

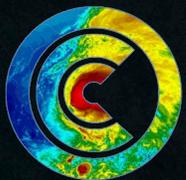
EV on H₂O?

The Feasibility
of Electrifying
Maine's
Lobster Fleet

by

John Hagan and
Richard Nelson

March 2022



OUR CLIMATE COMMON



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Richard enjoyed a career as a commercial lobsterman, fishing out of Friendship, Maine for over thirty-five years. He has served on Maine's Ocean Acidification Commission and subsequently on the steering committee of the Maine Ocean and Coastal Acidification (MOCA) partnership. He has participated in the Northeast Regional Ocean Planning process guided by the National Ocean Policy. He serves on the Steering Committee of the Maine Climate Table. He continues to write, speak, and advocate for ocean and climate issues.

Recommended Citation

Hagan, J. and R. Nelson. 2022. EV on H₂O?: The Feasibility of Electrifying Maine's Lobster Fleet. Maine Climate Table Report, Georgetown, Maine. 30 pp.

Note to readers

Throughout this report we use the term "lobstermen" and "fishermen" because most women who fish commercially for lobster prefer to be called lobstermen or fishermen. We are respecting the preferred name of the people we are referencing in this report.

Cover Photo

© Mark Fleming, LONE SPRUCE CREATIVE (<https://www.lonesprucecreative.com/>)

Acknowledgements

This was an expansive topic to tackle. Many, many people were very generous with their time and knowledge, and enthusiastic about this report. We especially thank [Martin Grimnes](#) of Arcadia Alliance in Belfast, Maine, who connected us to many people in the marine industry on the cutting edge of propulsion technology. We also thank [Tom Kittredge](#) and [Amy Leshure](#) at Maine Technology Institute for key connections early in the project. We also thank [Nigel Calder](#) (author of The Boatowner's Mechanical and Electrical Manual), [Peter Dion](#) (Cummins), [Nick Planson](#) (The Boat Yard in Yarmouth), [Chad Strater](#) (Sea Meadow Marine Foundation), [Joe Hudspeth](#) (British Aerospace), [Joe Ferrari](#) (MAN Energy Solutions), [Jim Gallea](#) (Casco Bay Custom Charters), [Matt O'Sullivan](#) (Yacht Eco), [Mike Gunning](#) (Yacht Eco), [Scott McMillan](#) (Electric Yacht), [Mike Shafer](#) (Danfoss), [Terry Howe](#) (Ballard Fuel Cell Solutions), [Heather Deese](#), (Dandelion Energy), [Chantel Leturneau](#) (Nova Scotia Boatbuilders Association), [John Howell](#) (ClearFlame), [Brent Dancy](#) (Oceans North), [Riva Krut](#) (formerly with Linde, a hydrogen supply company), [Gordon Beck](#) (A Climate To Thrive), [Susie Arnold](#), [Emma Wendt](#), and [Emily Roscoe](#) (Island Institute), [David Reidmiller](#) and [Jonathan Labaree](#) (Gulf of Maine Research Institute), [Jonathan Kruse](#) (Torqeedo), [Douglas Read](#) (Professor of Engineering) and [Brendyn Sarnacki](#) (Research Engineer), both at Maine Maritime Academy, [John Joseph](#) and [Alan Joseph](#) (Coastal Energy, Ellsworth), [Eric Graves](#) (Boothbay Harbor Shipyard), [Cathy Fetterman](#), [Dierdre Gilbert](#), and [Loraine Morris](#) (Maine Department of Marine Resources), and [Sue Molloy](#) with Glas Ocean Electric. [Jim McMahan](#) (lobsterman, Five Islands, Maine) helped us understand the various "duty cycles" of lobster boats today. We thank [Mark Fleming](#) for the exceptional cover photograph and for the lobster boat hull shapes in Figure 14. Finally, we thank the [Seal Bay Fund II](#) at the [Maine Community Foundation](#) and a Maine Community Foundation [anonymous donor](#) for making this report possible.

Friendship, Maine wharf (photo by J. Hagan)



Executive Summary

Every sector of our economy is working to reduce the greenhouse gas emissions that are warming the planet. In some industries, such as commercial fishing, the warming ocean and changing conditions (weather, seasons, fisheries management) are directly affecting fisheries landings. Reducing emissions therefore has economic implications, not just in terms of the cost of fuel, but in terms of viability of our New England fisheries.

Fishing, especially lobster fishing, is core to both Maine's economy and heritage. It contributes \$1.5 billion to the economy and makes up 79% of the value of all fisheries landed in Maine. For many years the American lobster has ranked among the most valuable of all fisheries in the entire U.S. Conserving this fishery is critical to Maine and its coastal communities.

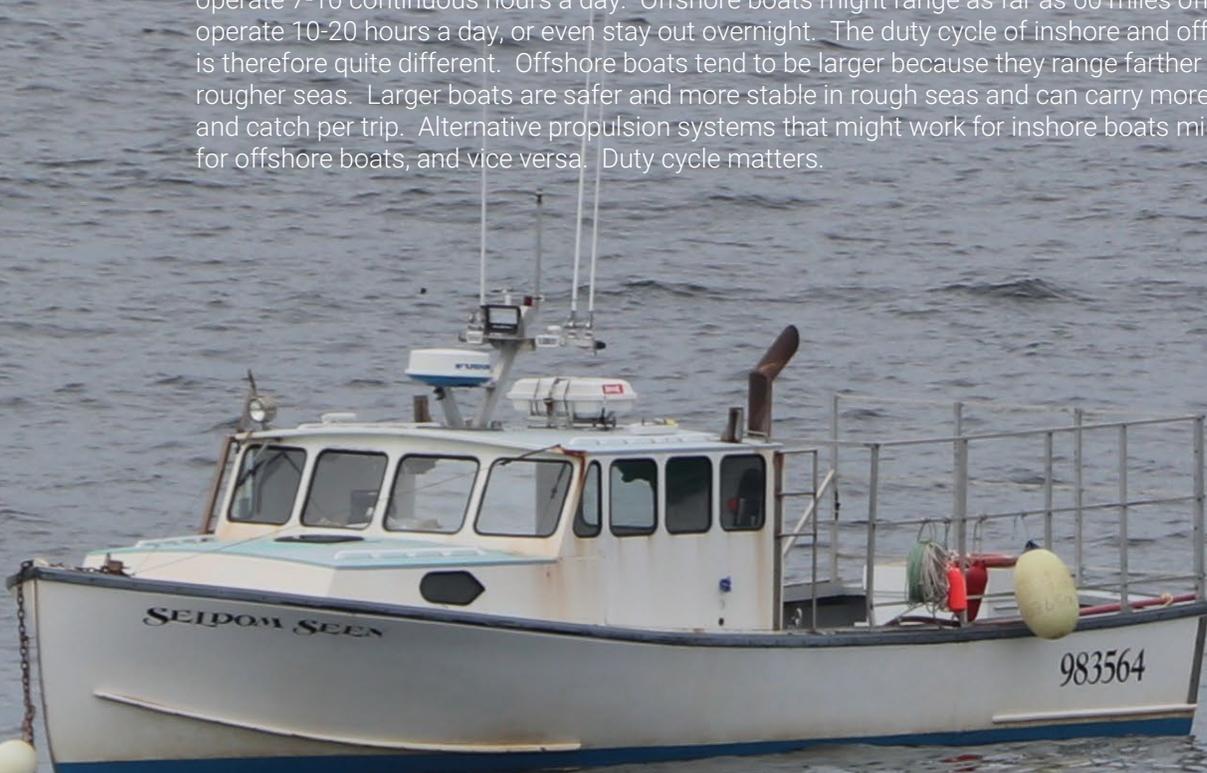
The State of Maine is taking steps to reduce greenhouse gas (GHG) emissions from burning fossil fuels. Maine has a goal of reducing emissions by 45% by 2030, and 80% by 2050. The purpose of this report is to map out possible alternative propulsion systems for the ~4,700-boat Maine lobster fleet that would reduce emissions and save fuel costs. We provide an overview of the major systems that show potential, either now or in the next 10 years. We hope that by laying out the possibilities, boatyards, boatbuilders, and fishermen will take the opportunity to test these systems in a real-world setting.

We discuss the following possible alternatives:

- Pure EV (electrovoltaic)
- Hybrid systems
- Hydrogen fuel cell systems
- Biofuels

Before any of these alternatives can be evaluated, the duty cycle of a lobster boat must be understood. That is, how long does the boat operate on a single fishing trip, at what speeds, and at what loads? What are the other energy requirements of a lobster boat besides propulsion (e.g., navigation equipment, trap hauler, live-wells)? Any alternative system will need to meet the full energy demands of a lobster boat.

The Maine lobster fishery today can be roughly divided into inshore boats and offshore boats. Inshore boats set traps within about 3 miles of shore (state waters) and 12 miles from port, and operate 7-10 continuous hours a day. Offshore boats might range as far as 60 miles offshore and operate 10-20 hours a day, or even stay out overnight. The duty cycle of inshore and offshore boats is therefore quite different. Offshore boats tend to be larger because they range farther and work in rougher seas. Larger boats are safer and more stable in rough seas and can carry more traps, bait, and catch per trip. Alternative propulsion systems that might work for inshore boats might not work for offshore boats, and vice versa. Duty cycle matters.



Based on our research, no **pure EV system** today can meet the duty cycle demands of even an inshore boat. The batteries required to run an inshore boat for 7-10 hours would be too heavy *and* too costly. This takes EV “off the table” for offshore boats too, which are even more energy demanding. Moreover, lobster boats in Maine generally moor rather than dock at night. There is no existing infrastructure to recharge moored boats. This infrastructure problem is solvable, but unless EV systems can meet the duty cycle needs of a lobster boat, the infrastructure problem is moot. Given the rapid advancements in battery technology in the auto industry, however, this question will need to be revisited in a few years.

In a **hybrid parallel system**, an existing (or smaller) diesel engine and an electric motor are connected mechanically to the propeller shaft. The diesel can take over at higher loads (speeds) where it is most efficient, for example while transiting to the fishing grounds. The electric motor can be used at slow speeds where it is more efficient, such as when hauling traps. The diesel, with a generator (called a “genset”), could also be used to recharge the battery storage system required by the electric motor. While there would still be greenhouse gas emissions, they could be 30-40% less than conventional diesel systems.

Hybrid serial systems also have both a diesel engine and an electric motor, but only the electric motor is connected to the propeller shaft. A smaller diesel engine than is typical would function solely to generate electricity for the battery storage system that in turn supplies electricity for the electric motor (and other boat functions).

We also investigated **hydrogen fuel cell systems**. Hydrogen systems are like pure EV systems, except the fuel cells constantly produce electricity for a battery storage system as long as there is a supply of hydrogen on board. Only water and heat are byproducts. Boats would fuel up with hydrogen rather than diesel at the dock—preferably “green” hydrogen produced from local renewable energy sources using an electrolyzer. Hydrogen fuel cells are being used in larger boats, such as ferries, but the technology has not made it to commercial fishing boats in any significant way. Both hybrid and hydrogen fuel cell systems rely on a battery storage system, so battery overheating must be managed.

