Fishing Energy Efficiency Review for the Fisheries Research and Development Corporation.

Dr D. Sterling

Australian Government

Fisheries Research and
Development Corporation

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Fishing Energy Efficiency Review for the Fisheries Research and Development Corporation.

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The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

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OBJECTIVES:

1. Examine the degree to which rising fuel costs have impacted on different fisheries
2. Examine new and existing technologies developed both within and outside of Australia in the field of increased fishing efficiency through reduced energy usage and innovation
3. Examine opportunities for applying innovative solutions and developments which are most likely to produce the best return for the Australian fishing industry
4. Develop a publication that scopes potential innovations, whether they be existing or have the potential for development, that reduce energy usage
5. Provide advice on potential R&D that could assist industry in reducing energy usage.

NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED TO DATE

The project achieved a synthesis of available information to produce conclusions targeted at benefiting the fishing industry in terms of improved energy efficiency.

A significant outcome of the project has been the linking of high level Australian engineering expertise to the task of scrutinising the energy intensive fishing conducted in this country and formulating initiatives to improve the economics of fishing.

Such analysis focussed mostly on two areas; engine efficiency/alternative fuels and boat design (both hull and appendages). Due to the wide range of processes in Australian commercial fishing that directly consume energy; there are many other subject areas where relevant expertise could undertake an equivalent investigation to draw valuable conclusions. Although this was beyond the resources of the current project the situation was at least made clearer in the early phase of the project due to the development of a conceptual framework of energy related issues in Australian fisheries.

Because of the framework and the professional network formed by the project, work is continuing with volunteer professional input and a small amount of industry funding to progress higher-level outcomes in other important areas; like propulsion devices, refrigeration, and fishing gear (principally trawl gear).

In response to the project forming a list of prioritised initiatives towards improving the economics of fishing, a range of related research proposals were developed. Tasks looking at alternative fuels for fishing have received funding from FRDC and are well progressed.

Throughout industry, there is a large amount of hardship and concern connected with the high cost of fuel. This has created a great deal of interest and debate at the wharf regarding potential mitigation measures. The output of the project has made available to industry well grounded information from the detailed technical discussion on the prospects of utilising cheaper alternative fuels and efficiency issues associated with engines and boats. This has helped guide industry thinking along realistic themes and suppressed the propagation of suspect claims in relation to many dubious, highly-priced “efficiency” products.

The degree to which rising fuel costs have affected different fisheries depends in each case on the proportion of their gross revenue spent on the cost of fuel. This proportion increased for all fishing businesses as the pump price of fuel rose sharply by nearly 100% from 2004 to the end of 2008. To any business in the economy that uses a lot of fuel, the rapid fuel price rise had a large impact on profitability. However, the impact on fisheries was even greater than the pump price rise indicated because, after correction for the GST and excise paid back to fishers, their actual fuel cost price increased by a factor of 3 (200%) over that time period. For the fuel intensive sectors of the fishing industry, this sharp rise in fuel price caused the proportion of revenue paid for fuel to rise typically from 25% to 50%. The proportionally “low” impact on business costs is due to businesses taking immediate action to protect profitability. The “low hanging fruit” in this respect relate to changing relevant operating procedures that could be quickly implemented; for example, selecting fishing grounds that are closer to home port, and steaming and trawling at reduced engine rpm.

The project defined priority subject areas within the research framework and produced a report in each area providing prioritised research and development initiatives. Each initiative is designed to explore opportunities to assist industry further in reducing energy usage. This involves taking interesting ideas to the next “stage”, being feasibility studies and demonstration projects to bring increased clarity, to researchers, fishers, and entrepreneurs as to the strength of the potential benefits.

The project explored many new and existing technologies suitable for fisheries that potentially improve energy efficiency or reduce the cost of fuel. This was documented for the areas covered, in the three interim reports.

The benefit to industry of adopting engine modifications to allow use of alternative fuels depends on the relative cost per unit of energy of the different fuels to fishers and is necessarily complicated by the costs and practicality of storing and procuring the alternative fuels, and also any change in energy efficiency of the engine. After consideration of all known fuels, no alternative fuel strategy to diesel was identified that would give fishers clear financial benefits.

For some technologies considered, experts did not universally accept the claims of improved energy efficiency made by suppliers. In these cases, the various arguments were presented and a balanced conclusion was attempted.

There were no commercially available technologies identified as having a clear and significant benefit for fishers and therefore strongly recommended for adoption. This mainly arises because of the paucity of credible public information related to the evaluation of new and existing technologies designed to improve fishing performance.

It is recognised that fishing businesses are complex operations and the suitability of changed hardware has to be carefully assessed against detailed contextual knowledge before recommendations can be made. Therefore, substantial improvements in energy efficiency must start with businesses themselves forming a strategic response to the problem. Initially, the most important changes might need to occur with management rather than at the operational level; although ultimately well directed, and well received operational changes are the necessary outcome.

The resources available for fishing businesses to formulate and undertake complex internal change are limited and dependent on business size. Universally very small businesses will need substantial assistance in this task.

Given that the Australian fishing industry is composed mainly of many very small businesses, desperately required are innovative eco-efficiency enhancement programs designed specifically for fisheries. These programs must work effectively at the enterprise level, such that detailed data on the operation and management of the business is recorded and analysed before sensible action plans are proposed. Benchmarking the performance of enterprises provides the opportunity for the business to look internally and externally, at various scales, for opportunities to improve efficiency. Eco-efficiency rather than energy-efficiency needs to be pursued to encourage a view of the “big picture” when developing strategically powerful action plans.

Of very high priority is the need to further develop the depth and capacity of the fisheries engineering community - that being the component of the engineering community engaged directly or indirectly in fisheries matters - so that technology development can be progressed in a strident, efficient, and professional manner. A specific initiative to achieve this development would be to organize a biannual gathering of stakeholders and fisheries engineering professionals at a workshop or conference. A second beneficial initiative would be to emphasize more highly fisheries engineering in under- and post-graduate courses offered by tertiary education institutions, so that a stream of research based at teaching institutions can provide an expanded range of research support and infrastructure for industry development work. The scope and degree for this type of support has reduced markedly over the last decade.

KEYWORDS: **energy, efficiency, fishing, fuel, Australia**

ACKNOWLEDGMENTS

The Author wishes to thank Dr Laurie Goldsworthy and Dr Kim Klaka for their strong collaboration on the project and acknowledge their substantial input. They were the primary providers of project outcomes on the subjects of alternative energy/engine efficiency and hull characteristics/efficiency respectively. Thanks also to Dr Giles Thomas for his interest, advice, and valuable contributions to the project reports, and to John Wakeford for his valuable assistance in galvanising AMC support for the project.

The project was supported by funding from the FRDC on behalf of the Australian Government.

BACKGROUND

Fuel is a vital, but costly, input to seafood production, accounting often for 30% or more of the operating costs of a fishing vessel in Australia. An estimated 270 million litres of diesel fuel is currently consumed in Australian fisheries each year, as well as a substantial amount of petrol.

Australia is fortunate in having access to potentially large sources of alternative fuels and new sources of conventional fuels. Australia has large reserves of natural gas and naturally occurring liquefied petroleum gas (LPG). Significant resources for the production of biofuels also exist, as does the potential to produce hydrogen from a variety of sources. Moreover, the sun, wind, waves and tidal currents all offer potential sources of renewable energy.

The FRDC Board discussed where it could invest in the short term to address the rising costs of fishing. To offset rising petroleum-based-fuel prices, it was agreed to fund an initiative to review potential developments in energy efficient fishing practices; for example, improved gear efficiencies and vessel design including propulsion systems. The intent was to develop a guide that can inform the industry on existing and new developments in this area, and where the greatest potential for fuel efficiencies lies. The review will also provide an analysis of potential R&D that could assist industry in developing and adopting energy efficient fishing practices.

NEED

Australian commercial fishers are facing a very challenging period, with the prospect of further price rises in petroleum-based fuel, combined with a domestic oil deficit predicted to emerge past 2015, and a global need to reduce greenhouse gas emissions. The Australian fishing industry is seeking ways to improve the energy efficiency of its operations and to find viable alternative energy sources.

Whilst the development and trial of alternative energy technologies is well advanced in the road transport sector, the maritime sector has received less attention, particularly in Australia.

There is a need to bring together alternative energy providers, fishing vessel and gear designers, fishing operators, industry representatives, researchers and funding providers to produce alternative energy technologies and energy-efficient design for commercial fishing operations in Australia. To achieve this it is highly desirable to scope methods of reducing energy usage through, for example, improved gear efficiencies and vessel design including propulsion systems, and to develop an R&D agenda for advancing alternative energy use and energy efficiency in Australia’s fishing fleet.

A beneficial spin-off of the scoping study would be to develop a guide that can inform the industry on existing and new developments in this area, and where the greatest potential for fuel efficiencies lies.

OBJECTIVES

1. Examine the degree to which rising fuel costs have impacted on different fisheries
2. Examine new and existing technologies developed both within and outside of Australia in the field of increased fishing efficiency through reduced energy usage and innovation
3. Examine opportunities for applying innovative solutions and developments which are most likely to produce the best return for the Australian fishing industry
4. Develop a publication that scopes potential innovations, whether they be existing or have the potential for development, that reduce energy usage
5. Provide advice on potential R&D that could assist industry in reducing energy usage.

METHODS

The project process was formulated and initiated by two events occurring in 2005:

- The AMC Maritime Engineering Conference 20-21st Oct. 2005.
- Energy Efficient Fishing Workshop 28-29th Nov. 2005.

Project outputs were based on a structured synthesis of information on fuel usage in Australian fisheries according to a systematic framework. Broadly, the framework covered energy sources, energy conversion process, efficient energy use, and efficient production.

The framework was as follows:

- Alternative fuels and energy transformation technologies
  - Alternative Fuels
    - Natural Gas, Liquefied Petroleum Gas, Biofuels – methanol, ethanol, bio diesel, fish oil
  - Alternative/more efficient Engines
    - Design, Optimum operation, Waste heat recovery, Fuel additives
  - Alternative Energy
    - Solar, wind, waves
- Energy Efficient Design
  - More efficient propulsion
    - Propeller/nozzles etc
  - Drag reduction
    - Steady state hull drag
      - Skin friction
      - Viscous pressure drag
      - Wave making resistance
    - Vessel drag in rough seas
      - Importance of reduced vessel motion
      - Drag of motion reducing devices
    - Fishing gear
      - Optimum matching of gear
      - Low drag components

      - Thin twine – spectra, dynema
      - Otter boards
      - Ground gear
  - Other energy usage
    - Refrigeration
    - Hydraulics
- Other production efficiency issues
  - Catch efficiency in trawling
    - Trawl speed, headline height, leadahead etc
  - Management induced inefficiencies
    - “Input controls”
    - Co-management

The focus of the review was guided by prioritisation of the framework topics; a process whereby synthesis of available information firstly aimed to establish areas of high opportunity for industry to improve energy efficiency. Subsequent investigations of these areas were strongly aided by close consultation with highly qualified experts in respective subject areas to formulate clear industry development initiatives. Prospect-full initiatives were further developed, in semi-quantified terms, to clearly outline the scope for improving energy efficiency and improving industry profitability.

The progression of the project was defined by the following milestones:

Milestone Details

Signing of project agreement.

Attend AMC maritime engineering conference and hold meetings on the capacity of the maritime engineering community to develop energy efficiency in Australian fisheries.

Attend/synthesise Energy Efficiency Workshop.

Research subject matter relating to energy efficiency in fisheries and produce draft review document at 50% completion.

Complete draft review document.

Produce final review document and final report.

RESULTS/DISCUSSION

AMC MARITIME ENGINEERING CONFERENCE

Attend AMC maritime engineering conference (20th-21st October 2005) and hold meetings on the capacity of the maritime engineering community to develop energy efficiency in Australian fisheries.

Results

The AMC Maritime Conference was effective at laying the foundation for the FRDC Energy Efficiency Workshop, to be held 28th-29th November, in terms of canvassing the event and gathering support from presenters and participants. The workshop was shaping up to be a very effective source of advice and background material for the final phases of the project.

Contacting people connected to the AMC Maritime Engineering Conference was well facilitated by John Wakeford who organised a meeting with AMC staff on the 19th. This ran from 1.30pm to 5.00pm and involved 20min presentations from:

John Wakeford – Overall view of the problem from the fisheries perspective.

Laurie Goldsworthy – A complete framework of options regarding alternative fuels and the types of engines utilizing these alternative energy sources.

Giles Thomas – A list of issues to do with hull design that impact on fuel efficiency.

Jonathan Duffy – The potential role of the tow tank in R&D to improve fishing vessels.

Paul Brandner – Informal discussion on issues connected to propulser design.

Others present at the meeting were Prasante Sahoo, Jinzhu Xia, Norm Laurence (maritime engineering staff), and Steve Eayrs

On the 20th, the PI had a meeting with people who had come over from Curtin Uni (Kim Klaka and Tim Gourlay). All people contacted, who were named in the draft program for the Energy Efficiency in Fishing Workshop in November, indicated a willingness to participate and were keen to understand the plans being laid to support for the fishing industry through the fuel cost crisis. (Laurie Goldsworty, Giles Thomas, Kim Klaka, Paul Brandner, Tim Gourlay)

During the rest of the day (20th) the PI heard presentations from the final year AMC maritime engineering students on their thesis research. Many topics were directly relevant to the fishing industry while collectively they thoroughly showcased the capabilities of the engineering faculty at the AMC to conduct high-class technical research.

Discussion

The Australian Maritime College (AMC) has Bachelor of Engineering programs in Naval Architecture, ocean Engineering, and Marine and Offshore Systems. These are supported by an impressive suite of facilities including a towing tank, model test basin, cavitation tunnel, and flume tank. AMC recently received a significant grant under the Major National Research Facilities to further enhance these facilities. As the owner of the only suite of hydrodynamic test facilities in Australia, AMC is uniquely placed to provide a very comprehensive research and consultancy service to the maritime industry.

The Department of Maritime Engineering maintains a close liaison with the maritime industry to ensure that the education, training, and research expertise of their students continues to be relevant to the needs of the maritime community. As part of this close liaison Final Year Engineering students conduct ‘Thesis Presentations’ highlighting their areas of interest and the knowledge they have gained.

The schedule of presentations for 2005 is given below. The topic marked in yellow where relevant to the fishing industry.

Name	Project Topic	Supervisor
Adrian Parkins	*An investigation into the optimal design of the wave wall for a wave energy converter*	G. Macfarlane
Benjamin Adamson	*Resistance characteristics with respect to change in bow forms*	P. Sahoo
Christopher Hutchison	*Structural optimisation*	G. Thomas
Crystal Anderson	*UUV operational characteristics*	D. Ranmuthugala & P. Brandner
Gavin Shepherdson	*Experimental study into the water-entry of a sphere on free-fall motion*	I. Penesis
Danielle Hodge	*Vessel machinery reliabilty studies*	N. Lawrence
Iain Larkins	*Following seas performance of yachts*	G. Thomas
Jackson Dryne	*Dynamics of compliant towers*	J. Xia
James Clarkson	*Wave slam loads*	G. Thomas
Wesley Heckendorf	*Characterisation of corrosion behaviour under marine conditions*	A. Belle
Luis Conde	*Time domain simulation*	I. Penesis & C. Chin
Luke McCarthy	*Energy and Exergy (Boags)*	A. Belle
Mark Niven	*Effects of bathymetry on FPSO Dynamics*	J. Xia
Michael Hoult	*Deepwater research*	J. Soeholt
Nick Browne	*Motion analysis of high-speed vessels*	J. Xia & G. Macfarlane
Peter Henry	*Motions of high-speed Catamarans*	G. Thomas
Ross Ballantyne	*Effect of altering LCF & LCG position of semi-swath catamarans*	P. Sahoo
Samuel Baghurst	*Bulbous bow optimisation on fishing vessels*	P. Sahoo
Thor Schoenhoff	*Investigation into the effect of initial trim on vessel squat*	J. Duffy
Timothy Hale	*Parametric rolling & guideline development*	J. Xia
Warren Lund	*Effect of entrained water on submarine motions*	D. Ranmuthugala & G. Macfarlane

ENERGY EFFICIENCY IN FISHING WORKSHOP

Attend/synthesise Energy Efficiency in Fishing Workshop

Results

The Energy Efficiency in Fishing (EEF) workshop occurred on the 28th-29th November 2005.

The expected outcome of the EEF Workshop was to identify short-term and long-term directions/priorities for technological development in fisheries that address the challenge of rising fuel costs. In summary, this was not achieved in the PI's opinion. Specific technological fixes were not forth coming, but rather a strategy emerged to integrate within the fishing industry a process for defining quantitative benchmarks, which would help identify where developments might be most effective, and give technologists an opportunity to begin understanding the complex processes that make up fishing businesses. Via this strategy, the expected outcomes of the EEF workshop may be achieved at some point in the future through a self-sustaining process with clear market driven support.

Discussion

The major outcome from the EEF Workshop was recognition of the energy audit process, which was developed for land based service establishments, and its potential value in addressing the escalating fuel cost problem for Australian fisheries. The energy audit process supplies a framework and a flexible approach for quantitatively describing the energy profile of a business. This (first) step is important as it provides a baseline (benchmark) for comparing future performance (efficiency) of businesses. Along with an understanding of the structure, function, and mechanics of each business, the energy audit can lead to proposals as to how energy efficiency can be improved. Continuation of the auditing process over time, allows proper assessment and re-evaluation of changes to the business in terms of accrued benefits.

Another avenue for developing proposals for business improvements comes from comparing energy efficiency indicators (benchmarks) across different businesses and in the case of the fishing industry, could be particularly relevant when businesses across different fisheries are compared. It seems that detailed cross-jurisdictional analyses of fishing activities have been rare in Australia.

Another outcome from the workshop was a realisation of the extent to which the operational characteristics of the fishing industry is undocumented; particularly aspects related to the use of energy. This characterised heavily the background environment to the workshop and shifted the outcomes away from what was expected (a list of solutions) in a profound way towards the high priority need to gather information using energy audits of fishing businesses. The small amount of available information is due to the small amount of attention given by researchers/managers collectively to operational (engineering) issues in Australian fisheries. This low level of interest over 25 years manifested low R&D funding priorities in this area over the same time period and has caused the volume (breadth X depth) of expertise in fisheries technology/engineering in Australia to become currently very low. A significant investment of time and resources is required to form a community of dedicated technologists with the capacity to effectively deal with the energy efficiency issues facing the fishing industry. It seems logical to the PI that the new seafood CRC is an ideal opportunity for the long run imbalance in fisheries research to be redressed, but this is not a view shared by the "industry leaders" empowered to set the direction for this multi-million dollar opportunity to inject life and solutions into the troubled fishing industry.

One concern the PI has with the energy auditing process is that it can be viewed as somewhat narrow. It is adequate for specifically assessing energy efficiency and well suited to managing technological developments in fishing businesses in that respect, with some ability to enhance the systemic environment for fishing as well. However, it can be argued that the ideal goal here is resource efficiency rather than energy efficiency and that a more holistic analysis boundary would allow detection of more significant systemic flaws and beneficial technological developments. Given the more intimate relationship that exists between supporting ecosystems and commercial fishing than for most centres of economic activity, expansion of the energy auditing process to a broader eco-efficiency analysis that includes audits of all resource impacts and wastes should highlight the most far reaching opportunities for large improvements in ecologically sustainable profits for fishing businesses.

REVIEW OF ENERGY EFFICIENCY IN FISHING

Research subject matter related to energy efficiency in fisheries and produce draft review document.

Background and methodology enhancement

Subsequent to the EEF workshop conducted in Melbourne in November 2005, information was collected on highlighted areas, and leads from searching relevant subjects on the Web. A draft report outline for the Energy Efficiency in Fishing Review (EEFR) was produced and circulated early in Feb 2006.

Investigation of each subject area within the review quickly uncovered many related matters, technically complex issues, and much uncertainty in trying to identify economically rational strategies for improving energy efficiency in fishing.

In order to increase the progress rate of purposefully working through the wide range of subjects, the PI proposed a strategy of organising a team approach to the review. In this way subject areas could be worked on in parallel by respective specialists, rather than the PI working sequentially through each area. Clusters of subjects that relate to different fields of specialisation were recognised and requests made to key experts to collaborate on the project. An expanded version of the report outline for the EEFR was produced at the end of June 2006.

The review therefore progressed by a three pronged approach; with Dr Laurie Goldsworthy (AMC) contributing to the subject areas, alternative fuels and engines, Dr Kim Klaka (Curtin) contributing to, alternative energy, hull efficiency and appendage drag and thirdly, the PI responsible for the remaining subject areas.

Results

Initially the PI investigated a number of ideas for improving the fishing industry's viability.
Major topics investigated in some detail included:

- Arrangements to make available biodiesel at fishing ports.
- Discussions with Hampidjan representatives regarding the performance, availability and cost of 1.1mm dyneema netting for prawn trawling
- Appropriate fuel meters so that fuel consumption can be monitored in real time and operators/investigators can start learning a lot more about how the fuel is used and may be

saved. Only one manufacturer of general-purpose fuel meters for diesel engines could be found. These were manufactured by flowscan in the US.

- Potentially beneficial products or ideas (hydrogen injection, bingo gas, skewed propellers, propeller boss cap fins) including enquiries regarding implementation and costs for fishing boats.
- Propulsion systems and performance prediction software; with quotes for commercial products.
- Optimum propeller size selection.
- Waste heat recovery for diesel engines (compound cycles, turbo generators, Stirling cycle engines, thermoelectric generators)
- The pros and cons and economics and practicalities of hydrogen injection.
- alternative engines
- fuel/production-processes (producer gas or syngas, Fischer-Tropsch process)
- Alternative energy - wave and wind (horizontal axis, vertical axis, the disk-style wind turbine).
- Hull design, especially planning hulls and stern wedges.
- Better winch control methods for trawlers to improve fuel efficiency when experiencing side winds and currents,
- The potential advantages of positive traction for trawling
- Positive refinements for the batwing otter boards and also otter boards with movable fins giving L/D = 6.
- The benefits of co-management.

At this point the PI was able to cluster the ideas and find a practical way forward to achieving a timely and worthwhile review by instituting a team approach to the review.

A decision was made to produce three semi-independent documents to cover the broad area of the review. This was designed to facilitate a team approach to the project and allow information and conclusions related to high priority areas to be circulated without having to wait for the entire review to be completed.

Part A of the review, which involved Dr Laurie Goldsworthy (AMC) provides a framework for investigating the energy efficiency of Australian fishing and includes a brief description of energy audits, which is an avenue for pursuing this question in the longer term. The body of the report contains a consideration of alternative fuels, alternative energy, and engine efficiency. Part A was progressed first due to the availability of Laurie Goldsworthy's input and a sense that that component scoped some of the more important issues in the review. Disappointingly, some of the alternative fuels options considered failed to be as attractive at the end of the exercise as first thought (e.g. Biodiesel and CNG). However, it is an important outcome to progress the investigation through to a point where firmer conclusions could be formed. Besides the disappointments, some alternative fuel prospects have emerged; e.g. MGO, a readily available cheaper marine diesel fuel, and increased combustion efficiency (10% claimed) for diesel engines through injection of small amounts of gas fuel.

Part B, which involved Dr Kim Klaka (Curtin), is a consideration of hull characteristics and efficiency. The scope of this report is subdivided into two areas covering steady state and dynamic aspects of the topic.

For Part C of the review three important areas were considered; propulsion systems, refrigeration, and fishing gear (particularly trawl gear). This was not done to a great depth due to a lack of resources. Propulsion is a particularly problematic topic in that it is highly complex technically, and the historical development of propulsion efficiency in fishing has been poorly studied and documented. For refrigeration, many of the efficiency issues are similar to land based freezers and cold stores; so relevant material on this topic is readily available. Some of the key issues presented in the literature are highlighted in the report. For fishing gear, the report summarises some of the work conducted by the author on the efficiency of prawn-trawling systems.

Stand alone reports pertaining to Parts A, B and C have been produced and give the detailed findings of the review. The main points of the review are briefly discussed below.

Discussion

Fundamentally, the problem facing the commercial fishing industry is the increasingly unaffordable cost of procuring the energy required to carry out fishing activities. To date, the energy fuelling the fishing industry has predominately come from petro-diesel due to its practical nature and the low cost of diesel-powered support systems. Diesel, as an energy source is practical for fishing because it has a high volumetric energy density and is a liquid that is safe to handle, easy to distribute and store. Supporting technologies allow diesel to be applied to fishing for propulsion, electricity generation and heating with relatively high efficiency.

The problem of high fuel cost is partly one of dwindling supply, accentuated by rapidly expanding global demand. Curbing the expanding demand and indeed reducing fuel requirements within the fishing industry is part of the solution and this will occur naturally in response to the higher price.

Avenues for relieving the bad economic situation broadly include using alternative sources of energy, developing fishing operations that inherently require less energy, improving the energy efficiency of devices used in fishing, increasing revenue and decreasing other fishing business costs.

Alternative fuels

The consideration of alternative fuels for fishing has two substantial aspects. Firstly there are the issues associated with simply using the new fuel; whether it requires completely new engines or can be used with existing engines with various levels of modification and supporting processes. Secondly, there are the issues associated with storage, refuelling and safety. Given that fishing vessels are mobile, spend long periods at sea - often in remote areas - questions of storage volume/complexity and fuel availability are dominant issues.

The bulkiness and expense of dealing with gaseous fuel (even highly compressed) are important factors and appear quite problematic. The cost of conversion to dual fuel utilisation - the cheapest, most flexible and practical approach - is substantial and the medium to long-term benefits are uncertain. However, potential fuel cost savings from natural gas are substantial.

Considering that the domestic and global market for diesel fuel is massive and growing, and that Australia holds vast reserves of coal and natural gas it seems likely that production of synthetic diesel from these reserves based on Fischer-Tropsch technologies will become established to underpin and stabilise the price of a blended diesel fuel. Over time, the blend is likely to become more dominated by its synthetic portion, which increasingly could be derived from renewable feedstocks.

It is likely that the price differential between LPG and Diesel for fishers will expand when LPG becomes subject to excise, but that is some time off (2.5cpl in 2011), and the current meagre price differential along with the limited substitution rate from the dual fuel conversions makes that prospect less interesting.

Given the cost of fuel is likely to remain a very high proportion of revenue for fishers, irrespective of the type of fuel used, it is important to work hard at reducing the energy intensity of fishing operations and improving associated equipment efficiencies.

Engine efficiency

Improved energy utilisation begins with the efficient conversion of chemical energy into mechanical work at the engine and making the most of the opportunity to utilise the low grade waste heat produced during this process. To develop higher efficiencies in this area, a detailed understanding is required of the engine and the loads attached to it and the processes occurring during fishing. Armed with this information it is possible to find opportunities to reduce energy needs and/or losses. This may occur by a) improved engine and load efficiencies, b) better matching of engine with its connected loads or c) more appropriate interaction between engine and fishing processes that may be able to utilise waste heat.

It is an indisputable conclusion that lower speed engines, are more efficient than high speed engines. Also, due to the slower rotational speed, many medium speed engines can operate on heavy fuel oil, which costs considerably less than the higher quality diesel fuel needed for high speed engines. An evaluation of high speed and medium speed engines of a power capacity relevant to fishing boats shows that dedicated medium speed engines would be viable only for a small number of applications due to the factor of five increase in weight.

Waste heat from the cooling water and the exhaust stream represents approximately 60% of the energy supplied by the fuel input. Recovery of some of this energy can represent a sizable amount of energy, which could be used to produce heating (if it is useful) or mechanical power from a heat engine (e.g. steam cycle). The latter idea (combined cycle engines) is commonly fitted to large cargo ships, however small scale applications are not being marketed. It is encouraging to see internet information that suggests Volvo have made some progress with developing a compact steam cycle heat engine driven by waste heat from the engine of a car. It is not disclosed how far the technical development has progressed, however it is claimed that the combined cycle engine for an automobile lifts engine efficiency from 33% to about 60%.

Devices are being developed to extract more thermal energy from the exhaust gas; e.g. the turbo-generator. The electricity so produced can be applied to the propulsive drive train. Caterpillar is working on a combined turbo-generator, air-charge system (on a single shaft). This is to be electrically connected to a starter motor/generator unit to increase power extraction from the engine and also optimise turbo charger operation (by applying electric spin up when required). Scania have implemented similar technology in a truck engine. Other possible uses for waste heat are absorption cycle chillers for refrigerating fresh seafood and creating hot dry air to manufacture dried seafood products while at sea.

Injection of gaseous fuels (hydrogen, natural gas, LPG) at low levels into the air stream of a diesel engine is claimed by many sources to change the combustion process and lead to improved thermodynamic efficiency and lower exhaust pollution. Scientific literature strongly demonstrates the benefit of dual fuel combustion on lowering harmful exhaust emissions but tends to leave an impression that thermodynamic efficiency is not altered. It would be of great interest to establish via testing on a diesel engine test bed the extent to which thermodynamic efficiency is affected by the inclusion of small amounts of gaseous fuel.

Hull drag

The bare hull of a vessel can be considered to have three main hydrodynamic resistance components when travelling in calm water:

Skin-friction resistance: The effect of viscous friction between the water and the ship's hull.

Viscous pressure resistance: The result of the distribution of pressure around the hull that is related to the thickness of the boundary layer and wake (separated flow) in the flow pattern. It is often called form drag.

Wave-making resistance: Is actually caused by water pressure on the hull, but is associated with generating a pattern of waves on the water surface as a vessel moves along. The resistance is due to the energy required to create these waves.

At low speeds, the waves made by a vessel are very small and the resistance is almost wholly viscous friction. As speed is increased the viscous resistance increases moderately with speed. However, the wavemaking resistance increases greatly with speed.

Planning craft travel faster than hull speed by having a light hull that generates fewer waves. With speed, these boats are lifted out of the water by the pressure forces generated on the bottom of the hull, reducing the immersed volume of the hull and the making of waves. At planning speeds frictional resistance is again a dominant resistance component and also pressure drag, if the vessel operates at a non-optimum trim.

The single most important method of reducing fuel bills for vessels that spend a significant proportion of their time travelling to and from their fishing grounds is to reduce speed. For a 15m long displacement hull, the power required to travel at 10 knots can be about 205kw. However, if steaming speed is reduced to 9 knots the power would only be 115kw, a reduction of more than 40%.

The effect of adding 2% weight on the example 15m vessel at 9 knots, would an increase in required power of about 2%.

A typical paint roughness of 250 microns will increase the friction by about 2.5% compared to a perfectly smooth hull. The effect on engine power is typically a 1% increase. Excessive weed or barnacles that are allowed to grow on the hull will easily cause friction to increase by 50%.

Significant reduction in drag (> 10%) is the benefit of a bulbous bow on displacement craft moving at higher speed; Froude number greater than 0.3. For a 15m vessel this corresponds to 7 knots.

Excessive form drag often occurs if a vessel with a transom stern is trimmed by the stern. Proper trim adjustment is important, even extra weight (ballast) in the bow to achieve level trim. Trim tabs or stern wedges can be beneficial at higher speed (Froude number > 0.35) by modifying trim.

All vessels have additions to the underwater hull (appendages), like the rudder, bilge keels, transducer mounts and cooling water pipes etc. The total appendage drag can easily add up to 20% of the total hull drag. Where the design of appendages has focused on simplicity, low capital cost and robustness, excessive drag may exist. For a vessel travelling at 10knots, an aerofoil rudder consumes nearly 6kW (4%) less engine power than a flat plate rudder. If the rudder is turned to 10 degrees, the aerofoil rudder consumes about 4kW (3%) less than the flat plate rudder. Similarly, it is estimated that cooling pipes consume about 2-3% of the total engine power generated. Using a different method to cool the engine water would remove this drag component.

When a fishing vessel is exposed to side currents or wind, the effective resistance to forward motion is increased due to a number of reasons; rudder drag increases because of the application of rudder to produce the necessary angle of leeway and angled flow onto the hull to resist the side loads; hull drag is increased because it is travelling at an angle of attack (leeway); and lastly, because of the misalignment of the flow into the propeller, the thrust force is slightly reduced. Adjustments to the vessel that can reduce the amount of rudder and/or leeway required for these situations could produce a significant improvement in fuel efficiency. Slow moving vessels (e.g. trawlers) are vulnerable to significant problems in this area, particularly those using trawl systems that are a continuous unit towed equally from a wire on each side of the vessel.

The optimum fishing vessel should be one that earns the maximum in its lifetime and therefore its form needs to match the conditions in which it operates. Minimum resistance and large hold capacity are conflicting objectives and a compromise solution is required for the maximum earning ability. An appropriate optimisation tool, such as the Decision Support Problem (DSP) technique (Pal, 2006), could identify optimum hull forms for specific Australian conditions and also explore the impact of regulatory constraints.

Alternative hull designs, like Catamaran, SWATH, Cathedral, and M hull, might produce substantial benefits in some fishing applications where their distinct technical qualities are appropriately married to the particular operational circumstances. For example, catamaran and SWATH vessels have improved sea-keeping properties in moderate sea states, but can be worse in sever weather. They have greater deck area for a given vessel length and good high speed performance. These craft can be more fuel efficient than planing vessels in many instances.

The pitch, roll, heave and yaw motions of a vessel travelling in ocean waves decrease economic efficiency for several reasons; the motions cause non optimal conditions (for example, incorrect trim and incorrect flow into the propeller); drag from various pieces of equipment used to reduce motions (paravanes, bilge keels etc); and reduced task progress rates and sea sickness due to boat motion.

In fishing, specific devices and strategies for reducing vessel motion exist principally for the reduction of roll. Roll is generally the motion of greatest magnitude, since it has relatively low restoring force (stiffness) and is lightly damped. The range of devices employed to reduce roll focus on either one of these aspects of the roll problem:

Increase damping – paravanes, bilge keels, sails
Increase effective stiffness - active fins, anti-roll tanks, gyroscopes

The design principles and associated practical implications for many of these devices have not been extensively studied and documented. There is considerable scope for optimising existing anti-roll systems and in the first instance establishing an adequate technical description of current industry best practice. The most popular approach to reduce roll currently is to increase damping, which typically also involves significantly increasing resistance to forward motion. Non-drag devices such as anti-roll tanks and gyros offer alternative solutions that have much lower running costs.

Other vessel motions, particularly pitch and yaw, underlie significant efficiency problems for fishing vessels. Ideas are emerging as to the structure of these problems and technical solutions.

Systemic changes

Achieving substantial improvements in energy efficiency starts with businesses forming a strategic response to the problem. Initially, the most important changes might need to occur with management rather than at the operational level; although ultimately well directed and well received operational changes is the necessary outcome.

