

# Overview of Alternative Fuels and Their Drivers to Reduce Emissions in the Shipping Industry

Aevelina Rahman , and Md. Mashud Karim

**Abstract**—Shipping industry is facing challenges to reduce engine exhaust emissions and greenhouse gases (GHGs) from ships. The International Maritime Organization (IMO) and national environmental agencies of many countries have issued rules and regulations to reduce GHG and exhaust emissions emanating from marine sources. The establishment of these new national and international regulations on the shipping industries worldwide has brought alternative fuels such as liquefied natural gas, methanol, biodiesel, marine fuel cell etc. to the forefront as a means for realizing compliance. Each of these alternative fuels has advantages and disadvantages from the standpoint of the shipping industry. This Paper discusses the possible alternative fuels for marine propulsion and their prime drivers and significant features.

**Index Terms**—Alternative fuels, emission regulations, driver, shipping industry.

## I. INTRODUCTION

Maritime transport accounts for over 80% of world trade by volume and for approximately 3% of global greenhouse gas emissions. It is also a contributor to air pollution close to coastal areas and ports [1]. Today the contribution of shipping industry to emission of sulphur oxide (SO<sub>x</sub>), nitrogen oxide (NO<sub>x</sub>) and carbon dioxide (CO<sub>2</sub>) is considerable which have a great negative impact on world environment. Thus the need for reduction of harmful emissions is mandatory. International regulatory bodies such as the International Maritime Organization (IMO) and national environmental agencies of many countries have issued rules and regulations that drastically reduce the allowable GHG and emissions emanating from marine sources. These new rules are impacting ships that engage in international and coastal shipping trade, the cruise industry, ship owners and operators. Many ship operators, with present-day propulsion plants and marine fuels, cannot meet these new regulations without installing expensive exhaust after treatment equipment or switching to low-sulfur diesel, low-sulfur residual, or alternative fuels. All of them contain properties that reduce engine emissions below mandated limits but impact bottom-line profits [2].

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However, this paper discusses the possible alternative fuels for marine propulsion and their prime drivers and significant features. The most common fuels or energy carriers in shipping industry are liquefied natural gas (LNG), biodiesel, methanol, marine fuel cell, solar cell and wind powered propulsion. All the alternatives has certain driving factors behind them to be considered as a viable contender as next generation marine fuel in full scale for some and as auxiliary power for others. Their overall features contain some bright prospects along with some significant challenges to be dealt with for them to act as a fruitful alternative solution.

## II. OVERVIEW OF ALTERNATIVE FUELS

The increasing demand for clean fuel sources in the marine industry has led to the growing demand of alternatives for fuelling the shipping industry. The overview of alternate fuels will cover various aspects of the alternatives as well as their significant features and challenges.

### A. Vaporized Or Liquefied Natural Gases

Tighter regulations on air emissions are prompting rapid change within the shipping industry. Due to the rapid strengthening of environment friendly regulations market for LNG-powered engines broke new ground. Choosing vaporized natural gas as fuel of diesel engine can save up to 35 percent of fuel cost and reduce harmful emission and is largely better than common diesel oil in environment protection [3]. There are several priming factors for upholding LNG as maritime fuel which discussed below.

#### Drivers for LNG as Marine Fuel

The driving factors that boost up the prospect of establishing LNG as a fruitful marine fuel are:

- Increased Production of Natural Gases: The increasing production of natural gas, especially from unconventional

sources, provides the ship operators an opportunity to reap benefits of cheap gas prices. LNG can be easily produced from natural gas conversion.