Finally, we investigated **biofuels**, specifically biodiesel. Biodiesel is generally made from plants which have already removed CO₂ from the atmosphere, making the *net* emissions much lower than using traditional diesel. Biodiesel could simply replace diesel fuel without costly retrofits and is the simplest and most cost-effective immediate solution for significantly reducing emissions in the lobster fleet.

Innovators will be needed to test any or all of these systems in Maine. In the near term, we recommend testing a hybrid system, either as a retrofit or possibly with a more efficient hull design for even greater emissions reductions. Pure EV is not yet ready to meet the energy demands of most commercial lobster boats in Maine. With its diverse and capable boatbuilding industry, 3,000 miles of coastline, and a large fishing fleet, Maine is the perfect place to pioneer these new technologies.

Introduction

Globally, fisheries provide 17% of all animal protein consumed by humans (FAO 2014). Per pound of protein, fisheries tend to have a far lower carbon footprint than land-based sources (e.g., poultry, pork, beef) (Pimentel and Pimentel 2003, Tyedmers et al. 2005, Nijdam et al. 2012). In a world where 25% of human-caused greenhouse gas emissions come from the production of food, eating a greater proportion of fish relative to land-based sources of protein would be beneficial to the climate.

Nevertheless, the carbon footprint of global fisheries is significant. An estimated 11 billion gallons of fuel, mostly diesel, is combusted annually (2011 data) to land fish at the dock (Parker et al. 2018). This amount of fuel generates 179 million metric tons of greenhouse gases (mostly carbon dioxide, CO₂), or about 4% of total global food production emissions. Fuel consumption in global fisheries is increasing without an increase in landings, meaning fuel consumption is increasing per ton of fish landed (Parker et al. 2018). Despite the relative efficiency of fisheries compared to other sources of protein, the fishing and maritime industries are working to reduce emissions for both climate and cost reasons.

With over 3,000 miles of coastline and a nutrient-rich cold ocean, fishing is a major part of Maine's economy and cultural heritage. The well-being of many of Maine's coastal towns is tied to the sea. In 2020, the lobster fishery alone made up 79% of the value of all fish landed in Maine (NOAA 2020). Maine's lobster fishery is the largest among the New England states (Figure 1). For many years the American lobster has ranked among the most valuable of all fisheries in the entire U.S. There are 4,686 registered commercial lobster boats in Maine, and an additional 10,000 Mainers work directly within the industry. Altogether, the lobster industry in Maine generates about \$1.5 billion to Maine's economy (Donihue 2018).

Five Islands Harbor, Georgetown, Maine (photo by J. Hagan)



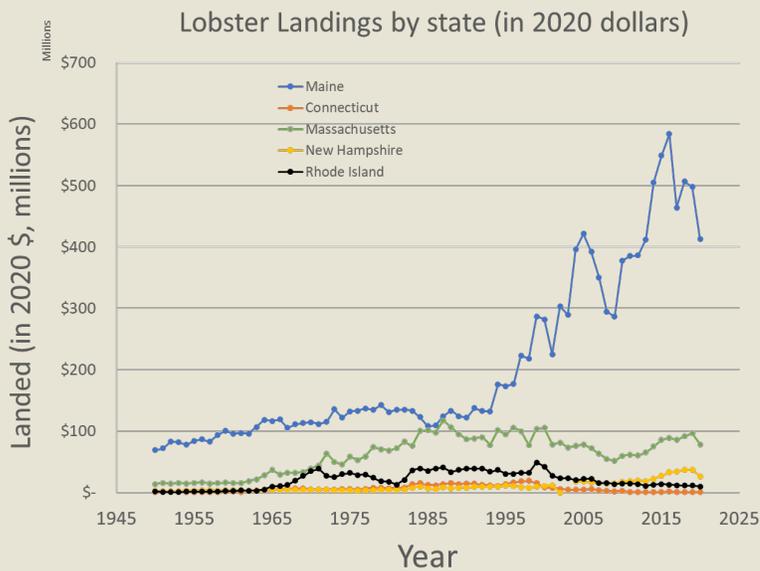


Figure 1. Lobster landings in 2020 dollars, by New England state.
Source: NOAA (www.fisheries.noaa.gov/foss/).

The Climate Challenge

The State of Maine has set a goal of reducing greenhouse gas emissions from fossil fuels by 45% by 2030 and by 80% by 2050 (Maine Climate Council 2020). Most nations understand that fossil fuel emissions need to be drastically reduced over the next three decades to avert widespread economic impact. All sectors of the global economy face the challenge of reducing greenhouse gas emissions in a carbon-constrained world. For example, in April 2018 the International Maritime Organization adopted a policy to reduce greenhouse gas emissions by at least half by 2050 (relative to 2008) and to phase out emission entirely as soon as possible in this century (IMO 2018).

Reducing greenhouse gas emissions is a business imperative in the 21st century. Maine seafood businesses already know this because they hear it from

customers. Increasingly, fish consumers want to know their fish comes from a sustainable source. Greenhouse gas emissions from landing fish are a big part of the sustainability equation. Millennials (age 26-40) especially are calling for these actions. They make up the largest consumer block today (Bollani et al. 2019).

There is another imperative especially relevant to Maine fisheries that has to do with physics. New England is warming significantly faster than most of the planet (Young and Young 2021), and the Gulf of Maine is one of the most rapidly warming bodies of water on earth (Pershing et al. 2015 2021). Gulf of Maine warming is thought to be driven by increased glacial melting in Greenland and the disruption of the cold Labrador Current that flows into the Gulf of Maine from the northeast.

Partly because of these changes, the lobster fishery is almost gone in Connecticut and Rhode Island due to warming waters and other stressors (Figure 1). Although the Maine lobster fishery is the largest and most robust in New England and has grown in the last two decades, if waters continue to warm in response to atmospheric concentrations of greenhouse gases, Maine's lobster fishery could be at risk. Reducing emissions in the Maine lobster fleet alone cannot stop warming in the Gulf of Maine, but it can contribute to the solution. Everyone needs to help reduce emissions in whatever way they can.

This report was prepared to help lobster fishermen, boat builders, boatyards, and others understand the state of technology of alternative propulsion systems that could generate lower greenhouse gas emissions from fishing and save money in the long run. We describe these alternative systems, including their advantages and disadvantages, with respect to current technology. Because of the long history and reliability of diesel engines in the commercial fishing industry, there has been little



Friendship Harbor, Maine (photo by J. Hagan)

real-world application of alternative propulsion systems for commercial fishing vessels to date. We hope this report spurs new thinking and new applications within the boat building and fishing industry in Maine and beyond.

A “Life-cycle Assessment” of Lobster Emissions

Before we discuss alternative propulsion systems, it’s instructive to understand the greenhouse gas emissions of getting a lobster from the bottom of the ocean to a plate for consumption. The Island Institute is presently working with Luke’s Lobster to evaluate the emissions of various segments of the lobster supply chain (E. Wendt, pers comm). We refer interested readers to this forthcoming report.

A life-cycle assessment (or LCA) is the common method for evaluating the greenhouse gas emissions of any product, from the extraction of the raw materials needed, to processing or manufacturing, to transportation, to re-use, recycling, or final disposal. Life-cycle assessment can be applied to a food product such as lobster, or a piece of equipment such as a computer or a cell phone. A well-done life-cycle assessment indicates where emissions are generated in the supply chain of the product. This, in turn, informs us about where in the supply chain the greatest emissions occur, and where opportunities lie to reduce emissions. The most cost-effective emissions reductions opportunities may or may not align with where emissions are greatest. A life-cycle assessment could also be done on impacts on water use, or other types of emissions, such as soot or particulate matter. But given the pressing concern for greenhouse gas emissions associated with climate change, many life-cycle assessments are now focused on greenhouse gas emissions.

As an example, a pioneering life-cycle analysis by Stonyfield Farms in 2001 showed that most of the greenhouse emissions from a cup of yogurt are generated by eructation (belching) from the cow that produced the milk for the yogurt (Keoleian et al. 2001). Stonyfield concluded that changing the cows’ diet was the most cost-effective way to reduce the carbon footprint of a cup of yogurt.

This report is not a life cycle assessment. We are focused specifically on reducing the emissions in just one part of the supply chain—catching and landing the lobster. Still, it is instructive to know what proportion of the carbon footprint of a pound of lobster on a consumer’s plate is due to catching and landing the lobster.

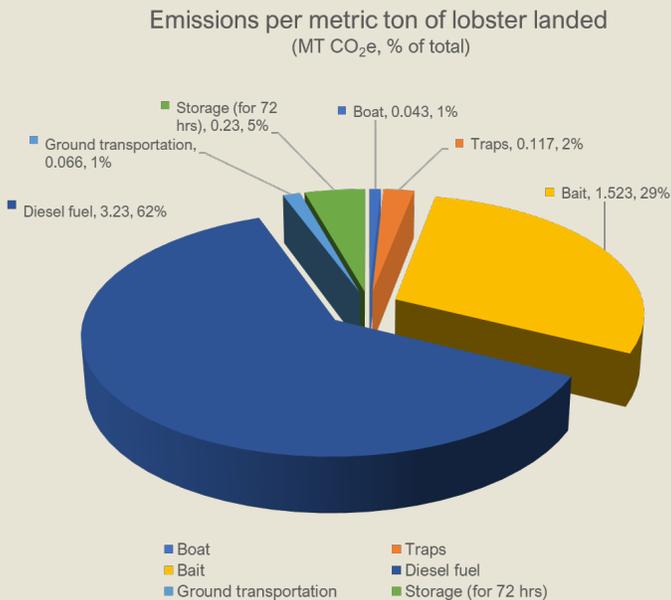


Figure 2. Greenhouse gas emissions per ton of lobster landed for different parts of the lobster supply chain. MTCO₂e = metric tons of CO₂ equivalents (the warming potential of all greenhouse gases converted to the warming potential of CO₂). (adapted from Driscoll et al., 2015).

The only detailed, peer-reviewed life-cycle assessment of greenhouse gas emissions in the lobster industry was conducted by Driscoll et al. (2015). This study compared greenhouse gas emissions of the Maine lobster fishery to the Nova Scotia lobster fishery. The study was based on surveys of lobster fishermen in both geographies in 2006. These two areas are very different in many ways, from days-at-sea to the size of fishing boats. Despite these differences, the greenhouse gas emissions were about the same for a pound of lobster ending up on a consumer’s plate.

For the fishing component of the supply chain, on average, burning one gallon of diesel fuel delivered about 8.3 pounds of live lobster to the dock in Maine (Driscoll 2010). One gallon of diesel fuel, combusted, yields about 22.4 pounds of CO₂ (EPA 2005).

