Lessons from Fishing Vessel Energy Audits

A Vessel Energy Audit is a process for determining how much energy is used in each of the vessel's systems, including propulsion, AC and DC electrical, hydraulic, and refrigeration.

An energy audit involves skilled application of sensitive instrumentation that records fuel flow, shaft speeds, torque, AC and DC current flow, radiated heat, hydraulic fluid flow, and other parameters. Once data are collected, an analysis is required to identify high-energy-use areas and suggest energy conservation measures (ECMs). The substantial cost of a true vessel energy audit normally puts it out of reach for small boat owners.

The Alaska Fisheries Development Foundation has secured State of Alaska funding and collaborated with the Alaska Longline Fishermen's Association, the Alaska Sea Grant Marine Advisory Program, and the marine engineering firm Alaris Companies, to develop a low-cost self-guided energy analysis tool that small vessel owners can use to evaluate their energy use. Alaris conducted detailed technical energy audits on a range of Alaska fishing vessels to get baseline data on various vessel types.

The Energy Analysis Tool (Tool) is based on a library of energy use data collected from the vessels in the Alaris study. The Tool allows vessel owners to enter vessel specifications and operational performance measures for each vessel's operating modes. Vessel owners can then assign horsepower or kilowatt loads from various systems on their vessels to these operating modes, if they know them, or use stored data on a similar vessel collected during the onboard energy audits conducted by Alaris. The Tool then calculates baseline energy use, expressed as gallons or dollars, and presents summary data in tables and pie charts for each system and operating mode.

Goals of this project are:
1. To provide the vessel owner a format for understanding a vessel's baseline fuel energy use and how much each component the vessel and operation consumes.
2. To gather baseline data for doing energy cost analyses.
3. To help the owner identify energy conservation measures that are practical and cost-effective.

Vessel Energy Use Overview

None of the power used aboard a fishing vessel is free. Mechanical, electrical, and hydraulic power all come at a fuel cost. The only exceptions would be sail power and solar or wind electricity generation.

All conversion of vessel fuel energy into useful work has inherent inefficiencies. Energy is lost to heat, noise, vibration, friction, thermal conversion, drag, and wave-making resistance. Most (60%) of the fuel energy delivered to an engine escapes as heat through cooling jacket water, oil, radiation from the block, and exhaust. Another 3-5% is lost through friction in the
transmission (reduction gear) and bearings. Propellers are only 55-65% efficient due to slip and cavitation. Most of these losses are unavoidable but many can be minimized.

**Brake specific fuel consumption (BSFC)*** is a measure of thermal conversion expressed as units of fuel (grams, pounds, or gallons) per unit of power (kW or hp) produced at a given power setting. A typical diesel engine has high BSFC at low power (below 30% of its rated horsepower, depending on engine type) and becomes more efficient (uses less fuel per hp) at higher speed and load.

**Engine efficiency** and **propulsion efficiency** are not the same thing. Running at slower speed reduces hull losses and saves a lot of fuel even if the engine is operating inefficiently. There is a point, however, where engine efficiency becomes so low that the fuel cost per mile increases. The energy audit identified this minimum speed for the most efficient operation on several types of vessels.

The project considers six categories of energy consumption, and takes into account the following:

**Transit propulsion**

- **Engines that are more powerful than necessary are under-loaded under normal operating conditions** and suffer inefficient conversion of fuel to work.
- **Wave-making resistance** occurs when a hull pushes aside a bow wave and drags a wake. The energy consumed in making those waves increases exponentially with speed. A vessel also loses energy to hull skin friction, and the faster it passes through the water the more energy is lost.
- A typical **propeller only uses about half of the horsepower** that the engine can deliver. Improperly sized or nonoptimal design are even less efficient. Even a small amount of marine growth or a rough surface on propeller blades decreases propeller efficiency.
- **Underwater appendages**, including struts, transducers, rolling chocks, and stabilizer fins, increase drag and reduce fuel efficiency. Operating factors such as comfort and safety may outweigh fuel considerations, but vessel operators should be aware and make conscious choices.

**Fishing propulsion**

- Fixed-pitch **propellers usually are optimized for transiting** and are even less efficient during fishing operations.
- **Low speed operation achieved by running a large engine at low output results in high brake specific fuel consumption**, which means high cost for the amount of power produced. It also means high capital and maintenance costs and can shorten engine life.
**AC electrical**

- AC electrical generation has inherent inefficiencies. **More than half of the fuel energy supplied to a properly loaded diesel generator is lost to heat and friction.** The efficiency of the generator depends on the construction of the generator as well as the size. A properly sized high efficiency generator will be the most fuel efficient. High output generators are about 98% efficient, and smaller units are about 75% efficient.