- **Feasible Prices:** The increasing fuel oil prices are also another major driver for encouraging investments in utilization of LNG as a marine fuel. In some of the major bunker markets, LNG is priced at a discounted rate compared to conventional marine fuel oils. Thus LNG provides an economical option to ship operators for fueling their vessels.
- **Strict Environmental Regulations:** The strict environmental regulations imposed by MARPOL (short for marine pollution) further encourages shipping companies to adopt LNG as a marine fuel. LNG meets the sulfur content and emission requirements set by the governing bodies.
- **Feasible Methods for Delivering:** The methods for delivering LNG to ships to be used as fuels are feasible, functionally simple and most importantly quite achievable with existing technology. The market for LNG as a bunker fuel can be segmented depending on the various methods of delivering the fuel to the vessel. For example, LNG can be stored in storage vessels in bunker terminals which can be further supplied to ships through pipelines. LNG can also be transported to the anchored location by use of large-frame trucks. Another viable method is transferring the LNG fuel from one vessel to another at anchorages.
- **Improved and Strong Infrastructure:** Bunker supplying facilities Supporting LNG use are majorly located around the major shipping centers of the world including Singapore, Rotterdam, Fujairah and Houston. The Royal Academy of Engineers points out in its study that a number of major commercial ports on the world trade routes have LNG terminals in the vicinity which serve land-based consumers and these facilities might be adapted to additionally serve the marine community [4]. Various world regions has shown promising interest in strengthening the infrastructure for establishing LNG as a marine fuel as shown in Table 1.
- **Increasing World Interest:** The world has recently shown a great interest in promoting LNG as marine fuel due to the establishment of environmental regulatory bodies. Table 2 shows major contenders of operators in LNG fuelling market.
- **Commercial Feasibility:** LNG is now a mature and proven fuel option. Innovation studies are based around solutions that can develop the technological propulsion supporting LNG fuel. Kim yeon-tae [5] presented a feasibility study evaluating the economics of operating a 9,000 twenty-foot equivalent (TEU), dual-fuel, ocean-going containership with the initial cost of the gas system estimated at US\$18 million. The study concluded a payback time of 11 years if the vessel runs on 50% LNG and 50% HFO (heavy fuel oil), with LNG priced at US\$13 per million British thermal unit (mmbtu), and HFO priced at US\$600 per metric tonne (pmt) [5].
- **Supply and Demand:** The demand for LNG as a marine fuel is increasing day by day. According to Jorn Bakkelund [6] "The double-digit growth trend in supply and demand we have seen in the LNG shipping market since 2006 finally came to an end in 2012. Our estimates suggest that demand growth was 6 percent and the fleet grew by less than 4 percent. This resulted in a 3 percentage points rise in the utilisation rate, and a subsequent hike in the average spot rate for modern standard sized steamship to US\$125 000 per day." [6]. However, the uptake of LNG will be impacted by market conditions, global trade and bunker fuel prices.

## Challenges of Using LNG as Marine Fuel

LNG is a fantastic fueling opportunity for industries, shipping included, with lower combustive emissions, cheaper rate than other types of fossil fuels and a cleaner source of energy. However, there are some challenges regarding LNG:

- The additional capital required to convert conventional ships to LNG fuelled ships, may hamper the growth.
- The hazards and risks associated with LNG fuel are different when compared to conventional marine fuels.
- There is nonetheless a carbon footprint inherent in LNG production and consumption although it is hugely superior in terms of environmental sustainability than the current diesel-based system.
- The pitfalls of LNG use as an energy source were apparent when Nigeria LNG's export were blocked by the Nigerian Maritime Administration due to a disagreement over delayed payments, and resulted in a loss of more than US\$475 million in revenue by the company [4].
- Norway experienced unplanned stops in production, whilst Egypt, Indonesia and Oman are indulging in resource nationalism by putting domestic demand first and not producing up to capacity [4].
- Lack of a network able to fully support LNG powered vessels worldwide, can have a disproportionate impact, as with the newly commissioned Angola LNG [4].

TABLE I  
LIST OF INTEREST IN ESTABLISHMENT OF PROMISING WORLD REGIONS  
SHOWN FOR LNG AS MARINE FUEL.

<b>Europe</b>	Anticipated to be the major market for LNG Bunker fuel. As the ECA's (Emissions control area) are located in this region; hence ships operators are coerced to use clean fuel sources
<b>North America</b>	Expected to declare new ECA's which would further enhance the requirement of LNG as a bunker fuel. The cheap natural gas prices in this region are also a major motivating factor.
<b>Asia pacific &amp; Middle-East</b>	Major prospective region for the growth of LNG marine fuel market.