To put this number in the larger context, the Maine Department of Environmental Protection reports that Maine emitted 17.51 million metric tons of CO₂ from burning fossil fuels in 2017, the last year emissions data are available (DEP 2021). In 2017 Maine fishermen landed 112,169,126 pounds of lobster to the dock. Using Driscoll’s average estimate of fuel use per pound of lobster, 112 million pounds of lobster in 2017 would have generated about 137,032 metric tons of CO₂ emissions. That means Maine’s lobster fleet contributed an estimated 0.78% (137,032/17,510,000) of Maine’s total greenhouse gas emissions in 2017.

The Driscoll et al. study also considered the emissions associated with catching the bait that was used to catch the lobster, the emissions associated with building and maintaining the lobster boat, the emissions from building the traps, running on-shore live wells, refrigeration of the lobster once landed, and transportation of the lobster to market. Among all these segments of the lobster supply chain, the question is— ‘where are the greatest greenhouse gas emissions and how can we reduce them?’

For the Maine lobster fishery supply chain, Driscoll et al. found that 62% of the total emissions came from burning diesel fuel to catch and land lobster (Figure 2). The second-largest source of emissions (29%) came from catching the bait (mostly herring trawls at the time) used in the lobster traps. Refrigeration was the next largest source (5%), and supply chain transportation post-landing was only about 1% of emissions. Emissions from post-landing transportation were higher for the Nova Scotia fishery, which, at the time, shipped its lobsters to Kansas City by land for initial processing and then by air freight to Las Vegas. By contrast, much of the Maine catch went by land freight to Boston (in 2006, when the study was done). The Nova Scotia lobster fishery was more efficient (more pounds of lobster per gallon of diesel used), but that efficiency was largely negated by the longer transportation chain. While air transportation emissions can be significant, they are

still small in comparison to the diesel fuel used by the lobster boat to catch and land the lobster to the dock. For this reason, our evaluation of alternative propulsion systems is an important focus for greenhouse gas reductions in the lobster fishery.

The “Duty Cycle” of a Lobster Boat

Boats and ships present challenges for alternative propulsion systems, such as electrovoltaic systems (battery-powered, or EV). Moving an object through water requires a tremendous amount of energy relative to moving a *rolling* object of equivalent mass through air on land (Tupper 2015). Cars, trucks, and buses can coast, especially when going downhill, which yields kinetic energy that can be captured to recharge electrovoltaic batteries. Because of the friction of the water, small and mid-sized boats stop quickly when power is removed. There is no “downhill” coasting on the ocean. This issue of basic physics makes alternative propulsion systems a bit more difficult to apply in commercial fishing applications.

“Duty cycle” refers to the amount of time an engine runs under different loads. For performance, efficiency, and longevity, an engine should be matched to the particular demands that will be placed on it. To understand the suitability of any alternative propulsion system, we first must understand the duty cycle of a lobster boat. And every boat is different.

Today, lobster boats can be categorized into **inshore** and **offshore** boats based on how far they go each day. The duty cycle of inshore and offshore lobster boats is very different. Inshore boats might operate 7-10 hours a day and remain mostly within the 3-mile state waters limit and within 12 miles from port. Offshore boats might run 10-18 hours a day, or even overnight, and range as much as 60 miles offshore. Increasingly, Maine lobstermen are steaming farther offshore to fish. Offshore boats tend to be larger, wider, and have larger diesel engines because of the greater energy requirements. The differences in distance, speed, time at sea, and engine requirements have implications for what kind of alternative propulsion system might be suitable. Even the same boat, used inshore some days and

offshore other days, would have a different duty cycle. The size of registered commercial lobster boats in Maine ranges from 8’ to 80’, with most (87%) in the 20-50’ range (Figure 3).

Lobster boats typically run at cruising speed to arrive at a string of traps. Then, they run at idle, or low rpm’s and low loads while hauling traps. The boat will then run at cruising speed or even maximum speed (high load) to reach the next string of traps. This pattern of high-speed high-load followed by low-speed low-load repeats all day (Figure 4.) Offshore boats may follow this pattern except for long periods (1 to 3 hours) running at cruising speed to get to the fishing grounds and back to the dock. This is a very different duty cycle relative to most other commercial non-fishing marine vessels that operate at more constant

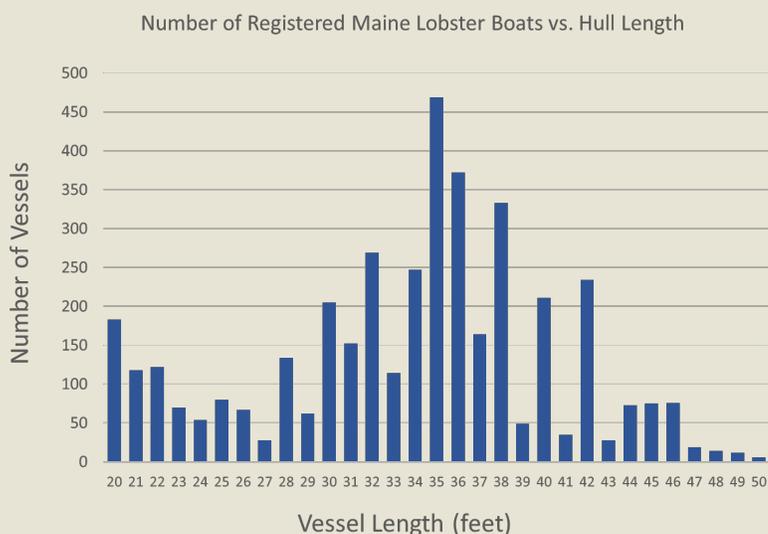


Figure 3. The number of registered commercial lobster boats by length. Boats less than 20’ and greater than 50’ are not shown. (data source: Maine Department of Marine Resources).

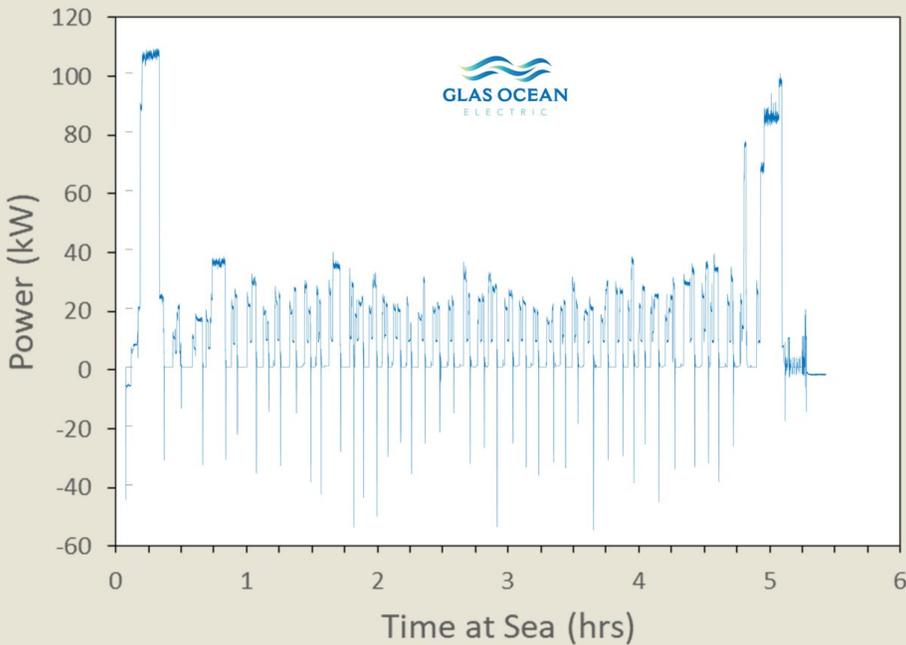


Figure 4. Real-time diesel engine rpm (revolutions-per-minute) data for a typical inshore lobster boat day trip in Nova Scotia. After high and steady rpm's to the fishing site, rpm's switch to repeated patterns of idle or high-idle while hauling traps. Then, rpm's return to cruising speed to return to the dock. The negative power is the propeller going into reverse as the boat approaches a trap buoy. A battery-electric propulsion system would be more efficient at slow speeds while trap hauling. A diesel is more efficient for fast transit to the fishing site. (graph courtesy of Sue Molloy, Glas Ocean Electric)

speeds, such as ships and ferries. Present-day battery systems lose their charge rapidly under a high load, such as cruising to the fishing grounds. At cruising speed, cars and trucks are under a relatively light load, which is one reason electrovoltaic systems are better suited to land vehicles.

Lobster boats also need power to run navigation instruments, radios, radar, lights, bilge pumps, washdown pumps, live-well tanks, and hydraulics for hauling traps. Thus, diesel engines also must function as a generator to produce auxiliary power not used for propulsion but rather for other essential operational needs. Thus, diesel engines run non-stop from the time the boat leaves the mooring until it is back on the mooring at the end of the day's operations.

Legally, the maximum number of traps a lobsterman can set is 800. A typical fisherman might set 600-800 traps. On any given day, a lobsterman might haul 150-300 traps, depending on whether inshore or offshore fishing. The procedure is repeated the next day, except Sundays. Most lobstermen pull their traps from the water in December and set them in late June, with some offshore fishermen fishing year-round.

Alternative Propulsion Systems

Diesel engines are reliable. The technology is well established. Fishermen understand diesel engines. Switching to a new propulsion system will have to overcome what already works *and* save money too. What has worked in the past, however, is not likely to be true in a world where public demand to reduce carbon emissions will affect all businesses, fishing or otherwise, or if a tax on carbon emissions makes diesel engines (or any internal combustion engine) more costly to operate. Canada already taxes fossil fuel emissions and broad societal pressure to solve the climate problem is engaging all sectors of the economy, including the seafood industry.

Unlike cars and trucks, alternative propulsion systems have been slow to be developed for boats and ships. Part of the reason is that the market for cars and trucks is so much larger, but part derives from the high energy required to move objects through water, at least at moderate speeds. They cannot recharge batteries by coasting downhill or by braking. Batteries are heavy, creating further drag due to greater hull displacement. Still, the time is now to understand alternative propulsion systems that might work in a lobster boat.

We considered four categories of “technologies” for alternative propulsion systems for lobster boats:

1. Pure electrovoltaic (EV)
2. Hybrid diesel/electric
 - a. Serial hybrid
 - b. Parallel hybrid
3. Hydrogen fuel cell
4. Biofuels

In the following sections, we describe each of these systems and discuss the pros and cons of use in a lobster boat.

In this report we do not discuss what is called diesel-electric systems. Diesel-electric systems are common in the marine industry and in rail transportation. Diesel-electric systems use a diesel engine to drive a generator that produces electricity, which then powers an electric motor connected to a propeller shaft or drive train. There is no storage of the electric power generated in a traditional diesel-electric configuration. Rather, the diesel engine provides electricity in real-time as the drive train demands it. By contrast, hybrid diesel-electric systems have a means of storing energy in batteries onboard. The energy can be produced by the diesel engine, shore power, and/or onboard solar panels. Traditional diesel-electric systems have made the use of electric motors more acceptable in the marine industry. The technology that needs to be developed is the energy storage system and battery recharging needs for commercial fishing vessels—in our case, Maine lobster boats.