- If onboard AC electrical generators are oversized they are under-loaded most of the time, and brake specific fuel consumption is dramatically higher at low load. A **diesel generator run at 10% of its rated output consumes at least 40-50% more fuel per kW than when run a full load.**

- **Onboard generation typically costs two to four times as much** per kilowatt-hour as shore power at the dock.

- Energy losses (and safety concerns) can be considerable if electrical systems are not properly sized, installed, and maintained. Undersized wiring, improper or poorly maintained terminals and connections, inadequate grounding, and other errors generate heat that robs energy, causes devices to operate inefficiently, and can cause fires and other damage.

- All electrical devices have inherent inefficiencies, often detectable as radiated heat. **Incandescent light bulbs consume up to ten times as much energy** as LED lights and up to four or five times as much as compact fluorescent lights (CFL). Efficiency varies significantly by manufacturer, lighting output, and service. LED lights also have longer service life, which is not diminished by turning them on and off frequently. Pumps, fans, and other electric motors experience 5-20% energy loss to heat. Modern premium efficiency motors waste less energy.

**DC electrical**

- Common engine-driven **DC alternators are about 45-55% efficient** in converting engine mechanical energy into DC electrical current. Premium efficiency alternators are as much as 75-85% efficient. A standard V-belt saps some additional energy. A DC alternator takes about 1 hp from the engine for every 25 amps at 13.5 volts.

- Each electrical device has a nominal amperage draw, and **induction motors have a much larger start-up surge demand.** Name-plate amperages can be entered in the Energy Analysis Tool along with the percent of total time it is powered up, and whether there is a transmitting or full-power demand that is far greater than the standby usage. Radios and radars, for example, use a lot more power when transmitting than when on standby.

**Hydraulics**

- Hydraulics drawing power from the main or auxiliary engines operate at a wide range of efficiencies depending on manufacturer of pump and motor, size of system, and load, with efficiency of optimized systems at about 98%. Wherever a hydraulic system makes **noise or heat it is wasting energy.** Proper sizing of components, and assuring that plumbing allows unrestricted flow, minimizes heat loss.

- **Continuously running hydraulics waste energy** when not engaged.

- **Hydraulic power demand can be** calculated from pump displacement, pressure, and flow rate. If good hydraulic system data are entered in the Energy Analysis Tool it will show the fuel cost in gallons and dollars per year.

**Refrigeration**

- Most fishing vessel refrigeration is either blast freezer or refrigerated seawater (RSW), powered by electricity or hydraulics. The biggest energy demand in both types of refrigeration is the compressor; lesser energy inputs power the seawater pump for the condenser and the circulation pump (RSW) or the fan (blast freezer).

- Both types of refrigeration are most **energy efficient under heavy load.** At full load RSW refrigeration typically requires about 1.6 hp per ton of capacity, and blast freezer about 4.6 hp per ton of compressor rating.

- When an operator enters blast freezer compressor capacity, evaporator fan, and saltwater condenser pump, the Energy Analysis Tool **can calculate horsepower use.** Likewise, with RSW load rating (in tons) the program will calculate hydraulic power refrigeration demand in horsepower.
Some of What the Energy Audits Show

1. **Each type of fishing vessel uses energy differently.** Typically transiting constitutes half of vessel energy use, but the range is 8% to 55%. Propulsion while fishing ranges from 10% to 33%. On some vessels hydraulic power consumes more than half of the total energy use, and on others refrigeration takes as much as 65% of total energy.

2. An **under-loaded vessel burns fuel inefficiently.** The energy audits show that a typical naturally aspirated four-stroke diesel engine operating at 10% of its rated horsepower burns about 0.13 gallons of fuel/hp/hr but at 30% load it uses only 0.08 gal/hp/hr.

3. **Turbocharged engines are typically more efficient** than naturally aspirated engines, particularly at higher loads. The data show that at 10% of rated output a turbo engine is using 0.07 gal/hp/hr, at above 30% it uses only about 0.05 gal/hp/hr, and it becomes even slightly more efficient at higher power settings.

4. At very low power output the two-stroke diesel is less efficient than four-stroke but at higher power settings the **two-stroke can have similar efficiency** to most naturally aspirated four-strokes in the study.

5. At **very low vessel speeds fuel efficiency decreases** due to the increased brake specific fuel consumption noted above. One vessel in the audit was just as efficient at 6 knots as at 4 knots, with lowest gal/nm at 5 knots.