Source: Shipping Fresh maker [4]

TABLE II  
MAJOR PLAYERS OPERATING IN LNG FUELLING MARKET

<b>Port of Gothen-burg, Sweden</b>	Expected to have LNG fuel available for shipping by 2015 at the latest.
<b>EU Shipbuilding Sectors</b>	Fostering the uptake of LNG with 'Motorways of the Seas' project at Gothenburg which is expected to receive funding from the EU.
<b>Vopak, Netherlands</b>	Viable investors in LNG market
<b>Swede gas, Sweden</b>	According to Lars Gustafs son, president of Swede gas [4], LNG will be available at the largest ports in Europe and the Nordic region.
<b>Royal Dutch Shell</b>	Major Operating contender for establishment LNG as marine fuel
<b>GDF-Suez S.A.</b>	Viable investors in the LNG market.
<b>OW Bunker</b>	Viable investors.
<b>Gazprom Neft Marine Bunker</b>	Expected to play as a major operator.

Source: Shipping Fresh maker [4].

As the shipping industry regulatory landscape has become far more multifaceted than it was a few years ago, it seems that LNG may turn out to be the next best thing that the market has made available. There are also obvious kinks that need to be ironed out such as supply needs to be extensive, secure and

guaranteed; infrastructure must be fully developed; and efforts to switch should continue to be recognized by the industry, investors and regulators. However, the concept of LNG as a bunker fuel is still very new, with very few shipping companies actually adopting this as a marine fuel. The market for LNG as bunker fuel is anticipated to rise at a substantial pace in future.

#### *B. Methanol & Di-methyl ether (DME)*

Methanol is most commonly produced from natural gas but it can also be produced from a wide range of biomass. The growth of possibilities for methanol to be used as a maritime fuel has accelerated due to the rapid establishment of environment safety measures. The Baltic Sea is part of a designated Sulphur Emission Control Area (SECA) where the maximum allowable sulphur content in marine fuels will be reduced to 0.1% in 2015 [7]. To help meet these requirements, as well as for other environmental reasons, in 2012 several companies and governmental agencies partnered to form SPIRETH ("Alcohol (spirits) and ethers as marine fuel"), a full-scale pilot project for testing the application of methanol and DME as sulphur-free marine fuels. The project emphasized on the drivers of the fuel methanol market to emerge, broadening the base for methanol producers around the world [7]. Before the shipping industry can use methanol as fuel two preconditions must be fulfilled i.e. availability of the respective engine and development of rules for low flashpoint maritime fuels.

#### *Actions towards Engine Supporting Methanol as Fuel:*

The shipping industry has undergone several measures to ensure the availability of engines supporting methanol as a marine fuel which are discussed below

- MAN Diesel & Turbo [8] are developing a new ME-LGI dual fuel engine which enables the use of more sustainable fuel like Methanol, for Waterfront Shipping, owned by world's largest methanol producer, Methanex.
- The engines will run on 95% Methanol and 5% Diesel.
- Should Methanol-based marine fuels deliver the anticipated emissions and fuel cost reductions, it could usher in a bolster demand for methanol worldwide.
- Methanol and LPG carriers have already operated at sea for many years and many more LPG tankers are currently being built. With a viable, convenient and economic fuel already on-board, exploiting a fraction of the cargo to power a vessel makes sense with another important factor being the benefit to the environment.
- MAN Diesel & Turbo states the four G50ME-LGI units are targeted for delivery in the summer of 2015.

#### *Actions on Rules for Low Flashpoint Maritime Fuel*

Flashpoint is the lowest temperature at which a volatile liquid can vaporize to form an ignitable mixture in air. Methanol has a lower flashpoint (12°C) than conventional fuels (in range of 40°C) which can cause some unwanted hazardous situations [7]. So additional safety barriers are required to ensure a safe use of Methanol as a marine fuel. DNV (Det Norske Veritas) is the first body with new rules for low flashpoint maritime fuels. DNV's new notation, an industry first, covers every aspect of safe design considering a flashpoint of just 12°.

#### *Advantageous Features of Methanol as Marine Fuel*

Methanol possesses great possibility to be a permanent contender in the field of alternative marine fuels. Some positive features of methanol are:

- Methanol is a clean fuel.
  - Methanol does not contain sulphur.
  - Emissions of particulate and NOx from methanol are expected to be lower than those of conventional fuels.
  - Methanol is widely available and can be safely transported and distributed using existing infrastructure.
  - Currently methanol is much cheaper than marine distillate fuel based on energy content.
  - Methanol can be produced from both renewable and non-renewable feedstock, by recycling CO<sub>2</sub> from flue gases and recycling of atmospheric CO<sub>2</sub>.
- However, when "green" methanol becomes more available it will help ship operators meet GHG reduction targets.