1. Pure Electrovoltaic (EV) Systems

In current-day lobster boats using diesel engines, think of the fuel tank as stored energy, drawn upon as needed. The diesel engine is an internal combustion engine. A diesel fuel/air mixture is compressed by a piston which causes the mixture to explode and push back on the piston, which in turn drives a crankshaft that drives the propeller, as well as other functions. In a pure-EV system, the internal combustion engine is replaced with an electric motor and the fuel tank with a bank of batteries (Figure 5).

For a conventional lobster boat, the diesel engine is essentially a “power plant” that produces power for propulsion *and* power for all the other energy demands of the boat (pumps, hydraulics, navigation equipment, lights, etc.). Presently, most diesel engines drive a hydraulic pump connected to the crankshaft by a belt for operating the trap hauler. In addition to powering all electrical systems, this is another reason diesel engines must run constantly, even while the boat is stopped to haul traps.

Pure EV Propulsion System

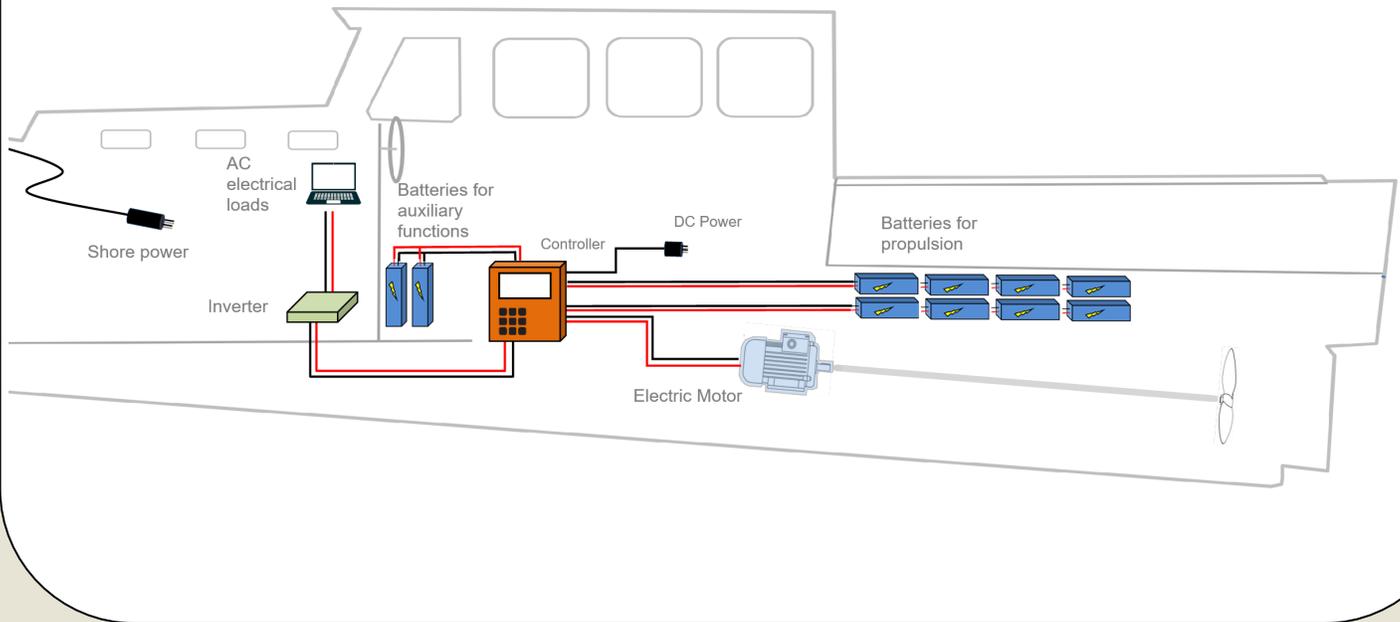


Figure 5. Pure EV schematic: There is no diesel engine, only an electric motor powered by batteries. The two important questions are: (1) 'Can current battery technology meet the power demands (duty cycle) of a lobster boat for 7-20 hours at sea?', and (2) 'How would the battery system be recharged?' The answer to the first question is "no." It would take too many batteries to run a boat for that long with today's technology. The answer to the second question is that we would have to build fast-charging infrastructure to charge boats at the wharf. But the first question makes the second question moot. Hybrid systems that have a diesel engine on board are more likely to meet the duty cycle requirements of a lobster boat.

An electric motor would be much smaller, lighter, and simpler than a diesel of equivalent power output. There is little maintenance needed for electric motors compared to diesels. Although reliable, diesel engines are complex machines that have hundreds of moving parts that must remain well lubricated and cooled. Electric motors have just one main moving part, the rotor, which is driven by a rotating electromagnetic field. Electric motors provide instantaneous torque. They are quiet. In addition to the greenhouse gas CO₂, diesels have other harmful emissions (e.g., sulfur dioxide, particulate emissions). Electric motors have virtually no emissions if the power to recharge the batteries is from a renewable source. In addition, the cost of electricity is about half the cost of diesel fuel in terms of usable power, and diesel fuel price historically has fluctuated much more than electricity prices (Figure 6). In theory, electricity would be a more cost-effective "fuel."

In the way diesel engines are rated in horsepower (hp), electric motor power output is rated in kilowatts (kW). As a general rule, multiply the diesel horsepower by 0.75 to estimate the equivalent electric motor in power production. So, a 400-hp diesel would be approximately equal to a 300-kW electric motor.

The electric motor is the "easier" part of an EV system for a commercial fishing boat. The challenge is the battery storage system. The boat needs to carry as

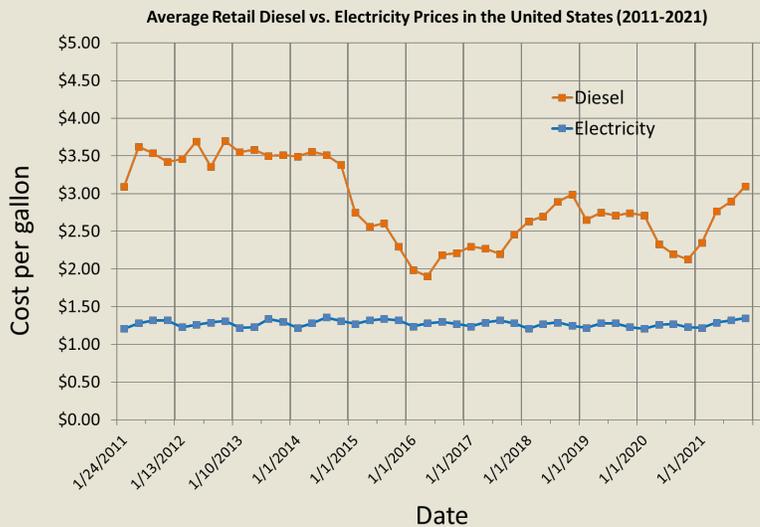


Figure 6. Price of diesel fuel relative to electricity over the last decade. Electricity prices are reduced by a factor of 3.54 because electric motors are 3.54 times more efficient than internal combustion engines. Source: afdc.energy.gov/data

much “fuel” in the form of stored electric energy as it can carry diesel in a diesel fuel tank. Batteries are heavy and large, and even though the price has been coming down per kWh (Nykqvist and Nilsson 2015), they are still expensive. The batteries would need to provide all the power requirements for the boat, not just for propulsion. Hydraulic pumps would need to be replaced with electric pumps.

At present, it would be prohibitively expensive to run even an inshore Maine lobster boat on only batteries. Even if battery prices were cheap, the number of batteries required to run a boat for the day would be too bulky and too heavy for the boat to carry.

Although the electric motor is much simpler than a diesel engine, the various electrical loads of an EV boat must be managed by a power management system (essentially a computer) (see Figure 5). This would add complexity to the boat and require “tuning” to make sure the batteries are managed optimally and safely. Self-maintenance or self-repair would be less of an option for boat captains.

Another major challenge for running lobster boats on electricity is recharging the batteries. Lobster boats in Maine moor rather than dock during non-operation hours, so it is not currently possible for Maine lobster boats to “plug in” for overnight recharging (Figure 7). Offshore charging moorings have been developed for wind energy service vessels, so a mooring-based recharging system in commercial fishing harbors in Maine is technically feasible. But that infrastructure would have to be built. Some recharging could be accomplished by solar panels or small wind turbines on the boat’s cabin roof, but they could not keep up with the daily power demands of a pure-EV lobster boat.

The efficacy and cost-effectiveness of a pure-EV boat would change if boats went slow (below 7 knots) and stayed close to shore. Electric motors and batteries systems are most efficient when power demands are low. At high power demands, such as transiting to the fishing area at cruising speed, batteries discharge quickly (Figure 8). Given the alternating high-load/low-load duty cycle of a lobster boat during the day, we need to look to some form of a hybrid system to meet the power needs of most Maine commercial lobster boats today.

The good news is that all-EV propulsion is emerging in the marine setting where duty cycle demands are compatible with current technology. Ferries and tour boats are better suited for pure EV because they go relatively slow, can recharge frequently, and have the space for large banks of batteries. In March 2021, Norway launched the largest (to date) all-electric ferry. The 456’ ferry will reduce emissions by 75% relative to the previous diesel-driven ferry. Siemens Energy has developed a fast-charging system for the ferry’s 4.3 MWh battery bank. The much smaller 95’



Figure 7. Friendship Harbor, Maine. Lobster boats moor rather than dock when not fishing. This makes “plugging in” overnight to recharge an EV system problematic at present. An underwater charging grid would need to be installed if EV became commonplace in the lobster fleet. Or, floats and docking slips outfitted with shore power would need to be built for lobster boats. (photo by J. Hagan)

Gee’s Bend ferry was the first all-electric ferry in the U.S. and went into service in Alabama in 2020. The ferry makes a 19-mile crossing and can recharge in about 15 minutes.

On the smaller marine end, several companies have been developing all-EV propulsion systems. *Torqueedo* is a pioneer in electric outboard motors and battery storage systems for marine applications. However, their largest outboard currently available is 100 hp, which does not have enough power for most lobster boats, nor can the batteries meet the daily duty cycle demands of a lobster boat. More powerful inboard electric motors are available, but again, the battery storage technology does not exist right now to operate a lobster boat 8-10 hrs or more on the water without recharging. The Sea Meadow Marine Foundation is testing the efficacy of small outboard workboats with *Torqueedo* motors in association with The Boat Yard in Yarmouth. This is the kind of innovation that is needed in the marine and fishing sector. The Island Institute has also launched a new program to test outboard electric motors in a variety of working waterfront situations to better understand their potential.