The resources available for fishing businesses to undertake complex internal change are limited and dependent on business size. Therefore the style of strategic response to the fuel crisis and appropriate structural change are strongly case dependent, however some broad generic concepts are applicable to all.

Relevant concepts at the forefront of professional advice to fishing business managers are Eco-efficiency, Energy audits, and Energy Management Systems. Informative web based references for these concepts are:
http://www.deh.gov.au/settlements/industry/corporate/eecp/index.html
http://www.energysmart.com.au/sedatoolbox/emg.asp
http://www.epa.qld.gov.au/environmental_management/sustainability/industry/ecobiz_queensland

Trawling gear

Trawl gear technology affects business outcomes through engineering performance and catch efficiency and can be modified in a number of ways to generate improvements in energy efficiency:

- High order multiple net systems.
- Optimum trawl system variables.
- High performance components.

A large proportion of the overall drag of a prawn trawl system is associated with the netting in the trawls, particularly for the higher order systems. This indicates that reducing netting drag, for example by reducing twine diameter, should have a very significant impact on improving the fuel efficiency of prawn trawling. The potential gain is even higher than first impressions because the size of otter boards required in the system (and the resulting otter board drag) are directly governed by the drag of the trawls. Therefore small twine diameter, properly implemented, should equivalently reduce trawl drag and otter board drag; seemingly making twine diameter the most powerful energy efficiency variable in prawn trawling.

The latest and most refined version of the Batwing otter board for prawn trawling incorporates rigging features to achieve stable and efficient operation at much lower angle of attack. This reduces the drag of the otter board by about 70%. A flexible sail is used so that the centre of gravity position of the board is more optimally located, and construction costs become very low.

BENEFITS AND ADOPTION

A significant outcome of the project has been a greater involvement of the Australian maritime engineering community with fisheries matters through the process of engaging relevant high-level expertise on project tasks. This work has forged close links between valuable professionals and fishing industry problems associated with its energy intensive nature. This is a solid step forward in formulating developments to improve the economics of fishing in this country.

The undertaken work focussed mostly on two subject areas, engine efficiency/alternative fuels and boat design (both hull and appendages). Outcomes for each area included the publication of a concise report describing the associated broad range of technically complex issues with an emphasis on defining options to reduce fuel costs and generate a prioritised list of research and development initiatives. These publications were published on the FRDC website as quickly as practicable, which allowed industry benefits to accrue as soon as possible and also provided the opportunity for broad based feedback to the project team.

Because there are many processes in Australian commercial fishing that consume energy, there are many other subject areas where relevant expertise could be engaged further, and this would produce more options for fishers to reduce fuel costs. Although this was beyond the resources of the current project, the situation was at least made clear by the project due to the development of a workable conceptual framework of energy related issues in Australian fisheries. In essence, a work agenda with some momentum was setup by the project, and the work is continuing with volunteer professional input and a small amount of industry funding. On track is the achievement of higher-level outcomes in the propulsion area.

In response to the project forming a list of prioritised initiatives for improving the economics of fishing, a range of related research proposals were developed. Many of these were funded, and tasks looking more deeply into alternative fuels for fishing are very well progressed.

Throughout industry, there is a large amount of hardship and concern connected with the high cost of fuel. This has created a great deal of interest and debate at the wharf regarding potential mitigation measures. This situation has benefited from the output of the project because it made available to industry well grounded information on key aspects of the debates. Being credibly sourced, the information has been well accepted by industry and has helped guide their thinking along realistic themes; while suppressing the propagation of suspect claims made by various salespeople during the peddling of dubious, highly priced “efficiency” products on the internet and by direct marketing.

The information contained in the reports was also made available to industry through other channels. At the November 2006 prawn bycatch workshop in Cairns, “Options to improve bycatch reduction in tropical prawn fisheries”, a presentation was given by the PI on a range of measures to reduce costs for fishing businesses. The presentation and associated 10 page paper, “The Fuel Crisis”, was published in the proceedings of the workshop. The December 2006 issue of Tasmanian Fishing Industry News carried an article, “Alternative fuels – the real story” and a similar article was published in Fisheries R&D News (Nov. 2006).

During May 2007 the New Zealand Seafood Industry Council held a workshop on energy-wise fishing. The workshop provided an opportunity for information sharing with the catching sector including presentations on; the fundamental issues of energy management; reports from around the world (particularly England and Denmark) on efforts to lower the cost of energy for the fishing industry; and reporting of progress for the FRDC Review of Energy Efficient Fishing. The latter involved a presentation by the PI on the strategic significance and scope of the project, along with information and conclusions in relation to alternative fuels and the efficiency of diesel engines; and secondly, Dr Giles Thomas covered the results of the project in the area of fishing vessel hull design.

Discussion at the NZ workshop was very significant in terms of putting together strategic responses to the energy problem. The international researchers demonstrated a keen enthusiasm to link resources and share outcomes with the Australian efforts. There were also encouraging discussions concentrating on identifying and removing the critical difficulties in achieving desperately needed industry development.

In November 2007, Dr Laurie Goldsworthy and Dr Giles Thomas jointly delivered a workshop on the Energy Efficiency in Fishing Review at Seafood Directions 2007 in Hobart.

FURTHER DEVELOPMENT

Steps forward from the project at several levels would be beneficial.

There are a number subject areas that where not fully explored during the project. Most notably is propulsion, where there is significant scope for improved energy efficiency for fishers; given the marketing-hype coming from hardware manufacturers. However, the willingness of operators to invest bravely in modern propulsion technology is dampened by the severe uncertainty of performance benefits and the associated return on investment. Much of this problem stems from the lack of uniformity in the fishing fleets of Australia, because the results of retrofits on one vessel have limited applicability to the majority of other vessels. However, a quantitative review of propulsion devices based on a robust technical assessment of performance benefits associated with generic retrofit scenarios would create a more congenial environment for operators to make sound business decisions and institute appropriate propulsion hardware changes; particularly if the generic scenarios were highly contextualised to Australian fishing.

Within the outcomes of the project, there emerged quite a number of interesting ideas potentially returning significant reductions in fuel cost for fishers. The next “stage” for these ideas is to set up feasibility studies and demonstration projects to bring increased clarity, to researchers, fishers, and entrepreneurs as to the strength of the potential benefits.

The biggest problem we face in Australia and New Zealand is a lack of capacity to do a large amount of obvious work quickly, including:

- complete the energy efficiency review in the area of propulsion and other areas;
- implement and roll out energy (or more broadly, eco-efficiency) audits for fishing businesses, which would in part gather vast information on factors affecting energy efficiency;
- raise industry awareness, at the enterprise level, of energy management/development; and
- undertake key research and development (R&D) activities.

Key R&D activities include:

- practically integrate "high strength" netting into commercial trawl gear;
- commercialise Batwing otter boards in prawn trawling;
- seek improvements to course control systems;

- improve vessel motion reduction equipment; and
- utilise engine waste heat.

Of very high priority is the need to further develop the depth and capacity of the fisheries engineering community - that being the component of the engineering community engaged directly or indirectly in fisheries matters - so that the above work schedule can be progressed in a strident, efficient, and professional manner. A specific initiative to achieve this development would be to organize a biannual gathering of fisheries engineering professionals and stakeholders/clients at a workshop or conference. A second beneficial initiative would be to emphasize more highly fisheries engineering in under- and post-graduate courses offered by tertiary education institutions, so that a stream of research based at teaching institutions can provide an expanded range of research support and infrastructure for industry development work. The scope and degree for this type of support has reduced markedly over the last decade.

PLANNED OUTCOMES

The planned outcome for the review was the publication of a document that describes existing and new developments in the area of fishing efficiency that can assist industry in reducing energy requirements and flag potential R&D gaps and priorities. The review documents, Part A and Part B, produced in May 2007 achieved this outcome for the subject areas “Alternative fuels and efficient engines” and “Hull characteristics and efficiency”. This final report and the production of a Review Part C extend the outcome into other areas, including fishing gear (prawn trawling), and provides a summary of the review components.

The project outputs were to be a:

1. written draft report and recommendations for consideration

This was achieved by way of the four documents produced by the project.

2. brief ‘user friendly’ summary of the project and outcomes suitable for publication on the FRDC website.

The interim review reports; Part A, Part B and Part C, provide executive summaries of their detailed contents. This final report contains a non-technical summary of the project outcomes and a comprehensive summary of the main issues discussed in the interim review reports.

3. a guide for industry describing review findings

The project did not specifically provided a guide for industry describing review findings although the results and discussion for Milestone 3 in this final report may be suitable for industry members requiring a detailed discussion of the issues covered by the project. A guide to industry was produced by FRDC and published in the December edition of FRDC news: FISH. This well presented guide was partly based on the results of the review and further information from ABARE and Seafish.

The following project timetable shows the proposed schedule of project outcomes and the schedule of outcomes achieved.

Date	*Action*	*Date Accomplished*
31/10/05	Attend AMC Maritime Engineering Conference and hold meetings on the capacity of the maritime engineering community to develop energy efficiency in Australian fisheries	31/10/05
30/11/05	Attend/synthesise Energy Efficiency in Fisheries Workshop	10/2/06
31/1/06	Research subject matter related to energy efficiency in fisheries	ongoing
15/2/06	Produce draft review document	Part A - 12/10/06 Part B - 6/2/07 Part C – 10/6/09 Final Report – 10/6/09
28/2/06	Produce final review document, executive summary and a guide to industry	Part A – 6/2/07 Part B – 15/6/07 Part C - 1/7/09 Final Report – 1/7/09 Industry Guide – 12/08 (FRDC)

CONCLUSION

The results of the project produced conclusions with respect to the objectives of the project as outlined below:

1. Examine the degree to which rising fuel costs have impacted on different fisheries.

The degree to which rising fuel costs have affected different fisheries depends in each case on the proportion of their gross revenue spent on the cost of fuel. This proportion increased for all fishing businesses as the pump price of fuel rose sharply by nearly 100% from 2004 to the end of 2008. To any business in the economy that uses a lot of fuel, the rapid fuel price rise had a large impact on profitability. However, the impact on fisheries was even greater than the pump price rise indicated because, after correction for the GST and excise paid back to fishers, their actual fuel cost price increased by a factor of 3 (200%) over that time period. For the fuel intensive sectors of the fishing industry, this sharp rise in fuel price caused the proportion of revenue paid for fuel to rise typically from 25% to 50%. The proportionally "low" impact on businesses costs is due to businesses taking immediate action to protect profitability. The "low hanging fruit" in this respect relate to changing relevant operating procedures that could be quickly implemented; for example, selecting fishing grounds that are closer to home port, and steaming and trawling at reduced engine rpm.

2. Examine new and existing technologies developed both within and outside of Australia in the field of increased fishing efficiency through reduced energy usage and innovation

The project explored many new and existing technologies suitable for fisheries that potentially improve energy efficiency or reduce the cost of fuel. These were discussed in the written reports for the areas covered by the project.

The benefit to industry of adopting engine modifications to allow use of alternative fuels depends on the relative cost per unit of energy of the different fuels to fishers and is necessarily complicated by the costs and practicality of storing and procuring the alternative fuels, and also any change in energy efficiency of the engine. After consideration of all known fuels, no alternative fuel strategy to diesel was identified that would give fishers clear financial benefits.

For some technologies considered, experts did not universally accept the claims of improved energy efficiency made by suppliers. In these cases, the various arguments were presented and a balanced conclusion was attempted.

There were no commercially available technologies identified as having a clear and significant benefit for fishers and therefore strongly recommended for adoption. This mainly arises because of the paucity of credible public information related to the evaluation of new and existing technologies designed to improve fishing performance.

3. Examine opportunities for applying innovative solutions and developments which are most likely to produce the best return for the Australian fishing industry

It is recognised that fishing businesses are complex operations and the suitability of changed hardware has to be carefully assessed against detailed contextual knowledge before recommendations can be made. Therefore, substantial improvements in energy efficiency must start with businesses themselves forming a strategic response to the problem. Initially, the most important changes might need to occur with management rather than at the operational level; although ultimately well directed, and well received operational changes are the necessary outcome.

The resources available for fishing businesses to formulate and undertake complex internal change are limited and dependent on business size. Universally very small businesses will need substantial assistance in this task.

Given that the Australian fishing industry is composed mainly of many very small businesses, desperately required are innovative eco-efficiency enhancement programs designed specifically for fisheries. These programs must work effectively at the enterprise level, such that detailed data on the operation and management of the business is recorded and analysed before sensible action plans are proposed. Benchmarking the performance of enterprises provides the opportunity for the business to look internally and externally, at various scales, for opportunities to improve efficiency. Eco-efficiency rather than energy-efficiency needs to be pursued to encourage a view of the "big picture" when developing strategically powerful action plans.

4. Develop a publication that scopes potential innovations, whether they be existing or have the potential for development, that reduce energy usage

The information collated by the project provides highly synthesised yet detailed coverage of energy utilisation issues for fisheries in many of the key areas. This is a good reference source for a publication to fishers that scopes innovations to potentially reduce energy use. Such a document was produced in house by the FRDC and published in the December edition of FRDC news: FISH.

5. Provide advice on potential R&D that could assist industry in reducing energy usage.

The PI undertook to achieve this objective in a detailed and rigorous manner, but early in the project it was found that the subject area was exceptionally broad and realistically required a team approach and some narrowing of scope for a meaningful result to be practically produced.

The project defined priority subject areas within the research framework, and produced a report in each area that provides prioritised research and development initiatives exploring opportunities to assist industry in reducing energy usage.

APPENDIX 1: INTELLECTUAL PROPERTY

There is no intellectual property arising from this project.

APPENDIX 2: STAFF

Dr David Sterling - Director: Sterling Trawl Gear Services

Dr Laurie Goldsworthy - Research Leader (Marine Engines): Australian Maritime College
University of Tasmania

Dr Kim Klaka – Director: Centre for Marine Science & Technology
Curtin University of Technology

Energy Efficient Fishing: A 2006 review

PART A - Alternative fuels and efficient engines

David Sterling and Laurie Goldsworthy

Australian Government
Fisheries Research and Development Corporation

Project No. 2005/239

Final Report: Part A - May 2007

Table of contents

Executive summary

Aims and objectives

The objectives of the review are:

- examine the degree to which rising fuel costs have impacted on different fisheries
- examine new and existing technologies developed both within and outside of Australia in the field of increased fishing efficiency through reduced energy usage and innovation
- examine opportunities for applying innovative solutions and developments which are most likely to produce the best return for the Australian fishing industry
- develop a publication that scopes potential innovations, whether they be existing or have the potential for development, that reduce energy usage
- provide advice on potential R&D that could assist industry in reducing energy usage.

This report contains part 1 of 3 of the review of energy efficient fishing. The introduction provides a framework for investigating the Australian fishing industry in this context and includes a brief description of energy audits, which is an avenue for pursuing this question in the longer term. Of the entire subject space to be considered by the review, which is given in Appendix A, this report contains the consideration of alternative fuels and engine efficiency.

Introduction

Fundamentally the problem facing the commercial fishing industry is the unaffordable cost of procuring the energy required to carry out fishing activities. To date the energy fuelling the fishing industry has predominately come from petro-diesel. In fact it is reasonable to say that the development of diesel as a fuel source, and the associated engines that convert diesel into mechanical power, have been the enabling technology that has largely allowed commercial fishing as we know it today to exist. So dependent is the fishing industry on the practical nature and low cost of diesel-powered systems that a viable alternative would require a substantial transformation of the industry in terms of hardware (including supporting infrastructure), worker skills and work practices. The convenience of diesel, as an energy source, is due to it having a high volumetric energy density and being a liquid that is safe to handle, easy to distribute and store. Supporting technologies allow diesel to be applied to fishing for propulsion, electricity generation and heating with relatively high efficiency.

The problem of high procurement cost is partly one of dwindling supply, but the situation is dramatically accentuated by rapidly expanding global demand. Curbing the expanding demand and indeed reducing requirements within the fishing industry is part of the solution and this will occur naturally in response to the higher price. Avenues for this broadly include using alternative sources of energy, developing fishing operations that inherently require less energy and improving the energy efficiency of devices used in fishing.

The impact that the globalised fuel market is having on fishing businesses in Australia is made clearer by Figure 1. It shows the terminal gate price (TGP) for diesel in Brisbane since 2004. The lower trend-line is the actual cost of diesel to fishing business after GST and excise is removed. Although the real cost to fishers is lower than the gate price the impact of the fuel price rises on business viability is higher, because as the TGP has risen by 55% the real cost to fishers has risen by 106%. This is particularly challenging to fishing business where this typically equates to the cost of fuel rising from 20% of turnover to 40% of turnover; assuming that the value of product caught has remained unchanged. In general the price/kg received for seafood has reduced over this period as markets for Australian caught seafood become more competitive and margins in the distribution chain are squeezed; for example, by higher transport costs.

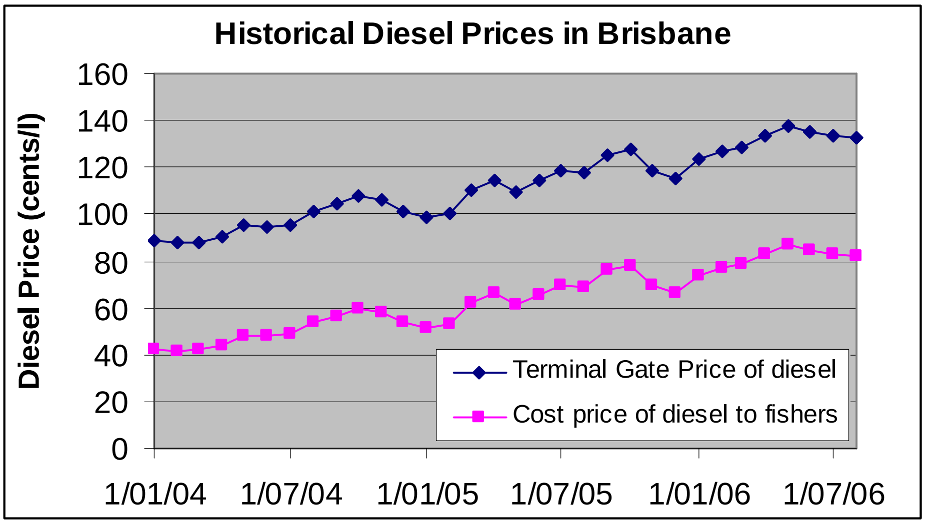


Figure 1. Terminal gate price of diesel for BP in Brisbane and the net cost to fishers

Alternative fuels

Alternative fuels to petro-diesel include biodiesel, liquid petroleum gas (LPG), liquid natural gas (LNG), compressed natural gas (CNG), Ethanol and Hydrogen. The right choice of fuel may reduce fuel costs and improve business viability. A further aim would be to reduce greenhouse gas emissions and this issue could have a bearing on the net cost of converting to an alternative fuel, considering government grants and rebates that might be applicable.

The engines used in fishing boats are classed as heavy duty, whereby they are required to operate under loaded condition for long periods. Automotive engines are generally classified as light duty. Fuel options for light duty diesels, such as the use of unmodified vegetable oils, may not be applicable to heavy duty engines. Also, in the marine context, engine reliability has significant safety implications, so fuel/engine strategies must carry a low risk of failure.

Obviously, for all fuels, the environmental impacts of production as well as usage need to be fully accounted for. The key to fuel security lies in the adoption of a diversity of approaches.

Cost savings from alternative fuels also depend on government excise policies and market forces. Current Government policy is:
- natural gas, ethanol, biodiesel and LPG have no excise at present
- 50% discount on excise for alternative fuels when full excise applies (2011)

Fishing vessel operators have exemption from diesel excise and GST.

Natural gas is an interesting option for reduced fuel costs and can reduce greenhouse gas emissions (CO_2) due to lower carbon to hydrogen ratio than diesel fuel. The primary constituent of natural gas, methane, is also a strong greenhouse gas and methane leakage during handling and methane emissions from gas burning engines may negate greenhouse benefits unless great care is taken. Australia has significant reserves and a wide reaching pipeline network of low pressure natural gas. It can be stored as a liquid (LNG) or in compressed form (CNG), although such storage and associated refuelling facilities are not widely available. The cost of converting low pressure natural gas to CNG and LNG is significant, particularly LNG, and onboard storage tanks for the fuels are far from straight forward. For CNG the storage pressure is usually 200 bar, which is more than a factor of 10 higher than the working pressure of typical pressure vessels manufactured from steel for LPG storage. However, CNG storage at 200 bar is a well established technology which is regularly applied worldwide. The price of natural gas is not tied to the price of oil because they currently supply independent energy markets - this might not be a relevant factor in the pricing of natural gas products that are specifically supplied to replace crude oil based fuels. Table 1 shows the current excise-exempt price for natural gas compared to other fuels.

Biofuels such as biodiesel and ethanol can potentially reduce greenhouse gas emissions because much of the carbon released as CO_2 in the exhaust has been captured from the atmosphere by photosynthesis in the growing of the feedstock for the fuel. The net reduction in carbon emissions relative to the use of a fossil fuel depends on the energy consumed (and thus carbon released) in the production of the biofuel. Biofuels offer a sustainable source of fuel produced in Australia. Currently processes are under development for the production of ethanol and good quality diesel fuel (Fischer Tropsch diesel) from plant fibre (biomass) such as wood waste and agricultural waste, reducing reliance on higher quality crops such as sugar or grain for ethanol and vegetable oil (eg canola) for biodiesel. Fish waste is a potential biofuel. Methane produced from anaerobic digestion of biomass is a viable biofuel that could use the infrastructure developed for natural gas.

Biodiesel can be used in unmodified diesel engines, subject to issues of engine durability and degradation in storage. At present there is little price advantage to off- road users because it is excise free (see Table 1).

Liquefied Petroleum Gas (LPG) is the generic name for mixtures of hydrocarbons (mainly propane and butane). When these mixtures are lightly compressed and cooled they change from a gaseous state to a liquid. This is a large advantage for the utilisation of LPG because the liquid fuel, having an acceptably similar volumetric energy-density to diesel (23.6 MJ/litre vs 36.3 MJ/litre), can be comfortably stored at ambient temperature in conventional pressure vessels. LPG occurs naturally in crude oil and natural gas production fields and is also produced in the oil refining process. LPG only offers limited price advantage to off- road users because it is currently excise free. It does however have lower greenhouse gas emissions (Table 1).

Hydrogen is a clean fuel that can be produced from fossil fuels, biomass or electricity. The potential for reduced greenhouse gas emissions depends on the production method. Production from fossil fuels could involve capture and sequestration of the fossil carbon. Cost of production, storage and utilisation on-board are relatively high at present. It can be stored as a liquid, or in compressed form (700 bar) or with the use of metal hydrides.

Hydrogen enriched compressed natural gas (HCNG) is easier to handle and utilise than hydrogen and yields greater greenhouse gas reductions than natural gas, due to the lower carbon to hydrogen ratio.

MGO (Marine Gas Oil) and MDO (Marine Diesel Oil) are heavier fuels than diesel, but not as heavy as fuel oil. They are more viscous and have lower ignition quality (Cetane number) than diesel. These fuels have normally been used in larger, slow revving engines. The use of ignition enhancing additives and fuel heating to lower viscosity could allow the use of lower quality fuels in the high-speed engines typical of fishing vessels. These fuel however, has higher sulphur content and there are no greenhouse gas advantages. The availability of these fuels in Australia is limited as fuel companies have rationalised their product range. If an operator asks for MGO they will now be supplied with automotive diesel, at a similar cost.

Table 1. Standardised physical and economic comparison of fuels relative to petro-diesel

	LHV MJ/litre	Density kg/litre	price before excise** cents/MJ	greenhouse gas reduction	Viscosity cSt @ 40 Deg C	Flash point Deg C	Ignition temp Deg C	Cetane number	Fuel conversion technology	substitution rate and efficiency
Petrol	32.2	0.75	2.8	0%		-45	260	5 – 20	Spark ignition	100% subst. 20% lower efficiency
Kerosene	34.7	0.815	4	0%		51	230		lubricity improver	100% subst. Same efficiency
Diesel	36.3	0.85	2.8	0%	3.2	60	207	50 – 55	NA	
Marine Gas Oil	37.2	0.89	1.95 + additives	0%	1.5 – 6	60	207	40	fuel heating, ignition additive?	100% subst. Same efficiency
Marine Diesel Oil	38.1	0.91	1.62		11 – 14	60	207	35	Medium and low-speed only	0% subst
Residual Fuel Oil	40.5	0.991	1.05		180 – 380	60	207		Low–speed only	0% subst
Biodiesel	32.4	0.88	3.6	50%	4.5	120		> 47.5	no modifications required	up to 100% substitution similar efficiency
Straight Vegetable oil				60%	37	245		40	Mixed with diesel, no modification required	20% subst – dependent on oil used Same efficiency
Ethanol	21.3	0.796	2.8	80% - 0% depending on manufacture		13	430		Diesohol	< 15% subst
									Premixed Diesel pilot “Dual fuel”	Low subst similar efficiency
									Direct injection compression ignition	95% ethanol + 5% ignition enhancer

	LHV MJ/litre	**Density kg/litre**	**price before excise** cents/MJ**	**greenhouse gas reduction**	**Viscosity cSt @ 40 Deg C**	**Flash point Deg C**	**Ignition temp Deg C**	**Cetane number**	**Fuel conversion technology**	**substitution rate and efficiency**
Methane 1bar	0.035	0.0007	0.8 to 1.68	20%		-188	540		Premixed Diesel pilot "Dual fuel"	<85% subst. Same efficiency
LNG	20.3	0.41	1.2 + liquefaction costs						Gas injection - diesel pilot or glow plug "gas only"	<95% or 100% subst High efficiency and output
CNG 200bar	7.9	0.16	1.2 + compression costs						Premixed Spark ignition	100% subst 20% lower efficiency unless lean burn
Liquid Propane	23.6	0.51		15%		-90	482		Premixed Diesel pilot "Dual fuel"	15% - <50% subst. Same efficiency
HD5	23.1	0.50	2.35						Premixed Spark ignition	100% subst 20% lower efficiency
Autogas	25.7		2.3							
Liquid Hydrogen	8.7	0.07	4.7 + liquefaction costs	80% - 0% depending on manufacture			600		Premixed Diesel pilot "Dual fuel"	50% subst. 20% lower efficiency unless lean burn
Compressed Hydrogen 700bar	5.4	0.045	4.7 + compression costs						Gas injection spark ignition	100% subst improved efficiency if lean burn
									Fuel cells	100% subst

** Energy costs are a guide only and will vary regionally and over time.

Fuel/engine options offering potential for reduced fuel costs and reduced greenhouse gas emissions for fishing vessels are:

Engine retrofit/modification:

- Biodiesel (standard marine diesel engine)
- Dual fuel conversion (LNG, CNG, LPG, HCNG, Hydrogen, ethanol)
    - substantial modifications to fuel storage systems (cost, volume, weight, safety)
    - up to 20% greenhouse gas reduction (C/H ratio of fuel), more for HCNG and hydrogen
    - dual fuel by mixing gas with intake air - continuous mix or timed port injection
    - potentially increased power due to extra fuel flow into engine
    - can revert to full diesel immediately
    - lower substitution rates with LPG- more prone to knock
    - high substitution rates require modifications to diesel injection system
    - can use biodiesel as diesel component
    - Clean Air Power have successfully converted a number of Caterpillar diesel engines to LNG dual fuel
- Diesel to gas only conversion (LNG, CNG, LPG, HCNG) - spark ignition, premixed, timed port injection, modified pistons, complete rebuild, reduced efficiency due to reduced compression ratio and throttling losses
- Diesel/ethanol blends

Engine replacement:

- Common rail electronically controlled diesel engines (petrodiesel, biodiesel)
- Dual fuel diesel engine (LNG, CNG, LPG, HCNG, Hydrogen, ethanol)
- Direct injection gas diesels (glow plug or pilot diesel ignition) (LNG, CNG, HCNG, Hydrogen)
- Spark ignition premixed lean burn gas engines (LNG, CNG, LPG, HCNG, Hydrogen)
- Spark ignition premixed or compression ignition direct injection (with ignition additive) ethanol engines
- Fuel cells (hydrogen, methanol, kerosene)

The cost of engine conversion and fuel tanks are a significant consideration. The Australian Government has been funding 50% of truck and bus engine conversion costs for conversion to natural gas or LPG, where a greenhouse gas emissions reduction can be demonstrated [1].

Alternative energy

Alternative energy utilisation relates to moving away from the use of chemical energy in the form of fuel and the conversion of the heat of combustion into mechanical work using a heat engine (i.e. internal combustion, gas turbine, steam power, etc). Alternatives that have practical possibilities include wind power, solar power and wave energy. There are two facets to the problem of harnessing such energy; collection and conversion of the energy to a more usable form and storing the energy until it is required in the fishing operation.

For all these forms of energy it seems unlikely that either or all of them combined would be able to satisfy the total energy demand of a typical fishing operation; at least in the foreseeable future. The energy densities of these energy forms are very low and there is very limited opportunity to align the timing of alternative energy capture with the energy demands of fishing, so some form of energy accumulation and storage is required so that a slow input of energy over a long period of time will be able to contribute significantly to the high energy demand of fishing that might occur over a relatively short period of time. In this arena batteries or hydrogen gas production/storage seem to be most applicable. Although the total energy demands may not be met by such systems it is likely that a sizable and worthwhile contribution might be feasible, thus reducing substantially the amount of more expensive fuel utilised, in traditional ways, to cover peak demand.

It likely to be more viable for the installation that converts low density renewable energy into higher intensity electrical energy (charged batteries) or compressed hydrogen to be located on-shore and transfer the value-added energy to the ship as fuel stores; rather than attempt an on board unit – unless the energy intensity of fishing was vastly reduced and there was a need to be semi-self sufficient for energy.

Utilisation of both wind and solar energy in fishing are easily conceptualised based on the proven and well known technologies that exist. The practicalities and performance of such systems on fishing boats would depend on the exact application of current or emerging technologies used. Not so easily conceptualised is the utilisation of wave power. Technologies in this area are developing mainly from the perspective of land based energy demand and has lead predominately to ideas based on large fixed structures. In fishing, the process of damping the wave induced motions of a vessel (both roll and pitch) dissipates energy; it may be possible to capture and accumulate this low-density energy. For example, a vertical axis wind turbine would extract energy from a rolling vessel and from the wind at the same time. Devices at large radius of gyration (bow and stern, at the end of trawl arms, at the top of masts) move a long way and at high speed during waves induced vessel motions. This allows the opportunity to generate and capture significant amounts of energy over time; therefore damping the motions for no net energy cost to the operation of the boat - in fact a small gain.

IC engines

It is an indisputable conclusion that lower speed engines and also large capacity engines, which are usually of low speed design, are more efficient than high speed engines. An evaluation of high speed and medium speed engines of a power capacity relevant to fishing boats shows that dedicated medium speed engines would be viable only for a small number of applications due to the factor of 5 increase in weight. Nevertheless it seems very relevant to explore this question in more detail to establish the extent of efficiency improvement possible and the scope for application in Australian fisheries.

Waste heat from the cooling water and the exhaust stream represents approximately 60% of the energy supplied by the fuel input. Recovery of some of this energy can represent a sizable amount of energy, which could be used to produce heating (if it is useful) or mechanical power from a heat engine (e.g. steam cycle). The latter idea (combined cycle engines) is commonly fitted to large cargo ships, however small scale applications are not being marketed. It is encouraging to see internet information that suggests Volvo have made some progress with developing a compact steam cycle heat engine driven by waste heat from the engine of a car. Steam is generated from an exhaust gas heat exchanger and drives a high torque screw-type turbine that is directly connected to the transmission. It is not possible to determine from the email chatter, how far advanced the development of the technology has progressed, however claims are made that this implementation of a combined cycle engine for an automobile lifts the efficiency of the engine from 33% to about 60%. Such claims might not be realistic.

Devices are being developed to extract more energy from the exhaust gas; e.g. the turbo-generator. The electricity so produced can be applied to the propulsive drive train. Caterpillar is working on a combined turbo- generator, air-charge system (on a single shaft). This is to be electrically connected to a starter motor/generator unit to increase power extraction from the engine and also optimise turbo charger operation (by applying electric spin up when required). Scania have implemented similar technology in a truck engine.

It is plausible that the waste heat lost from internal combustion engines might be reduced by allowing engines to run at higher temperature. Pressurized primary water cooling circuits would be required to avoid boiling of cooling water. Electric water pumps that are decoupled from the speed of the engine would assist in ensuring a temperature ceiling is not exceeded by thermal inertia when the load of an engine is quickly reduced through reducing engine rpm.

Injection of gaseous fuels (hydrogen, natural gas, LPG) at low levels into the air stream of a diesel engine is claimed by many sources to improve the combustion process and lead to improved thermodynamic efficiency and lower exhaust pollution. Scientific literature strongly demonstrates the benefit of dual fuel combustion on lowering harmful exhaust emissions but tends to leave an impression that thermodynamic efficiency is not altered. In general the scientific literature describes research with objectives other than improved thermodynamic efficiency. It would be of great interest to establish via testing on a diesel engine test bed the extent to which thermodynamic efficiency is affected by the inclusion of small amounts of gaseous fuel.

Conclusions and research questions

Alternative fuels

The utilisation of alternative fuels for fishing has two substantial aspects. Firstly there are the issues associated with simply using the new fuel; whether it requires completely new engines or can be used with existing engines with various levels of modification and supporting processes. Secondly there are the issues associated with fuel storage and refuelling infrastructure, given that fishing vessels are mobile, spend long periods at sea - often in remote areas.

The bulkiness and expense of dealing with gaseous fuel (even highly compressed) are important considerations and appear quite problematic. The cost of conversion to dual fuel utilisation - the cheapest, most flexible and practical approach - is substantial and the medium to long term benefits are uncertain. However, potential fuel cost savings from natural gas are substantial.

Considering that the domestic and global market for diesel fuel is massive and growing, and that Australia holds vast reserves of coal and natural gas it seems likely that production of synthetic diesel from these reserves based on Fischer-Tropsch technologies will become established to underpin and stabilise the price of a blended diesel fuel. Over time the blend is likely to become more dominated by its synthetic portion, which increasingly could be derived from renewable feed stocks.

It is likely that the price differential between LPG and Diesel for fishers will expand when LPG becomes subject to excise, but that is some time off (2.5cpl in 2011), and the current meagre price differential along with the limited substitution rate from the dual fuel conversions makes that prospect less interesting.

This picture of the future gives rise to a framework for cautiously prioritising research questions from the perspective of the fishing industry. The conclusion tends to dampen enthusiasm for a switch to gaseous fuels. The storage of large amounts of CNG on board is very problematic and the supporting infrastructure is not being enthusiastically provided. Similarly, the feasibility of developing an LNG market within domestic transport and mobile power applications seems overwhelmed by the economic benefits of using well proven techniques for producing GTL (Gas to Liquid) diesel and capitalising on the existing petro-diesel supply chains to the existing enthusiastic market. Serious arguments have also been raised that using GTL diesel is more environmentally sound than using LNG [2].