#### *Challenges of Methanol as Marine Fuel*

There are some shortcomings of methanol which may challenge its use in the shipping industry as a fuel. They are:

- Methanol has a lower flashpoint than conventional fuel, so additional safety barriers are required.
- Methanol is toxic when it comes into contact with the skin or when inhaled or ingested.
- Its vapor is denser than air.

However, appropriate safety measures could help to avoid these challenges.

#### *C. Biofuel*

Biofuels for use in ships can help to cut emissions in marine transport such as biodiesel and crude vegetable oil. However, pyrolysis oil and other biofuels are also potential alternatives [9]. Biodiesel is a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant greases [10]. The significant features of biofuel are:

- Commercial marine use of biodiesels involves compression ignition engines, boilers and gas turbines.
- Biofuels can be blended with conventional fuels, but can also fully replace the use of conventional fuels.
- Biofuels are sulphur-free, thus the use of biofuels will remove the SO<sub>2</sub> problem from shipping.
- Also the emissions of particulate matter will be significantly reduced resulting in a reduced health risk.
- Only renewable CO<sub>2</sub> will be emitted during combustion. Even though there are some GHG emissions during production, the climate change gas reductions will be substantial when changing from fossil to biofuels [9].
- The emission saving potential depends on the type of biofuel, how it is produced and the amount used.

Some technological challenges exist when converting to biofuels from petroleum based fuels, such as:

- Use of biofuels can increase the risk of engine shut down, storage stability, bio-fouling (accumulation of microorganisms and algae) in the fuel tank and increased engine deposits. Those technical issues can be avoided by using biofuels which are first hydrogenated [11].
- The acidity of the fuel requires the need for acid resistant material and careful temperature control [9]. These modifications are not technically complex operations and biofuels can thus be used in most ship engines.

- Biofuels are more expensive than fossil fuels but using lower priced biofuels, such as pyrolysis-oils, the price gap could be significantly reduced.
- Using biofuels as marine fuel can have adverse effect on food price as the major portion of raw material of biofuel production comes from food industry.

Biofuels are not yet available on market as large a scale as would be needed for shipping industry. However, acceptance of biofuels in deep-sea transportation can only take place if these fuels can be produced in large volumes and at a competitive price around the world. As development on new biofuels technologies evolve, biofuels that does not affect food price at all such as biofuels produced from agricultural waste and residues from the forest industry will be available.

#### D. Marine Fuel Cells

A fuel cell converts the chemical energy of the fuel directly to electricity, through electrochemical reactions. The process requires supply of a suitable fuel such as LNG, biofuels or hydrogen and a suitable oxidizer such as air (oxygen) [12]. Fuel cell is becoming a viable alternative in marine industry for its following promising features:

- CO<sub>2</sub> emissions from fuel cells are significantly lower.
- There are no particulate or SO<sub>x</sub> emissions.
- NO<sub>x</sub> emissions from fuel cells are negligible.
- A strong contender for auxiliary power supplier.

However, significant barriers associated with commercial use of fuel cells onboard ships remain to be overcome:

- At present, fuel cells must be operated in fairly constant loads, accepting only very slow load changes, in order to avoid overheating.
- Installation and maintenance costs are relatively high. The initial investment cost is 2-3 times higher.
- Requires significant crew expertise.

As a result of these barriers and current size of installations, the first marine-related market for fuel cells is expected to be within auxiliary power. In the longer term, fuel cells might become a part of a hybrid powering solution for ships.

DNV has coordinated a Fellowship project in partnership with Eidesvik and Wärtsilä, supported by the Norwegian Research Council and Innovation Norway [12]. Figure 1 shows the first project to test large-scale marine fuel cells onboard a merchant vessel.

#### E. Solar Power Cells

Solar power is seen as a form of additional energy supply to a vessel due to the current efficiency of solar cells. But for the non-permanent availability of sun like at night, back-up power is needed. The important features of solar power with respect to ships requires sufficient available deck space. Therefore, most suitable for tankers, vehicle carriers and Ro-Ro vessels. If an entire deck is covered with solar cells it may be possible to meet the auxiliary energy demand. Between 0.2 and 3.75% power can be saved when 40 kW of the auxiliary engines are replaced by solar cells [11]. However, the current cost levels and the efficiency of solar cells make solar power score low on cost-effectiveness.