It seems that Maine commercial lobster boats, and most commercial fishing boats in other parts of the U.S., fall in the middle of these two ends of the spectrum, and their demanding duty cycle precludes 100% EV systems today. This could change as battery technology improves for the auto industry. The marine application of EV largely depends on research and development in the auto industry where the

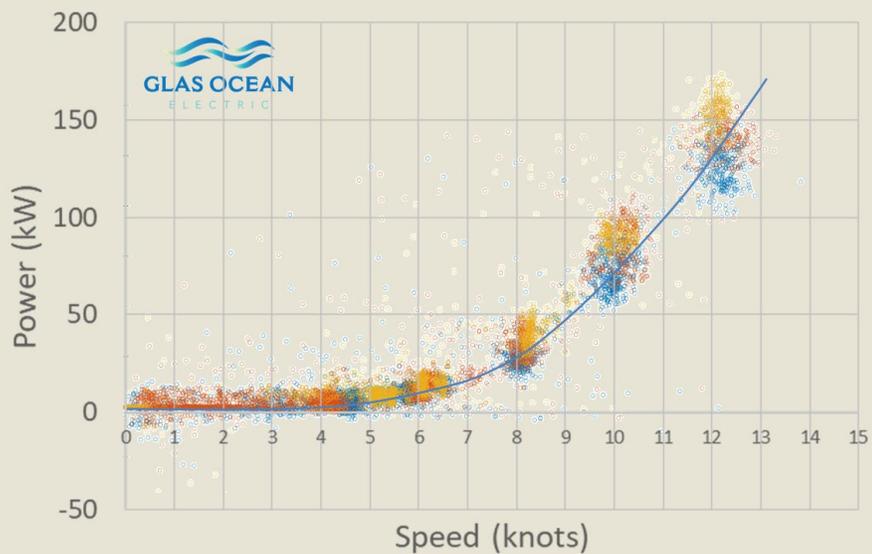


Figure 8. The relationship between power requirement and boat speed. Power requirements are low at low speeds (below about 7 knots), but power requirements increase rapidly (exponentially) at higher speeds. Batteries lose charge rapidly at high speeds. Power requirements can vary by boat size, hull shape, propeller form (the different color dots), load, etc. Graph courtesy of Sue Molloy, Glas Ocean Electric.

enormous market for EV vehicles makes the capital investments in battery R&D worthwhile. Auto battery advancements can be adapted for marine applications.

2. Hybrid Propulsion Systems

Because current-day battery storage systems would be too bulky and heavy to run a lobster boat all day, we need to consider alternatives, at least until battery storage technology improves.

Though less desirable from a greenhouse gas emissions standpoint, one alternative is a hybrid system that combines a traditional internal combustion engine (ICE) and an electric motor.

There are two kinds of hybrid systems: **serial and parallel**. Each system is discussed separately below. Hybrid systems have been used in cars for over two decades. Hybrid systems have not been used much in the marine environment for a variety of reasons, including lack of demand. However, this is changing as all sectors are seeking ways to reduce emissions. Moreover, a hybrid parallel system in which the diesel ICE operates during the phases of the duty cycle where it is most efficient and the electric motor operates when it is most efficient, may be a good bridge to a time when battery storage systems become more compact and lighter weight.

Greenhouse gases will be emitted anytime an ICE is being used. As with hybrid cars, the question is whether a hybrid lobster boat will significantly reduce fuel use, and therefore cost and emissions. Work by Sue Molloy and colleagues in Nova

Scotia at Glas Ocean Electric indicate that emissions can be reduced by about 30-40% with a hybrid system in a lobster boat, depending on a boat's duty cycle (Molloy 2021, Manouchehrinia et al. 2018). The same rough estimates of fuel/emissions savings were reported in a study of alternative propulsion systems for the Alaska commercial fishing fleet (Kemp and Atshan 2021).

Although there are many configuration possibilities, below we describe the two basic types of hybrid propulsion systems.

Hybrid Serial Systems

In a serial (or "series") hybrid system, an electric motor is the only motor connected to the shaft and propeller (Figure 9). The diesel engine functions purely as a generator to produce electricity for the battery system, which in turn powers the electric motor as well as other electrical needs of the boat. The combination of a diesel engine and an electricity generator is called a "genset." In a serial hybrid lobster boat, a smaller-than-usual diesel engine could be installed because it would function solely as a generator of electricity. A smaller diesel engine is less expensive, and because it would not have to run continuously (if hydraulic functions were converted to electric systems), its effective serviceable lifespan would be longer.

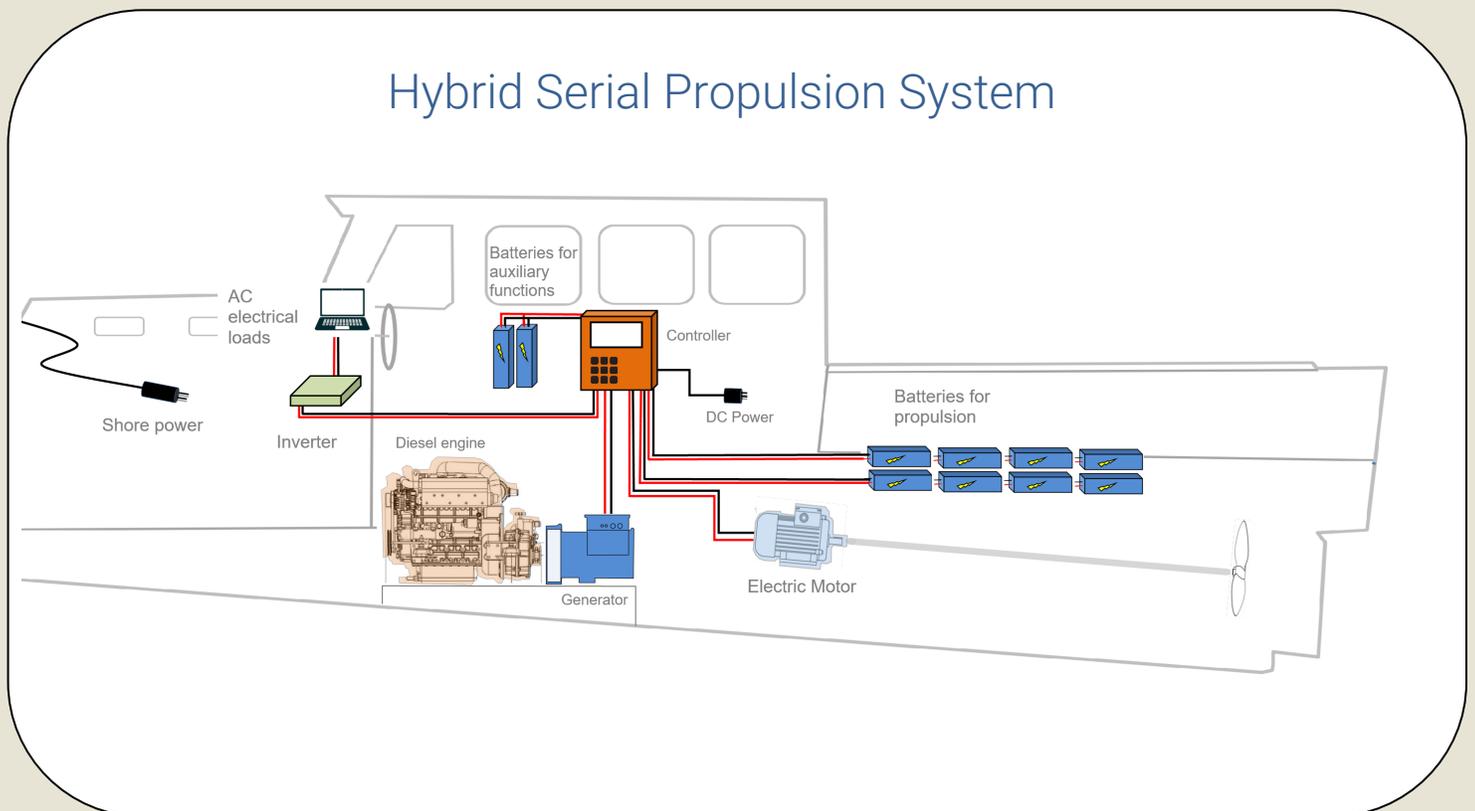


Figure 9. Hybrid Serial Propulsion schematic. A diesel engine and a generator create power that is stored in on-board batteries. The batteries supply the power to the electric motor connected to the driveshaft. The diesel engine is NOT connected mechanically to the propeller shaft. Its sole function is to generate electricity to keep the batteries charged. If shore power is available, the batteries can be topped off without using the diesel initially on the next day. The problem is that boats moor at night in Maine and have no access to shore power.

To be able to turn off the diesel engine and take advantage of the energy efficiency of electric power, the hydraulic system that hauls traps would need to be replaced with an electric hauler. This is a good example of why we must consider the full duty cycle requirements of a lobster boat before assuming any alternative propulsion system will work. The traditional diesel engine serves multiple functions on a commercial lobster boat. All systems would need to be converted to electric for a serial hybrid system to provide emissions reductions and a cost advantage.

As with pure EV ferry boats, hybrid systems are also being installed in ferries. Recently, Maine ferry operator Casco Bay Lines committed to building a hybrid electric ferry boat for the Portland-Peaks Island route. ABB Marine and Ports, a pioneer of hybrid systems for ships, will design the propulsion system. It will have 904 kWh of battery energy storage but also traditional diesel engines to generate electricity when needed. It will plug in to fast-charging shore power when docked.