Given that irrespective of the fuel used the cost of fuel is likely to remain a very high proportion of turnover for fishers, it is apparent that efforts to improve viability should also focus on reducing energy intensity and improving component efficiencies.

In conjunction with the above tentative conclusions the following research questions with respect to alternative fuels are of significance to fishing.

1. **Explore the scope for fishing businesses to produce fuels from recycled waste material and bycatch**
    - **there seems to be an immediate need to investigate the utilisation of fish oil as a fuel – it has been reported that fish oil is readily available to some operators and is currently dumped as waste; a practical diesel/fish oil blended fuel may be achievable.**
2. **Research the use of Marine Gas Oil (Distillate DMA) and Marine Diesel Oil in high-speed diesel engines**
    - **experimental trials of MGO/MDO on a high-speed engine testbed**
        - **investigate fuel additives and fuel heating as required to achieve appropriate ignition quality and viscosity**
    - **check that the fuel will be legal for inshore marine use - emissions issues**
3. **Evaluate natural gas (LNG, CNG) as a possible short term prospect for fuel cost savings, depending on supply issues**

    A) desktop study

    - **propose storage systems matched to fishing vessels, integration of tanks into hulls, estimated cost**
    - **propose on-board handling and safety systems matched to fishing vessels, estimated cost**
    - **propose infrastructure, cost of compression or liquefaction, technology for compression from mains supply**
    - **engine options - dual fuel, gas diesel, premixed lean burn**
    - **engine conversion technology - adapt and improve on-road alternative fuel technologies**
    - **cost of engine conversions and replacements**

        - **establish potential for cost subsidies, AGO**
        - **methane emissions - oxidation catalysts**

    B) implement and demonstrate technology on a typical vessel

4. **Evaluate LPG as a relatively user friendly option with established supply chain. Positive outcomes might be realisable with careful implementation and further technological development**
    - **desktop evaluation of engine options, especially fuel efficiency and diesel substitution rates, to ascertain if the small price advantage over diesel will be of significant benefit**
    - **propose storage, handling and safety systems matched to fishing vessels**
    - **evaluate cost of engine conversions and replacements**
    - **establish potential for cost subsidies, AGO**
5. **Further research on biodiesel as a relatively easy to implement means of reducing greenhouse gases, if not cost savings**
    - **issues with storage in the marine context - avoidance of water contamination or use of additives and filters to alleviate problems with water contamination**
    - **fuel quality variability, viscosity in cold weather**
    - **long term engine durability and manufacturers' warranties**
    - **monitor and critically evaluate the Seafish projects on biodiesel and straight vegetable oil for fishing vessels**
    - **consider the impact of improved eco-efficiency (including reduced greenhouse gas emissions) on the marketing of seafood**
6. **Monitor fuel prospects broadly for the fishing industry and seafood market conditions, with attention to interactions**
    - **there is a need to monitor and continually update the prognosis for future sources of energy for the fishing industry. This would include:**
        - **monitoring the relative prices (to fishers) of available fuels**
        - **monitor fuel industry production forecasts for the short, medium and long terms**
    - **identify addressable supply chain gaps and technological shortfalls in the provision of more viable fuels to fishing**

IC engines

Improved energy utilisation begins with the efficient conversion of energy into work at the engine and making the most of the opportunity to utilise the low grade waste heat produced during this process. To develop higher efficiencies in this area, a detailed understanding is required of the engine and the loads attached to it and the processes occurring during fishing. Armed with this information it is possible to look into the details and exercise opportunities to reduce energy needs and/or losses. This may occur by a) improved engine and load efficiencies, b) better matching of engine with its connected loads or c) more appropriate interaction between engine and fishing processes that may be able to utilise waste heat.

The following research questions and project themes develop initiatives in this area and where possible link to the energy auditing framework in terms of the level of complexity involved. A pilot implementation of energy audits in the fishing industry is underway. This will tend to contribute to the identified research questions to the extent that the audits ultimately are applied across the industry.

1. Measurements on existing vessels

- **survey existing fleets**
    - **engine types, age, condition ...audit level 1**
- **measure duty cycles on representative vessels to allow proper assessment of engine optimisation and alternative fuel/engine options …audit level 2**
- **map engine performance off normal operating conditions to establish optimum fuel efficiency conditions ….audit level 2/3**
    - **measure torque, fuel consumption, rpm, other engine parameters, thrust under variable load conditions**

2. Optimise matching of engine to propeller/hull/tows, with emphasis on the engine side and considering duty cycles, for maximum engine efficiency at maximum fuel usage conditions - desktop and experimental studies in preparation for more thorough data from the later stages of the audit process

- **establish performance maps (which include fuel efficiency contours) for relevant engines (including medium speed engines) from published data and experimental studies on test bed**
- **study engine/propeller/hull/tow matching options such as the use of oversized/medium-speed engines, disabling cylinders for power control, electronic engines - desktop studies and experimental studies on test bed**
- **evaluate potential of advanced diesel/electric hybrid systems**

3. Evaluate potential fuel efficiency improvements from

(a) waste heat recovery systems - desktop studies - potential and state of development - turbo compounding, combined cycle

(b) combustion enhancement with on-board hydrogen generation or small amounts of other gaseous fuels such as LPG - industry claims, anecdotal data only - need rigorous experimental studies to ensure vessel owners do not waste their money

(c) fuel additives, improved lubricants and higher thermostat temperature

1 Introduction

1.1 Background

1.1.1 The rising cost of fuel

The price of fuel for fishing is the result of complex interactions between factors occurring at the local and global scale. Fundamentally the cost of fuel is linked to the costs of feedstock into the production process and a premium dependent on the degree of competition. While supply capacity has been much higher than demand, the base price of fuel has been low. This was the situation from 1986 through to 2000, after the 70's fuel crisis (see Figure 2 and Figure 3), where the fear by OECD countries that oil production and price would be dominated by Persian Gulf countries caused an intense exploration for oil outside the Persian Gulf. This finally led to a significant proportion of the demand being met by sources outside the Middle East– mainly expansion of production in USA and Canada and also in the North Sea (see Figure 4). During the 70's the sharp spike in oil price occurred because Persian Gulf Countries were able to take control of oil production within their borders from the global oil companies. They then attempted to produce a flow of wealth into their region from OECD countries by increasing oil prices to a market that for a period had limited alternative supplies.

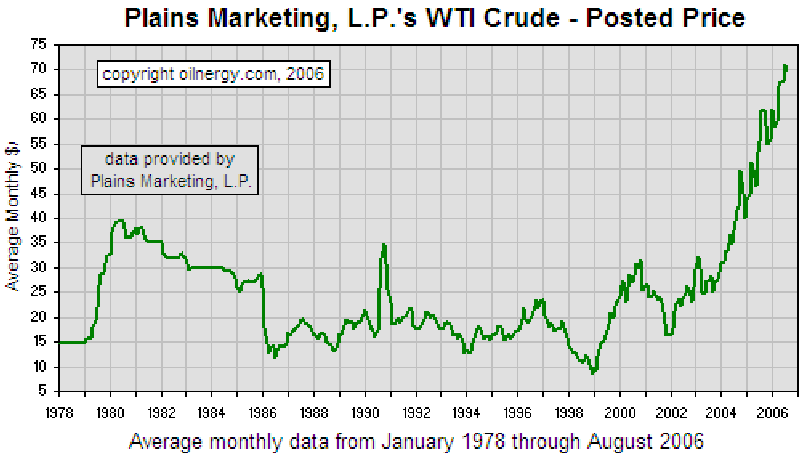


Figure 2. Movement in crude oil posted price since 1978 [3]

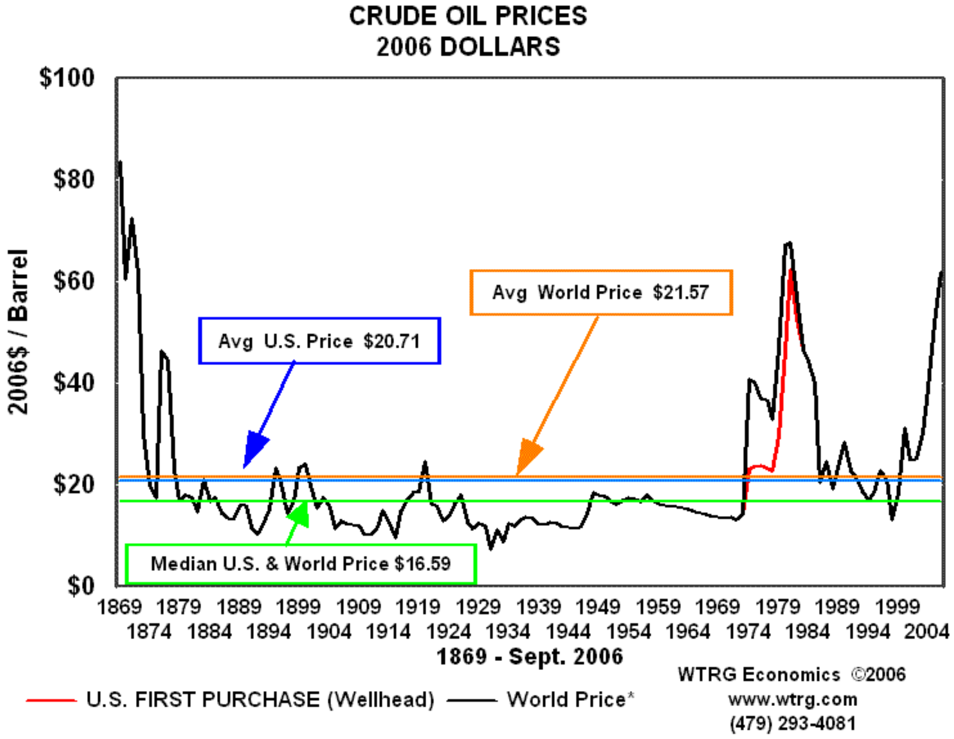
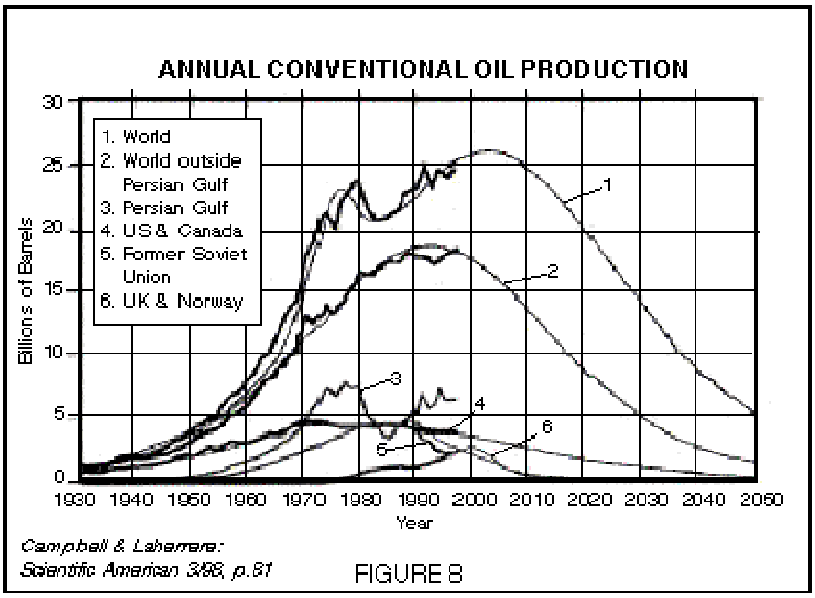


Figure 3. Historical crude oil price in 2006 US$ [4]

The current escalation in price is occurring because the excess capacity for production over demand that was with us during the 80’s and 90’s has dissipated. Demand during the 90’s increased strongly and production of oil from outside the Persian Gulf is in decline.

The total global production of conventional oil is estimated to be about 2000 billion barrels. Half that production is expected to have occurred at around 2005. This sounds reassuring in that it means that half the relatively easily obtained oil reserves are still available for production. However the time taken to consume the remaining reserves is likely to be much shorter than the time taken to consume the first half due to the high current consumption rate. Additionally, it is known that historically the rate of production from oil reserves peaks at about the point where they have been 50% exhausted [5]. This means that it is all down hill now for the level of oil production (see Figure 4); so demand will be increasingly outstripping supply in the future. This will presumably lead to ever increasing prices for that commodity as the trend in Figure 2 strongly suggests.



Campbell & Laherrere:
Scientific American 3/98, p.81

FIGURE 8

Figure 4. Global production of crude oil [5]

“By 2050 the Golden Age of Oil, the world we know today, will be over. We will have become preoccupied with adapting to a shrinking oil supply in the new century. The risk of chaos, disorder and destruction could face us if we fail to adapt appropriately in time. We are confronted with the greatest transformation of human affairs in all history.

Challenging times are here. Hard-nosed decisions are required and there will not be much room for error. But we must be caring for people and the environment in our approach. The more caring we are the more hard-nosed the decisions can be, the easier and faster we can proceed down the path of constructive change. If everybody pursues their own self-interest we can become locked in conflict, unable to adapt and will dissipate destructively and unproductively the scarce high quality petroleum fuels that are so essential for the transformation to a world "beyond oil" [5].

Given the escalation in the price of crude oil on the global market, the local sale prices of petro-diesel and alternative fuels are now of primary concern to fishing businesses. The local sale price of fuels fluctuates over time and is the result of complex interactions between the availability and price of feed stocks, local production process issues and the dynamics of fuel markets. As an example, the following figure shows the sale price trend ($/litre) for conventional crude-oil based transport fuels over the last year in Brisbane [6].

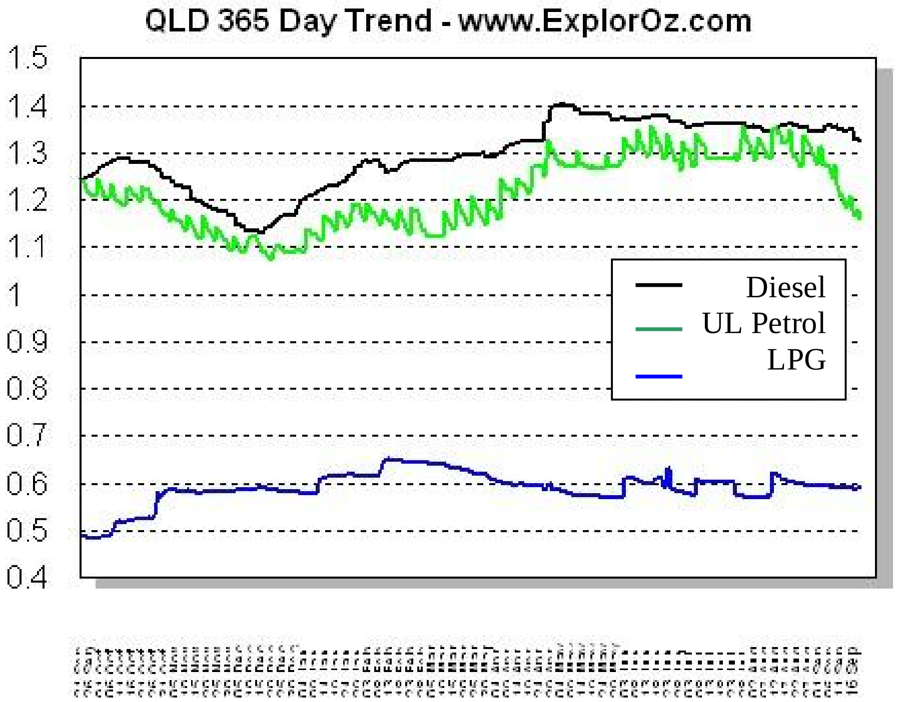
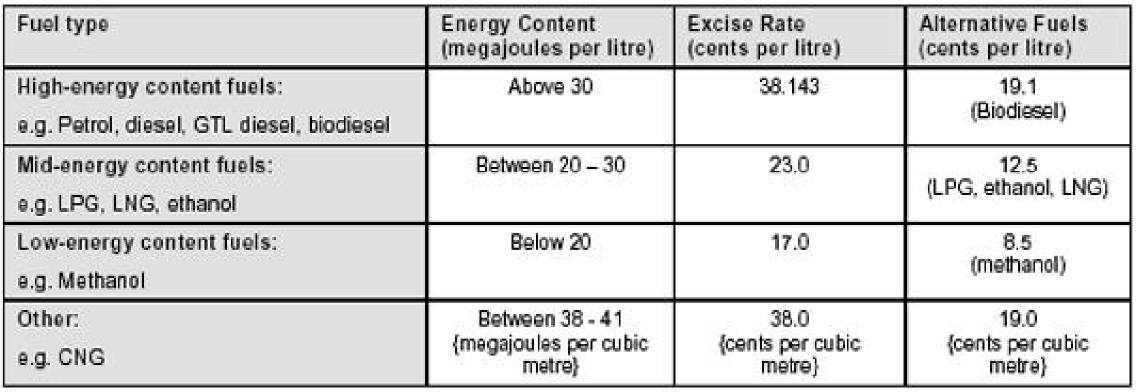


Figure 5. Transport fuel prices in Queensland [6]

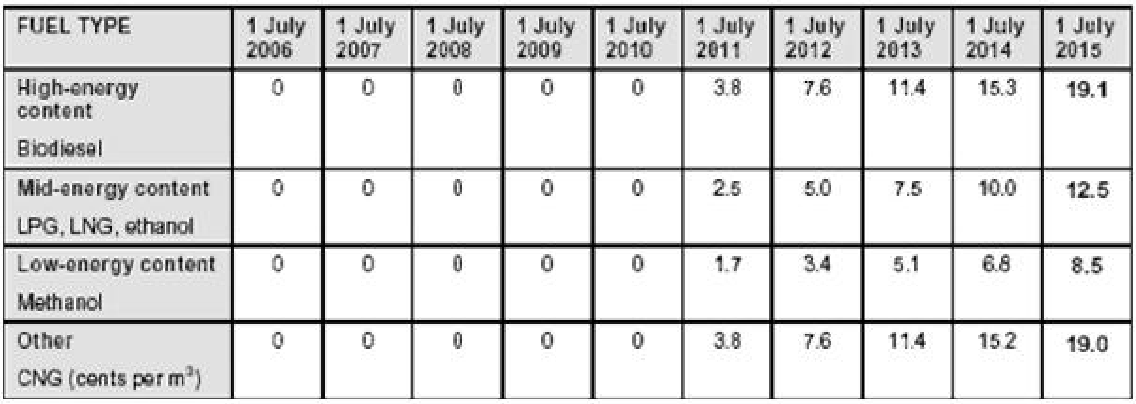
The relative cost of different fuels options are complicated by varying levels of excise attached to the sale price, all of which is currently refunded back to fishers through government rebates. There has been a distinction made between "conventional" fuels and "alternative" fuels, based on assessments of each fuels impact on the environment. Fuels that have the "alternative" status attract only half the excise (as per Table 2) and this is to be phased in over a considerable period of time (as per Table 3).

Table 2. Excise policy for fuel products [7]



Fuel type	Energy Content (megajoules per litre)	Excise Rate (cents per litre)	Alternative Fuels (cents per litre)
High-energy content fuels: e.g. Petrol, diesel, GTL diesel, biodiesel	Above 30	38.143	19.1 (Biodiesel)
Mid-energy content fuels: e.g. LPG, LNG, ethanol	Between 20 – 30	23.0	12.5 (LPG, ethanol, LNG)
Low-energy content fuels: e.g. Methanol	Below 20	17.0	8.5 (methanol)
Other: e.g. CNG	Between 38 - 41 {megajoules per cubic metre}	38.0 {cents per cubic metre}	19.0 {cents per cubic metre}

Table 3. Excise schedule for alternative fuels [7]



FUEL TYPE	1 July 2006	1 July 2007	1 July 2008	1 July 2009	1 July 2010	1 July 2011	1 July 2012	1 July 2013	1 July 2014	1 July 2015
High-energy content Biodiesel	0	0	0	0	0	3.8	7.6	11.4	15.3	**19.1**
Mid-energy content LPG, LNG, ethanol	0	0	0	0	0	2.5	5.0	7.5	10.0	**12.5**
Low-energy content Methanol	0	0	0	0	0	1.7	3.4	5.1	6.8	**8.5**
Other CNG (cents per m^3)	0	0	0	0	0	3.8	7.6	11.4	15.2	**19.0**

1.1.2 Cautious predictions for seafood commodities

On the revenue side for fishing, the period of low stable oil prices has coincided with excellent commodity prices for Australian seafood, particularly on export markets. Buoyant international economies have been keen to pay high prices for quality seafood and the rapidly developed global transport infrastructure has made it possible to cost-effectively ship seafood products to the most lucrative markets. Higher oil prices are predicted to cause increasing problems for the economies supporting Australian seafood markets, exacerbating weaknesses that have already emerged. Additionally, global transport industries are expected to experience challenging times. The prospect for continuing high volumes of highly priced seafood exports would appear to be low. In the medium term it is expected that consumption of seafood might be closer to the point of production and more importantly the market price would presumably be reduced in real terms.

1.1.3 The greenhouse gas problem

The future decline in oil production and the inevitable reduction in its consumption are perhaps timely, if not overdue, considering the developing picture of global warming. The implications of reducing oil usage on the global warming problem will depend on how the world responds. The world faces a necessity to look for other fuels or alternatively, substantially reduce energy consumption. Desperate use of alternative fossil fuels and unsustainable harvesting of "living" fuel sources will only exacerbate the greenhouse gas problem, but similarly there exists the opportunity to select developments that do address the long term challenges, and ultimately find ways to have happy lives within the world's long-term carrying capacity.

Just how that can be achieved is by no means clear; however it is clear that the problem of global warming will increasingly dominate world affairs and substantially shape government policies. Business decisions, no less, will be guided by these large scale circumstances and good decisions will in part involve considering the alignment of business goals with government policy for no better reason than the possibility of attracting financial support for industry developments of mutual interest.

Therefore the details of greenhouse gas issues are significant to efforts to position the fishing industry for the best possible future, given the resources we have and what we know about the world. Not only is there likely to be financial incentives from government to develop in ways that are consistent with the greenhouse gas challenge, but the market for seafood could respond positively to seafood products, which involve low levels of greenhouse gas emissions and are marketed accordingly. In short, good greenhouse gas credentials would contribute strongly to a positive image for Australian seafood.

1.2 An appropriate framework for reducing energy intensity

Energy consumption in Australian fisheries occurs across many tasks within the various fishing enterprises that exist. The relative amount of consumption for each aspect of fishing depends on the fishing method, the efficiency (“quality”) of the hardware installed to perform the tasks and the detailed nature of each fishing business as shaped by the range of issues affecting its economic, social and ecological viability. Impacting issues include geographical, climatic, biological, market driven and governance factors. Over time, fishing businesses, with good management and a stable environment (in the broad sense), have an evolving structure that is increasingly in harmony with the locally felt mix of influencing factors.

Overall energy consumption and efficiency is the result of, yet part of, this complex web of issues affecting each fishing business. All these aspects interact in terms of costs and benefits to the viability and profitability of the business. The harmony mentioned above relates to a mode of operation (and business structure) that rests in relative comfort within the nest of applied environmental conditions.

The question of improvement with respect to energy costs to fishing businesses can be a very complex problem depending on how it is approached/scoped and on how high the bar is set in terms of the improvement sought and also the time horizon sought for these improvements to occur.

Fleay [5] suggests that the greatest potential for efficient use of energy is by reducing our present scale of consumption generally. Every use of material resources involves the use of energy, so resource use efficiency in the end amounts to energy conservation. The decline of oil will relentlessly impel us down this path.

“The role of oil in the economy and community life is so all pervasive that the commitment to demand management must be across the board involving all sources of energy and resources in general. It has two facets; one is the improvement of the material and energy efficiency at a local level such as in buildings and individual businesses. These local gains can be achieved relatively quickly. The other facet is structural change, reorganising social and economic systems to eliminate waste, material and energy inefficiency at the systems level. The greatest gains will come from structural change; it is unavoidable and takes time to achieve.” [5].

1.3 An energy audit

1.3.1 What is an energy audit

The purpose of an energy audit is to firstly establish an internal benchmark for the operation. This can then be compared to other similar enterprises and future energy consumption in order to establish the potential for improvement and monitor the results of projects to increase energy efficiency.

A standard specification for an energy audit of a business premises is covered by AS/NZS 3598:2000. An outline of the Standard is available on the Australian Green House website and has been reproduced in Appendix B.

Audits have been defined at 3 levels with different levels of achievement being sought for the energy usage problem:

- Walk-through (produce broad internal bench mark, comparison with external bench marks, identify “quick wins”, recommend next step)
- Standard (breakdown energy consumption to components of the enterprise, make recommendations regarding structural changes to enterprise with estimates of costs and payback periods)
- Detailed (produce long term strategies for gains in energy efficiency, improved confidence with setting priorities)

1.3.2 Applying an energy audit to Fisheries

Energy audits are applied at the business level and produce a standard measure of performance for each business that is audited. This in itself does not achieve a great deal despite possibly entailing substantial effort and cost. The value of the audits comes after a number have been completed and from comparing the standardised snap shots of business performance with each other (i.e. similar measures taken either at different times or for other business), while being cognisant of the accurate temporal profiles of the business structures involved. The investigative comparison allows linkages (causes and effect) between aspects of business structure and business performance to be inferred; and later tested through making insightful structural adjustments to fishing businesses with the objective of replicating the improved performance observed elsewhere. Under scrutiny in this process are not simply aspects of business structure, but rather all aspects of the business environment that affects the business’s energy efficiency. All such aspects need to be included/documented in each business’s structural profile; otherwise interpretation will be clouded by the influence of “unknown” variables. Issues of interest can be broadly based and may be effectively investigated by auditing boats across appropriate scales.

For example port level issues like fleet dynamics, communication, cooperation and local infrastructure can be evaluated by auditing vessels from different ports that have contrasting characteristics. Similarly issues at the fishery (bioregion) level (like Governance, stock management process and harvest strategy) can be evaluated by aggregating and comparing the audits on businesses at that spatial scale.

2 New sources of energy for fishers

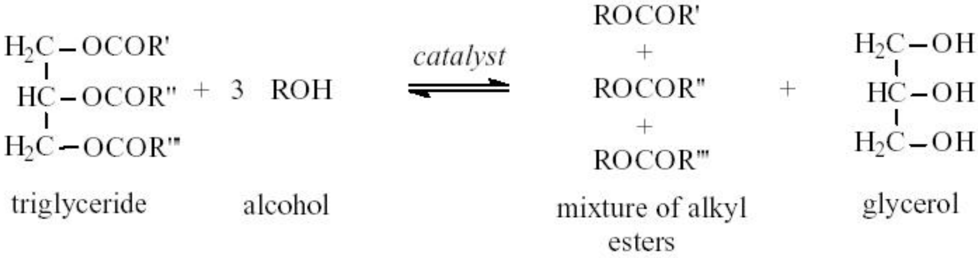
2.1 Alternative fuel

The utilisation of alternative fuels for fishing has two substantial aspects. Firstly there are the issues associated with simply using the new fuel; whether it requires completely new engines or can be used with existing engines with various levels of modification and supporting processes. Secondly there are the issues associated with storage and refuelling, given that fishing vessels are mobile and therefore have many of the same constraints as transport vehicles. The necessity of having to carry the fuel around as fishing boats go about their business is a major factor simply because it immediately makes impractical, or at least very difficult, the use of seemingly cheap environmentally friendly fuels that unfortunately do not have a high volumetric energy density.

2.1.1 Biodiesel and SVO

The most suitable currently available biofuel for existing engines is biodiesel, manufactured from vegetable oil or animal fat by modifying the chemical structure of the fats, through a relatively simple process called esterification, using methanol or ethanol as a catalyst [8-11].

The process is illustrated in the following diagram [12]:



Biodiesel can be used straight in existing engines. Often it is blended with conventional diesel (petrodiesel). At present biodiesel may be more expensive than excise free petrodiesel. As oil prices continue to increase and biodiesel production increases there may come a point where it is cheaper than petrodiesel to the industry. Currently there is no government excise on biodiesel if it meets the Australian Standard. The excise is planned to ramp up to 50% of the petrodiesel diesel excise in 2015. Biodiesel will become more attractive to the fishing industry when the excise applies.

Engine manufacturers tend to recommend against the use 100% biodiesel or of blends greater than 5% or 10% biodiesel in petrodiesel. The long term reliability of biodiesel in heavy duty engines in the marine context needs to be validated. The legality of engine warranties with alternate fuels also needs to be clarified.

Biodiesel is much more degradable in the marine environment than petrodiesel - 95% in 28 days in water, compared with 40% for diesel. It has reduced emissions of soot and toxic hydrocarbons, an occupational health and safety advantage. Depending on the source of the raw materials, biodiesel may be rated as about 50% renewable [11]. This means that the total greenhouse gas emissions from production and use could be about 50% of that from production and use of petroleum diesel. An Australian biodiesel standard is now in place [13, 14] There is a large amount of experimental data and operational experience for terrestrial diesel engines, but not so much for the marine application.

Biodiesel and ethanol have been identified by the Australian Government as viable biofuels [15].

In an unmodified engine, maximum power may be reduced with biodiesel, fuel consumption might increase, smoke emissions will probably reduce, and NOx emissions may increase slightly. The changes depend on fuel type and engine type. There is considerable scientific and operational data for biodiesel.

Some degradation of fuel lines and seals is possible on earlier engines. Biodiesel can degrade in storage. Water in fuel encourages fuel degradation. The ageing products can cause corrosion and filter clogging [10].

It has good lubricity, which is an advantage in injection systems. It can be used to improve the lubricity of low sulphur diesel. It has higher viscosity than petrodiesel, so injection pressure of conventional injection systems may increase, leading to reduced injection pump life. It has higher modulus of elasticity than petrodiesel so injection timing in mechanical injection systems might advance slightly. Electronically controlled common rail engines would offer less sensitivity to these properties.

Biodiesel has a lower energy content on a mass basis than diesel but higher density [10]. The net result is a small increase in volumetric fuel consumption.

Biodiesel has a higher flash point than diesel and so is marginally safer in terms of ignition of fuel vapours in handling and storage.

Straight vegetable oil is in use in light duty diesel engines with fuel pre-heating and thorough filtration. The use of unmodified vegetable oils in heavy duty diesel engines, such as the engines used in fishing boats, is not recommended, as it can lead to significant engine deterioration, including clogged injectors, stuck piston rings and lubricating oil contamination. These effects are probably due to pyrolysis of the oil molecules. As the fuel spray enters the combustion chamber it is heated rapidly due to the high temperature combustion process which is underway. The core of the fuel spray has very little air mixed in with it. When the fuel is heated without significant oxygen present, carbonaceous products of a higher molecular weight than the original fuel can be formed. These high molecular weight carbonaceous products may not be burned completely, leaving deposits. Straight vegetable oil appears to be particularly susceptible to this pyrolysis process. The biodiesel process modifies the chemical nature of the oil to avoid such problems. Heating SVO to reduce viscosity would help by improving atomisation. That is what is usually done in light duty diesels. Filtering out waxes is another strategy. Neither of these strategies is likely to eliminate the problems caused by pyrolysis of the fuel. Blends of SVO with diesel would be better than 100% SVO. Babu and Devaradjane [16] provide a comprehensive review that highlights the problems but does not rule out solutions.

2.1.2 Ethanol

Ethanol (C_2H_5OH) is an alcohol, an oxygenated organic carbon compound. It is the intoxicating component of alcoholic beverages, and is also used as a solvent (methylated spirits). By contrast, diesel is a mixture of a range of hydrocarbon compounds, none of which contains oxygen. In blended fuels, the addition to diesel of the oxygen contained in the alcohol changes a number of important fuel characteristics. These include changes in combustion properties, energy content and vaporisation potential.

Ethanol as a renewable fuel produces less fossil CO2 than conventional fuels and will easily blend with gasoline but not with diesel. Alcohols can be used in diesel engines by either modifying the fuel or by extensive engine adaptations. Ethanol can be produced in two forms – hydrated and anhydrous. Hydrated ethanol has a purity of 95% suitable for blending with an ignition improver, or as a 15% emulsion in diesel that is known as Diesohol. A second stage refining process is required to produce anhydrous ethanol (100% purity) for use in ethanol blends in petrol.

Ethanol can be manufactured from:

- biomass via the fermentation of sugar derived from grain starches or sugar crops;
- biomass via the utilisation of the non-sugar lignocellulosic fractions (structural component) of crops - trees, grasses, and from cereal and paper wastes;
- petroleum and natural gas via an ethylene (C_2H_4) intermediate step (reduction or steam cracking of ethane [C_2H_6] or propane [C_3H_8] fractions).

For the near future, ethanol produced from non-lignocellulosic biomass sources is likely to be the only feasible option for economical large-scale ethanol production, such that the costs become competitive with that of diesel. The mass production of ethanol from lignocellulose is still largely in the research and development stage. Production facilities operate mostly at laboratory or pilot scale and involve technologies using either acid or enzymatic hydrolysis, with the enzymes used being derived from micro-organisms. After hydrolysis the sugars produced are fermented and the ethanol in solution is distilled out, as for ethanol produced from starch and sugar crops [17].

Automotive spark ignition engines which run successfully on 85% ethanol and 15% petrol are well developed [18]. Diesel engines require some modification to run on ethanol. Scania are successfully operating 9 litre diesel engines in buses on 95% ethanol with 5% ignition improver, modified injectors and increased compression ratio up to 28:1 [19]. Ethanol can be blended with diesel fuel up to 15% using an emulsifier [11], or at higher concentrations using mechanical mixing at the point of usage, for use in standard diesel engines. Ethanol can be used in the dual fuel mode in a diesel engine, whereby it is mixed with the intake air while the normal diesel injector continues to operate, at limited substitution rates [20]. Further development of ethanol engines is likely. Ethanol has a lower flash point and higher evaporation rate than diesel or biodiesel and so is not as safe on vessels in terms of fire risk. Scania employ water sprinklers on their ethanol powered buses in case of fuel fires. Ethanol biodegrades quickly.

2.1.3 Other biofuels

BP has recently announced a new process for converting animal fat (or other biomass) into biodiesel by hydrogenation [21]. They call the fuel renewable diesel and plan to produce it from animal fat at an oil refinery in Queensland by 2007. It will be blended with petroleum diesel and will not be subject to the biodiesel standard, which applies to fuels produced by the esterification process.

Fischer-Tropsch (FT) diesel is a high quality synthetic liquid diesel fuel. It can be produced from coal, gas or plant fibre [11, 22]. FT diesel produced from renewable biomass could yield significant greenhouse gas reduction. It is likely that there would be few operational issues associated with this fuel. It has high cetane number and virtually no aromatics or sulphur, leading to low emissions [11].

