing industry lends itself to renewables.

Recommendations

- The fishing industry should work with the Federal Government and infrastructure teams with the aim of revamping current boat building facilities. The objective should be to enable boat builders to utilise modern technology in all newly built vessels.

- The fishing industry should adopt new ‘green’ technologies to add environmental value to its image and products.

- “Clean-Green” Loan Scheme. Fiscal incentives should be offered by Government bodies and safety authorities to have modern power generators fitted in all new boats. Loans to commercial fishing enterprises that renew their fleet with clean and green technology can be repaid by savings made on fuel and maintenance.

- The fishing industry needs to attract young participants with modern boats that are technologically advanced, with an improved working environment with less noise and vibration and a lower environmental impact.

- The fishing industry should work with the FRDC to investigate a professional cost benefit analysis for the technologies investigated in this report.

- The fishing industry should work with Governments and financial institutions to create an environment to stimulate investment in new boats and career paths for young people.

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Plain English Compendium Summary

Project Title:	Old Men: Older Boats Electric Drive, Power Storage and Power Generation in Commercial Fishing Vessels
Nuffield Australia Project No.:	1603
Scholar:	Dennis Holder PO Box 430, Port Adelaide SA 5015 6 Galway Terrace, Largs North SA 5016
Phone: Email:	08 8341 8028 or 0428 814 854 silverspectre2010@gmail.com
Objectives	To identify new technologies in vessel design and propulsion and assess whether they can be applied to fishing vessels in Australia.
Background	The fishing industry has stagnated in fleet renewal and innovation in vessels, which is leading to a very poor attraction to young fishers.
Research	New technologies were investigated to see how they could best be applied to Australia's fishing fleet.
Outcomes	New boats need to be seen as an investment in the future of the commercial fishing industry, where you can reduce running costs substantially, and attract new people with the necessary skills and passion to operate those boats.
Implications	The fishing industry can become respected and profitable in Australia with very good environmental outcomes. The next step would be better fishing selectivity, which would improve the sustainability of the industry as a whole.
Publications	The findings of this study were presented at the Nuffield Australia National Conference in Darwin, Northern Territory, in September 2017.