Hybrid Parallel Systems

In a parallel hybrid system, both the ICE and the electric motor are mechanically connected to the propeller shaft through a gearbox, so either one can provide

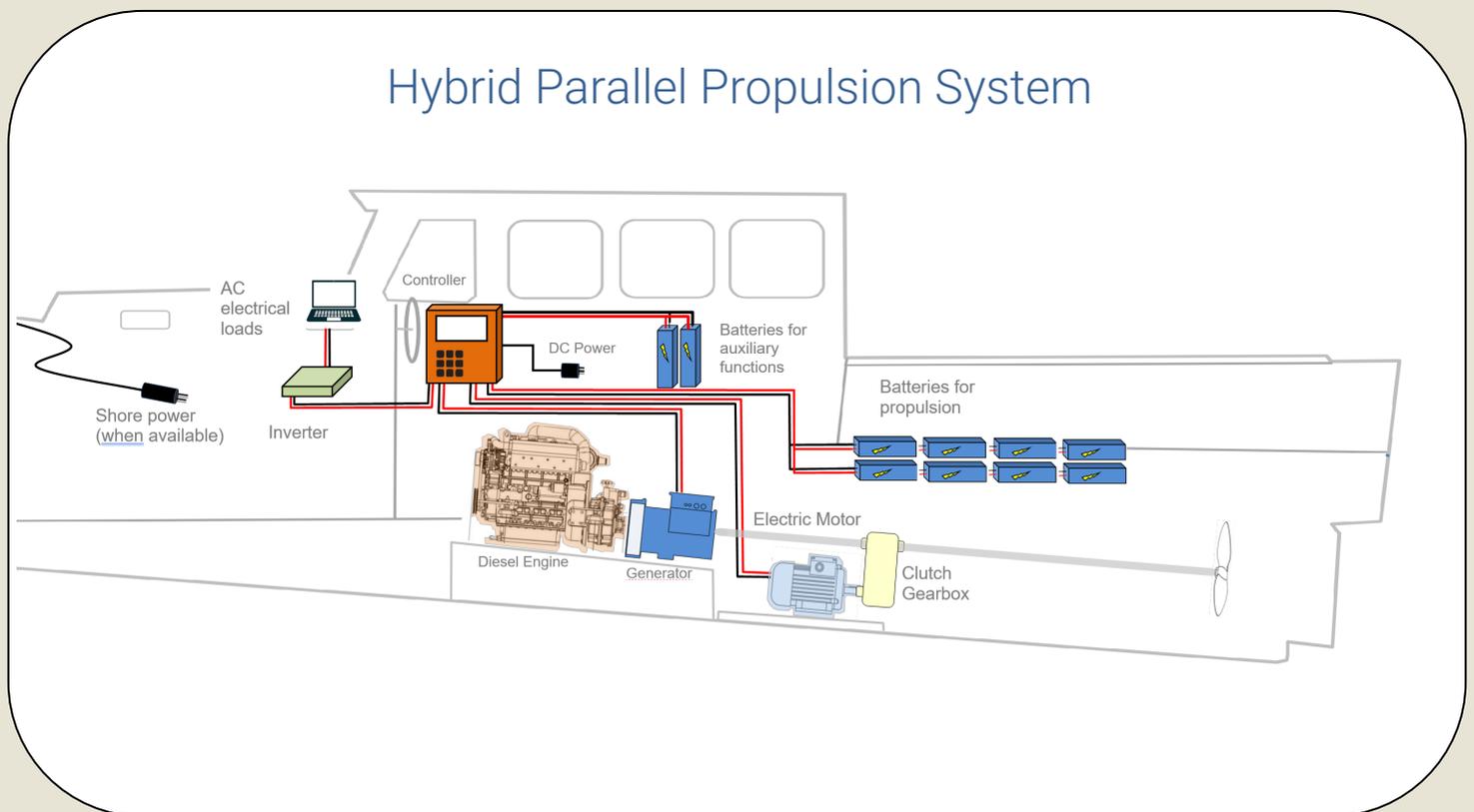


Figure 10. Hybrid Parallel Propulsion schematic. Either the diesel engine or the electric motor can drive the driveshaft through a gearbox. The diesel engine, combined with a generator, can also recharge the batteries that power the electric motor and other auxiliary functions. The hybrid parallel system guarantees that the boat can always be propelled by a traditional diesel engine, but also can take advantage of the energy/emissions savings by using the electric motor when operating at slow speeds. The electric motor can be linked into the propeller shaft by a belt, a gearbox (as shown), or by other means. If the energy management system is operating at optimum, and depending on the duty cycle (speed, load, etc.) of the boat, emissions and fuel savings might be reduced by 30-40%.

propulsion (Figure 10). The diesel engine is combined with a generator (called a “genset”) and can both recharge the battery array and drive the propeller shaft directly. This is how most hybrid cars are configured. This system is perhaps more reassuring to boat captains because the boat can always be propelled by the ICE alone, the same as conventional boats today.

In a parallel hybrid system, the diesel engine and the electric motor share the job of providing the boat with propulsion power. The diesel engine provides propulsion when it is the more efficient mechanism for generating propulsion and the electric motor and the battery system provide propulsion when it is the more efficient mechanism. Managed by a computer (Controller in Figure 10), both may provide power at times. In a hybrid system, the diesel engine and generator (genset) can also recharge the battery array that powers the electric motor. The diesel might recharge the batteries when operating at cruising speed to get to the fishing grounds, when it is operating at peak efficiency. Diesel engines in most lobster boats already power a generator (or alternator) because electricity is needed for lights, water pumps, electronics, etc.

There are more prototypes of hybrid parallel boats than hybrid serial because a hybrid parallel can still use the diesel for propulsion, and this is a safer step toward a serial electric or a pure EV boat. But most examples of hybrid serial or hybrid parallel boats have come just in the last few years.

An Alaska gillnetter, Fabian Grutter, retrofitted his 34’ commercial fishing boat, the Sunbeam, with a parallel hybrid system. The boat consists of a 330-hp John Deere diesel, a battery storage system, and an electric motor. The hybrid system matched well the duty cycle of this gillnetting boat because it operates for long periods at

slow speeds setting or hauling nets most of the day when the electric motor is more efficient than the diesel engine. This is an example of why the duty cycle of the boat matters for selecting an alternative propulsion system. What works for a gill-netting boat might not work for an identical boat that is lobster fishing.

The Sunbeam retrofit required considerable reorganization of systems under the deck. For example, the forward fuel tank was removed to make room for the batteries. The battery management system (part computer) is critical in a hybrid or pure EV system. For the Sunbeam, the lithium-ion battery voltage must stay between 2.5 and 3.6 volts or the batteries could overheat and create a fire hazard.

Another recent example is the *Alutasi*, a 44’ Cape Islander retrofitted



Figure 11. The ‘Alutasi’, a hybrid parallel retrofit of the 44-ft fiberglass boat Cape Islander style, used extensively in Atlantic Canada fishing. The original diesel engine was retained, but an electric motor drive was added to operate the boat more efficiently at slow speeds. It is now used as a whale watching tour boat out of Halifax, Nova Scotia. (photo courtesy of Sue Molloy, Glas Ocean Electric)

and launched in Halifax, Nova Scotia, in August 2020 as a whale-watching tour boat (Figure 11). The hybrid system was designed by Sue Molloy of Glas Ocean Electric, a pioneer in electrifying commercial fishing boats. The configuration is also a hybrid parallel system. The boat uses the diesel engine to cruise out to the whale watching grounds and then uses the battery-electric motor for slow-speed touring within the watching area. Fuel savings is estimated at 40-60%. Again, the hybrid system is well-suited to the duty cycle of the tour boat. The retrofit took 17 months to complete. Gaining permission from Transport Canada (analogous to the U.S. Coast Guard) to operate as a passenger vessel was considerable because of the risk of fire with lithium-ion batteries. The key is to purchase batteries that have the proper safety rating.

But the bottom line for near-term hybrid applications for commercial lobster boats depends on the time operating at low loads relative to the time at cruising speed. A more detailed analysis of duty cycle requirements for any particular fishing boat would be needed to design an alternative hybrid system that would meet the needs of the boat. For example, Maine lobster boats set more traps and fish longer during the year than Nova Scotia lobster boats. These factors would not only affect the choice for a propulsion system, but also affect the payback period of the retrofit (the more fishing the sooner the payback) (S. Molloy, pers comm).

3. Hydrogen Fuel Cell Systems

The problem of not having enough stored battery power in a pure EV system to run a lobster boat all day could potentially be overcome by a hydrogen fuel cell system.

In this system, fuel cells (similar in function to batteries) produce a constant supply of electricity using hydrogen stored in a tank onboard (Figure 12). This eliminates the range issue with the pure EV system. The fuel cells must be coupled with a battery storage system as in the examples above. The fuel cells keep the batteries charged, which in turn provide power to the various boat functions. There would be no diesel engine for backup. The fuel cells essentially replace the power production function of the diesel engine in the serial hybrid system described above.

Hydrogen becomes the stored fuel onboard rather than diesel fuel. Instead of fueling up with diesel at the dock, a boat would fuel up with hydrogen. Of course, there is no hydrogen fueling infrastructure at docks in Maine today, so that would have to change with fuel cell technology. Hydrogen is a gas, except at very cold temperatures (-253°C), which for practical reasons would not be achievable on a lobster boat. As with all other possible systems, first we must understand whether a hydrogen fuel cell system could meet the duty cycle needs of a lobster boat.

While a fuel cell produces electricity, it does so differently from EV lithium-ion batteries. In a fuel cell, hydrogen and oxygen are combined to produce electricity, with heat and water produced as byproducts. The heat produced by the electrochemical reaction can be substantial, so a cooling system is needed to keep the fuel cells from overheating. In addition, hydrogen is a flammable gas and must be handled safely. Still, hydrogen fuel cell city buses are increasingly common, so these issues have been successfully addressed on land. Many companies are aggressively pursuing fuel cell systems for widespread application in heavy-duty truck transportation. Such trucks are somewhat analogous to commercial fishing boats in terms of engine size and power requirements. Still, boats do not roll like trucks, so the energy demands will be higher for boats.

Hydrogen Fuel Cell Propulsion System

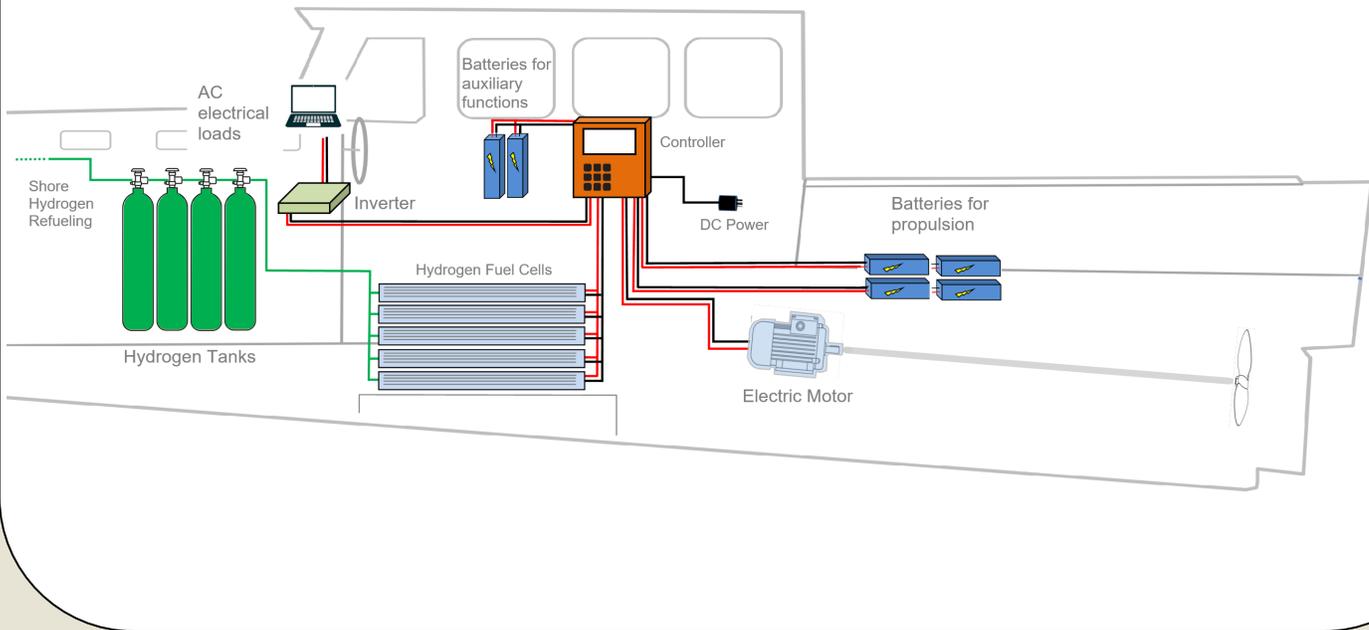


Figure 12. Hydrogen Fuel Cell Propulsion schematic. On-board hydrogen tanks continuously supply hydrogen to fuel cells, which in turn produce electricity that keeps the battery storage system charged. There is no diesel engine. Fuel cells can produce electrical power as long as there is a supply of hydrogen, thus extending the range over a pure-EV system. Shore-side infrastructure for hydrogen fueling would need to be built. The hydrogen would need to be “green” hydrogen produced from renewable energy to reduce the boat’s effective emissions.