Biomethane can be produced from waste organic matter, and can be used in engines in the same manner as natural gas [23], if it is sufficiently purified. The production process involves anaerobic digestion in special reactors, as illustrated below. A water scrubber can be used to purify the gas. The waste from the digestion process can be used as fertiliser.

An advantage of biomethane is that it can use the same engine and storage technology as natural gas. Biomethane from waste disposal areas and from specially built digesters is in significant use worldwide.

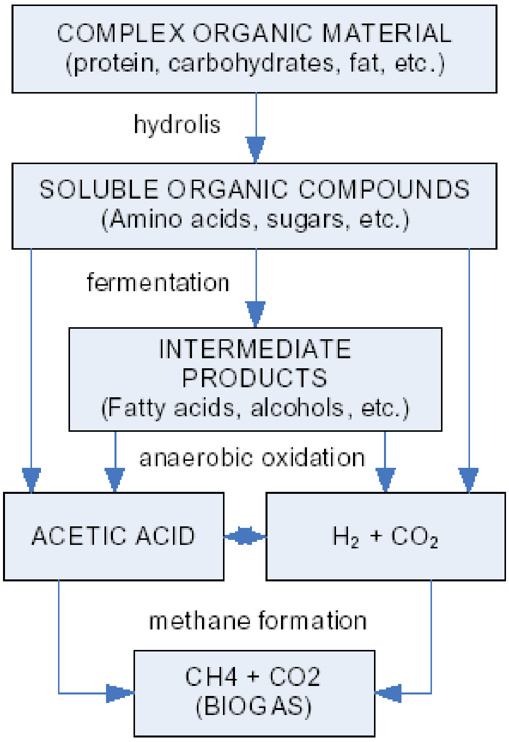


Figure 6. Biogas Production Schematic [23]

There are several other ways to make use of the energy contained in the biomass from direct burning to gasification, pyrolysis. Pyrolysis is thermal degradation of biomas with a limited supply of oxidising agent. Three products are usually produced: gas, pyrolysis oil and charcoal, the relative proportions of which depend very much on the pyrolysis method, the characteristics of the biomass and the reaction parameters. At relatively low temperature (500 to 800 °C) more solid and pyrolysis oil is produced, while at higher temperature (800 to 1000 °C) complete gasification occurs. Producer gas is made by passing air through a hot bed of coal, wood or other dry organic matter. The resulting gas contains carbon monoxide and hydrogen as the primary fuels, with up to 55% nitrogen [24]. It is a low quality fuel with low heating value. It is necessary to filter out soot and tar from the gas before it can be used in an internal combustion engine [25, 26]. This technology was extensively used on domestic motor vehicles during WWII when crude oil was in short supply [27]. A higher quality gas (water gas) can be produced by blasting the hot bed of organic matter with steam, resulting in more carbon monoxide and hydrogen and less nitrogen. Pyrolysis oil (bio-oil) is a low quality fuel with as yet uncertain suitability for heavy duty diesel engines.

A New Zealand company, Aquaflow Binomic Corporation, claims to have developed a process, which yields diesel fuel from algae, which are grown in waste nutrient and sunlight. This product could reduce the need to grow specialty crops for biodiesel production and simultaneously allow reduction of harmful nutrients in waste streams. The product has not been extensively tested in diesel engines and the details and economics of the process have not been published.

2.1.4 Natural Gas

Australia has vast reserves of natural gas. Pipeline quality natural gas is generally around 80 to 90% methane. The remainder is primarily ethane, inert gases (N_2, CO_2), and smaller amounts of propane and higher hydrocarbons [28]. Natural gas potentially offers 25% greenhouse gas reductions due to a lower carbon to hydrogen ratio than petrodiesel. Methane leakage and methane in the exhaust can remove the greenhouse benefits, as methane is a powerful greenhouse gas in its own right [29]. Methane oxidation catalysts in the exhaust may overcome this problem.

Natural gas is intrinsically safe in that it is lighter than air and so leaked gas is unlikely to accumulate in the hull. Also, despite the flash point for natural gas being quite low (-188deg C) it has a much higher ignition temperature than diesel, making it more difficult to auto-ignite. Methane flammability limits are relatively narrow, mainly due to a low rich limit [30]. This means that unless there is a significant amount of air mixed with methane, it will not ignite. However, a natural gas installation would need thorough safety systems including gas detectors and active ventilation.

2.1.4.1 Dual fuel engines

Engines of the size and type used in fishing boats are operating successfully on natural gas, using dual fuel combustion. Natural gas on its own in a diesel engine will not ignite, so successful use of natural gas involves use of a small injection of diesel to ignite a mixture of natural gas and air, which is admitted during the normal air intake process. NOx and soot emissions are lower compared with petrodiesel. Gas only engines are available, but these lose the advantage of dual fuel operation where the engine can be switched back to full diesel operation in the event of gas supply failure. This safety feature is desirable in the marine context but not essential.

Dual fuel engines operate best at medium to high loads.

Caterpillar electronic engines converted to dual fuel on natural gas achieve 85% diesel substitution. That is, 85% of the energy originally supplied by diesel fuel is supplied by natural gas. Other aftermarket conversions are available. The reliability of all the commercial conversion options is not certain. There have been problems, possibly associated with poor maintenance of conversion systems.

High diesel fuel substitution rates require control of diesel injectors, overriding the normal mechanical or electronic controls on injection duration, to ensure only a small quantity of diesel fuel is injected. To avoid knock at high loads, reasonably high purity natural gas is required. The Methane number indicates the percentage of methane. Methane itself is unlikely to cause knock. It is the higher hydrocarbons present in the mix. Knock can be alleviated by controlling the rate of diesel fuel injection at higher loads so that the majority of fuel energy is supplied by the natural gas. Dual fuel natural gas engines are well developed technology in large marine propulsion engines [31].

An example of a dual fuel conversion is the Caterpillar C15 dual fuel natural gas engine (power output of 500hp), developed by Clean Air Power (USA) and Caterpillar with help of a grant from the Australian Government's Alternative Fuels Conversion Programme. Gas is injected into the intake air stream after the turbocharger compressor, using a bank of electronically controlled standard gas injectors.

Wartsila supply medium speed dual fuel engines which use gas injection in the inlet ports to supply premixed air and gas to the cylinder, where it is ignited by pilot injection. The engines can also operate in full diesel mode. The smallest engine available is the 6 cylinder 32DF at 2020kW output at 720 rpm and weighs about 30 tonnes.

2.1.4.2 Gas diesels

Direct injection gas diesels maintain diesel efficiency. The gas is injected at pressure directly into the engine cylinder, much like diesel fuel in a conventional diesel engine. Pilot diesel injection or glow plug/hot surface ignition is required. Westport have applied their high pressure direct injection (HPDI) technology to a Cummins ISX truck engine [32]. A single injector injects both gas and a small quantity of diesel directly into the cylinder in much the same way as diesel fuel is injected in a conventional diesel engine. Significant reductions in greenhouse gases, NOx and particulates compared with conventional diesel engines, are claimed. It is possible that this direct injection technology will achieve low methane emissions in the exhaust. This can be a problem in conventional dual fuel engines [29] which mix the natural gas into the inlet air stream. The Cummins/Westport HPDI engine will not operate on 100% diesel. The Westport/Isuzu gas diesel [33] uses glow plug (hot surface) ignition instead of diesel pilot ignition.

Wartsila supply medium speed gas diesel engines which can operate on gas or diesel. The smallest engine available is the 12 cylinder 32GD, with 4500kW output at 750 rpm.

2.1.4.3 Gas only engines

Premixed gas only engines use spark ignition. They are not as efficient as diesel engines due to reduced compression ratio and throttling losses. Power output is controlled by reducing the pressure of the air/gas mixture through a throttle valve, as in a spark ignited petrol engine. Numerous industrial spark ignited gas engines are available. The use of excess air in the fuel air mixture (lean burn) can recover some of the efficiency disadvantages. Cummins-Westport sell 6 cylinder lean burn premixed spark ignition natural gas engines, (“Gas Plus”) at 195 to 320 hp, compression ratio 10:1. They require Methane number 65 or greater. They can all run on hydrogen enriched natural gas (HCNG (20% H_2)).

Larger lean burn gas engines may use prechamber ignition for reliable ignition of the lean mixture. Wartsila supply medium speed lean burn gas only engines with prechamber ignition. The smallest engine available is the 9 cylinder 34SG, with 3758kW output at 720 rpm.

The Australian Greenhouse Office Alternative Fuels Conversion Program assisted truck users to convert to natural gas usage. Table 1 summarises the outcomes. Clean Air Power/Caterpillar dual fuel engines, a Cummins spark ignited gas engine and an Isuzu spark ignited gas engine were involved.

Table 4. Alternative Fuels Conversion Program Projects from Baker [29]

Figure 1 **Summary of AFCP Demonstration projects (either completed or underway)**

LOCATION	Sydney, NSW	Perth, WA	Perth, WA	Koroit, Vic.	Gosford, NSW	Perth, WA	Esperance, WA
FLEET SIZE	470	34	650	160	94	220	30
FLEET TURNOVER RATE	10 years	5 years	10-12 years	10 years	10-12 years	6-8 years (includes rebuild)	4 years
AVERAGE KM/VEHICLE/YEAR	80,000-100,000	200,000	75,000	220,000	17,000	300,000	150,000
ENGINE TECHNOLOGY	Caterpillar C-12 engine with Clean Air Power dual-fuel gas kit	Caterpillar C-12 & C-15 engines with Clean Air Power dual-fuel gas kit	Cummins 8.3G+ dedicated natural gas engine	Caterpillar C-12 & C-15 engines with Clean Air Power dual-fuel gas kit	ISUZU NPR Series 400 (gas series)	Caterpillar C-15 engine with Clean Air Power dual-fuel gas kit	Caterpillar C-15 engine with Clean Air Power dual-fuel gas kit
FUEL COMBUSTION	Diesel ignition with gas combustion at load	Diesel ignition with gas combustion at load	Spark ignited dedicated natural gas	Diesel ignition with gas combustion at load	Spark ignited dedicated natural gas	Diesel ignition with gas combustion at load	Diesel ignition with gas combustion at load
FUEL TYPE	CNG/diesel	LNG/diesel	LNG	LNG/diesel	CNG	LNG/diesel	LNG/diesel
REFUELLING REGIME	Depot-based and public CNG refuelling	Depot-based LNG refuelling	Tanker to truck deliveries (daily)	Depot-based LNG refuelling	Depot-based CNG refuelling	Depot-based LNG refuelling	On-site storage (ISO) and tanker to truck refuelling
SUBSTITUTION RATE	Approx 21% (1)	80%	100%	70-85%	100%	80%	80%
NO. OF GAS VEHICLES AT FEBRUARY 2006	2	8	5	33	5	13	3
PLANNED FUTURE GAS VEHICLES (NEXT 3 YEARS)	7	21	15	108	7	175-200	11

[1] Gas substitution rate for the project life was low due to substantial operation issues. Fault-free running periods suggested optimal substitution rate of between 60 and 70%

The conversion subsidy has been offered to land based vehicles only. To make a strong case for the subsidies to be extended to the fishing industry, it would be necessary to establish representative engine duty cycles and to demonstrate actual greenhouse gas reduction, probably by monitoring methane emissions in the engine exhaust.

2.1.4.4 Natural gas storage

Natural gas can be stored in compressed form (CNG) or as a liquid at -160°C. LNG energy density (20 MJ/litre) is about 56% of the energy density of diesel fuel. CNG energy density (7.9 MJ/litre at 200bar) is about 20% of the energy density of diesel. This means that for the same vessel range on natural gas alone, CNG storage tanks would need to occupy approximately 4.5 times the volume of diesel tanks. For LNG, the volume of fuel required is approximately 1.8 times that for diesel. Additional volume is required for LNG tank systems due to the need for thorough insulation.

The technology for LNG storage is well developed and in use in large trucks [34, 35]. Storage pressures range from 5 to 7 bar. Liquid fuel is passed through a heat exchanger where it is vaporised before being supplied to the engine, using waste energy in the engine coolant. Heat transfer through the tank walls to the LNG causes boil-off, which will raise the tank pressure. Venting would release methane, a powerful greenhouse gas, into the atmosphere. Super insulation allows standby times around a week, without venting. If long term storage without reliquefaction is required, means would need to be provided for consumption of the boil-off. Pressure build-up can be avoided by venting vapour into fuel lines during engine operation. There have been some problems with damage to LNG tanks in trucks due to vibration.

LNG infrastructure is developing. Fishing vessels could potentially share the infrastructure being developed for road transport.

CNG tanks are becoming lighter with the use of composite materials. The most advanced CNG tanks, which are made entirely of composites, have approximately 25% of the mass of all steel cylinders. The large volume requirement of CNG would generally require CNG storage to be provided in the hull at the design stage. Future CNG storage tanks may be non-cylindrical [23].

An advantage of CNG is that CNG cylinders can be slow charged from the gas mains using a small compressor. Other charging options include fast charge from a pressurised holding tank and fast charge from an LNG supply. Full cylinder packs can also be transported and exchanged for empty cylinders.

2.1.5 Liquid Petroleum Gas

Liquefied Petroleum Gas (LPG) is the generic name for mixtures of hydrocarbons (mainly propane and butane). When these mixtures are lightly compressed and cooled (approx. 8 bar or 120 psi), they change from a gaseous state to a liquid. LPG is colourless, odourless and heavier than air. A sulphur based chemical (ethyl mercaptan) is added to give it a smell like rotten cabbage, so that even a very small leak can be easily detected. LPG has a lower carbon to hydrogen ratio than diesel fuel. This can lead to reduced greenhouse gas emissions if thermal efficiency is similar.

LPG occurs naturally in crude oil and natural gas production fields and is also produced in the oil refining process. Australia has five sources of naturally occurring LPG. Refinery production is from seven refineries. Australia produces currently about 3,300 kt of LPG annually. Of these volumes, 80% is naturally occurring (i.e. extracted from oil and gas production) and 20% is extracted from crude oil in the refining process. Australia's production of LPG is projected to grow to 5,024 kt by 2020.

LPG can be used in dual fuel diesel engines, giving reduced NOx and smoke. The best quality LPG (HD5) is composed primarily of propane [11]. Propane is more prone to cause knocking in diesel engines than methane, so diesel substitution rates with LPG (around 15%) are much lower than for natural gas. Autogas contains heavier hydrocarbons as well as propane, and these heavier hydrocarbons are more likely to cause diesel knock than propane, so HD5 is recommended for diesel engines.

HD5 LPG has an energy density of about 23 MJ/litre or 64% that of diesel. Storage of LPG is easier than natural gas. LPG tanks are well developed for the automotive market. Storage pressures are up to 20 bar.

LPG is heavier than air and can accumulate in the hull. On a vessel, it may be necessary to fully enclose tanks, valves and lines, with forced ventilation of the enclosures.

LPG may not compete cost wise with excise free diesel. There is currently no excise, but it will ramp up to 12.5c/litre. LPG pricing is tied to the oil price. HD5 is 1 to 2 cents per litre more expensive than Autogas.

2.1.5.1 Dual fuel engines

As with natural gas, dual fuel operation of a diesel engine can be achieved by mixing LPG gas with the engine intake air, as with natural gas.

Diesel substitution rates are low (15%) if the diesel injection system is uncontrolled when the engine is converted to dual fuel (“torque topping”). Torque topping systems can lead to excessive engine temperatures. To achieve greater diesel fuel substitution rates, it is necessary to override the normal diesel injection rate control system. For example, the Isense system claims to achieve 30 to 50% substitution, using engine mapping and diesel injection control. Numerous conversion systems are available on the market. Their reliability needs to be assessed.

2.1.5.2 Gas only engines

The Australian Greenhouse Office granted $600,000 to BP and IMPCO to develop an LPG single fuel engine for heavy vehicles. Cummins Westport sell a 195 hp, 5.9 litre, LPG lean burn premixed spark ignition engine, with compression ratio 9.1:1 ("B LPG Plus")

"Was Diesel Now Gas" convert diesels to premixed spark ignition engines operating on LPG. Such conversions can result in reduced fuel efficiency due to reduced compression ratio and throttling, so greenhouse gains may be marginal.

2.1.6 Hydrogen

Hydrogen is a useful medium for storage and transport of energy. Hydrogen gas (H_2) exists only in very small quantities in the natural world. It has to be generated by the application of energy, which will only be partially returned when the hydrogen gas is eventually used. One presumes therefore that the manufacture, storage, distribution and consumption of hydrogen gas represents a far better proposition than delivering battery held energy.

A key advantage of hydrogen is greatly reduced exhaust emissions at the point of usage. It also has potential as a long term sustainable mobile fuel source.

Hydrogen can be produced by electrolysis of water using electricity produced from renewable sources such as wind, to yield a significant greenhouse benefit if the hydrogen is used as a fuel instead of fossil fuels. It should be noted that the electricity that is produced renewably might better be used to substitute for electricity being produced from fossil fuels, if reduction in greenhouse gas emissions is the main goal. Most hydrogen is produced from natural gas (steam reforming) or coal (gasification), releasing CO_2 [11, 36]. Unless the CO_2 produced is captured and sequestered, there is no greenhouse benefit from converting natural gas to hydrogen rather than using natural gas directly as an engine fuel.

Hydrogen can be produced from biomass and algae [36].

Hydrogen cannot be used readily in dual fuel mode heavy duty diesel engines, due to problems with backfire and knock [37]. This is partly due to the wide flammability limits of hydrogen. Very fuel lean mixtures in air will ignite and it has a low ignition energy requirement [30]. Direct injection spark ignited hydrogen engines are under development [32, 38]. Hydrogen lends itself best to fuel cells, which produce electricity directly from the hydrogen and emit virtually no emissions. Theoretically, fuel cell efficiencies can be higher than the efficiencies of the best engines. However, fuel cells are relatively heavy and expensive [11]. Hydrogen fuel cell technology and storage technology are the subject of intense development efforts. An example of the state of play is the Honda FCX fuel cell vehicle, scheduled for production in three to four years [39]. Numerous fuel cell powered buses are in operation around the world.

Hydrogen is light and will dissipate rapidly if leaks occur. It is stored as compressed gas, typically at around 700bar or as a liquid at - 253°C. It can also be stored by use of metal hydrides, whereby the hydrogen combines with metals in a tank to form hydrides, and is later released for use by heating the hydrides. Hydrogen has an energy content per unit mass 2.8 times higher than diesel, but the energy density of liquid hydrogen is approximately the same as that of CNG. Thus, liquid hydrogen will require at least 5 times the storage volume of diesel fuel for the same vessel range, if the conversion efficiency of the hydrogen engine/fuel cell is similar to a diesel engine. Compressed hydrogen energy density is still lower. Liquefaction of hydrogen requires around 30% of the energy content of the hydrogen [23].

2.1.7 Marine Gas Oil and Marine Diesel Oil

Marine Gas Oil (MGO or Distillate DMA) and Marine Diesel oil are diesel fuels that are more viscous than standard diesel fuel but still much lighter than heavy fuel oil. They are typically used in medium-speed diesel engines [40]. The main issue with their use in high-speed engines is ignition quality (low cetane number). That is, these fuels do not ignite in the cylinder as readily as standard diesel fuel, and so could lead to rough running, high exhaust temperature and possibly engine damage. The use of ignition enhancing additives could possibly overcome this problem. The cost of such additives would be a factor in potential cost savings. However, the price of MGO/MDO can be substantially less than standard diesel fuel, so there is a significant margin to work with. A further option would be to dilute MGO/MDO with standard diesel. Fuel heating might be necessary to maintain low enough viscosity for good atomisation in the engine.

The sulphur content of MGO/MDO is higher than standard diesel, but low sulphur forms are also available. Sulphur in the fuel can lead to low temperature corrosion problems in the exhaust system, increased particulate emissions and acid rain. Greenhouse gas emissions would be marginally higher than standard diesel due to higher carbon to hydrogen ratio. Low temperature corrosion can be alleviated by maintaining the exhaust gases above a certain minimum temperature, called the acid dewpoint. The lower the sulphur content, the lower the acid dewpoint.

Engines which operate at steady loads for long periods of time, such as those used on fishing vessels, are more tolerant of poorer quality fuel. Engines with electronically controlled injection systems may also be more tolerant of reduced ignition quality fuel due to the use of sequential fuel injection, an injection process whereby a small amount of fuel is injected prior to the main injection. This reduces the significance of the small time delay required for the fuel to ignite after the start of injection.

2.1.8 Other fuels

The carbon to hydrogen ratio of natural gas can be reduced by mixing in hydrogen (HCNG), giving reduced greenhouse gas emissions. The mixture can then be handled and utilised in much the same way as CNG. Thus, HCNG allows some of the advantages of hydrogen, but with fewer problems. HCNG offers intermediate solution between CNG and $H_{2.}$ HCNG volumetric energy density is better than compressed $H_{2.}$

Hydrogen alone is more knock prone than propane and prone to backfire because of high flame speeds and wide flammability limits.

The use of 20% H_2 in CNG in engines is proven [41].

HCNG allows more fuel lean operation than natural gas, thus giving better engine efficiency.

Heavy Fuel oil is much cheaper than standard diesel fuel and MGO, but cannot be used in high speed diesel engines. To use heavy fuel oil, vessels would need to be much larger to enable the use of medium speed diesel engines.

2.2 Alternative energy

The common problem with renewable energy sources is that the energy density (power production) is very low. Their advantage though is that the actual energy source is free and generally continuously available. To use energy at higher intensity, when it is required, the low density energy must be accumulated – usually in batteries. A large accumulation of energy that would allow high power applications over a reasonable time frame (e.g. trawling for 10 hours) would require a large volume of very heavy and expensive batteries. Alternatively, the energy could be stored in a pressure cylinder as Hydrogen gas. Hydrogen could represent a common storage medium for a range of energy traps (solar, wind power, wave power, waste heat recovery etc). This multi-faceted energy accumulator could function while the vessel is idle as well as at sea, thus quietly accumulating energy for the next fishing trip while ever the driving forces are active.

Hydrogen can then supplement the fuel usage of a diesel engine to a varying extent depending on the amount that has been successfully stored.

An alternative form of energy storage is the use of flywheels or gyros. This is particularly relevant due to the possibilities that arise in association with the use of Sea Gyro for motion stabilisation (see Review-Part B Section 2.2). That is, Sea Gyro could be used as an energy storage bank, where the energy is used at a time when it is most beneficial. This might be to overcome peak demand or alternatively extend the period where a fishing boat can meet low level energy demands from stored energy rather than operate high capacity power generation equipment at low efficiency. The use of hydrogen in this context would be to run an efficient fuel cell that can meet energy demands during low power phases of the fishing operation.

2.2.1 Solar power

For a trawler using 150kW, a 2% contribution to the power requires 22 sq m of solar panels. Unless a quantum leap in solar cell efficiency is imminent, there would need to be a radical redesign of fishing vessels in order to incorporate the required unshadowed and unused deck space.

It is apparent that even if the general idea of using solar collectors is to capture and store the low level energy over a period of time so that it could be used more intensely at some later time, the installation would be better off located on-shore and transfer the produced hydrogen to the ship as fuel stores. It would be far cheaper, due to economies of scale, to have a centralised hydrogen production plant based on solar energy rather than attempt an on board unit – unless the energy intensity of fishing was vastly reduced and there was a need to be semi-self sufficient for energy.

One novel way of providing the area required to install a unit having a significant output would be to devise a kite (see the next section) made of light-weight solar panels. The extra weight of the kite would increase the threshold wind speed, and the kite cable would have to transmit the generated power back to the fishing boat, but that is a problem readily solved by applying technology developed for power umbilicals of Remotely Operated underwater Vehicles.

2.2.2 Wind power

2.2.2.1 Propulsion

Wind energy has played an important role in fishing in many parts of the world for many centuries. However for contemporary fisheries in Australia it plays a very minor role. As outlined previously the energy intensity of modern fishing has become very high, due to the availability of cheap convenient fuel for many years. Sail systems for harnessing wind energy for propulsion have become very developed and are very efficient. In fishing application where sailing technology is appropriate, such systems can be adopted readily. Critical issues are mean wind speeds, wind angles, and transverse stability of the fishing vessel. Limit of practical sail size is maybe 30 sq m, which would give about 1000N thrust, which would be a contribution of 6% to the required power; when the wind blows. Traditional type rigs may be useful for fishing that involves a lot of travelling time, but would still be hard to compete against efficient hull; driven sensibly by an efficient diesel engine. Sail rigs aren't cheap to build, operate and maintain.

The kite as a wind propulsion device has under gone some substantial development in recent times. They require new skills for the operator, but they have the advantage of having a wide wind range, lower heeling moments, and are positioned quite a distance above the sea surface, where the wind is stronger and more steady [42].

Note that there are roll stabilisation benefits to sail assisted propulsion, which may provide further fuel savings (see Review-Part B Section 2.2).

2.2.2.2 Trawling

Wind assist while a vessel is trawling would only be practical with traditional sail technology while the wind was generally coming from astern. For typical sails and with the wind on the beam sufficient resistance to the generated side forces would be practically impossible at slow speed (while trawling), as it would require a very large keel area. For vertical axis wind turbines the side force produced would be much lower, for a given amount of useful power extracted from the wind.

2.2.2.3 Electrical Power

Using wind for the generation of electrical power is a different matter. Once again the economies of scale overwhelmingly dictate that units for the generation of power would be better sited on-shore along with a robust and efficient method for storing the energy and allowing it to be transferred to the fishing boat for later use. Small scale units for onboard use would only be viable for special circumstances – possibly for periods where the demand was quite low and the availability of wind power would allow large capacity (diesel powered) generators to be shut down. For energy capture, vertical axis wind turbines (VAWTs) are relatively simple and compact, and are not sensitive to the direction of the wind. The concept is about 100 years old, with a few companies marketing them e.g. Windside. Consider their model WS-2. Height 3m, diameter 1m, output 50W in 12 knots wind, 100W in 16kn wind, 200W in 20kn wind [43]. If the threshold of useful benefit is 1% of shaft power i.e. 1.5kW, then this would be achieved in 16kn wind speed by fitting 15 VAWTS units. An innovative NZ wind turbine is presented on the web [44], but there is no technical evaluation of its performance.

2.2.3 Wave power

Technologies in this area are developing mainly from the perspective of land based energy demand and has lead predominately to ideas based on large fixed structures. In fishing there is an intimate interaction with ocean waves. Energy from the ocean waves is continuously being transferred to fishing vessels causing undesirable motion of the boat (roll, pitch, heave and surge). The violence of the motions induced is dependent on the dynamic characteristics of the vessel, particularly the ability of the vessel to dissipate the transferred energy (dampen the resulting motion). The damping capacity of fishing vessels is often enhanced by the deployment of devices designed to dissipate energy that is drawn from the kinetic energy of the unwanted motions; usually with the penalty of adding extra resistance to the forward motion of the vessel and adding an undesirable load on the propulsions system. From an efficiency point of view it is desirable to organise an arrangement to dissipate energy from the unwanted vessel motions without adding extra resistance, and ideally have a system that can continually capture the transmitted wave energy and store it for later use; rather than have that energy wastefully dissipated. The amount of energy being considered though is very small compared to the energy intensity of current fishing practices.

For example, a vertical axis wind turbine would extract energy from a rolling vessel and from the wind at the same time. Devices at large distances from the centre of gravity (bow and stern, at the end of trawl arms, at the top of masts) move a long way and at high speed during waves induced vessel motions. This allows the opportunity to generate and capture significant amounts of energy over time; therefore damping the motions for no cost - in fact a net gain.

3 Engines

3.1 Introduction

By far the most convenient engine for the propulsion of fishing boats to date has been the compression ignition engine designed to be fuelled by diesel. They have suited fishing for a variety of reasons:

- the engine is relatively simple, robust, reliable and efficient
- diesel fuel is safe to use, has a high energy density and of a consistent high standard
- engines and fuel have been readily available, cheap to procure and backed up by good service.

The objective of this section is to explore the prospect for adopting improved engines and achieving higher engine efficiency. For this we need to look at:

- engine design
    - optimal chemical, mechanical and thermodynamic function
- optimal matching of engine with the primary load
- the connection of auxiliary loads and equipment to increase the utilisation of the fuel used.

This objective connects to a massive number of questions and issues that have been the subject area for a large developmental effort over many years. Similar to the previous chapter on fuels it is only possible for this project to scan the surface of the subject area and hope to detect most of the relevant issues and correctly determine their significance.

3.2 Efficient design

Diesel engine technology has become highly developed to match demands for reduced exhaust emissions and reduced fuel consumption. Diesel engines have made a comeback in the automotive world. Common rail, electronically controlled fuel injection and exhaust gas after-treatment are the two main areas of development that allow diesel engines to meet the strict emissions legislation requirements for on-road vehicles, such as Euro4.

There are three main classes of diesel engine: slow speed, medium speed and high speed. The slow speed engines operate at around 100rpm, are the biggest and most fuel efficient (up to

55%, compared with around 40% for high speed diesels). They operate on the 2-stroke cycle. Medium and high speed engines are now almost exclusively 4 stroke, as this gives the greatest fuel efficiency for these engines. The large slow speed propulsion engines, because of their size and slow rotational speed, are well suited to the 2 stroke cycle, primarily because there is ample time available within the working cycle for efficient scavenging of the burnt gases from the cylinder, without the need for an exhaust and intake stroke.

Fuel efficiency is often measured as specific fuel consumption (sfc), which is the fuel flow rate per unit of power. Manufacturer data indicates that modern high speed diesels generally achieve around 210 g/(kWh) at full load.

The plot shown in Figure 7 of sfc data from the Baird electronic data base of engines sold between 1982 and 1999 [45] displays improved efficiency for slower revving engines (medium speed and slow speed diesel engines). The data indicates that a considerable number of high speed engines (> 1000rpm) are reported to have a sfc at less than 200 g/(kwh). This is somewhat lower than that which can be found for popular modern engines. It is possible that modern engines suffer a little loss in efficiency in order to have a high power to weight ratio, which is important for lowering the cost of manufacture and is an important positive characteristic for engines fitted in planning craft. It is also possible that some of the Baird data is inaccurate.

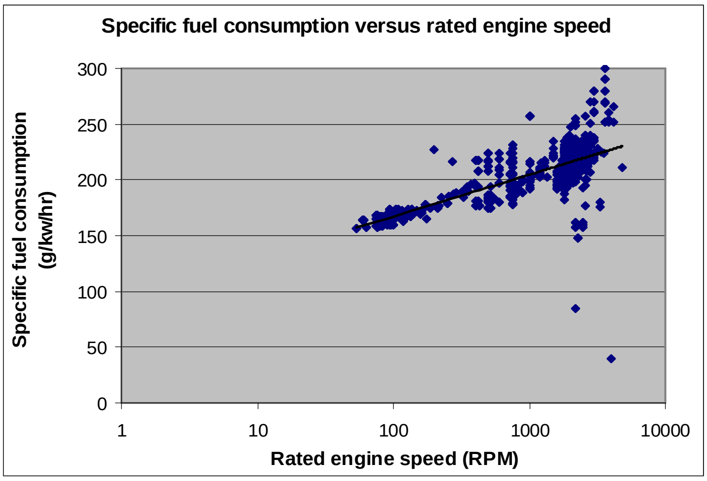


Figure 7. Engine efficiency as depicted by specific fuel consumption data plotted against rated engine speed (plotted from data given in [45])

Fishing vessels in the Australian fleet primarily use high speed diesel engines, rated at around 1800 to 2000 rpm. It could be feasible that larger fishing vessels could use medium speed engines that are more efficient.

The sfc data plotted against engine power in Figure 8 shows improved efficiency for larger engine power. This indicates quite clearly that the efficient high speed diesels identified in Figure 7 (having sfc < 200 g/kwh) are generally of higher power capacity and operate at the lower end of the high-speed range. For typical fishing engines (100 – 500kW) a specific fuel consumption of 200g/(kWh) seems to be best practice (The outliers in this power output range that have sfc of around 150g/(kWh) were checked against published specification sheets and found to be erroneous due to incorrect conversion of non SI units).

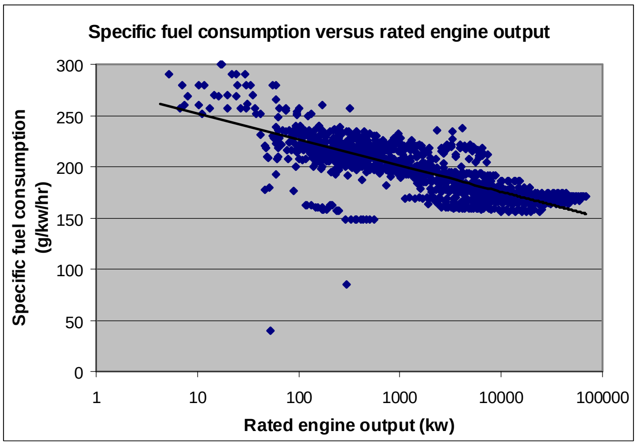


Figure 8. Engine efficiency as depicted by specific fuel consumption data plotted against rated engine output (plotted from data given in [45])

3.2.1 Medium Speed Engines

Medium speed engines offer better fuel efficiency but are too large for most current fishing vessels. The greater fuel efficiency primarily arises from increased cylinder size and lower rotational speed.

Due to the slower rotational speed, many medium speed engines can operate on heavy fuel oil, which costs considerably less than the higher quality diesel fuel needed for high speed engines. The slower speed allows more time for ignition of the poorer quality fuel. Indicative rated engine speeds are in the range of 400 rpm to 1000rpm, and rated power outputs are around 1,000 kW to 15,000 kW. Generally the largest engines have the lowest rotational speeds. Makers include MAN B&W, Wartsila, ABC and MaK. A smaller 3 cylinder medium speed engine by ABC (3 DXS - 44.15 litres) is rated at 720 rpm to provide 236 kW. It has a sfc of 200 g/(kWh) and weighs 6.9 tonnes. This represents about 8% fuel efficiency improvement over the popular Cummins NT885 (14 litres), rated 224 kW at 1800 rpm; but the ABC engine is 500% heavier. Appendix C provides the specification details for this extraordinary engine by Australian fishing standards.

3.3 Exhaust emissions

Emissions of oxides of nitrogen (NOx) from marine diesel engines are recognised as a significant source of atmospheric pollution globally. They contribute to photochemical smog, acid rain, eutrophication of the ecosystem and global warming. All new engines installed in ships and boats should meet NOx limits defined by MARPOL Annex VI. These restrictions are not particularly severe compared with those for diesel engines on land, such as the European or US EPA requirements. Further restrictions are in train.