6. **Nearly all main engines are oversized** for propulsion needs. At transiting cruise speed audited vessels were using only 13% to 33% of available horsepower, averaging 20%.

7. Small boats in the audit have DC electrical costs ranging from $388 to $1040 per year. Incandescent lighting, galley refrigerators, and autopilot pumps are major uses of DC power.

8. Hydraulics consume a lot of energy, up to 55-57% of the total energy budget on some vessels.

9. Fish hold refrigeration compressor **head pressures tend to be kept higher than necessary.** One audit shows that reducing head pressure can save 23% in refrigeration fuel cost.

Some Possible Energy Conservation Measures (ECMs)

**Propulsion—transiting**

- **Slow down.** Audit results illustrate that from a vessel’s theoretical “hull speed” an 11% decrease in speed reduces fuel consumption by 43%; a 25% decrease in speed reduces fuel consumption by as much as 75%.

- **Use stabilizers only when needed.** Paravane stabilizers impart significant drag and increase fuel costs. One test on a 39 foot troller shows that the fuel cost per nautical mile increased by 60% with stabilizers deployed. Other devices, such
as gyro or anti-roll tanks, do not create drag.

- **Install a fuel-flow meter** and use it. If wired to the GPS to show gallons per mile rather than per hour, it will help the operator adjust speed to optimize propulsion fuel efficiency.

- **Keep hull and prop free of fouling organisms and slime** to reduce skin drag resistance.

- **Use waste heat** from the engine cooling circuit for water heaters and cabin heaters.

- **Ensure that steering is properly adjusted and tight.** Steering pumps use a lot of energy, and a vessel zigzagging through the water is traveling much farther than if going straight. Ensure the autopilot is tuned to minimize yaw.

- **“Right-sizing” main engines.** When doing a new-build or re-power, select engines only powerful enough to do the job efficiently.

### Propulsion—fishing

- It may **save money to use a small auxiliary engine** with a second prop shaft, or with hydraulic or electric drive for low speed operation. A diesel-electric hybrid drive could be the solution.

- **Variable pitch or controllable pitch propellers** can to some extent compensate for the changing loads and power demands of fishing. Propeller ducts, nozzles, or tunnels can improve propeller efficiency, as can more advanced propeller and drive train design.

### AC electrical

- **“Right size” generators** to match the load. It may be more efficient to install a second, smaller genset for “hotel” loads rather than to run a large unit under-loaded.

- **Use a sine wave inverter**, where possible, in place of diesel generator for “hotel” and other light loads. True sine wave power is more energy efficient and less harmful to delicate electronics than square or modified sine wave.
• If lights, pumps, refrigeration compressors, or other high demand electrical units are required at dockside, use lower-cost shore power rather than run an onboard diesel generator.
• Where possible, select Energy Star–certified light fixtures and bulbs, fans, entertainment devices (TVs, stereos), vacuums, cordless power tools, and other tools and appliances.

DC electrical
• Turn off lights, fans, pumps, and other devices when not needed.
• Switch to a premium efficiency alternator, which can save 30% in DC generation cost. Using cogged belts or serpentine belts can save another 2%.
• Keep alternators cool with adequate ventilation, and ensure pulleys are sized so that the alternator runs at optimal rpm, commonly 4500-6000.
• Replace incandescent lights with CFL or LED, which can save 75% in lighting costs.

Hydraulics
• Declutch hydraulics when not in use, if possible.
• Keep hydraulic fluid and filters clean to reduce back pressure and wear.
• Use the lightest grade fluid recommended by equipment manufacturers, and use synthetic fluid if allowed.
• Ensure the hydraulic lines run smoothly without tight bends or obstructions.
• Consider installing a dedicated small auxiliary engine to run hydraulics.
• Variable frequency drive (VFD) controls on electric-driven hydraulics and hydraulic steering save energy.
• In some applications more efficient electric power could replace hydraulics.

Refrigeration
• Ensure thorough insulation of fish hold and coolant plumbing.
• Reduce compressor discharge pressure (head pressure). An audit of a large Alaska trawler shows that decreasing head pressure from 180 psi to 140 psi reduces energy demand by 23%.

In Conclusion
This is a preliminary report. The Alaska Fisheries Development Foundation, Alaska Longline Fishermen’s Association, and Alaska Sea Grant Marine Advisory Program continue development of the energy audit project, and the Energy Analysis Tool is undergoing further refinement. Fishermen are encouraged to work through the Tool and report to the project team with their data and comments on the experience. Test drive the Tool with a jump drive from AFDF. For a copy of the Energy Analysis Tool contact Julie Decker at jdecker@afdf.org or Dan Falvey at myriadfisheries@gmail.com.

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