Producing pure hydrogen for a fuel cell takes energy. In considering the climate benefits of a fuel cell system, we must understand how the hydrogen that supplies the fuel cells is generated. Unless “green” hydrogen (hydrogen made from renewable energy sources) is being used in the fuel cells, a hydrogen fuel cell propulsion system could emit more greenhouse gases than it saves. Green hydrogen can be produced with an electrolyzer, powered by solar or wind energy. Often fuel cell vehicles are celebrated as “zero-emissions” without accounting for emissions resulting from the process that generated the hydrogen in the first place. The hope is that fuel cells will take off in the transportation sector, thus precipitating growth in green hydrogen and hydrogen distribution infrastructure.

If a fuel cell system can meet the demands of a lobster boat, we could look to Maine’s growing solar energy production or even its proposed offshore wind projects to provide the needed electricity to convert water to hydrogen. This could be done on-site and the hydrogen transported where needed, or through renewable energy credits via the grid and produced with electrolyzers right at shore side. While this technology seems far removed at present, the production of hydrogen fuel is already planned for the North Sea with hydrogen production replacing the need for cabling power to shore, and in anticipation of a huge forthcoming demand for fuel

cell energy applications in all transportation sectors. Perhaps offshore wind in Maine would be viewed more positively by fishermen if projects came with a community benefits package that included low-cost hydrogen, shoreside infrastructure, and funding for conversion to electric-powered lobster boats.

Many options are open in the future if fuel cells can meet the energy needs of a lobster boat. A marine engineer working with a fuel cell manufacturer would need to “spec out” a hydrogen fuel cell system for a lobster boat, including calculations of the amount of hydrogen that would need to be stored onboard for each fishing trip.

4. Biofuels

A simpler, cheaper, and effective alternative to all of the above would be to run existing diesel engines on biofuels—liquid fuel made from plants (e.g., soybeans, algae), waste animal fat, bio-syngas, and biomethane. While burning biofuels in an internal combustion engine emits CO₂ into the atmosphere just like diesel, the advantage of liquid biofuels is that they can be made from plants which already *removed* CO₂ from the atmosphere, or from animal and food waste which would otherwise decompose into greenhouse gases (Demirbas and Demirbas 2010, Balajii and Niju 2019). Biofuel (our interest is primarily biodiesel) can be produced in a variety of ways, some requiring heat (thermochemical processes) and others involving biochemical processes (Osman et al. 2021).

Biodiesel can be blended with regular diesel, thus improving (reducing) the emissions proportionally. The most common blends are 5% biodiesel (called B5 fuel) and 20% biodiesel (B20). B100 is pure biodiesel and is rarely used as a transportation fuel by itself, but it could be with minor modifications. But even 20% blended biodiesel-to-diesel could add up to a significant, low cost, and almost immediate emissions reductions.

California is aggressively encouraging the deployment of biodiesel blends. California’s Low Carbon Fuel Standard is a regulation implemented by the California Air Resources Board to reduce greenhouse gas emissions in the state. Biodiesel is one of the most popular alternatives to conventional diesel fuel. However, other undesirable emissions can result from biodiesel, such as nitrous oxides (NO_x).

Coastal Energy, based in Ellsworth Maine, has experimented with producing and blending biodiesel with home heating oil and conventional diesel. Coastal Energy built a small biodiesel processing facility as a pilot project. Almost any free fatty acid feedstock can be used, such as waste cooking oil or soy oil. According to Coastal Energy, biodiesel can be used just like diesel, without any modification to the engine. However, biodiesel acts like a solvent relative to conventional diesel and can therefore mobilize carbon deposits in engines or fuel tanks. While “cleaning” can be good, at first an engine might run rough when switching to biodiesel. Biodiesel also is a lubricant, which can extend the lifespan of an engine. Using biodiesel might also nullify the warranty on engines, but this could change as the demand for low emissions biofuels grows. Like diesel, biodiesel can gel at cold temperatures, but that is not a problem for lobster boats in the water.

Even switching to B20 (20% biodiesel) could make a huge and near-immediate reduction in greenhouse gas emissions in Maine. Because 54% of Maine’s annual emissions come from transportation, creating a biodiesel delivery infrastructure system would be good for both land transportation (trucks and heavy-duty



Figure 13. The historical price of diesel vs. B20 (20% biodiesel blended with diesel) vs. B100 (100% biodiesel). Maine lobster boats might start with a B20 blend, which would significantly reduce greenhouse gas emissions. Perhaps price incentives (subsidies) could be instituted to encourage switching. Source: afdc.energy.gov/data

equipment) and for commercial fishing. The big challenges are (1) creating a large-scale demand for biodiesel while (2) simultaneously creating the supply and infrastructure to deliver it throughout Maine (A. Joseph, pers comm).

Because biodiesel costs a little more per gallon than diesel (Figure 13), the state might offer an incentive to match the conventional diesel price, or even make it cheaper and therefore more likely to be used. Lobstermen are not likely to switch to biodiesel if it costs more. They will more likely consider switching if it saves money and has been proven to work well in conventional engines.

The Maine Maritime Academy’s (MMA) Marine Engine Testing and Emissions Laboratory (METEL) is testing biofuels in a diesel engine for marine applications. MMA is also studying how waste heat energy from the exhaust and coolant systems of marine diesels might be recaptured and stored in batteries. As much as 50% of combustion energy is lost to heat. These projects are worth tracking to understand the efficacy of using biofuels.

Another biofuel possibility is a technology trademarked *ClearFlame*. *ClearFlame* involves a modification of existing diesel engines so they can run on pure ethanol (or alcohol) made from plants, completely replacing diesel fuel. Burning ethanol also avoids other unwanted emissions, such as nitrous oxides and sulfur dioxide, an advantage over diesel and biodiesel. However, unlike biodiesel, the diesel engine requires a modification that can be costly and must be customized for each brand, make, and model of diesel engine. The *ClearFlame* solution would be more cost-effective if all lobstermen used the exact same diesel engine, but there are hundreds of different engines being used today. Each make and model would need a custom modification (J. Howell, pers comm).

Maine's 2020 four-year climate action plan calls for increased biofuel and biodiesel production in Maine transportation sectors, especially heavy-duty vehicles (Maine Climate Council 2020). Given that 54% of Maine's greenhouse emissions come from transportation (cars, trucks, boats), focusing on building biodiesel production and demand for biodiesel would significantly reduce greenhouse gas emissions quickly and cheaply.

There are still important questions to consider in making liquid biofuels from biomass, whether soybeans, waste wood, or animal fat. Life cycle analyses are needed to ensure the production of biodiesel provides real emissions gains (see Osman et al, 2021). For example, if food crops are redirected to make biofuels, people still need food. More forest may need to be cleared in the U.S. or elsewhere in the world to make room for new food crops that have been displaced by biofuel crops. Such a shift to renewable fuels derived from crops could also increase food prices, creating climate equity issues (e.g., Subramaniam et al. 2019). A recent study by Harvard scientists shows that ethanol, while not carbon neutral, is carbon friendly compared to fossil fuels (Scully et al. 2021). As explained earlier in this report, life cycle analysis is key to all the proposed solutions to climate change (e.g., Pavlenko and Searle 2020). Life cycle assessments should include climate justice and food security issues, not just CO₂ emissions, so that we don't get unwanted and unintentional consequences.

What Would it Cost?

While recognizing the long-term economic impacts of *not* decarbonizing our economy, we also need to consider the costs of decarbonizing today. On that question, what would it cost to decarbonize the Maine lobster fleet?

By far the cheapest and most immediate solution would be switching to biodiesel, perhaps a blend at first (e.g., B20- 20% biodiesel), but then to B100 with newer diesel engines. Lobstermen would not need to change anything in their boats to switch to B20, except monitor the initial "cleaning effect" that biodiesel will have on the fuel tank and engine. B20 is very slightly more expensive than 100% diesel fuel.

Any of the other alternatives provided in this report—pure EV, hybrid serial or hybrid parallel, or hydrogen fuel cell, will involve costly retrofits. Lobster boats last for 10 to 20 years or more, so building a new fleet is neither necessary nor economical. The critical question is whether the fuel savings over 5 or 10 years would be worth the cost of the retrofit today.

The reports by Kemp and Atshan (2021) and Molloy (2021) provide some data on the projected cost of switching to EV or hybrid systems. The cost of retrofitting to a hybrid parallel system (most compatible with the duty cycle demands of most lobster boats today) would be between **\$150,000 and \$250,000**, largely depending on the size of the boat and the size of the battery array.

Batteries today cost from \$300-\$1000 per kWh. If a 300 hp diesel were replaced with an equivalent 225 kW electric motor, the cost of batteries alone would range from \$67,000 to \$225,000. The goal of the U.S. Department of Energy is to get the cost of batteries down to \$80/kWh.

With duty daily duty cycle data from a boat (such as shown in Figure 4), it is relatively straightforward to calculate how many batteries would be needed to

optimize the energy use for that boat. Keep in mind that if the boat operates differently on different days (e.g., switching from inshore fishing to offshore fishing), the best hybrid configuration might be different, whereas a traditional diesel works in both situations. In addition, access to shore power for recharging batteries can factor into calculating the pay-back period. If there is no shore power, the diesel engine will need to recharge the batteries, and emissions savings are much reduced. All of these factors must be taken into account by a marine systems engineer *before* a retrofit or a new boat is considered.