Other emissions of concern from marine transport are oxides of sulphur (SOx), which contribute to acid rain. The primary control for SOx emissions is reduction of fuel sulphur content. Generally, the heavier and cheaper fuels have higher sulphur content.

Greenhouse gas emissions from shipping are comprised mainly of carbon dioxide (CO_2), with some contribution from refrigerant gases (HFC), methane (CH_4) and nitrous oxide (N_2O). NOx emissions also have a role in global warming. The primary means of controlling CO_2 emissions are reduced fuel consumption, the use of fuels with lower carbon to hydrogen ratio and the use of renewable fuels (biofuels, hydrogen).

3.4 Electronic engines

Electronically controlled high speed marine diesel engines with common rail or similar injection technology can achieve the current MARPOL NOx limits and maintain good fuel efficiency. These engines offer some fuel efficiency improvements over modern mechanically governed engines, plus reduced emissions and reduced noise. Other possible advantages are better tolerance of variable fuel quality and better matching of fuel efficiency characteristics to demand. Fundamentally, full injection pressure and thus good atomisation and mixing can be maintained down to low engine speeds. Further, multiple injections can be used to improve combustion and reduce emissions.

3.5 Optimum operating condition

For a given engine, fuel consumption depends on engine speed and load. Fishing vessel engines are subject to a range of demands due to the need to steam to a fishing ground at speed, perhaps tow a trawl at low speed and power the vessel through varying seas and winds. Minimum specific fuel consumption occurs at intermediate loads and speeds, as illustrated in the engine efficiency map (Figure 9), derived from manufacturer fuel consumption rate data. Different engines have different characteristics. Indications are that modern electronic engines may have the region of maximum efficiency closer to the maximum power conditions.

Variation in efficiency for a given engine may be about 15% across plausible operating conditions.

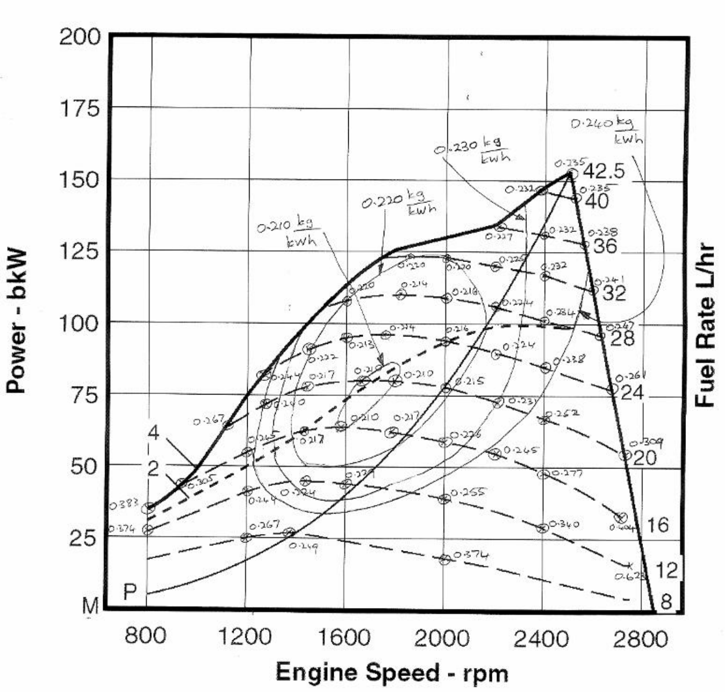


Figure 9. Performance and efficiency map for a typical high speed diesel engine

The size and pitch of the propeller determines the speed at which the engine operates for a given propulsion demand. Good matching of the propeller to the engine can improve fuel efficiency. Use of controllable pitch propellers, variable speed gearboxes or electric drives could potentially reduce fuel consumption by allowing the engine to operate more closely to its minimum fuel consumption conditions for more of the time. Modern electric generator and control technology may allow significant fuel efficiency gains.

The use of an electrical generator driven by the engine, with an electric motor driving the propeller, increases drive train losses due to limited generator and electric motor efficiency. However, by continuously adjusting the engine to operate closely to the minimum fuel consumption condition, and with a generator and electric motor that have good efficiency over a range of operating conditions, there could be a net gain in fuel efficiency [46].

3.6 Waste energy recovery

Of the chemical energy supplied to an engine in the fuel, around 60% is not converted to useful work. The unconverted energy is expelled mainly in the exhaust gases and engine cooling water. For a typical 300kW 11 litre modern marine diesel engine with a water cooled aftercooler and water cooled exhaust turbine, approximately 40% of the fuel energy is delivered as useful power, 20% is expelled in the exhaust and 36% is expelled in the cooling water. The remaining is lost as radiation and noise and vibration. The turbocharger extracts 8% of the fuel energy from the waste in the exhaust, some of which appears in the useful power and the rest is lost through heat transfer.

3.6.1 Exhaust turbine

Electric turbocompound technology can recover some of the waste energy in the exhaust by the use of an efficient exhaust gas turbine, which drives an electrical generator. The electrical power produced could be used for electrical power requirements on board, or as a contribution to the propulsive power. The amount of exhaust energy that can be recovered by this method is limited by the available difference in pressure between the engine exhaust and the atmosphere. The efficiency of turbocharging systems has improved significantly, so not all the available pressure drop in the exhaust system needs to be used for the task of pressurising the engine air supply. An extra turbine after the turbocharger, or a larger than normal turbine in the turbocharger, can convert more of the waste energy in the exhaust into useful work, driving an electrical generator. The electrical energy can be used to drive an electric motor, which contributes, to the propulsive power. Similar systems are in use in large ship propulsion engines. The useful work recovered may be applied directly to the engine shaft, without the use of an electrical, generator-motor coupling.

Turbocompounding systems are under development by Caterpillar, Cummins and John Deere and Volvo [47]. Caterpillar [48] estimates that up to 5% fuel savings are possible.

3.6.2 Rankine cycle

Energy recovery potential also exists in systems that do not rely on a pressure drop to convert the waste internal energy in the exhaust gases. Using the hot exhaust as the energy supply for a heat engine cycle has significant potential. Large ships have for many years used a steam power cycle driven from the waste energy in the exhaust to supply much of the ship’s electrical power requirements. This effectively places two heat engine cycles in series, a diesel engine and a Rankine (steam) cycle; this produces what is referred to as a Combined Cycle Power Plant. The use of working fluids other than steam can allow recovery of waste energy, which exists at lower temperatures, such as in the engine cooling water.

As an example, BMW were developing a steam hybrid vehicle, which uses waste heat in the exhaust to produce steam which drives a steam turbine connected to the drive shaft of an automotive engine [49]. In addition, a lower temperature vapour cycle, using ethanol as the working fluid, recovers waste heat from the engine cooling water. In the same manner as the steam cycle, ethanol is vaporised under pressure in a heat exchanger and the vapour used to drive a turbine connected to the drive shaft. It is stated [49] that 15% fuel savings are possible for an automotive engine. It may be that the savings from a turbocharged diesel engine will be less due to some of the exhaust energy being consumed in driving the turbocharger.

Exergy analysis can be used to show the maximum possible thermal efficiency improvements that can be achieved by waste heat recovery. The savings are dependent on the waste stream temperature and the amount of energy that is rejected in the exhaust and cooling water. These in turn are related to the unimproved thermal efficiency. That is, an inefficient engine will have a high exhaust temperature and reject a larger proportion of the fuel energy in the exhaust and thus allow greater potential for thermal efficiency improvement by waste heat recovery. It is preferable to improve the primary energy conversion efficiency of the engine, rather than relying on recovery of waste energy. However, it is well established that the use of waste energy recovery systems can yield significant fuel savings. A further practical limitation on the amount of energy that can be recovered is the temperature to which the waste streams can be cooled. To maintain useful heat transfer rates a temperature gradient must be maintained in the heat exchangers, so the final temperature of the gas or cooling water must ultimately be greater than the seawater temperature. Table 5 illustrates typical upper limits to efficiency gains from waste heat recovery systems. The useful work that can be recovered from the cooling system is substantially less than the exhaust system due to the low temperature at which the energy exists. Real heat recovery systems will achieve substantially less than the ideal maximum.

Table 5. Exergy analysis for upper limit to waste heat recovery, with seawater temperature at 30°C, 30% of the fuel energy in the waste stream and original thermal efficiency 40%

waste stream temperature °C	final temperature °C	maximum conversion efficiency (% of energy in waste stream) by exergy analysis	thermal efficiency (%) improvement	% thermal efficiency improvement
700 (exhaust gas)	100	52.1	16	40%
500 (exhaust gas)	100	45.4	14	35%
400 (exhaust gas)	100	41.0	12	30%
100 (cooling water)	50	13.6	4	10%

An exhaust gas temperature of 700°C is a high value and would represent an inefficient engine or a naturally aspirated engine.

3.6.3 Direct heating

Rather than recovering waste exhaust energy for propulsive or electrical power, it can be used for direct heating tasks on-board, by the use of suitable heat exchangers and heat transfer fluids. This is also common practice on large ships. Uses for such heat on fishing boats could be cooking seafood, domestic hot water and absorption refrigeration. The potential exists to use a significant amount of free energy, but it involves the provision of bulky hardware and new processes and a need to holistically manage all processes occurring in the fishing operation.

3.6.4 Thermoelectric

Solid state thermoelectric devices are under development to recover waste energy in the exhaust and convert it directly to electricity. Current conversion efficiencies are around 5%, with longer term potential for increase to 20% [50]. Conversion of 20% of the waste heat in the exhaust into useful power at the drive shaft represents fuel savings of about 10% for an engine of 40% thermal efficiency which expels 20% of the fuel energy in the exhaust.

3.6.5 Higher operating temperature

Many applications of diesel engines in fishing boats utilise keel cooling and recirculating fresh water (with minimal additives – mainly anti-corrosion) to keep engines at the desired operating temperature. This type of cooling circuits is not pressurized (operate to atmospheric pressure (1bar) – no radiator cap) which means that any “high temperature incident” can result in the cooling water boiling inside the engine. The resulting volume increase causes cooling water in large quantities to be expelled from the cooling circuit and the cooling capability of the system to become very low. To lower the risk of boiling the cooling water, the operating temperature of the motor is set with a reasonable margin of safety. This is achieved by using low temperature thermostats e.g. 71°C. Higher temperature thermostats are often available for the engines (e.g. 83°C or 95°C), thus demonstrating that the motors themselves can be safely operated at higher temperature. To avoid boiling the cooling water the cooling circuit is usually pressurised as determined by a “radiator cap” which acts as a relief valve and sets the maximum possible pressure. At this elevated pressure the boiling temperature of the cooling water is elevated, thus providing the temperature safety margin required for operating the engine at higher temperature (for example at a pressure of 1.4bar the boiling point of water is 110°C).

It is supposed that as the operating temperature of the engine is increased the efficiency of the engine is improved because of the reduced thermal gradient between the combustion chamber and the cooling circuit reduces the waste heat flowing from the combustion process, thus allowing more energy to be converted to useful work (to turn the propeller etc). Elevated cooling water pressure apparently is not a good idea for keeled cooled motors because of the risk of rupturing the extensive circuit is high because of its inherently low internal pressure strength and elevated thermal expansion issues. The use of inboard heat exchangers instead of keel cooling gives rise to a much smaller primary engine cooling circuit. This reduces the scale of the problem of providing a circuit that can withstand elevated pressure and temperature and lowers the cost of effectively using expensive additives to the cooling fluid for boiling point elevation, anti corrosion etc.

Another possibility is that the elevated temperature of the primary cooling circuit may lend itself more favourably to waste heat utilization and the removal of keel pipes will reduce drag on the hull.

3.7 Gas injection

There are a number of devices on overseas markets (Canada and USA) that electrolyse water using engine generated electricity to produce a gaseous mixture of hydrogen and oxygen (e.g. [51]). This gas is fed immediately into the engine for combustion along with the normal fuel. There are claims of significant decreases in fuel consumption due to substantially improved overall efficiency. The energy required to produce the hydrogen/oxygen gas mix will be greater than the energy returned from the combustion of the gas in the engine. The energy for the electrolysis has to be provided by the engine alternator, which is not 100% efficient. The electrolysis process also wastes energy. The possible benefit of such systems would be in the ability of the added hydrogen/oxygen mix to improve the combustion efficiency of the normal fuel, leading to more rapid and possibly more complete combustion. These systems would need to be rigorously studied on diesel engines at operating conditions representative of fishing vessel practice before any firm conclusions as to their value could be reached.

Similar claims are made for devices that inject small amounts of LPG into the combustion process [52]. No reports of improved efficiency are made by the developers of dual fuelled engines, which tend to erode the credibility of the claims. However dedicated dual fuel engines are designed for the maximum substitution (about 35%) while the web reference claims that the minimum overall fuel consumption occurs when only 5% - 10% substitution occurs. The disadvantage of using LPG is that LPG tanks are required, as opposed to hydrogen systems where the gas can be manufactured as required by electrolysis, thus removing the necessity of installing storage tanks and compression units.

Given that claims are made about the beneficial effect of introducing small amount of LPG and Hydrogen into the air intake stream, it is presumable that such claims could also be made about the use of Natural Gas. Assessing the affect of these three fuels at small substitution rates on the thermodynamic efficiency of diesel engines would be a straight-forward exercise for a well equipped thermodynamics research lab.

3.8 Stirling cycle

The Stirling cycle is a heat engine cycle that theoretically offers greater fuel efficiency than the diesel engine, which essentially operates on the Otto cycle. The technology of the diesel engine is highly developed and there is probably no Stirling engine available that can match diesel engine fuel efficiency, reliability and power.

Another application of the Stirling cycle might be the utilisation of waste heat, therefore producing a combined cycle power plant. Such application of Stirling engines might be better matched to gas turbines rather than IC engines because existing Stirling engines appear to utilise energy at a higher temperature than the exhaust from IC engines. Lower temperature operation is probably feasible but would likely require a large engine to achieve adequate heat transfer capability.

3.9 High performance lubrication oils

High performance lubricating oils can potentially reduce fuel consumption by reducing engine frictional losses, but no such oils have been demonstrated to achieve significant outcome benefits over oil recommended by manufacturers.

3.10 Fuel additives

A well maintained engine operating on reasonable quality fuel is unlikely to yield significant gains from the use of fuel additives. However, fuel additives could potentially be used to improve the ignition and combustion quality of less expensive fuels.

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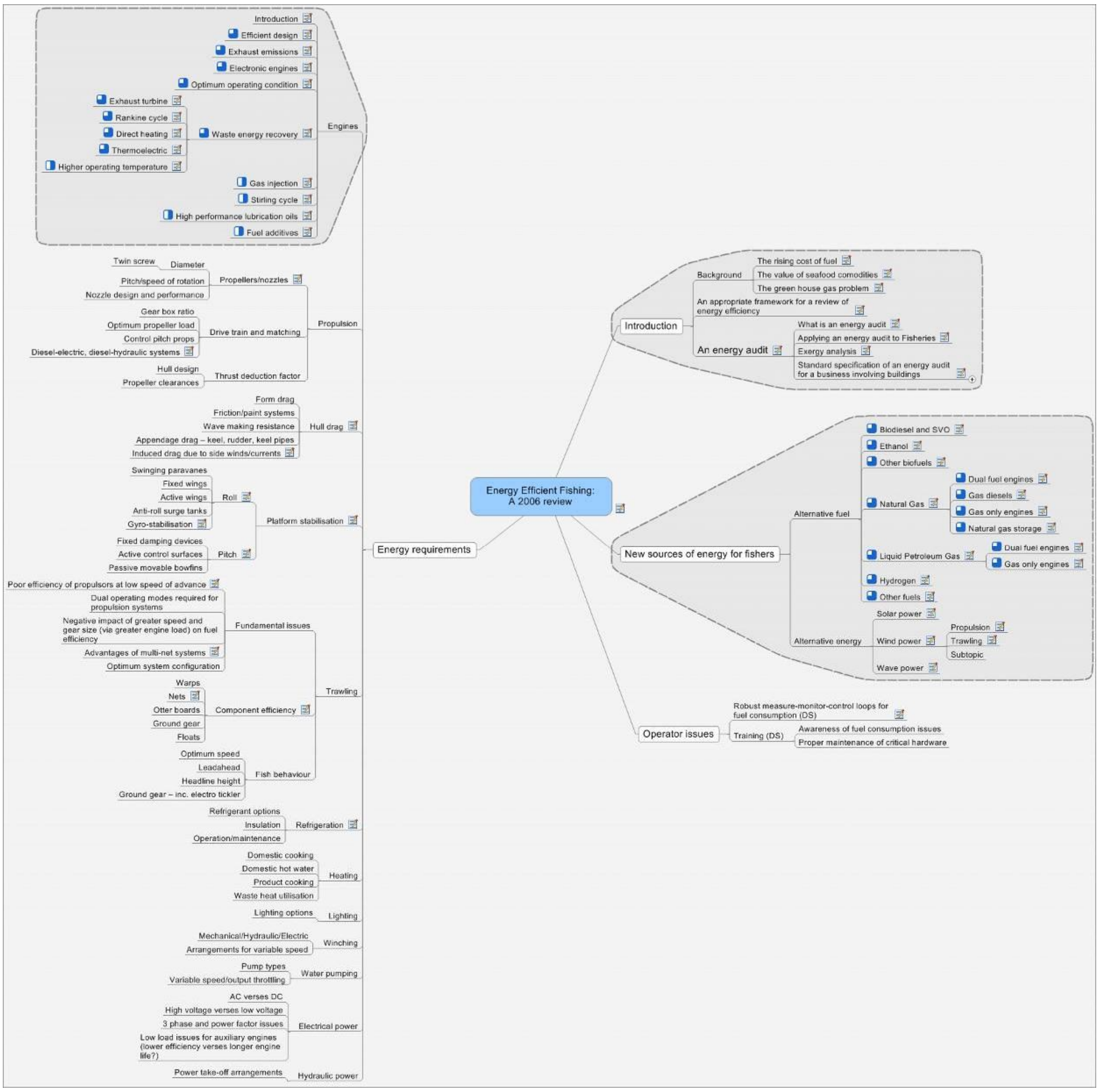
5 Appendix A. Road map for the Energy Efficient Fishing Review



6 Appendix B. Standard specification of an energy audit for a business involving buildings

The following information was found on the Australian Green House website and is consistent with the standard AS/NZS 3598:2000.

Audits have been defined at 3 levels with different levels of achievement being sought for the energy usage problem:

- Walk-through (produce broad internal bench mark, comparison with external bench marks, identify “quick wins”, recommend next step)
- Standard (breakdown energy consumption to components of the enterprise, make recommendations regarding structural changes to enterprise with estimates of costs and payback periods)
- Detailed (produce long term strategies for gains in energy efficiency, improved confidence with setting priorities)

6.1 Level One (Walk-Through) Energy Audit

The minimum requirements for a walk-through audit are:

- Ascertain the following information.

  i) Building construction type and fabric

  ii) Type and configuration of services

  iii) Appropriate unit of production and its quantity (e.g. net letable area for office space, number of students for a school, number of beds for a hospital).

- Determine total consumption of all fuels for the twenty four month period prior to the audit (ascertained from billing data provided by the energy user). If this data is unavailable the auditor shall estimate the consumption(s) based on the installed loads, clearly stating the relevant assumptions in the report.
- Evaluate load profile data, if available.
- Prepare monthly or seasonal energy consumption profiles (i.e. kWh/month, MJ/month), of all fuels for the previous two years (refer example in Appendix A).
- Prepare appropriate energy performance indicators (e.g. kWh/production unit, $/production unit kWh/m2, MJ/m2, $/m2, kWh/student, MJ/student $/student) and compare with industry norms, if available.
- Evaluate the tariff against comparable norms to determine the possibility of savings from alternative tariffs and/or tendered supply arrangements.
- Identify potential for reduction of energy consumption and cost at the site with regard to the above indices, and provide recommendations for further action which may include staff training, capital works, maintenance, substitution of fuels, tariff changes and a higher level energy audit.

Deliverables

A report detailing energy audit findings and recommendations shall be prepared in accordance with this specification and include any findings and recommendations arising from carrying out tasks as described above.

6.2 Level Two (Standard) Energy Audit

The minimum requirements for a Level Two energy audit are:

- Ascertain the following information.
  - i) Building construction type and fabric
  - ii) Type and configuration of services
  - iii) Appropriate unit of production and its quantity (e.g. net lettable area for office space, number of students for a school, number of beds for a hospital).
- Determine total consumption of all fuels for the twenty-four month period prior to the audit (ascertained from billing data provided by the energy user). If these data are unavailable the auditor shall estimate the consumption(s) based on the installed loads, clearly stating the relevant assumptions in the report.
- Evaluate load profile data, if available.
- Prepare monthly or seasonal energy consumption profiles (i.e. kWh/month, MJ/month), of all fuels for the previous two years.
- Prepare appropriate energy performance indicators (e.g. kWh/production unit, $/production unit kWh/m2, MJ/m2, $/m2, kWh/student, MJ/student $/student) and compare with industry norms, if available.
- Evaluate the tariff against comparable norms to determine the possibility of savings from alternative tariffs and/or tendered supply arrangements.
- Identify potential for reduction of energy consumption and cost at the site with regard to the above indices, and provide recommendations for further action which may include staff training, capital works, maintenance, substitution of fuels, tariff changes and a higher level energy audit.
- Meet with the auditors contact on site and carry out an inspection of the audit site observing energy usage patterns, plant and equipment operation and maintenance, and building fabric.
- Prepare energy consumption targets and indicators (e.g. kWh/m2, MJ/m2, kWh/student, MJ/student) of energy end use throughout the audit site (e.g. lighting, HVAC, domestic hot water) which compare actual, predicted, and post audit target levels. Where disaggregated energy consumption data are not available to determine these indicators, estimate the indicators based on observed loads, clearly stating relevant assumptions in the report.
- Provide an itemised list of recommendations to reduce energy consumption and cost. This shall include both capital works and general management options.
- Identification of measures or potential measures for which additional investigation (such as a Detailed Energy Audit) is required, with an explanation as to why such investigation is required, what the benefits will be and what the expected costs are.
- Recommend changes to the energy management program.
- Detail a cost effective program to implement the energy audit recommendations, including a prioritised list of capital works and general management activities.

Level of Detail Required

- Capital works recommendations shall include:
- A clear description of the work program involved in implementing each recommendation;
- Predicted annual energy and cost savings for each recommendation;
- Predicted cost of implementing each recommendation.
- Cost benefits analysis.
- General management options, which would facilitate more efficient energy use should include:
- Provision of energy sub-meters to facilitate ongoing sub-monitoring as both a management tool and to verify savings;
- Changes to maintenance and operating practices;
- Modifications and/or additions to existing plant;
- Alternative fuels;
- Alternative tariff structures;
- Alternative staffing arrangements;
- Staff training and involvement in energy management practices.

Place the recommendations in priority order using simple payback, benefit: cost ratio or other appropriate criterion. Recommendations must be categorised as follows:

- Those easily implemented at little or no cost;
- Those requiring capital expenditure with a payback period of less than 3 years;
- Those requiring capital expenditure with a payback period of 3 years or more.

Deliverables

The following deliverables shall be provided:

- A report detailing survey audit findings and recommendations prepared in accordance with this specification and including any findings and recommendations arising from carrying out tasks as described above.
- A briefing to the key personnel within the site on the results.

6.3 Level Three (Detailed) Energy Audit

This level of audit requires a detailed site inspection accompanied by energy metering and logging. Required items are as follows:

- Ascertain the following information.

i) Building construction type and fabric

ii) Type and configuration of services

iii) Appropriate unit of production and its quantity (e.g. net lettable area for office space, number of students for a school, number of beds for a hospital).

- Determine total consumption of all fuels for the twenty-four month period prior to the audit (ascertained from billing data provided by the energy user). If this data are unavailable the auditor shall estimate the consumption(s) based on the installed loads, clearly stating the relevant assumptions in the report.
- Evaluate load profile data, if available.
- Prepare monthly or seasonal energy consumption profiles (i.e. kWh/month, MJ/month); of all fuels for the previous two years (refer to example in Appendix A).
- Prepare appropriate energy performance indicators (e.g. kWh/production unit, $/production unit kWh/m2, MJ/m2, $/m2, kWh/student, MJ/student $/student) and compare with industry norms, if available.
- Evaluate the tariff against comparable norms to determine the possibility of savings from alternative tariffs and/or tendered supply arrangements.
- Identify potential for reduction of energy consumption and cost at the site with regard to the above indices, and provide recommendations for further action which may include staff training, capital works, maintenance, substitution of fuels, tariff changes and a higher level energy audit.
- Meet with the auditors contact on site and carry out an inspection of the audit site observing energy usage patterns, plant and equipment operation and maintenance, and building fabric.
- Prepare energy consumption targets and indicators (e.g. kWh/m2, MJ/m2, kWh/student, MJ/student) of energy end use throughout the audit site (e.g. lighting, HVAC, domestic hot water) which compare actual, predicted, and post audit target levels. Where disaggregated energy consumption data is not available to determine these indicators, estimate the indicators based on observed loads, clearly stating relevant assumptions in the report.
- Provide an itemised list of recommendations to reduce energy consumption and cost. This shall include both capital works and general management options.
- Identification of measures or potential measures for which additional investigation (such as a Detailed Energy Audit) is required, with an explanation as to why such investigation is required, what the benefits will be and what the expected costs are.
- Recommend changes to the energy management program.
- Detail a cost effective program to implement the energy audit recommendations, including a prioritised list of capital works and general management activities.
- Provide a detailed analysis of the site or process to determine where, when and how energy is used. This should include, but not be limited to; evaluation of the audit site’s building operation and services, plant and equipment operation, control systems, maintenance schedules, hours of operation and analysis of staff working hours, including cleaners. Identify any anomalies between predicted energy use and actual energy use.
- Obtain copies of drawings and other documentation required to fulfil the requirements of this specification. Such documentation shall be returned to the audit site upon completion of the audit.
- Prepare hourly consumption profiles of all fuels used in association with the relevant process(es) over a period of seven days.

- Provide all additional meters, instruments and equipment necessary to meet the intent of the audit and be responsible for their accuracy.

Level of detail required

- Capital works recommendations shall include:
  1. A clear description of the work program involved in implementing each recommendation;
  2. Predicted annual energy and cost savings for each recommendation;
  3. Predicted cost of implementing each recommendation.
  4. Cost benefit analysis.
- General management options, which would facilitate more efficient energy use should include:
- Provision of energy sub-meters to facilitate ongoing sub-monitoring as both a management tool and to verify savings;
- Changes to maintenance and operating practices;
- Modifications and/or additions to existing plant;
- Alternative fuels;
- Alternative tariff structures;
- Alternative staffing arrangements;
- Staff training and involvement in energy management practices.

Recommendations shall be placed in priority order using simple payback, benefit: cost ratio or other appropriate criterion. Recommendations must be categorised as follows:

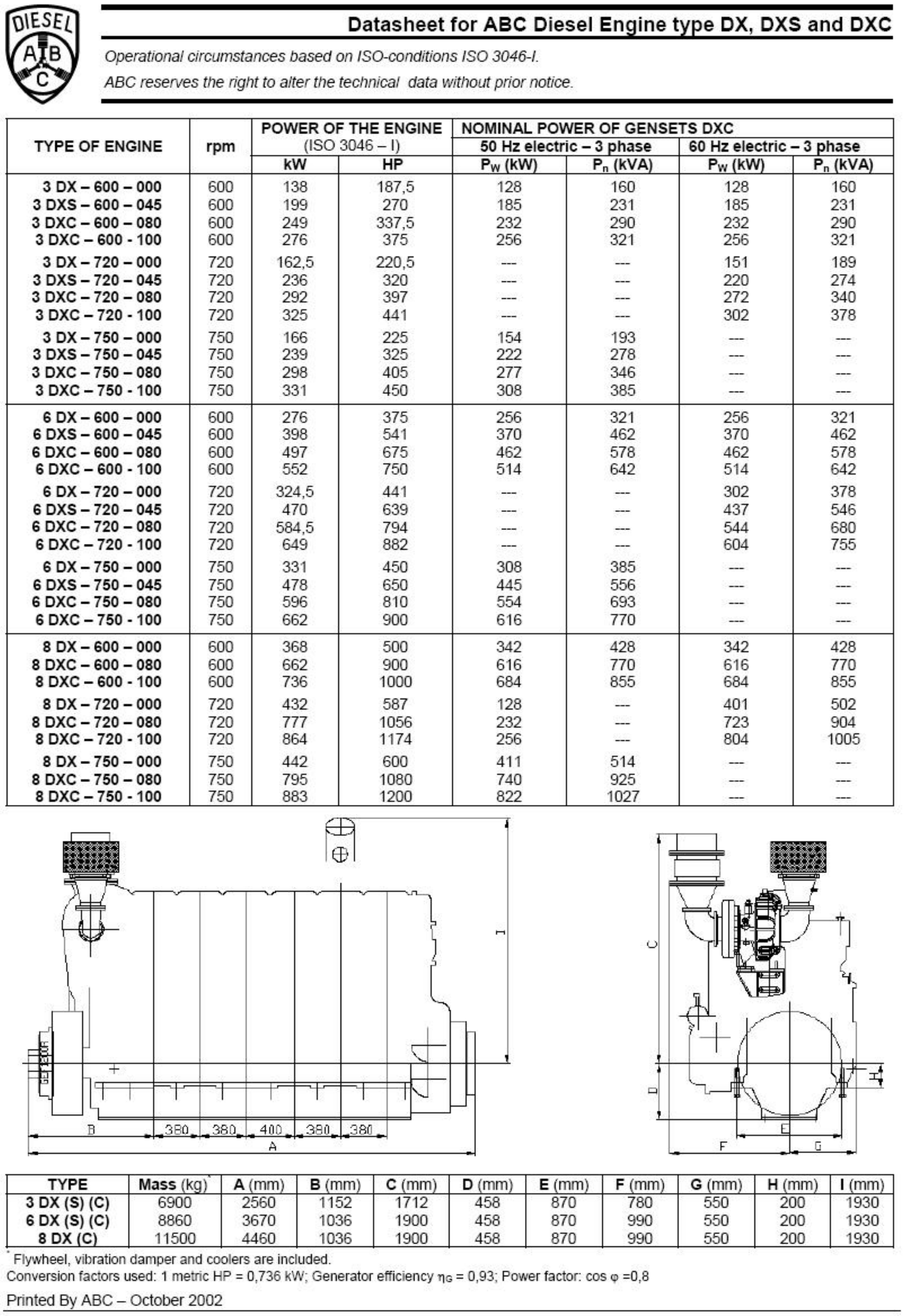
- Those easily implemented at little or no cost;
- Those requiring capital expenditure with a payback period of less than 3 years;
- Those requiring capital expenditure with a payback period of 3 years or more.

Deliverables

The following deliverables shall be provided:

- A report detailing survey audit findings and recommendations prepared in accordance with this specification and including any findings and recommendations arising from carrying out tasks as described above.
- Recommendations shall be defined in sufficient detail to meet normal expectation of preliminary design specification.
- A presentation to the key personnel within the site on the results.

7 Appendix C. Specifications of ABC 3 DXS engine



Datasheet for ABC Diesel Engine type DX, DXS and DXC

Operational circumstances based on ISO-conditions ISO 3046-I.

ABC reserves the right to alter the technical data without prior notice.

TYPE OF ENGINE	rpm	POWER OF THE ENGINE (ISO 3046 – I)		NOMINAL POWER OF GENSETS DXC			
				50 Hz electric – 3 phase		60 Hz electric – 3 phase	
		kW	HP	P_W (kW)	P_n (kVA)	P_W (kW)	P_n (kVA)
3 DX – 600 – 000	600	138	187,5	128	160	128	160
3 DXS – 600 – 045	600	199	270	185	231	185	231
3 DXC – 600 – 080	600	249	337,5	232	290	232	290
3 DXC – 600 - 100	600	276	375	256	321	256	321
3 DX – 720 – 000	720	162,5	220,5	---	---	151	189
3 DXS – 720 – 045	720	236	320	---	---	220	274
3 DXC – 720 – 080	720	292	397	---	---	272	340
3 DXC – 720 - 100	720	325	441	---	---	302	378
3 DX – 750 – 000	750	166	225	154	193	---	---
3 DXS – 750 – 045	750	239	325	222	278	---	---
3 DXC – 750 – 080	750	298	405	277	346	---	---
3 DXC – 750 - 100	750	331	450	308	385	---	---
6 DX – 600 – 000	600	276	375	256	321	256	321
6 DXS – 600 – 045	600	398	541	370	462	370	462
6 DXC – 600 – 080	600	497	675	462	578	462	578
6 DXC – 600 - 100	600	552	750	514	642	514	642
6 DX – 720 – 000	720	324,5	441	---	---	302	378
6 DXS – 720 – 045	720	470	639	---	---	437	546
6 DXC – 720 – 080	720	584,5	794	---	---	544	680
6 DXC – 720 - 100	720	649	882	---	---	604	755
6 DX – 750 – 000	750	331	450	308	385	---	---
6 DXS – 750 – 045	750	478	650	445	556	---	---
6 DXC – 750 – 080	750	596	810	554	693	---	---
6 DXC – 750 - 100	750	662	900	616	770	---	---
8 DX – 600 – 000	600	368	500	342	428	342	428
8 DXC – 600 – 080	600	662	900	616	770	616	770
8 DXC – 600 - 100	600	736	1000	684	855	684	855
8 DX – 720 – 000	720	432	587	128	---	401	502
8 DXC – 720 – 080	720	777	1056	232	---	723	904
8 DXC – 720 - 100	720	864	1174	256	---	804	1005
8 DX – 750 – 000	750	442	600	411	514	---	---
8 DXC – 750 – 080	750	795	1080	740	925	---	---
8 DXC – 750 - 100	750	883	1200	822	1027	---	---

TYPE	**Mass** (kg)*	**A** (mm)	**B** (mm)	**C** (mm)	**D** (mm)	**E** (mm)	**F** (mm)	**G** (mm)	**H** (mm)	**I** (mm)
3 DX (S) (C)	6900	2560	1152	1712	458	870	780	550	200	1930
6 DX (S) (C)	8860	3670	1036	1900	458	870	990	550	200	1930
8 DX (C)	11500	4460	1036	1900	458	870	990	550	200	1930

* Flywheel, vibration damper and coolers are included.