Fig. 1 Fuel Cell Equipment Being Installed On Eidesvik's Viking Lady, Source: Eide And Endresen [12]

#### F. Wind assisted propulsion

Wind assisted propulsion involves using rigid or soft sails, kites, or flettner rotors to convert energy from wind to thrust forces. Of these options, kites are currently the most advanced wind propulsion concept. The significant features of using wind power as an alternative energy source are:

- A number of different arrangements have been tested over the years, and presently four commercial ships have kites installed for testing [12].
- In order to optimize the effect, it will be necessary to adapt current designs, both technically and operationally.
- While using kites an average of 10-35% can be saved per ship. Surface area of kites determine the replaced power: a kite area of 160 m<sup>2</sup> equals 600 kW under standard conditions while 5,000 m<sup>2</sup> represents 19,200 kW [11].
- The minimum ship length to apply kites is 30 meters. Tankers and bulk carriers are most suitable for kites.
- Investment costs are applicable for purchasing the kite, and these depend on the kite area. Operational costs represent 5-15% of the purchase price [11].
- Wind power saves fuel and reduces GHG emissions.
- Fuel savings depend on the speed of ship and a higher speed results in lower reduction potential.

Wind energy has experienced a recent revival due to increased fuel prices and environmental concerns. However, the following challenges can occur:

- As the effectiveness of wind assisted propulsion is directly linked to the prevailing wind conditions (strength and direction) there is some uncertainty regarding efficiency.
- Wind assisted propulsion is relatively complicated to operate and adjust for changing wind conditions.
- It can pose problems with accessibility to ports due to the installation of wind assisted propulsion equipment, such as Flettner rotors and sails on masts.
- These installations can potentially come into conflict with bridges and cargo handling equipment.

However, new material technologies may enable installation of designs and ideas that might lead to wind assisted propulsion being introduced into new shipping segments.

### III. DRIVERS FOR ALTERNATIVE FUELS IN MARITIME INDUSTRY

Conventional marine fuel, also known as bunker fuel is the heavy distillate product obtained after vacuum distillation process in refineries. A large percentage of this fuel is diesel which is thick & heavy and contains sulphur and nitrogen compounds which negatively impact the environment. Hence the idea of alternative fuel is being more popular day by day.

The main drivers leading to the advent of alternative fuels in the future can be classified in three broad categories:

- Regulatory requirements and environmental concerns.
- Availability of fossil fuels, cost and energy security.
- Inconvenience of traditional Low sulfur bunker fuels.

A. Environmental Regulations and Concerns

The International Maritime Organization (IMO) has adopted a set of regulations for the prevention of air pollution by ships, outlined in Annex VI of the MARPOL Convention [1]. The main features of these regulations are:

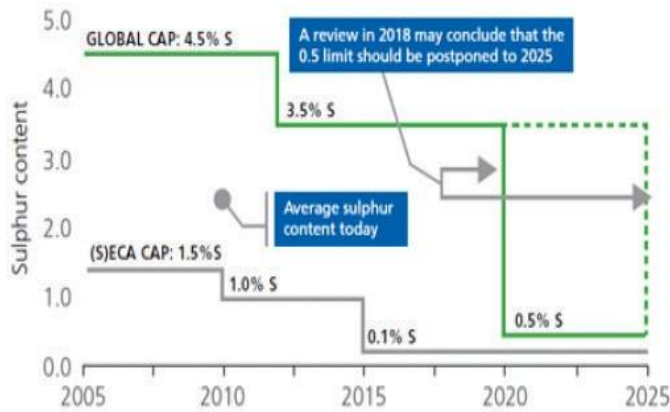


Fig. 2 MARPOL Annex VI Fuel Sulphur Content Limits, Source: Chryssakis, Balland, Tvete And Brandsaeter [1]; Adamchak And Adede [15].

- MARPOL Annex VI sets limits on the emissions of sulphur oxides (SOx) and nitrogen oxides (NOx) [13] from ships and contains provisions for setting up special SOx Emission Control Areas (ECAs), characterized by more stringent controls on as illustrated in Figure 2.
- The ECAs currently include the North Sea and the Baltic, and a zone extending 200 nautical miles from the coastline of North America, as shown in Figure 3.