Other Factors to Consider for Greenhouse Gas Emissions and Cost Savings

Although this report focuses on alternative propulsion systems and alternative fuels, there are other ways to significantly reduce emissions in the commercial lobster fleet. For example, hull design plays a major role in the energy efficiency of a boat. Long slim boats have much greater efficiency than short, wide boats (Figure 14). In a study of the duty cycle of Alaskan long-line fishing boats, it was found that propulsion power could be reduced 10-20% just by lengthening the hull while holding the beam constant (Kemp and Atshan 2021). Lobstermen generally prefer wider boats because they are more stable platforms at sea and are more maneuverable for hauling traps.

Douglas Read at the Maine Maritime Academy and the Maine Center for Coastal Fisheries based in Stonington, Maine, collaborated to design a more efficient lobster boat hull. The trimaran hull has significantly less contact with the water (less displacement) and therefore significantly increases fuel efficiency at speeds below about 20 knots (Figure 15). The design includes a wide deck, which lobstermen

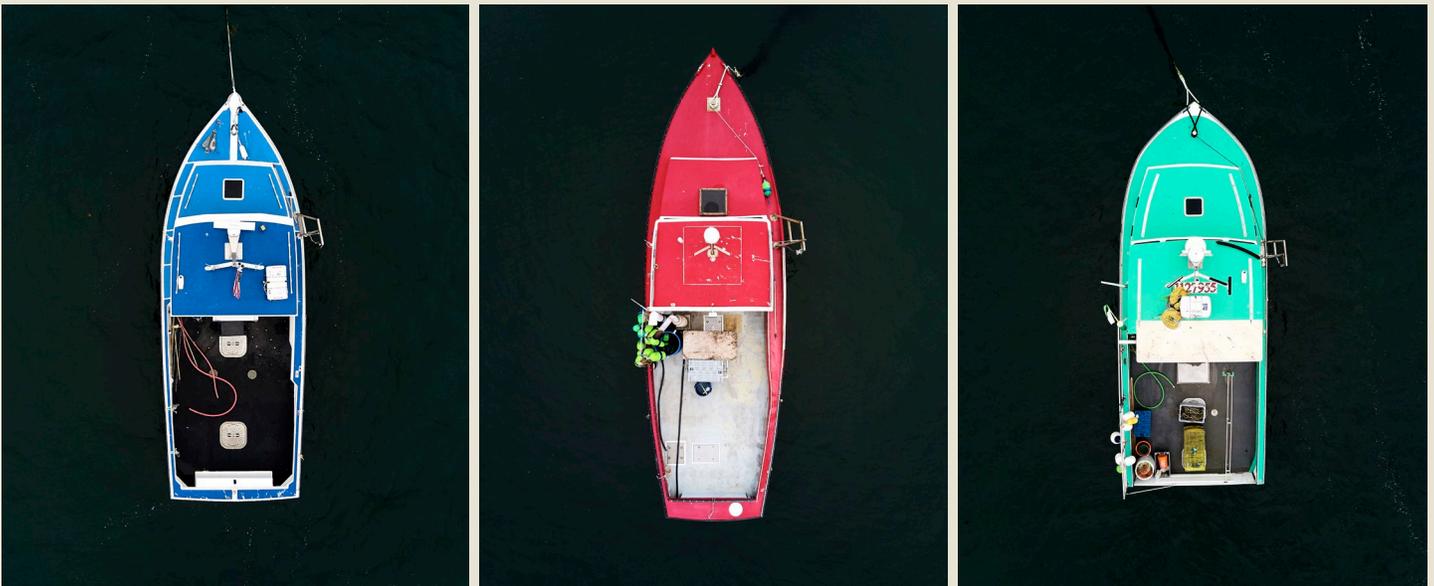


Figure 14. Some examples of different shaped lobster boat hulls. Longer, slimmer boats are generally more efficient (lower emissions), but have less deck, are less stable on choppy seas, and are less maneuverable than broader-beam boats. Photos by artist Mark Fleming.

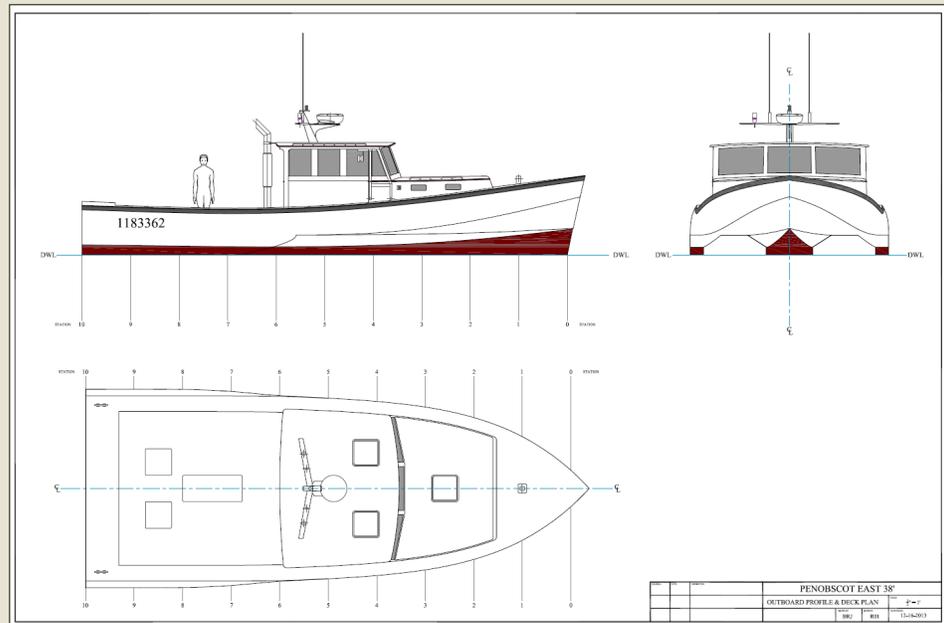


Figure 15. Trimaran lobster boat hull design by Douglas Read at Maine Maritime Academy developed for the Maine Center for Coastal Fisheries in Stonington, Maine. The reduced “wetted surface” significantly increases propulsion efficiency, therefore saving fuel costs. The design has the advantage of a broad deck workspace, which lobstermen like, but with the sleek and efficient hull of longer, slimmer boats. (diagram by Bruce Johnson, courtesy of Douglas Read)

prefer for working. A one-fifth-scale model has been built and is planned to undergo sea trials in 2022. A trimaran hull outfitted with a hybrid parallel propulsion system might be a good combination for testing in a new fuel-efficient lobster boat.

There are other ways to reduce the energy consumption of commercial fishing boats. Keeping the hull clean can improve fuel efficiency from 10-30% (Kemp and Atshan 2021). Because speed is exponentially related to fuel use and emissions, changing driving speed could also yield significant cost savings and emissions reductions (Bouman et al, 2017, Granado et al. 2021). For example, a 45’ boat will reduce propulsion power requirements 40% just by slowing speed by 1 knot, say from 15 to 14 knots (Kemp and Atshan 2021). The hydraulic hauler system can be shut down when not being used by installing a load sensing pump. LED lighting is 10 times as efficient as incandescent lights. A commercial fishing boat is a complex system, and all systems have opportunities for efficiency improvements.

Increasingly, lobster boats are becoming bigger, with more powerful engines as fishermen range farther offshore to fish. This evolving duty cycle has implications for what kinds of alternative propulsion systems to pursue. The further offshore fishermen range, the less likely pure EV systems will work in the near term (i.e., the next decade). Keep in mind the real measure of efficiency with respect to greenhouse gas emissions in the lobster fishery is the tons of CO₂ emitted per ton of lobster landed.

Next Steps

We have outlined a variety of propulsion systems (or alternative fuels) that could reduce emissions in the Maine lobster fleet over the long run. Eventually, everyone will need to reduce greenhouse gas emissions. We encourage boatbuilders and boatyards to test some of these systems. Retrofitting existing boats could become a lucrative business if fuel savings and emissions reductions can be demonstrated while maintaining catch volume. In addition, reducing emissions in the lobster fishery could stimulate a steady stream of orders of newly designed and built boats.

Batteries are becoming cheaper, lighter weight, and more compact as the auto industry rapidly scales up to meet the demand for EV cars and trucks, but pure-EV systems cannot currently meet the duty cycle demands of most lobster boats. It will be important to monitor battery improvements on an annual basis to see if the equation changes for Maine lobster boats.

In the near term, the most likely practical solution is a hybrid parallel system where an existing diesel boat is retrofitted with an electric motor. The diesel can be used for propulsion for high load cruising and the electric motor can be used at low loads (hauling traps). This combination would give fishermen the security of knowing they will always have the familiar and time-tested diesel engine for power.

It is still important to understand the duty cycle of a lobster boat before designing even a hybrid parallel system. With duty cycle data, marine engineers can do these calculations. We relied on three excellent studies that contained duty cycle information for this report. The first report was published in 2015 by the Nova Scotia Boatbuilders Association (NSBA 2015) and contains duty cycle data from two representative commercial lobster boats. The second was a study commissioned by the Alaska Longline Fisheries Association (Kemp and Atshan 2021). In our region, Glas Ocean Electric in Halifax, Nova Scotia is out front in designing alternative systems for commercial lobster boats (Molloy 2021). We encourage interested readers to review these key reports. All three reports deal with boats similar in size to Maine lobster boats.

We also recommend a study to get duty cycle information from both inshore and offshore lobster boats in Maine. This information can then be used to design hybrid systems that will meet the operational needs of that particular boat, remembering that modifications to the propulsion system might argue for a change in fishing behavior (e.g., speed) to optimize cost and revenue.

With duty cycle data, we would follow with three further recommendations, first and foremost begin with retrofitting a Maine lobster boat with a hybrid parallel system and then testing it in a real fishing environment with a willing lobsterman. Second, seek funding and build a new traditional-style lobster boat with one of the hybrid systems, chosen on engineering specs as to emissions and cost savings. Third, fund and build a new boat based on an efficient hull design such as the trimaran hull designed by Douglas Read at Maine Maritime Academy, and outfit it with a hybrid system. Pure-EV systems would be too limited in application in Maine's lobster fleet today but should be considered as the technology advances. Maine, with its diverse and capable boatbuilding industry, 3,000 miles of coastline, and a large fishing fleet, is the perfect place to pioneer these new technologies.

Recommended Reading

This report was intentionally high-level and non-technical to make it accessible to a wide audience. For those who might want a more technical presentation of the state of the knowledge for alternative propulsion systems for commercial fishing boats, we refer the readers to these reports:

- 1 NSBA. 2015. Review of All-Electric and Hybrid-Electric Propulsion Technology for Small Vessels. Nova Scotia Boatbuilders Association. Halifax, Nova Scotia, 30 pp.
- 2 Kemp, C. and S. Atshan. 2021. Electric Power Systems for Fishing Vessels: Feasibility, Fuel Savings, and costs. Kempy Energetics. 46 pp. ([link](#)).
- 3 Molloy, S. 2021. Feasibility Study on Moving Towards an Electric Powered Fishing Fleet. Report for the Fish, Food, and Allied Workers (FFAW). November 2021. 37 pp.

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