Conversion factors used: 1 metric HP = 0,736 kW; Generator efficiency η_G = 0,93; Power factor: cos φ =0,8

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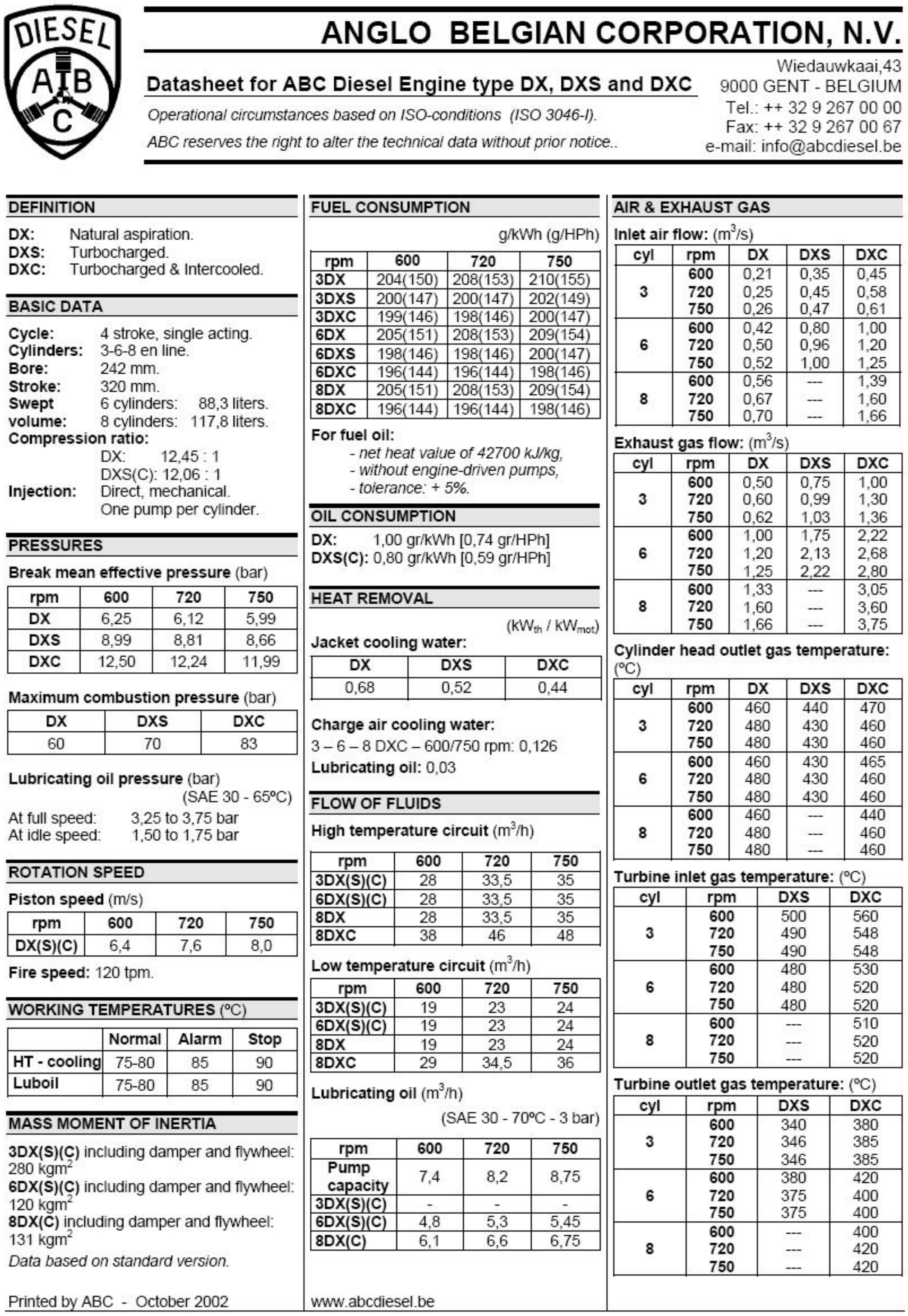

ANGLO BELGIAN CORPORATION, N.V.

Datasheet for ABC Diesel Engine type DX, DXS and DXC

Operational circumstances based on ISO-conditions (ISO 3046-I).

ABC reserves the right to alter the technical data without prior notice..

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e-mail: info@abcdiesel.be

DEFINITION

DX:	Natural aspiration.
DXS:	Turbocharged.
DXC:	Turbocharged & Intercooled.

BASIC DATA

Cycle:	4 stroke, single acting.
Cylinders:	3-6-8 en line.
Bore:	242 mm.
Stroke:	320 mm.
Swept volume:	6 cylinders: 88,3 liters. 8 cylinders: 117,8 liters.
Compression ratio:	DX: 12,45 : 1 DXS(C): 12,06 : 1
Injection:	Direct, mechanical. One pump per cylinder.

PRESSURES

Break mean effective pressure (bar)

rpm	600	720	750
DX	6,25	6,12	5,99
DXS	8,99	8,81	8,66
DXC	12,50	12,24	11,99

Maximum combustion pressure (bar)

DX	DXS	DXC
60	70	83

Lubricating oil pressure (bar)
(SAE 30 - 65ºC)

At full speed:	3,25 to 3,75 bar
At idle speed:	1,50 to 1,75 bar

ROTATION SPEED

Piston speed (m/s)

rpm	600	720	750
DX(S)(C)	6,4	7,6	8,0

Fire speed: 120 tpm.

WORKING TEMPERATURES (ºC)

	Normal	Alarm	Stop
HT - cooling	75-80	85	90
Luboil	75-80	85	90

MASS MOMENT OF INERTIA

3DX(S)(C) including damper and flywheel: 280 kgm^2
6DX(S)(C) including damper and flywheel: 120 kgm^2
8DX(C) including damper and flywheel: 131 kgm^2
Data based on standard version.

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FUEL CONSUMPTION

g/kWh (g/HPh)

rpm	600	720	750
3DX	204(150)	208(153)	210(155)
3DXS	200(147)	200(147)	202(149)
3DXC	199(146)	198(146)	200(147)
6DX	205(151)	208(153)	209(154)
6DXS	198(146)	198(146)	200(147)
6DXC	196(144)	196(144)	198(146)
8DX	205(151)	208(153)	209(154)
8DXC	196(144)	196(144)	198(146)

For fuel oil:
- *net heat value of 42700 kJ/kg,*
- *without engine-driven pumps,*
- *tolerance: + 5%.*

OIL CONSUMPTION

DX: 1,00 gr/kWh [0,74 gr/HPh]
DXS(C): 0,80 gr/kWh [0,59 gr/HPh]

HEAT REMOVAL

(kW_{th} / kW_{mot})

Jacket cooling water:

DX	DXS	DXC
0,68	0,52	0,44

Charge air cooling water:
3 – 6 – 8 DXC – 600/750 rpm: 0,126

Lubricating oil: 0,03

FLOW OF FLUIDS

High temperature circuit (m^3/h)

rpm	600	720	750
3DX(S)(C)	28	33,5	35
6DX(S)(C)	28	33,5	35
8DX	28	33,5	35
8DXC	38	46	48

Low temperature circuit (m^3/h)

rpm	600	720	750
3DX(S)(C)	19	23	24
6DX(S)(C)	19	23	24
8DX	19	23	24
8DXC	29	34,5	36

Lubricating oil (m^3/h)
(SAE 30 - 70ºC - 3 bar)

rpm	600	720	750
Pump capacity	7,4	8,2	8,75
3DX(S)(C)	-	-	-
6DX(S)(C)	4,8	5,3	5,45
8DX(C)	6,1	6,6	6,75

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AIR & EXHAUST GAS

Inlet air flow: (m^3/s)

cyl	rpm	DX	DXS	DXC
3	600	0,21	0,35	0,45
	720	0,25	0,45	0,58
	750	0,26	0,47	0,61
6	600	0,42	0,80	1,00
	720	0,50	0,96	1,20
	750	0,52	1,00	1,25
8	600	0,56	---	1,39
	720	0,67	---	1,60
	750	0,70	---	1,66

Exhaust gas flow: (m^3/s)

cyl	rpm	DX	DXS	DXC
3	600	0,50	0,75	1,00
	720	0,60	0,99	1,30
	750	0,62	1,03	1,36
6	600	1,00	1,75	2,22
	720	1,20	2,13	2,68
	750	1,25	2,22	2,80
8	600	1,33	---	3,05
	720	1,60	---	3,60
	750	1,66	---	3,75

Cylinder head outlet gas temperature: (ºC)

cyl	rpm	DX	DXS	DXC
3	600	460	440	470
	720	480	430	460
	750	480	430	460
6	600	460	430	465
	720	480	430	460
	750	480	430	460
8	600	460	---	440
	720	480	---	460
	750	480	---	460

Turbine inlet gas temperature: (ºC)

cyl	rpm	DXS	DXC
3	600	500	560
	720	490	548
	750	490	548
6	600	480	530
	720	480	520
	750	480	520
8	600	---	510
	720	---	520
	750	---	520

Turbine outlet gas temperature: (ºC)

cyl	rpm	DXS	DXC
3	600	340	380
	720	346	385
	750	346	385
6	600	380	420
	720	375	400
	750	375	400
8	600	---	400
	720	---	420
	750	---	420

Energy Efficient Fishing: A 2006 review

PART B – Hull Characteristics and Efficiency

David Sterling and Kim Klaka

Australian Government
Fisheries Research and Development Corporation

Project No. 2005/239

Final Report: Part B - May 2007

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Executive summary

Aims and objectives

The objectives of the review are to:

- examine the degree to which rising fuel costs have impacted on different fisheries
- examine new and existing technologies developed both within and outside Australia in the field of increased fishing efficiency through reduced energy usage and innovation
- examine opportunities for applying innovative solutions and developments that are most likely to produce the best return for the Australian fishing industry
- develop a publication that scopes potential innovations, whether they be existing or have the potential for development, that reduce energy usage
- provide advice on potential R&D that could assist industry in reducing energy usage.

This report contains part 2 of 3 of the review into energy efficient fishing. Of the entire subject space to be considered by the review, which is given in Appendix A, this report considers hull characteristics and efficiency. It is subdivided into two areas, hull drag and motion stabilisation. Notwithstanding the broad nature of the report, specific examples and data focus on displacement monohull forms rather than planing craft or multi-hulls.

The report contains two sets of recommendations – technical solutions that could be implemented immediately and longer term high priority research solutions. In both categories, all recommendations except optimisation of hull design are applicable as retro-fits to the existing fleet.

Hull drag

The bare hull of a vessel can be considered to have three main hydrodynamic resistance components when travelling in calm water:

Skin friction resistance: The effect of viscous friction between the water and the ship's hull.

Viscous pressure resistance: The result of the distribution of pressure around the hull that is related to the thickness of the boundary layer and wake (separated flow) in the flow pattern. It is often called form drag.

Wavemaking resistance: Is caused by water pressure on the hull, and is associated with generating a pattern of waves on the water surface as a vessel moves along. The resistance is due to the energy required to create these waves.

At low speeds, the waves made by a vessel are very small and the resistance is almost wholly viscous. As speed is increased the viscous resistance increases moderately with speed. However, the wavemaking resistance increases greatly with speed.

Planing craft such as crayboats travel faster than hull speed by having a light hull that generates fewer waves. With speed, these boats are lifted out of the water by the pressure generated on the bottom of the hull, reducing the immersed volume of the hull and the making of waves. At planing speeds frictional resistance is again the dominant resistance component and pressure drag is also significant, particularly if the vessel operates at a non-optimum trim.

The single most important method of reducing fuel bills for vessels that spend a significant proportion of their time travelling to and from their fishing grounds is to reduce speed. e.g., for a typical 15m long displacement hull, the power required to travel at 10 knots can be about 205kw. However, if steaming speed is reduced to 9 knots the power would only be 115kw, a reduction of more than 40%.

Adding 2% weight on the example 15m vessel at 9 knots, would increase the required power by about 2%.

A fairly typical paint roughness of 250 microns will increase the friction by about 2.5% compared to a perfectly smooth hull. The effect on engine power is typically a 1% increase. Excessive weed or barnacles that are allowed to grow on the hull will easily cause friction to increase by 50%.

A bulbous bow can yield a significant reduction in drag (> 10%) on displacement craft moving at Froude number greater than 0.3. For a 15m vessel this corresponds to >7 knots.

Excessive form drag often occurs if a vessel with a transom stern is trimmed by the stern. Proper trim adjustment is important, even extra weight (ballast) in the bow to achieve level trim might reduce total drag. Trim tabs or stern wedges can be beneficial at higher speed (Froude number > 0.35) by modifying trim.

All vessels have additions to the underwater hull (appendages), like the rudder, bilge keels, transducer mounts and cooling water pipes etc. The total appendage drag can easily add up to 20% of the total hull drag. Where the design of appendages has focused on simplicity, low capital cost and robustness, excessive drag may exist. For a typical 15m vessel travelling at 10knots, an aerofoil rudder consumes nearly 6kW (4%) less engine power than a flat plate rudder. If the rudder is turned to 10 degrees, the aerofoil rudder consumes about 4kW (3%) less than the flat plate rudder. Similarly, it is estimated that cooling pipes consume about 2-3% of the total engine power generated. Using a different method to cool the engine water could remove this drag component.

When a fishing vessel is exposed to side currents or wind, the effective resistance to forward motion is increased; rudder drag increases due to the application of rudder to produce the necessary angle of leeway and angled flow onto the hull to resist the side loads, hull drag is increased because it is travelling at an angle of attack (leeway) and lastly, because of the misalignment of the flow into the propeller, the thrust force is slightly reduced. Adjustments to the vessel that can reduce the amount of rudder and/or leeway required for these situations could produce a significant improvement in fuel efficiency. Slow moving vessels (e.g. trawlers) are vulnerable to significant problems in this area, particularly those using trawl systems that are a continuous unit towed equally from a wire on each side of the vessel.

Alternative hull designs, like catamaran, SWATH, cathedral, and M hull, might produce substantial benefits in some fishing applications where their distinct technical qualities are appropriately married to the particular operational circumstances. For example, catamaran and SWATH vessels have improved sea-keeping properties in moderate sea states, but can be worse in severe weather. They have greater deck area for a given vessel length and good high speed performance. These craft can be more fuel efficient than planing vessels in many instances.

Regulatory constraints on hull form have resulted in vessels with poor fuel efficiency. The optimum fishing vessel should be one that earns the maximum in its lifetime and therefore its form needs to match the conditions in which it operates. Minimum resistance and large hold capacity are conflicting objectives and a compromise solution is required for the maximum earning ability. An appropriate optimisation tool such as the Decision Support Problem (DSP) technique (Pal, 2006), could identify optimum hull forms for specific Australian conditions and also explore the impact of regulatory constraints.

Immediate solutions summary

Reduce speed

Maintain hull smoothness

Trim monitoring

Remove cooling water pipe drag

Change of rudder section

Fit high aspect-ratio bilge fins

Vessel motion stabilisation

The pitch, roll, heave and yaw motions of a vessel travelling in ocean waves decrease economic efficiency for several reasons; most importantly, the motions of the vessel cause extra hydrodynamic drag, further, the motions cause non optimal conditions (for example, incorrect trim and incorrect flow into the propeller), drag from various pieces of equipment used to reduce motions (paravanes, bilge keels etc), reduced task progress rates and sea sickness due to boat motion.

In fishing, specific devices and strategies for reducing vessel motion exist principally for the reduction of roll. Roll is generally the motion of greatest magnitude, since it is very sensitive to wave period and is lightly damped. The range of devices employed to reduce roll focus on either one of these aspects of the roll problem:

- paravanes, bilge keels, sails active fins, anti-roll tanks, gyroscopes

The design principles and associated practical implications for many of these devices has not been extensively studied and documented. There is considerable scope for optimising existing anti-roll systems and in the first instance establishing an adequate technical description of current industry best practice. The most popular approach to reduce roll currently is to increase damping, which typically also involves significantly increasing resistance to forward motion. Non-drag devices such as anti-roll tanks and gyros offer alternative solutions that have much lower running costs.

Other vessel motions, particularly pitch and yaw, underlie significant efficiency problems for fishing vessels. Ideas are emerging as to the structure of these problems and mitigating technical solutions.

Immediate solutions summary

Comparison of existing roll stabiliser devices

Fit high aspect-ratio bilge fins

Conclusions and research questions

Hull drag

Dominating the hull drag discussion are two issues; the large increase in wave making resistance at higher speed (for displacement vessels) and the highly variable drag component, pressure drag, which can become a significant factor in the high running costs of a fishing vessel through bad design of hull and appendages or bad operating practice (e.g. incorrect trim).

The following research questions and project themes should underpin initiatives in this area:

1. Retro-fit bulbous bows

Bulbous bow seems worthwhile for displacement vessels that spend a significant portion of time at steaming speed.

- Optimum bulb design for smaller vessels not certain.

- Are simple retrofit bulbs beneficial?

2. Stern wedges

Most applicable for planing vessels.

- Research required to identify range of application that returns an acceptable benefit.

3. Improved estimate of cooling water pipe drag

- Consider issue’s sensitivity to Reynolds number and shadowing effects to establish most cost effective research approach.

- Model or full-scale tests to indicate scale of drag increase associated with keel pipes.

4. Minimise yaw drag for trawlers with side loading by adjusting tow-line parameters.

- Develop a device so that the relative length of warp between the two sides of a trawler can be adjusted in conjunction with the location of the tow points. The device needs to be low cost, use little energy and be suitable for Australian trawling operations.

5. Optimum trawler design

- Formal design/optimisation exercise for test case desirable to establish range of benefits possible; a typical scenario might involve situations where regulations restrict the use of optimum hull shape.

Vessel motion stabilisation

Devices that are commonly used for reducing vessel motions contribute substantially to drag and fuel costs. A very low understanding of the dynamics of these motion stabilisers exists within industry and with technologists – most device installations are based on tradition.

Research questions and recommended tasks in this area are:

1. Optimisation of paravanes for minimum drag

- Review current designs to identify/document design principles and performance features.

- Numerically evaluate performance and practical benefits of devices to fishers.

- Short term sea trials of vessel-specific modifications and retrofits to quantify/confirm performance benefits.

- Test new innovative designs concepts.

2. Drag reduction using roll gyros

- Instrumented trials of fishing vessel fitted with a roll gyro (off the shelf) to determine motion reduction and fuel efficiency effects for various sea states.

3. Reduction of pitch motion using retro-fit bulbous bows or bow fins

- Tank testing model fishing vessels to establish the practical benefits of bulbous bows and bow fins in the reduction of pitching motion and fuel consumption.

- Based on tank tests and computer simulation propose optimum bulb/bowfin design that could maximise performance benefits to fishing vessels.

4. Minimising yaw drag during autopilot controlled voyages by using DGPS

- Establish the fuel efficiency benefit of using the more accurate DGPS rather than GPS input to the autopilots of fishing vessels. This could be achieved easily at relatively low cost by direct measurement.

5. Minimising yaw drag during autopilot controlled trawling by applying dynamic tow-line adjustments

- Determine retrofit options to improve the fuel efficiency of fishing vessels during autopilot controlled trawling operations, including the use of autopilot controlled dynamic tow-line adjustments and fitting high aspect-ratio bilge fins.

1 Hull drag

1.1 Introduction

For the purposes of this document, resistance and drag are the same thing. They are the force in the direction of travel, generated as a consequence of moving the boat forwards. Effective power is the ship resistance times the ship speed. Engine power (shaft power) is about twice the effective power because of efficiency losses (mainly in the propeller) i.e. overall propulsive efficiency is typically 50%

The bare hull of a vessel can be considered to have three main hydrodynamic resistance components when travelling in calm water [1] [2]:

Skin friction resistance: This is the component of resistance obtained by summing up the tangential forces over the hull surface. In other words, it is simply the effect of viscous friction between the water and the ship's hull.

Viscous pressure resistance: This is the component of resistance obtained by summing up pressures due to the thickness of the boundary layer and wake. It is essentially a drag due to viscosity other than skin friction (i.e. form drag).

Wavemaking resistance: When a vessel moves along the surface of the water it creates a pattern of waves. Energy is required to create these waves and the wavemaking resistance is the component of resistance associated with the expenditure of this energy.

At low speeds, the waves made by a vessel are very small and the resistance is almost wholly viscous friction (see Figure 1). As speed is increased the viscous resistance increases moderately with speed. However, the wavemaking resistance increases greatly with speed with a very steep increase occurring when the ship is travelling at the speed of a wave of its own length. In this case there will be a large crest at the bow and the stern with a deep trough amidships. This speed is sometimes known as maximum hull speed because of the power required to exceed it. The maximum hull speed in knots is approximately 1.4 times the square root of the waterline length in feet. e.g. for a 15m (49ft) length vessel the hull speed is 1.4 times square root of 49, which is 9.8kn.

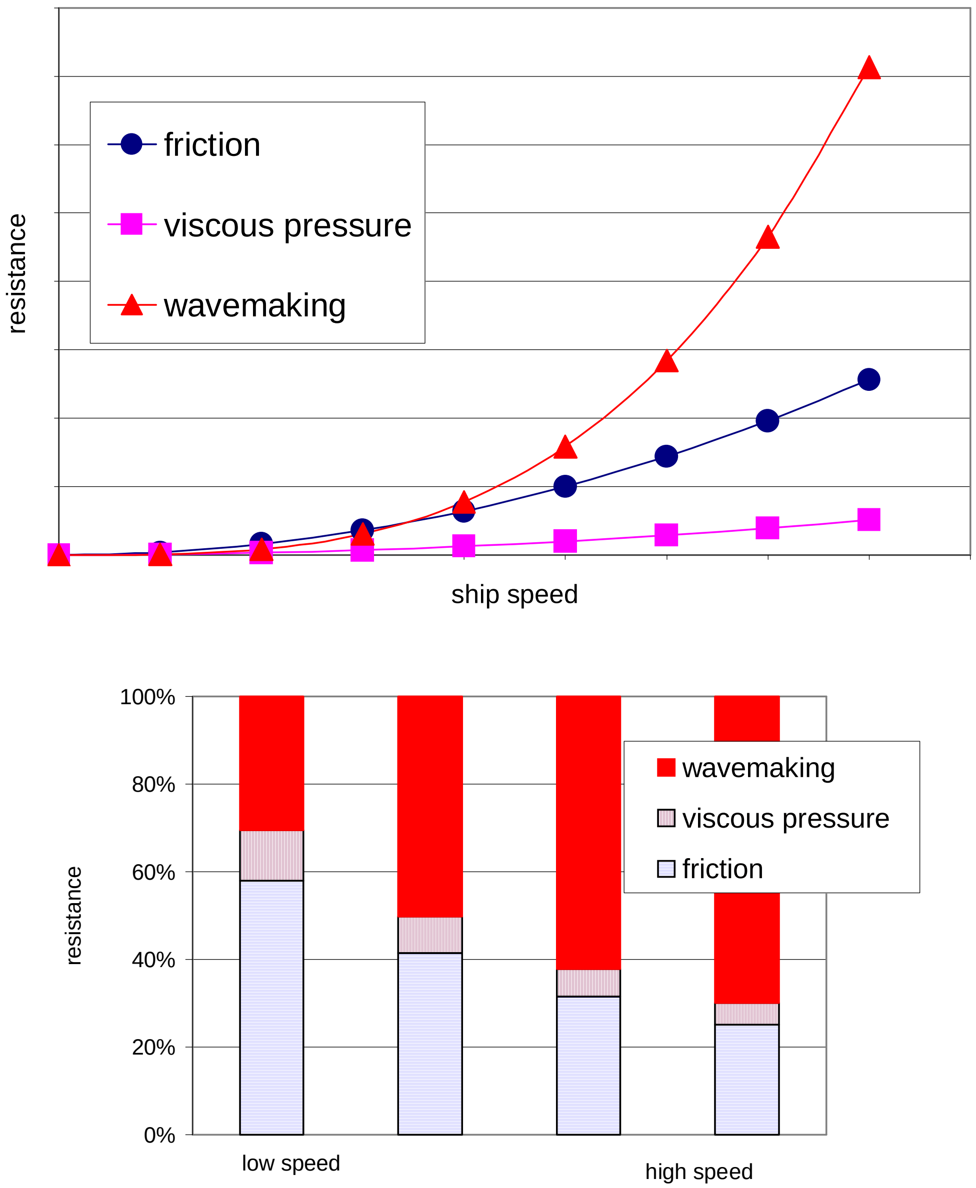


Figure 1. Breakdown of vessel drag for various operating speeds

Planing craft such as crayboats travel faster than this hull speed by having a light hull that generates fewer waves. Once the boat is travelling faster than hull speed it starts to lift out of the water, reducing the immersed volume of the hull and hence reducing the wave making (Figure 2). This is called planing. At these higher speeds, frictional resistance starts to become more important again. An additional component of drag is created as a consequence generating the planing lift force, called trim drag. If the vessel operates at a non-optimum trim at planing speeds, there can be a severe drag penalty and consequent increase in fuel consumption.

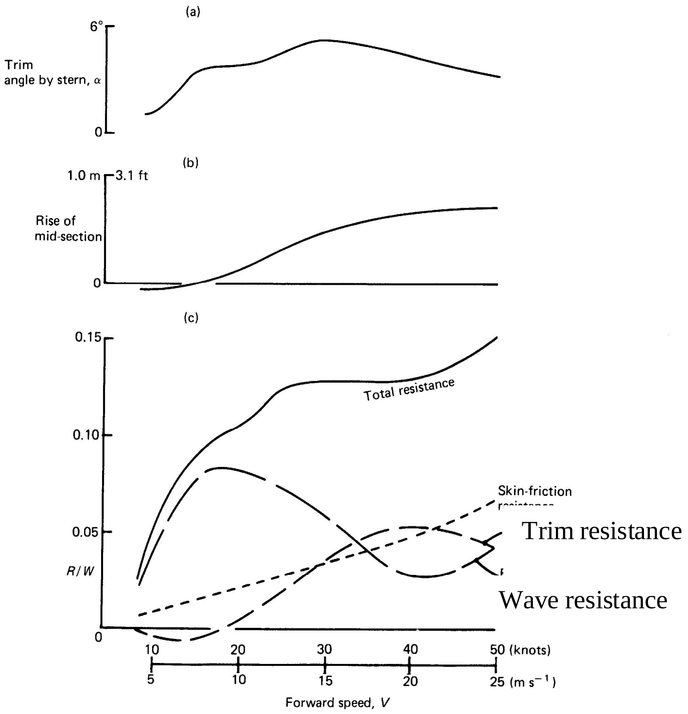


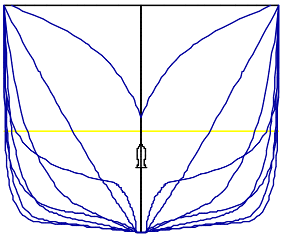
Figure 2. Breakdown of drag for planing hull over its range of operating speeds [3]

Immediate solution: reduce speed

Consider a trawler of 15m waterline length with the characteristics given in the table below.

Displacement kg	56125
Draft at FP m	1.500
Draft at AP m	1.500
Draft at LCF m	1.500
Trim (+ve by stern) m	0.000
WL Length m	15.000
WL Beam m	4.068
Wetted Area m^2	75.650
Waterpl. Area m^2	52.100
Prismatic Coeff.	0.661
Block Coeff.	0.598
Midship Area Coeff.	0.908
Waterpl. Area Coeff.	0.854
LCB from zero pt. (+ve fwd) m	0.282
LCF from zero pt. (+ve fwd) m	-0.386
Propulsive efficiency	50%

The resistance of the bare hull in calm water with no appendages or deployed trawl gear can be calculated using standard series data (the results of model tank tests of a series of geometrically similar hull forms). The resulting graph of engine power against speed is shown in Figure 3.



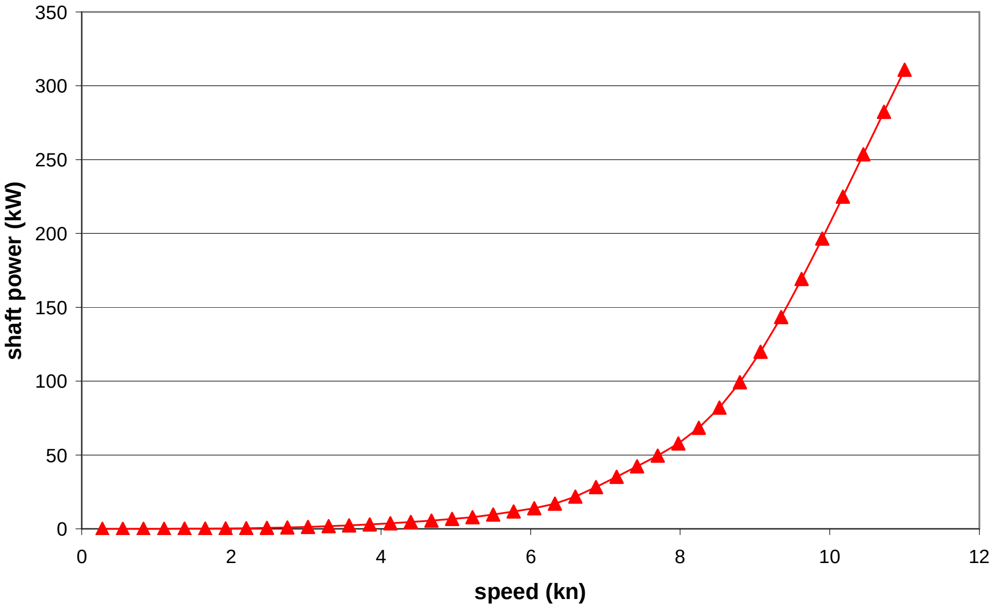


Figure 3. Required shaft power versus speed for 15m displacement fishing vessels (Hullspeed, 2006)

The most striking feature of this curve is its steepness at high speeds. If the vessel usually steams at 10kn, the power required is about 205kw. However, if steaming speed is reduced to 9kn the power is only 115kw, a reduction of more than 40%. This is probably the single most important method of reducing fuel bills for vessels that spend a significant proportion of their time travelling to and from their fishing grounds. It is also the easiest to implement. Offset against a steaming speed reduction must be considered the cost of extra time spent at sea.

1.2 Effect of increasing vessel weight

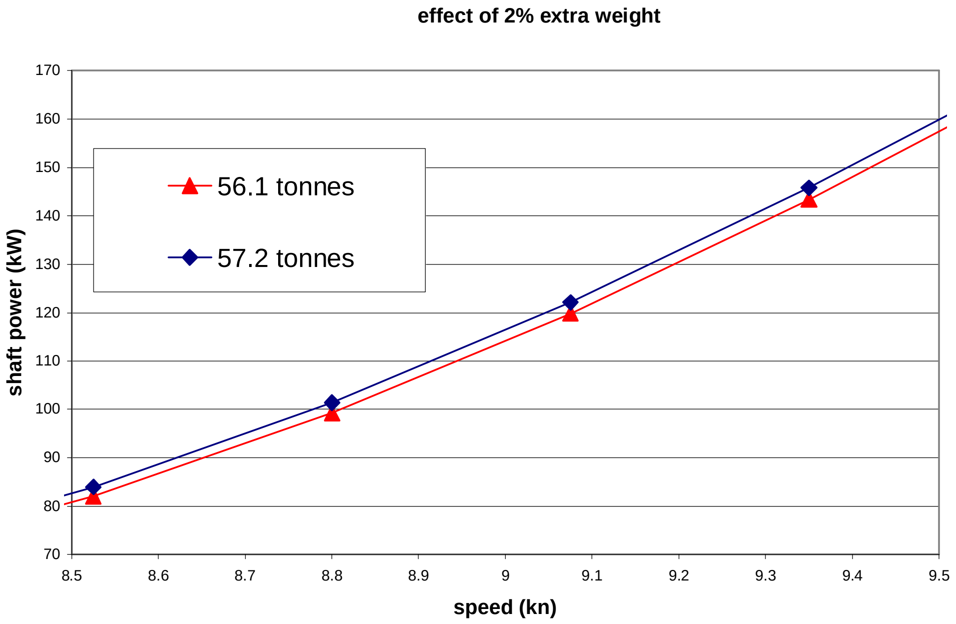


Figure 4 Effect of adding weight on required engine power

The effect of adding weight on required power for the example 15m vessel is illustrated in Figure 4 above. For example, at 9kn, an extra 2% weight (1.1 tonnes) increases the required power by about 2%.

1.3 Friction/paint systems

When water flows past the hull, as shown in Figure 5 below, the water nearest the hull surface tends to stick to it and will therefore have zero velocity.

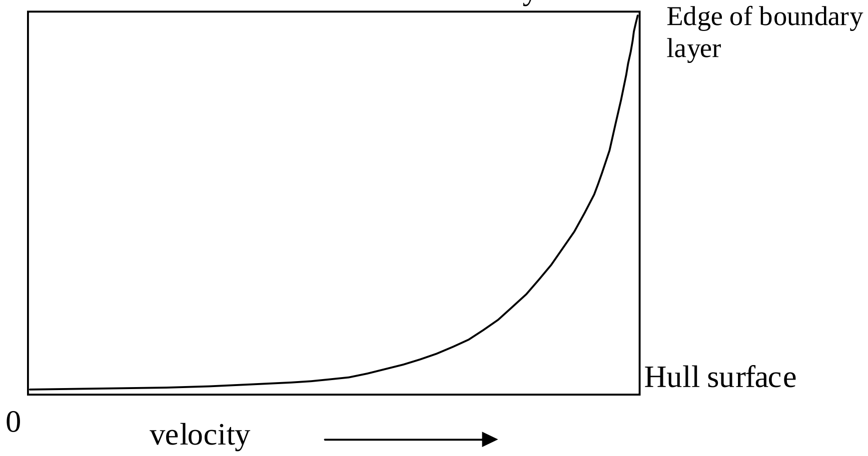


Figure 5. Speed of water flow against hull as a result of friction and boundary layer affect

With increasing distance from the surface the velocity approaches that of the ship speed. The region of slowed down water is called the boundary layer. It increases with thickness from the bow to the stern, but even at the stern it is only about 10-20mm thick.

The flow within the boundary layer over a fishing boat hull is turbulent (remember that this is at a very small scale, not really visible to the naked eye). However, very close to the hull this turbulence must die out (the turbulent motion hits the hull and flattens out), generating a smooth inner layer called the laminar sub-layer. This laminar sublayer is about 0.2mm thick (i.e. 200 microns), but it is very important for fuel efficiency. If the paint surface has a roughness which is large enough to protrude through the laminar sublayer into the main part of the boundary layer, then the frictional drag will increase. A typical marine paint finish roughness is between 200 and 400 microns height, so even if there is no marine growth, there will be an increase in friction drag compared with an ideally smooth hull surface. As an approximate guide, any roughness thicker than a human hair will generate some increase in friction drag.

A fairly typical paint roughness of 250 microns will increase the friction by about 2.5% [4]. The effect on engine power depends on what proportion of total drag is taken up by friction (which in turn depends on ship speed, hull shape etc.), but it might typically represent a 1% increase in required power.

If marine organisms such as weed or barnacles are allowed to grow this will cause a large increase in roughness, hence increasing frictional resistance. A barnacle is about 5000 microns high, so frictional drag can easily increase by 50% if the paint system is not well maintained.