Fig.3 Emissions Control Areas map, Source: Chryssakis, Balland, Tvete, Brandsaeter [1].

- Other parts of the world can be included in ECAs in the future. The most likely candidates today are the Bosphorus Straits/Sea of Marmara, Hong Kong and parts of the coastline of Guangdong, China.
- New and existing regulations derived from the International Convention for the Prevention of Pollution from Ships (MARPOL) affecting the SOx emissions from ships are summarized in Table 3.

TABLE.III  
MARPOL ANNEX VI MARINE SOx EMISSION REDUCTION AREAS WITH FUEL SULFUR LIMITS

Regions	Year	Fuel Sulfur (ppm)	Fuel Sulfur (%)
European SECAs			
North Sea, English Channel	Current Limits	10,000	1
	2015	1,000	0.1
Baltic Sea	Current Limits	10,000	1
	2015	1,000	0.1
North American ECAs			
United States, Canada	2012	10,000	1
	2015	1,000	0.1
Global	2012	35,000	3.5
	2020 <sup>a</sup>	5,000	0.5

Source: McGill, Remley and Winther [2].

- In addition to this, the EU will mandate 0.5% in EU waters from 2020, irrespective of potential IMO delay elsewhere, and it has already imposed a 0.1% requirement in ports and inland waterways.
- California also has special, stricter requirements in place.
- The Marine Environment Protection Committee has agreed on a three-tier structure, which would set progressively tighter NOx emission standards for new marine engines, depending on the date of their installation. Ships operating in the ECAs must meet the MARPOL Annex VI Marine Tier III NOx limits in 2016 [2]. Table 4 shows the applicable NOx limits for ships and the dates that they became or will become effective

TABLE IV  
MARPOL ANNEX VI NOx EMISSION LIMITS

Tier	Date	NOx Limit, g/kWh		
		n < 130	130 ≤ n < 2000	n ≥ 2000
Tier I	2000	17.0	45 n-0.2	9.8
Tier II	2011	14.4	44n-0.23	7.7
Tier III	2016	3.4	9 n-0.2	1.96

Source: McGill, Remley and Winther [2].

Ships operating in the ECAs have to use low sulphur fuel, or alternatively implement measures to reduce sulphur emissions, such as through the use of scrubbers.

B. Fuel Availability and Cost

Estimates of future oil production vary and are controversial. Due to high oil prices in the last few years the use of unconventional resources is gaining ground. It is not clear how much the global oil production could increase in the future. Precise information regarding the location and quantity of global oil reserves is difficult to obtain, because many oil producing nations often make public claims that cannot be easily verified [1]. In addition, the world largely depends on oil supplies from potentially politically unstable regions, which can have an adverse effect on fuel security. These are the major drivers for developing technology for exploitation of local unconventional resources, such as shale oil and gas in USA, and for

investing in the development of biofuels, such as ethanol in Brazil and in USA, and biodiesel in Europe [1].

### C. Inconvenience concerning Low Sulfur Bunker Fuel

Marine vessels running on conventional bunker fuels containing low sulfur, particularly marine distillate fuel, are likely to add to a surge in engine failures and/or electrical blackouts, according to a UK Protection & Indemnity Club study [14]. The study further noted an increase in propulsion-loss incidents, many of which it linked to vessels using marine distillate fuel. Besides the cost of low-sulphur fuel that is compliant with regulation is stated to be up to 30% higher than the price of standard bunker fuel.

## IV. CONCLUDING REMARKS

The increased awareness of human induced environmental crisis has created an interest in using cleaner renewable energy instead of fossil fuels. Marine transport is one of the sectors with the fewest available alternatives to fossil fuels. On a technical level, the introduction of alternative fuels will be accompanied by additional complexity, in the areas of fuel supply infrastructure, rules for safe use of fuels on board, and operation of new systems. It is expected that a number of different fuels may become important in different markets around the world. Introduction of any new alternative fuel will most likely take place first in regions where the fuel supply will be secure in the long-term. Due to uncertainty related to the development of appropriate infrastructure, the new energy carriers are more likely to be first utilized in smaller short sea vessels. As technologies mature and the infrastructure starts to develop, each new fuel can be used commercially in larger vessels, and eventually on ocean going ships.

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