Immediate solution: maintain hull surface smoothness

It is important to maintain a smooth paint system, and especially important not to allow marine organisms to grow. Pay particular attention to obtaining a smooth paint finish when applying antifouling, and clean the hull regularly – perhaps every 3 to 6 months – in order to minimise the friction increase due to marine growth.

1.4 Wave making resistance

The importance of wavemaking resistance has already been illustrated in the introduction of Section 1.1. The two biggest factors influencing wavemaking resistance are:

- Vessel speed. As a very rough guide, a 10% increase in speed results in a 40% increase in wavemaking resistance for displacement vessels such as trawlers.
- Vessel mass (displacement). Other things being equal, wavemaking resistance is directly proportional to displacement e.g. if the vessel mass is increased by 10%, then the wavemaking resistance will increase by 10%. In practice it will probably increase more than this, because the extra sinkage due to the mass increase may result in a non-optimum hull shape. The increased sinkage will also increase frictional resistance (more wetted surface area) and viscous pressure resistance (more separated flow from the immersed stern shape). See also section 1.2.

Research option: bulbous bows

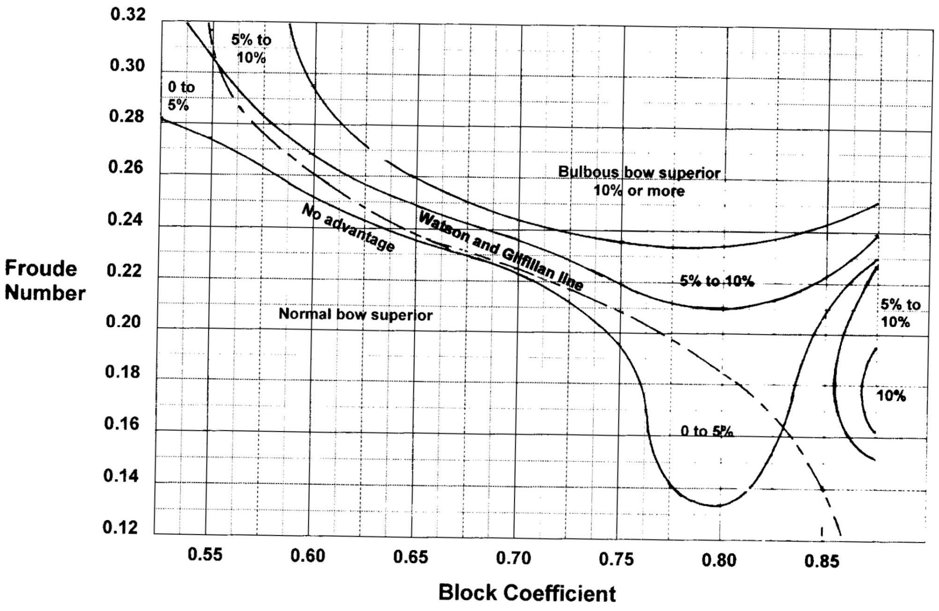


Fig. 8.1. The combination of Froude number and block coefficient at which a bulbous bow is likely to be advantageous.

([4])

The above diagram is a generalisation of the effect of a bulbous bow for different hull shapes (block coefficient on the x axis) at different ship speeds (Froude no on the y-axis). Most fishing vessels have a low block coefficient (around 0.5), so it is the left hand side of the graph that is of interest. It shows that a bulbous bow starts to have a drag advantage at Froude number greater than about 0.3. For a 15m LWL vessel this corresponds to a speed of about 7 knots. Therefore a bulbous bow is worth considering if the vessel spends a significant portion of its time at steaming speed. However, it should be noted that these calculations assume the ocean is calm. See Section 2.3

Research option: - stern wedges

Wedges and trim tabs work by altering the pressure distribution around the aft end of the hull. This results in a trim change, which itself alters the drag of the boat. If the wedge or tab does not alter the trim, it is unlikely to have a beneficial effect on drag, and could make it worse. The graph in Figure 6 shows that a tab starts to take effect at a Froude number of 0.35, which corresponds to a speed of 8.3kn for a 15m LWL. So there could be beneficial effects for a trawler at steaming speed, or a planing crayboat. However, wedges are usually at their most effective when correcting the trim of a vessel that is operating at the wrong (non-optimum) trim, either due to bad design or change in LCG from the design condition. The effectiveness of a wedge or tab on a vessel already operating at optimum trim angle is very dependent on hull shape and speed. Tank tests would be required for a variety of hull shapes and wedge sizes to find the best solution.

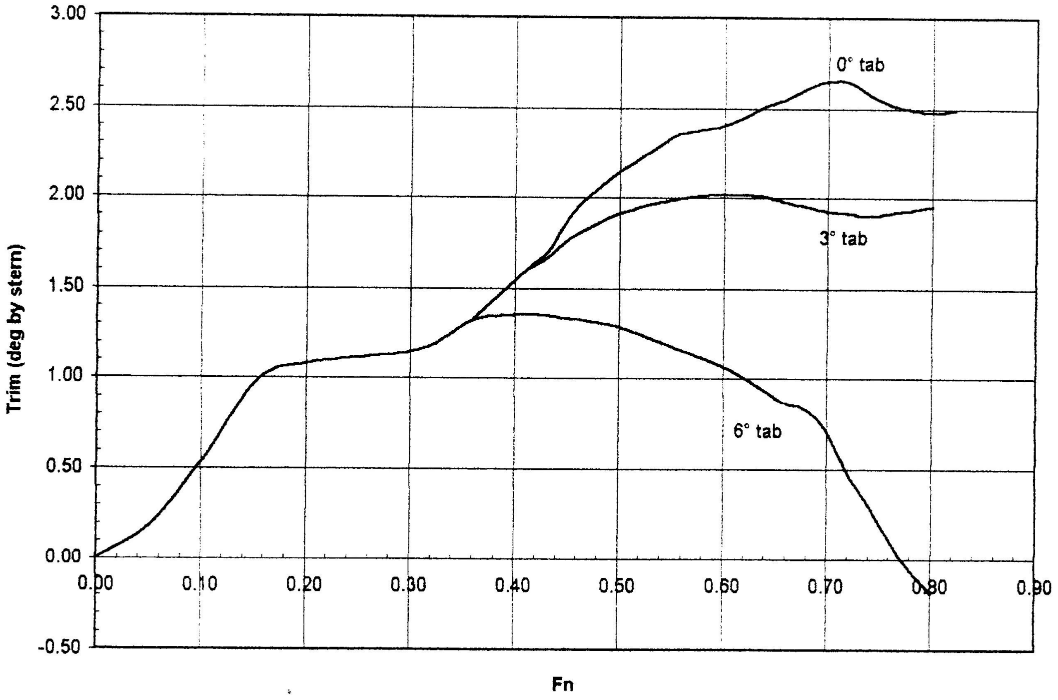


Figure 6. Effect of stern wedge in correcting vessel trim AMECRC

1.5 Form drag

Form drag is also called viscous pressure drag, pressure form drag, separation drag and eddy-making drag. It is mainly due to the boundary layer (see Section 1.3) separating or peeling away from the hull, leaving a void of water to be filled by back-eddies, which require a lot of energy to generate (hence a lot of resistance). Form drag of a well-designed hull is usually only about 5-15% of the friction drag, so about 1-5% of total drag. However, for a poorly designed hull, or one which is heavily trimmed, it may increase to 10-15% of total drag. The form drag tends to increase with the fullness of the hull. There is a trade-off here because a fuller hull allows for more cargo (fish hold) within a given vessel length. Therefore a high form drag might be acceptable if it increases overall cargo-carrying efficiency.

Immediate solution: trim monitoring

Beware of increased form drag if a vessel with a wide or a transom stern is trimmed by the stern. The stern was not designed to be immersed (except perhaps on planing craft), so dragging the stern will incur a severe form drag penalty. It might even be worth the extra weight (hence increased wave drag) of adding ballast in the bow to bring the boat back to level trim.

1.6 Appendage drag – keel, rudder, keel pipes

The drag of the basic hull is only part of the total drag. All vessels have additions to the underwater hull, which the naval architects classify as appendages. These include bilge keels, transducer mounts, cooling water pipes and the rudder itself is usually considered an appendage. The total drag of these appendages can easily add up to 20% of the bare hull drag. In many instances the appendage is retro-fitted, with little thought or understanding of the impact on drag, the emphasis being on simplicity, low capital cost and robustness. Examples are:

- Fitting a flat plate rudder instead of an aerofoil section rudder
- Adding external cooling water pipes.

Immediate solution – change of rudder section

Consider the same fishing vessel as in the cooling pipe example, with a rudder of chord 1m and span 1m. Compare a flat plate rudder to an aerofoil shape. This is difficult to do because a flat plate rudder would usually have the stock protruding outside the plate thickness, a shape for which there is no drag data. Instead we can reasonably compare a 5cm thick plate rudder with a 15cm thick aerofoil shape. Whilst this is thicker than a typical plate rudder, it allows for some of the extra drag of the stock. For the vessel travelling at 10knots, the aerofoil rudder consumes nearly 6kW (4%) less engine power than the flat plate rudder. If the rudders are turned to 10 degrees, the aerofoil rudder consumes about 4kW (3%) less than the flat plate rudder. An interesting aside from this analysis is that turning the rudder by about 10 degrees results in an additional 3kW (2%) engine power required. So minimising rudder angles can have a measurable effect on fuel economy (see also Section 2.4). Refs:[5] [1, 6] [7]

Immediate solution – remove cooling water pipe drag

Consider a 15m fishing vessel with installed power 300kW steaming at 10kn. It has a cooling water pipe fitted along 6m of the hull. The pipe has three sections, each of 35 mm diameter. The friction drag of the pipes is 62N and the viscous pressure drag about 138N [5]. The likelihood is that the pipes will not be exactly aligned with the flow, which adds a further 40N, and will be fouled by marine growth to some extent, which adds another 140N. Total drag is approximately 380N so the installed engine power required to overcome the drag of these pipes is about 4kW. Now the total installed power is 300kW, but only about half this is used whilst at steaming speed. Therefore the pipes are consuming about 2-3% of the total engine power generated. Using a different method to cool the engine water would remove this drag component.

Research option: Improved estimate of pipe drag

The above calculations rely on assumptions about pipe alignment to the flow, shadowing effects between pipes, hull boundary layer influences and marine growth rates. There is no directly applicable data to validate the assumptions made. A research program to generate such data would enable optimum design of external cooling water pipes and would also contribute to an accurate cost-benefit analysis for internal v external pipe options. Such a research program would require a combination of wind tunnel tests and CFD, preferably supported by full scale trials comparisons.

1.7 Induced drag due to side winds/currents

When a fishing vessel is exposed to side currents or wind it is able to resist the applied side force by travelling at a drift or leeway angle. The angled flow onto the hull generates a side force that balances the side force applied by the wind. The resulting sideforce usually generates a yaw (turning) moment that must be opposed by applying a rudder angle.

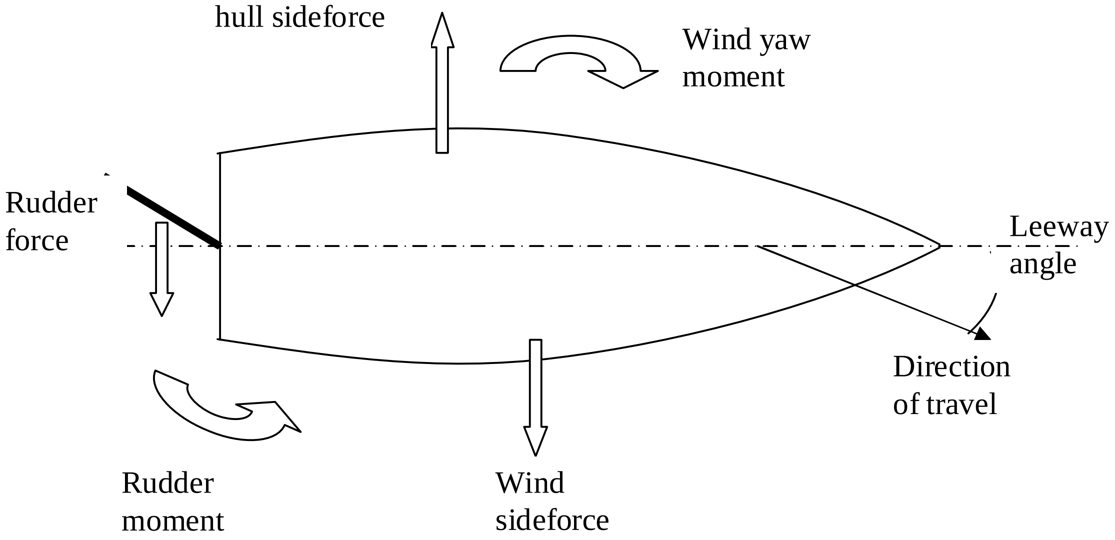


Figure 7 Dynamics of vessel travelling with a wind induced sideforce applied

As a result of this process extra resistance is generated in a number of ways:

1. The angle of the rudder causes extra drag ("induced drag"). The lift force on the rudder holds the hull at an angle of attack to the direction of motion. Unfortunately this lift force is also in the same direction as the wind side load, which means that the balancing hull side force from the hull has to match both the applied side force from the wind and the lift force from the rudder.

2. There is increased drag on the hull because it is travelling at an angle of attack to the direction of motion (leeway). This is probably the largest component of extra resistance for a fishing vessel, because the hull is not designed to generate sideforce efficiently.

3. The hull is at an angle of leeway so the propeller force is not aligned with the direction of motion. This misalignment of the flow means that the thrust force is slightly reduced because the propeller is designed to operate at its maximum efficiency with flow coming from directly ahead.

The above effects are greatest when the vessel is travelling at slow speed, because the hydrodynamic forces are proportional (approximately) to speed squared and leeway angle. So for a given sideforce generated by the wind, the vessel has to adopt a much larger leeway angle at slow vessel speed as compared with at high vessel speed. The vessel will then generate much greater hydrodynamic drag at this larger leeway angle. This situation is made worse if the trawl gear towed is a single unit towed with two wires (eg. Single prawn trawl, single fish trawl, triple rig, five rig). A trawler operating at a leeway angle using this type of gear will incur increased warp tension of the lee side compared to the windward side. This will require even larger rudder angles to hold the vessel on course. This detrimental effect can be compensated for by using a slight difference in port and starboard warp lengths to turn the boat (instead of the rudder). This would allow the vessel to travel in a straight line using a smaller rudder angle (thus reducing one source of increased resistance) and also ensuring that the nets are fishing square.

The problem of drag in a side wind is similar to the condition of a sail-assisted vessel, where the sail sideforce has to be opposed by a matching hull sideforce generated by adopting an angle of leeway (see Review-Part A Section 2.2.2).

Immediate solution – Fit high aspect-ratio bilge fins

To increase the capacity and efficiency of resisting wind sideforces whilst trawling, high aspect-ratio fins could be attached to the sides of trawlers at the turn of the bilge. Retractable passive fins are considered in section 2.3 (Figure 8) to improve roll damping efficiency. If these were operated in a lower position than indicated by Figure 8 they would provide components of force that would cover both applications for such fins. For resisting sideforces the high aspect-ratio fin will allow a larger and more efficient hull sideforce to be produced at lower angle of leeway. Given proper longitudinal location of the fins less rudder angler will be required to hold the smaller leeway angle, thus improving efficiency even further.

Research option: Minimising yaw drag for trawlers with side loading by adjusting tow-line parameters

The use of the rudder to maintain course increases drag and uses fuel. This is particularly exacerbated for a trawler travelling at slow speed and where the tow load substantially resists the vessel achieving the angles of leeway required. For trawling under conditions where a significant wind/current induced side loading exists, long periods of time occur where hull and appendage drag are far higher than normal; thus causing additional fuel consumption. A research project is proposed whereby a device is developed so that the relative length of warp between the two sides of the trawler can be adjusted in conjunction with the location of the tow points. Such a system would have similar features to the Marelec synchro winch system, but have greater utility and be specifically designed for Australian trawling operations. The design concept for a suitable low cost and energy-wise tow-line adjustment system for Australian prawn trawlers, based on movable boom tow points, is being developed by Sterling Trawl Gear Services. By offsetting the application of the tow load and in the process adjust the length of the warps it should be possible to produce the necessary angle of leeway to resist wind applied sideforces without the need to apply rudder, and simultaneously maintain a square tow on the trawl gear.

1.8 Hull design options

The principles described above and the resulting recommendations apply mostly to retrofits for existing vessels of conventional hull form. There is a wide range of new hull forms that may yield considerable fuel savings if applied to fishing vessels. Such hull forms include:

- Catamaran
- SWATH
- Cathedral
- M hull

However, their impact on the overall operation of the vessel must be evaluated, including such issues as safety, manoeuvrability, carrying capacity, performance in rough water, cost and so on For example, if we consider the advantages and disadvantages of catamarans and SWATHs (Small Waterplane Twin Hull). SWATHs may be generalised as forming a subset of catamarans.

Compared with conventional displacement monohulls, these vessels tend to exhibit improved seakeeping properties in moderate sea states, but worse in sever weather. They have greater deck area for a given vessel length, with consequent improvements in operational efficiency. If high speed performance is important e.g. for the crayfish industry, catamarans can require less power than planing craft in many instances, with lower fuel costs resulting. Catamaran resistance and seakeeping is sensitive to cargo load – SWATHs are especially sensitive owing to their low waterplane area yielding large draft increase for small mass increase. Catamarans often have shallower draft than an equivalent monohull, enabling them to work in shallow waters more effectively.

The importance of these various characteristics is overshadowed by the typeforming effect of vessel size regulations. .Many existing hull forms have been designed to maximise capacity within regulatory constraints. These vessels are often hydrodynamically very inefficient. Consideration of hydrodynamic effects in regulations could result in significant savings in fuel costs. For example, the use of length as a primary regulatory measure encourages abnormally beamy boats, which exhibit very high wavemaking resistance and viscous pressure resistance. Decreasing length-beam ratio from 3 to 2 can result in fuel costs increase by over 150% [8].

Research option: Optimal prawn trawler design
(This project could be applied to any fishing vessel type; prawn trawlers have been selected as an example)

Trawler hull forms may not be optimum for the conditions in which they operate. The optimum trawler should be one that earns her maximum in the lifetime. The form should be such that it offers minimum resistance and thus consumes least fuel. The optimum vessel is determined by comparing a large number of alternatives for a fixed set of requirements i.e. operating port and fishing ground particulars. This is made possible by applying a suitable optimization technique. The propeller to be fitted should operate in the running condition with maximum efficiency and develop maximum thrust while trawling. The form of the vessel will be finer for the minimum resistance and at the same time the earning capacity will be a maximum when the vessel is fuller. Therefore, the objectives are of conflicting nature and a compromise solution is required for the maximum earning. Using an optimisation tool such as the Decision Support Problem (DSP) technique [9] could yield a much improved hull form designed for specific Australian conditions. Such tools can also be used to explore the impact of regulatory constraints.

2 Vessel motion stabilisation

2.1 Introduction

The pitch, roll, heave and yaw motions of a vessel travelling in ocean waves decrease economic efficiency for several reasons:

- The motions cause changes to the incoming waves and they also generate their own waves, all of which requires energy, which in turn comes from the engine having to operate at a higher load.
- The various pieces of equipment used to reduce motions (paravanes, bilge keels etc) generate their own drag, which uses up fuel.

- The motions of the boat will result in an unsteady flow of water around the propeller, reducing its efficiency.
- Whilst not directly affecting fuel costs, sea sickness and injuries due to boat motion affect overall economic efficiency of the vessel.

2.2 Roll

Roll is usually the motion of greatest magnitude, because it is inherently very lightly damped. A review of roll stabilization devices is provided in [10]. There are several ways of reducing roll motion of an existing vessel:

- Paravanes
- Bilge keels and passive fins
- Active fins
- Anti-roll tanks
- Sails
- Gyroscopes

Paravanes

The most popular method of reducing roll motion on fishing vessels is probably paravanes [11]. They are reasonably effective at medium to high vessel speeds but not at slow speeds, because they rely on the vessel speed to generate enough water flow to create the required roll moment A slow speed version of them, often called flopper stoppers, is also available [12, 13]. Model tests (Bass, 1998) have shown that roll reduction from paravanes is 30-35% in small (0.6m high) waves at zero vessel speed, reducing to 20-25% in larger waves. During full scale trials 45% roll reduction was the highest achieved, at steaming speed. The main disadvantages of paravanes are the significant hydrodynamic drag (hence fuel use) and complexity of deployment and recovery. Their weight also adds drag to the vessel.

The drag associated with a paravane is not easy to calculate, as it depends not only on the paravane shape and vessel speed, but also on the rolling motion of the vessel.

There are three paravane types. Most paravanes used in fishing operate in a relatively “free” kite like fashion by being towed at the end of a flexible chain. These are easy to deploy, but operate at an angle of attack at all times thus producing a significant amount of drag - especially when the vessel is moving at high speed (steaming). Easy deployment means that these paravanes can easily be stowed when sea conditions are fair or while steaming for large distances and when roll stabilisation is of lower priority. A second paravane type has the damping plate fixed to a freely swinging pole. This increases the control over the angle of attack of the plate and there is the possibility of increasing the effectiveness of the device when vessel speed is very slow or zero (at anchor) because the pole is able to push against the plate in situations where a chain system would go slack. Potentially this arrangement has less drag and is more effective, but this has not been studied and documented. The third paravane type has the plate fixed normal to the axis of the pole and a number of restraining wires are used to fix the pole in a vertical orientation. This ensures the plate is at zero angle of attack to the direction of steady state motion and essentially reduces drag to that of the pole, which is usually streamlined. For this arrangement the plate works to resist rolling very effectively in both directions, however due to the more complex fixing system the arrangement is usually operated at all times the vessel is at sea irrespective of the wave conditions, therefore creating drag even when the vessel is not rolling.

Bilge keels and passive fins

Bilge keels can dampen roll motion by typically 20% whilst at trawling speeds, more at steaming speed [14, 15]. They have the advantage of being "fit-and-forget" technology. Their main drawback is the hydrodynamic drag, which is always present even when roll reduction is not required. In recent years a number of vessels have been fitted with short, almost square bilge keels, looking similar to fixed fins. This was largely a result of research described in [16], indicating that roll reduction of 60% is achievable with suitably large keels.

A variant of the fixed fin described above is the passive fin stabiliser described by [17] and shown in Figure 8. This device can be retracted when not required to reduce drag. It seems viable to consider lowering the working position of these devices so that they provide a component of lateral resistance; particularly for trawlers to improve their efficiency when travelling at slow speed in conditions where a sideforce on the vessel is occurring (see section 1.7).

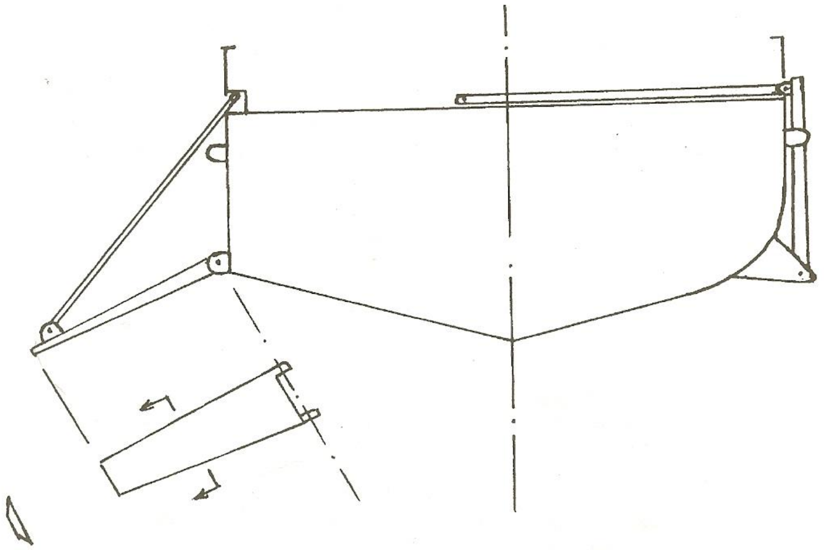


Figure 8 Passive fin stabilisers (from [17])

Active fins

Active roll stabiliser fins have been used in large ships (particularly passenger liners) for over 50 years. They are only effective at steaming speeds, though some progress has been made in using them at zero vessel speed by oscillating the fins at high frequency [18, 19]. Active fins are relatively expensive, prone to damage unless retractable (even more expensive) and the zero speed operation requires large amounts of energy. They also incur a hydrodynamic drag penalty.

Sails

Fishers have used sails for centuries to provide roll damping, though their effectiveness has only recently been quantified [20, 21]. They can provide considerable roll reduction, though there are operational constraints on deck space etc. (see also Review-Part A Section 2.2.2)

Anti-roll tanks

Anti-roll tanks have been used for over a century with some success. There are two main types – passive tanks with no control system, and active tanks that control the flow of water in the tank. Passive tanks [22] are relatively inexpensive but they are heavy, take up cargo space and can cause stability problems – GM reduction due to tank free surface alone is 20-40%, in addition to the shift in VCG due to the extra weight. They incur a hydrodynamic drag penalty only through their weight increasing the immersed volume of the vessel (see section 1.2). The tank will weigh typically 1.5-2.5% of displacement [23]. A significant disadvantage of passive anti-roll tanks is that they have to be tuned to work at a particular wave period (usually the natural roll period of the vessel), so they are not very effective at reducing roll in waves of any other period.

Active anti-roll tanks have a mechanism for regulating the flow of water as the vessel rolls. This might for example be a valve through which water must flow when sloshing from side to side. This allows the tank to be effective over a wider range of wave conditions compared with a passive tank, but the control system adds complexity and expense.

Roll reduction from passive tanks is roughly comparable with that achieved by paravanes at steaming speed, and more effective at trawling speed.

Gyro-stabilisation

Gyro stabilisation of roll motion has been used for over 70 years, though it fell out of favour in the 1960s and only recently reappeared. The principle is simple – the roll motion of a suitably gimballed gyro causes a precession which in turn creates an anti-roll moment. Roll motion reductions greater than 50% are readily achievable [24]. They are effective at all vessel speeds, but are most useful when trawling. There is no hydrodynamic drag, they are small and easily installed – almost “fit–and-forget” technology – and they are energy efficient when running. They are more expensive and slightly heavier than bilge keels or paravanes (about 1-2% of displacement),. Mitsubishi make them http://www.marinemaxarg.com/ and more recently a device has been developed at Curtin University, Perth which is sold by Sea Gyro Pty Ltd http://www.webace.com.au/~sea_gyro/ http://www.abc.net.au/newinventors/txt/s1415189.htm

The only drag penalty is due to the extra vessel weight and there are opportunities for reduction of drag through optimal coupling of vessel motions and reduced added resistance in waves.

Immediate solutions - comparison of existing roll reducing devices

A cost benefit analysis on the use of non-drag devices such as gyros, compared with conventional paravanes and bilge keels would provide operators with information for selecting the best roll reduction device for a set of prescribed operating conditions. However, there is currently insufficient information to include comprehensive drag reduction calculations in the analysis; this would require a separate investigation (see below)

Research option: Optimisation of paravanes for minimum resistance

There is considerable scope for optimising existing anti-roll systems for improved fuel efficiency, especially paravanes and bilge keels. In the first instance it might be appropriate to review current designs to identify/document design principles and performance features along with a theoretical evaluation of their overall benefits to fishers. This could be augmented by short term sea trials on vessel-specific modifications and retrofits, or longer term efficiency comparisons and/or testing of innovative new designs.

Research option: Drag reduction from using roll gyros

The drag reduction potential from optimising roll stabilisation devices is twofold:

- The absence of any device in the water.
- The reduction in rolling motion itself reduces the hydrodynamic drag of the hull.

The former requires the measurement of drag for the various roll reduction devices currently in use and proposed. Whilst some information is already available, further model tests and full scale trials would be required to fill the knowledge gaps.

The latter is more readily assessed, for instance by instrumenting a vessel fitted with a gyro, then comparing the engine power with the gyro turned on and turned off. Sea Gyro have expressed an interest in this project and have a gyro-stabilised vessel available for trials.

2.3 Pitch

Pitching motion, which occurs in combination with heave, increases resistance in waves therefore requiring additional engine power and more fuel. Pitching motion is a very limiting factor in trawling, especially for smaller vessels. The pitching characteristics of a vessel are mainly a function of its hull form and distribution of masses on the vessel. The main area of opportunities for reducing pitch motion of existing vessels is the retro-fitting of bulbous bows (see 1.4) and the use of anti-pitching fins.

Active anti-pitching fins and flaps

Active systems have been used in the high speed ferry industry for approximately 20 years ([25] There is very little data on the effect of active control surfaces on drag. The hydrodynamic drag of the fins is offset to some extent by the reduced added resistance in waves. Fins and flaps are only effective when the vessel speed is high enough for the fins to generate useful lifting force – typically15kn.

Passive bowfins – fixed and flexible

Fixed fins attached near the bow can alter the pitch motion through increased damping and inertia. If designed carefully, they could reduce the pitching motion for some hull forms. There is much discussion and some research on the use of fins that are allowed to flap or flex with the vessel motion, the fins themselves creating useful thrust – the “whale-tail” propulsion concept [26].

Research option – reduction of pitch motion using retrofit bulbous bow or bow fins

There may be scope to gain benefits through the use of passive fixed or flexible bowfins or bulbous bows. Potentially such bowfins will make trawlers much more comfortable to work, maintain forward propeller thrust to a greater extent in pitching seas and possibly provide augmented thrust through their own action. If the vessel is pitching in waves, a bulbous bow might, if designed carefully, reduce the pitching motion and also reduce the added drag due to the pitching. A program of tank testing and full scale trials validation would be required.

2.4 Yaw

No vessel steers an entirely straight course, even in calm water. The autopilot is required to make course adjustments through the steering system. The amount of course change affects fuel use in three ways:

- The autopilot requires power to run; the more course corrections required, the greater the power used.
- The vessel travels further because of its meanderings, compared with the straight-line distance
- As the vessel meanders, the hydrodynamic drag increases for two reasons: firstly, the rudder is being set at an angle which creates extra drag; secondly the entire hull will adopt a slight angle to the flow during these small turns, further increasing hull induced drag. There is also the varying inflow angle to the prop affecting its ability to generate thrust efficiently.

Research option: Minimising yaw drag during autopilot controlled voyages by using DGPS

The use of the rudder to maintain course increases drag and uses fuel. The rudder angles applied are a function of the autopilot controls, which in turn rely on input of vessel actual heading and required heading. Most autopilots use GPS input, older models relying solely on a magnetic compass and a user-input desired heading. The optimum control is obtained by applying course corrections that maximise the speed over the ground for minimum energy input. If the accuracy of the information used by the autopilot were increased, there could be a reduction in rudder angles used and an increase in velocity made good over the ground – hence reduced steaming time at a given engine revs. The use of Differential GPS (DGPS) increases positional and heading accuracy by an order of magnitude compared with conventional GPS. A research project is proposed whereby a vessel autopilot is connected to a DGPS input, the DGPS capability is turned on and off for suitable time periods, the resulting differences in distance made good at constant engine revs providing a measure of fuel saving. A provider of DGPS services, Omnistar Pty Ltd www.omnistar.com.au has expressed interest in contributing to such a project.

Research option: Minimising yaw drag during autopilot controlled trawling by applying dynamic tow-line adjustments

The above situation is exacerbated for a trawler travelling at slow speed and where the tow load substantially resists the vessel achieving the angles of yaw required. A research project is proposed whereby the trawler's autopilot controls a dynamic tow-line adjustment system (as proposed in section 1.7), instead of the rudder, to steer the desired trawl course. The objective is to keep to the desired course with the minimum of lost available thrust to the trawl gear. The alternative course control system could be turned on and off for suitable time periods while monitoring warp tension at constant engine revs to provide a measure of increased tow force for the same fuel consumption.

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Energy Efficient Fishing: A 2006 review

PART C - Other topics including refrigeration, propulsion and fishing gear

David Sterling

Australian Government
Fisheries Research and Development Corporation

Project No. 2005/239

Final Report: Part C - September 2009

Table of contents

Executive summary

Aims and objectives

The objectives of the review are:

- examine the degree to which rising fuel costs have impacted on different fisheries
- examine new and existing technologies developed both within and outside of Australia in the field of increased fishing efficiency through reduced energy usage and innovation
- examine opportunities for applying innovative solutions and developments which are most likely to produce the best return for the Australian fishing industry
- develop a publication that scopes potential innovations, whether they be existing or have the potential for development, that reduce energy usage
- provide advice on potential R&D that could assist industry in reducing energy usage.

This document mainly considers fishing gear; in particular prawn-trawling gear. A brief discussion on propulsion and refrigeration in fishing is also provided.

Fishing Gear

Trawl gear technology affects business outcomes through engineering performance and catch efficiency and can be modified in a number of ways to generate improvements in energy efficiency:

- High order multiple net systems.
- Optimum trawl system variables.
- High performance components.

A large proportion of the overall drag of a prawn trawl system is associated with the netting in the trawls, particularly for the higher order systems. This indicates that reducing netting drag, for example by reducing twine diameter, should have a very significant impact on improving the fuel efficiency of trawling. The potential gain is even higher than first impressions because the size of otter boards required in the system (and the resulting otter board drag) are directly governed by the drag of the trawls. Therefore small twine diameter, properly implemented, should equivalently reduce trawl drag and otter board drag; seemingly making twine diameter the most powerful energy efficiency variable in trawling.

The latest and most refined version of the Batwing otter board for prawn trawling incorporates rigging features to achieve stable and efficient operation at much lower angle of attack. This reduces the drag of the otter board by about 70%. A flexible sail is used so that the centre of gravity position of the board is more optimally located, and construction costs become very low.

1 Introduction

Part C of the review has been particularly difficult, because there is a need to cover all that which is out side Part A and Part B of the review. This is not possible at the level of rigor attempted, given the resources that are available. To make the task practical the scope of this document (Part C) is reduced to a detailed consideration of active fishing gear only. This decision under values subject areas such as propulsion devices and refrigeration, which are very important areas in fishing that involve quite a large amount of input energy.

A brief discussion on propulsion and refrigeration is provided in the document to give a rough direction for future work in these areas.

2 Propulsion

In the propulsion area, it is difficult to put together worthwhile material because of the lack of good technical information that is pitched at applications applicable to commercial fishing. A good discussion on the topic relies on a sizable contribution from a high level expert in the area, who's mind can be brought to bear on the specifics of propulsion in fisheries. Until recently, the project has not been able to establish a good collaboration with a propulsion expert and instead has tried unsuccessfully to procure good performance prediction software to fill the gap. Software purchased from SNAME was found to contain faults that make it unusable and there has been no attempt by SNAME to fix the problem. Alternative software is available, but very expensive ($10000) and outside the budget for the project.

As it happens this situation has turned around recently as a retired propulsion expert from defence has made contact and expressed great interest in being strongly involved in any program of industry assistance to do with propulsion. This new relationship is developing with the view to collaboratively produce a report on propulsion similar in style to those produced already for the review. This could be phase 1 of a longer term collaboration that ideally will extend into detailed studies of key issues (phase 2) and enterprise level assessments of propulsion systems on fishing vessels that would be part of level 2 energy audits (phase 3). It is hoped to complete the phase 1 task soon after finalisation of the energy review project.

3 Refrigeration

In many ways refrigeration in fishing is similar to refrigeration in other industries and therefore similar efficiency principles apply.

Some good efficiency documents are available already in this area [1, 2] and there are well developed services available to industry regarding the installation of modern refrigeration technologies and the application of best practice maintenance. In [1] it is supposed that the energy consumption of refrigerating systems could be reduced by at least 20% in the short term through a range of relatively straight forward modifications to equipment and operating procedures and a reduction of 30-50% would be realistic by 2020 — depending on applications. A significant culprit to high energy consumption mentioned is the use of conventional low cost thermostatic expansion valves. These apparently can be replaced by electronically controlled expansion valves to significantly increase refrigeration efficiency. In [2], mention is made of absorption (liquid sorption) and adsorption (solid sorption) refrigeration systems that use free waste heat to generate refrigeration. These systems can use diesel engine waste heat to refrigerate seafood directly with very little additional energy input or can be used to help condense refrigerant in the conventional vapour-compression refrigeration system. It is stated that each degree centigrade reduction in the condenser temperature of the conventional system gives a 2%-4% increase in compressor efficiency.

Calculations provided by a refrigeration engineer from GEA Grenco (Netherlands) indicated that the waste heat from a diesel engine operating at 250 hp for 10 hours could freeze 10 tons of fish using an absorption refrigeration system. Advice from that source was that the investment for such a system would be very high for this small capacity and not feasible, however information was also provided regarding adsorption refrigeration systems manufactured in china by DY Marine Refrigeration for the production of ice at sea on small fishing boats (2 tonne ice per day for waste heat from 250hp engine). A schematic diagram of such a system is shown in Figure 1, and the associated website for further information is http://www.dyrefrigeration.com/products/marine/index.htm .

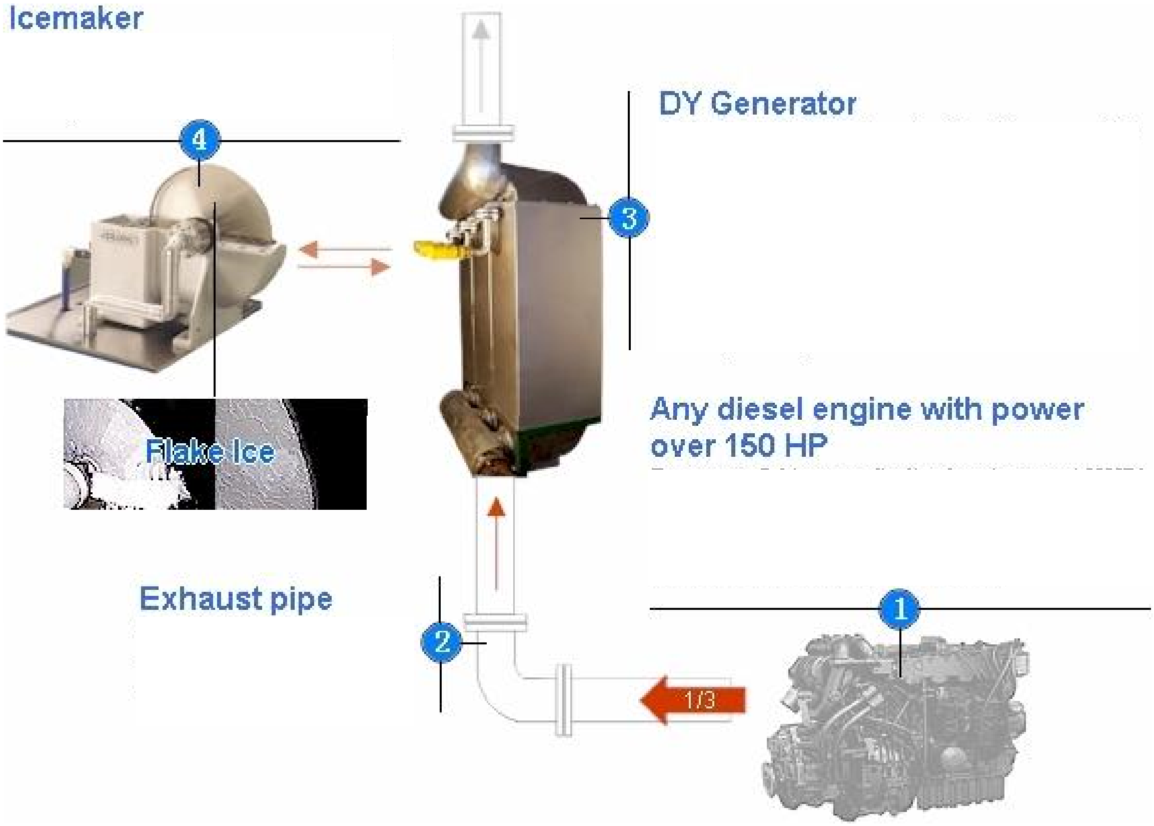


Figure 1 Schematic of adsorption icemaker powered from diesel engine waste heat.

4 Fishing Gear – Prawn Trawling

4.1 Fundamental issues

Given the mechanics of prawn trawling, which is characteristically active as depicted in the production flowchart of Figure 2, it can be seen that the natural resource inputs of direct concern to fishing businesses are fuel and time. Also indicated in the production flowchart is a complex array of opportunities to improve the efficiency of resource utilisation. This spans the production issues of engineering performance, catch efficiency, search power and time utilisation.

In this context trawl gear technology can play a role in the areas of engineering performance and catch efficiency and can generate improvements in energy efficiency through a number of identifiable initiatives:

- High order multiple net systems.
- Optimum trawl system variables.
- High performance components.

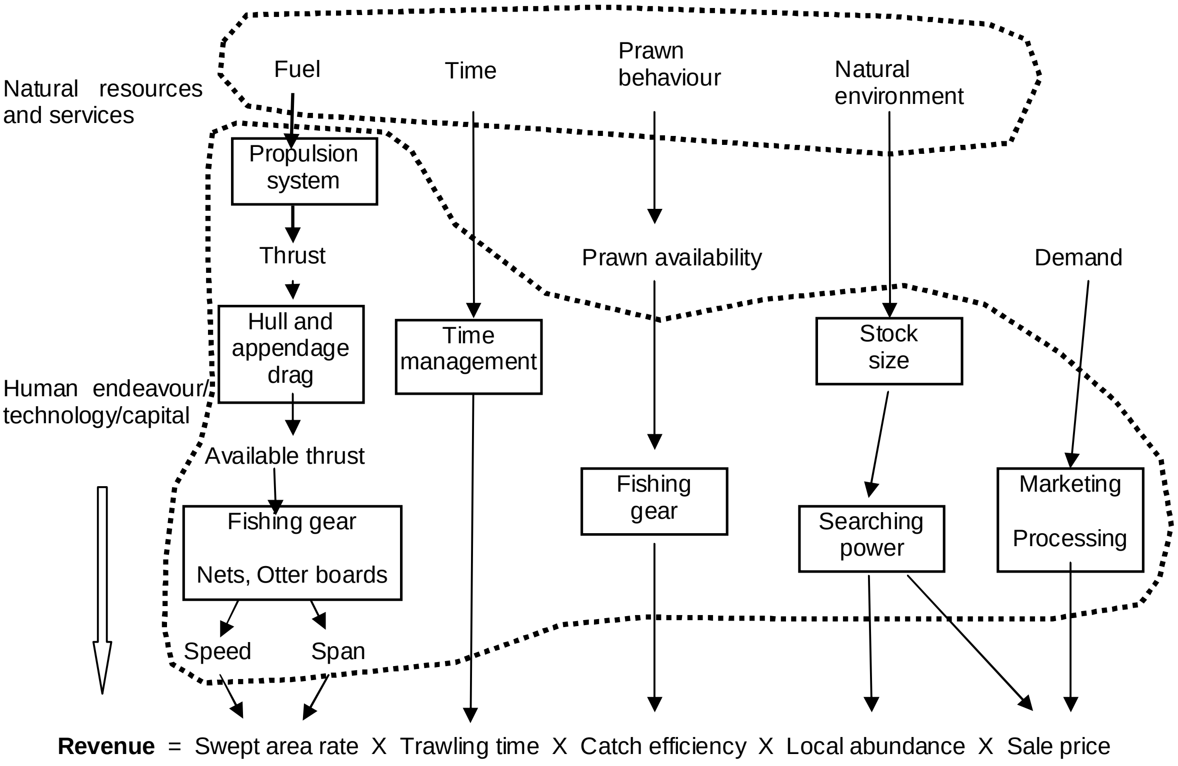


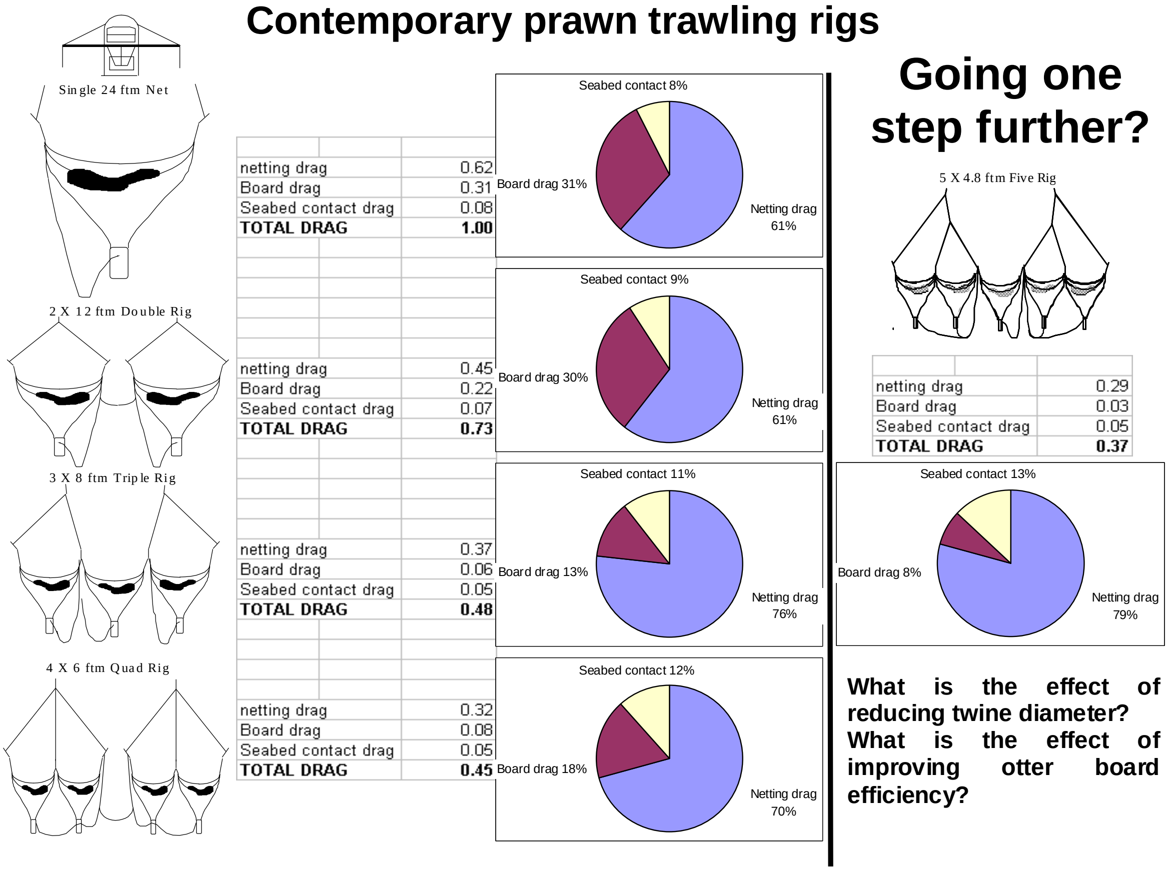
Figure 2 Fuel efficiency in fishing context.

4.2 Advantages of multi-net systems

By increasing the number of nets towed simultaneously in prawn trawling, the total amount of netting utilised in systems of the same size is reduced. This reduces net drag and makes it easier for the otter boards to open the gear laterally (see Figure 3).

Multiple net trawl systems can be expanded to incorporate even higher numbers of nets, for example the five net system. Properly configured, this underutilised trawl systems can improve swept area performance by about 12%.

A large proportion of the overall drag of a prawn trawl system is associated with the netting in the trawls, particularly for the higher order systems. This indicates that reducing netting drag, for example by reducing twine diameter, could have a very significant impact on improving the fuel efficiency of prawn trawling. The potential gain is even higher than first impressions because the size of otter boards required in the system (and the resulting otter board drag) is directly governed by the drag of the trawls. Therefore small twine diameter, properly implemented, should equivalently reduce trawl drag and otter board drag; seemingly making it the most powerful energy efficiency factor in prawn trawling.



netting drag	0.62
Board drag	0.31
Seabed contact drag	0.08
TOTAL DRAG	**1.00**

netting drag	0.45
Board drag	0.22
Seabed contact drag	0.07
TOTAL DRAG	**0.73**

netting drag	0.37
Board drag	0.06
Seabed contact drag	0.05
TOTAL DRAG	**0.48**

netting drag	0.32
Board drag	0.08
Seabed contact drag	0.05
TOTAL DRAG	**0.45**

netting drag	0.29
Board drag	0.03
Seabed contact drag	0.05
TOTAL DRAG	**0.37**

What is the effect of reducing twine diameter?
What is the effect of improving otter board efficiency?

Figure 3 Multi-net trawl systems for prawn trawling with estimated drag benefits and drag breakdown between significant components.

4.3 Optimum system configuration

Figure 4 shows a trawling optimisation chart generated for a vessel towing a particular trawl system type and utilising engine power of 185kw [3]. The chart shows that the efficiency of engine power utilisation, as indicated by the resulting swept area performance (SAR), depends on correctly matching the size of the trawl, in conjunction with the size of otter boards used, with the capacity of the trawler. The selection of basic trawl system parameters by industry is based on experience and tradition. This produces a likelihood that much trawl effort in industry occurs with gear that is not optimal. The difficulties of selecting optimal trawl gear for a given operation are compounded by the fact that the basic parameters interact with other variables in the system, for example, mesh size, twine diameter and otter board style/efficiency.

In the hypothetical situation shown, point A shows the current operating position for a trawler. It is clearly not where maximum performance occurs on the map. However, at the position of maximum swept area performance the trawl speed is only about 1.85 knots. This could well be too slow for practical trawling, whereby the operator might specify that the minimum trawl speed allowed is 2.25 knots. Under these circumstances, point B would give the maximum performance available. To operate at this point the operator is required to purchase smaller nets and larger otter boards and in so doing the swept area performance would increase by 12%.

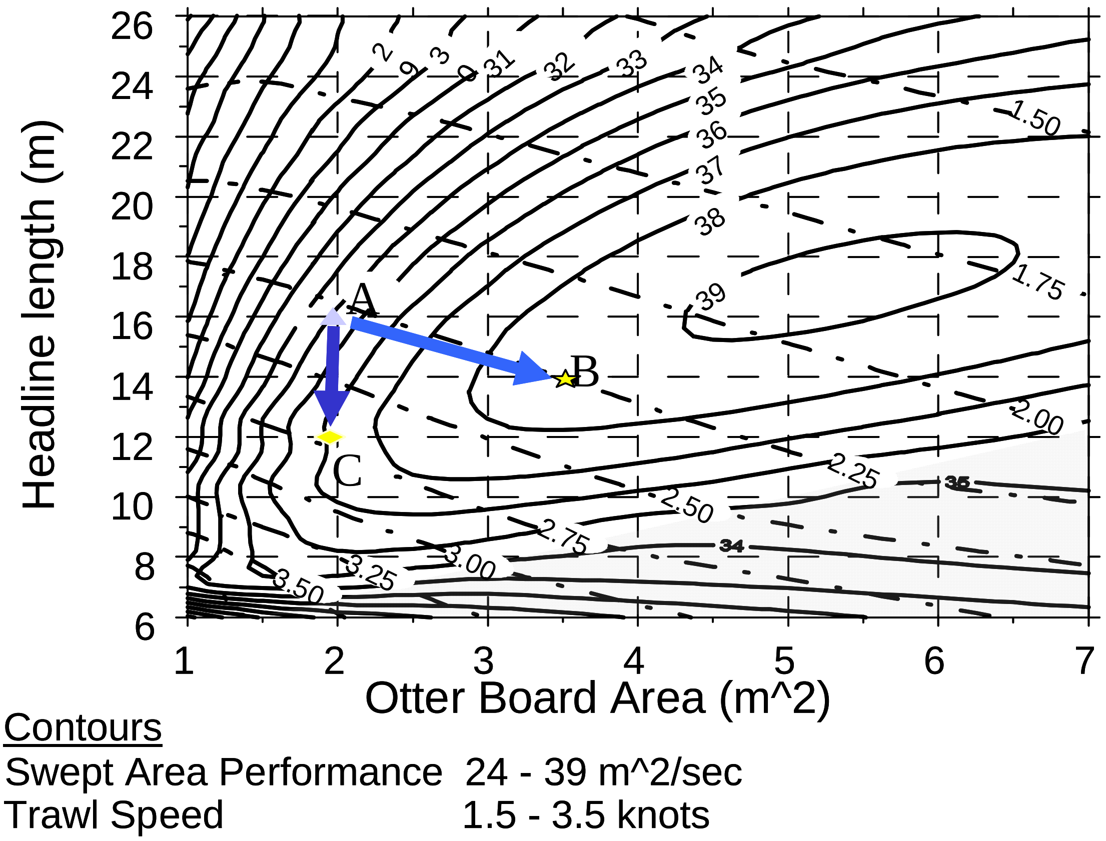


Figure 4 Optimum component matching using swept area performance map.

The diagram shows that this operator has made the classic mistake of trying to tow nets that are too large. If smaller nets were used in conjunction with the existing otter boards, as indicated by point C, the swept area performance would increase by 6%.

4.4 Component efficiency

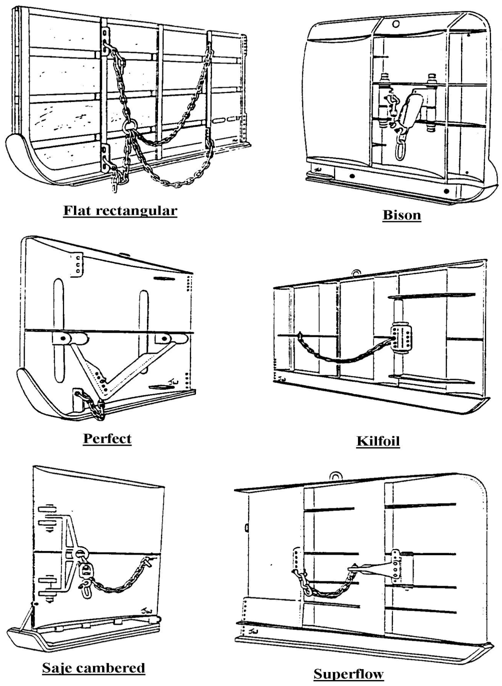
The components of trawl gear can be developed towards improved intrinsic performance by changing their structural form. For example, the use of low drag netting in trawls or curved foils in otter boards. However, the components of trawl systems also have performance qualities defined in terms of their role in the trawl system and how well that is achieved, as highlighted in the previous section where the size of the trawl is important and depends on the size of the boards selected and the horsepower of the boat.

Additionally, there is a deeper level of complexity regarding the design and optimal form of components, because it is also dependent on the characteristics of the rest of the system. That is, the optimum structural form of some components cannot be determined in isolation and has to be pursued in concert with the matching process identified above, as this pins down precisely the engineering environment in which the component is operating.

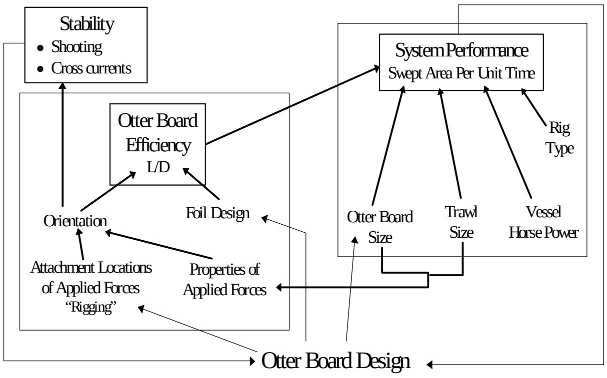
A good example of this interaction and the efficiency implications is the optimal design of otter boards for prawn trawling as depicted in Figure 5. A cursory look at the traditional flat rectangular otter board and the problem of otter board drag very often leads people to believe that big improvements can be achieved by developing better foil shapes alone. However, increased efficiency comes about by a combination of good foil design and appropriate otter board orientation.

Contemporary otter boards include many designs that have been developed with the narrow objective of incorporating more aerodynamic foils. From sea trial tests some of these boards produce small improvements in trawling performance, but most showed no significant improvement over the traditional flat rectangular otter board [4].

By following a broad approach to otter board design as shown in Figure 5, therefore recognising all aspects of the problem and understanding how they interact, it is very feasible that otter boards can be developed that have 65% less drag than current designs. This large gain is possible because the current efficiency of otter boards for prawn trawling is very low (shear to drag ratio about 1). Achieving an otter board with a shear to drag ratio of 3 (65% less drag) is not in itself an unrealistic expectation since that is still modest when compared to the efficiency of other common fluid-dynamic devices (eg. kites, sails, propellers, aircraft wings). The difficulty with this objective for prawn trawling otter boards arises because the need for good shooting away stability and highly spread trawls, which is optimal for prawn trawling, makes it very difficult to set prawn trawling otter boards at a low and efficient angle of attack.



Contemporary otter boards



- Provide large degree of spread
- Have low drag
- Be stable at all times

It appears quite feasible that new otter boards can be developed that produce 65% less drag and allow trawling efficiency to increase by about 15%.

Figure 5 Contemporary prawn trawling otter boards with framework and vision for improved performance.

4.4.1 Innovation in otter board design

The innovative features of the Batwing otter board are consistent with the design improvement strategy outlined above and the idea that the difficulties in achieving high fuel efficiency and good stability with traditional otter boards is due to the longitudinal separation of the towing (bridle) connection point and the net attachment points. That conventional arrangement makes it hard to set low efficient angles of attack. Bringing these connection points to a common longitudinal position inherently produces an otter board arrangement where this conflict is removed. These ideas produce an otter board that functions in the same way as a tailless kite on a single string.

Incorporated in the Batwing design is the feature that the main ground contact shoe is also aligned with the direction of tow and is hinged to the hydrodynamic wing at its trailing edge. This feature is principally designed to put the Centre of Gravity for the board under the tow point, such that the board maintains its operational orientation whilst at the trawl blocks and whilst being lowered into the water during the shooting-away process. Another advantage of the inline shoe is that it minimises the ploughing forces acting on the board, which although known to generate a spreading force, also generates an excessive amount of drag and inefficiency.

The latest and most refined version of the Batwing otter board, shown in Figure 6, incorporates a flexible sail so that the position of the centre of gravity can be more optimally located. Another advantage is that construction costs can be substantially reduced to produce a more cost competitive otter board product. This latest version of the Batwing otter board is the subject of an implementation project for Moreton Bay trawlers and is expected to produce a reduction in fuel use for that fishery of 20-25%. Consideration to commercialisation of the product is currently underway.

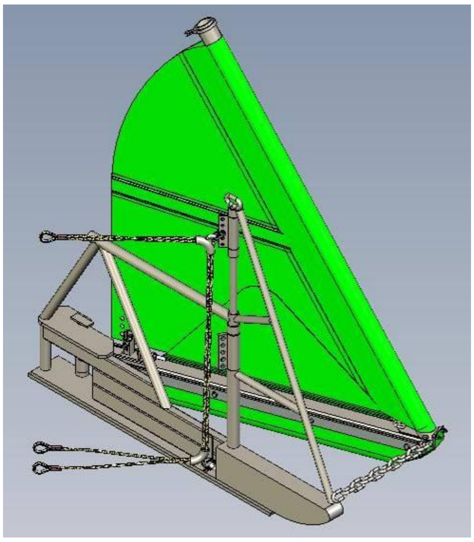


Figure 6 Concept model for the CP2 Batwing otter board.

4.4.2 Innovation in trawl net design

As mentioned in a number of instances above a logical initiative for improving trawl performance and efficiency is to develop designs that incorporate high strength netting so that the diameter of the twine can be reduced and less engine power (fuel) is required to tow the net. R&D in this area has been occurring around the world for a decade or so to implement ultra high-density polyethylene (Spectra and Dyneema) into trawl nets. A major impediment to this initiative is the much higher cost of high strength netting and negative side effects of implementation, including shooting away problems with the connected otter boards and entanglement issues with bycatch. The simplistic economic advantage of the high strength materials is clear-cut. Twine diameter can easily be reduced by 30% through using high strength netting, which theoretically reduces the drag and fuel consumption of the trawl system by a similar amount. This easily pays back the additional cost of the netting in a short period and contributes to improved profitability of the operation. However, the difficult side effects experienced in many cases still present R&D challenges for successful implementation of the initiative.

Another possibility for improving the engineering performance of trawl nets is developing design changes that make a net, with a given drag, easier to spread by the otter boards. European gear technologists stated a similar objective in the early 90’s in relation to designing fish trawls that obtained greater headline height for a given amount of headline floatation. Their objective was also to control the opening of meshes in the side sections of the trawl to improve size selectivity of the catch. A “Y-Design” trawl was developed in that instance and at the same time a “Pleated-panel” trawl for prawn trawling was developed at the Australian Maritime College and tested in the flume tank [5]. The principle behind the trawl design is shown in Figure 7. For the Pleated-panel trawl the drag force of the net is transferred more directly from the codend and netting to the towing points (Figure 7 (c)). The results of the flume tank tests showed that the pleated-panel trawl was in fact 20%-40% easier to spread over the range of spread ratios between 70% and 90%. However, the pleated-panel trawl itself had 20%-30% more drag than a traditional net over the same spread ratio range despite having about 10% less twine area. The extraordinary high drag results for the Pleated-panel trawl have not been conclusively explained, but must be linked to the changed shape of the trawl in the water flow and possibly the square-mesh orientation of the netting in the side sections of the trawl.

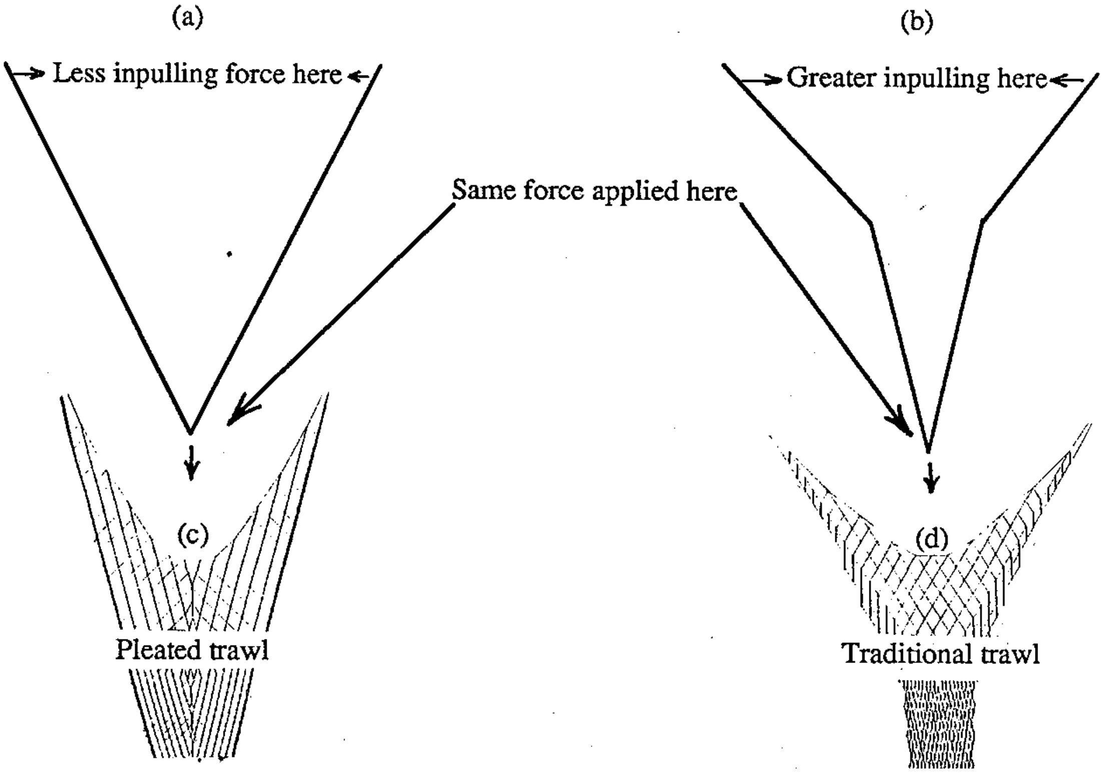


Figure 7 Principle of the pleated-panel trawl, giving rise to a net that is easy to spread [5]

The square-mesh orientation of the side sections was seen as a beneficial selectivity feature of the trawl design, but now appears may be detrimental from an engineering performance perspective. No full-scale tests in the field have been conducted to test the selectivity or economic performance of the pleated-panel trawl.

A novel trawl design shown in Figure 8 is an interesting advance on the objectives and outcomes of the Pleated-panel trawl experiment. This trawl design has square mesh orientation in the upper and lower panels, which allows the drag of the codend and much of the trawl to be directly transferred to a central towing wire rather than the otter boards. This trawl has a tongue in both the upper and lower panels and is similar to the "Twin Trawl" proposed by Collins in the mid 80's, except that it has a mesh orientation regime similar to the traditional Siebenhausen trawl. In the wings of the novel trawl, like the Siebenhausen, the side sections have netting that is oriented on the diamond but is held open by the strain transfer process within the trawl. This is very dissimilar to flyer style trawls, particularly 4 seam versions, where the meshes in the side sections naturally tend to close up during operation and would have low size selectivity characteristics.

The hypothetical properties of the novel trawl are:

- Easy spreading
- Low drag
- Good size selectivity

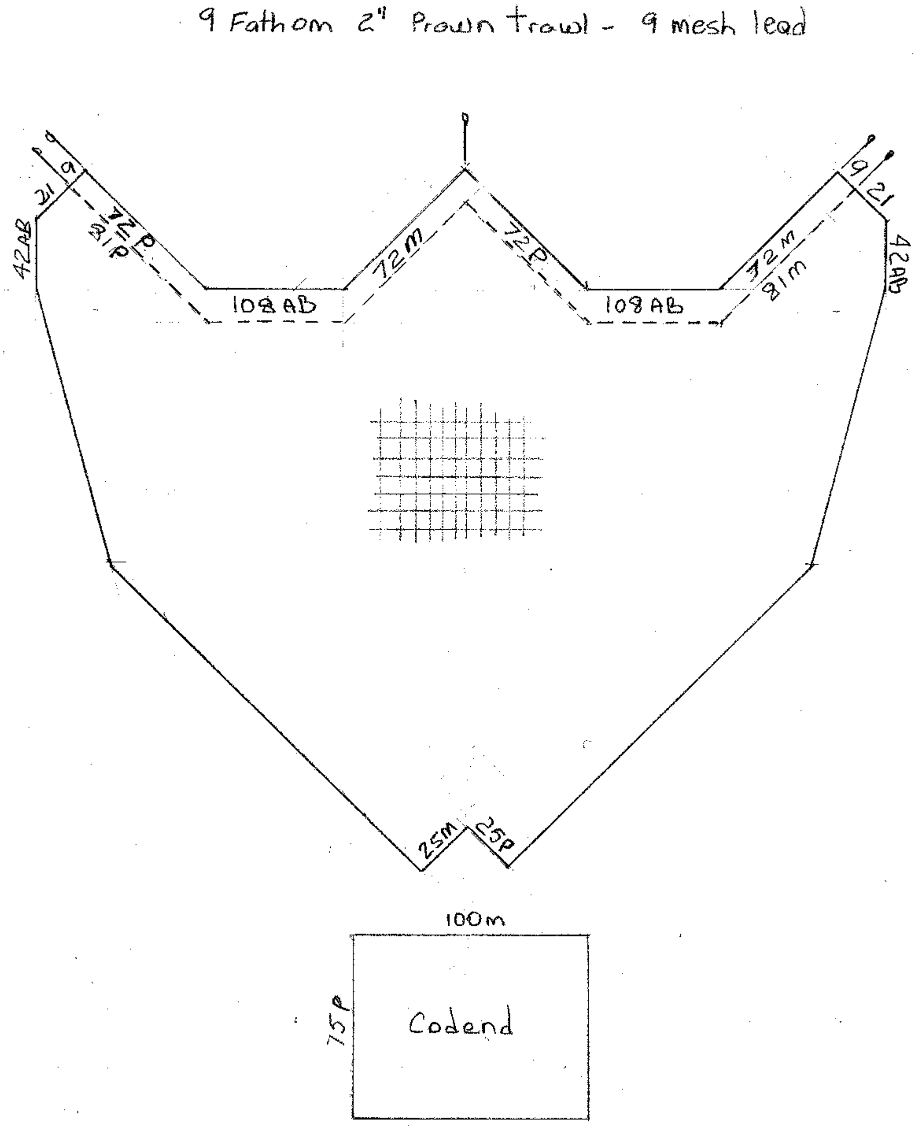


Figure 8 Novel trawl design aiming to produce high energy efficiency and selectivity

4.5 Conclusions

The proper utilisation of netting with reduced twine diameter in prawn trawls should proportionally reduce the rate of fuel consumption for prawn trawlers. Therefore, twine diameter is possibly the most powerful energy efficiency variable in prawn trawling.

The Batwing otter board is a new otter board technology for prawn trawling that incorporates rigging features to achieve stable and efficient operation at much lower angle of attack. Feasibly, the drag of the otter board is reduced by about 70% and the use of a flexible sail makes construction costs very low.

Innovative trawl design has the potential to improve the hydro-mechanical and selection efficiency of trawling, however the expertise and infrastructure required to pursue this initiative is at very low level of readiness and capacity in Australia.

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