Comparative Analysis of Combustion verses Hydrogen fueled Cargo Ships

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Abstract: The main objective of this paper is to present detailed analysis of hydrogen as fuel for shipping. The primary source of hydrogen considered for this purpose is methane reformers. The use of carbon sequestration technology and cost related effects will be discussed. Although water is the cleanest way to produce hydrogen, but the technology for compact, high volume hydrogen production by electrolysis is in the research stage and cannot be implemented for this purpose at this time. We will compare storage volume and total space required for a combustion engine and methane hydrogen reformer fuel cell electric propulsion system for cargo feeder ships.
Keywords: green ships, hydrogen, maritime, ship propulsion

1. INTRODUCTION

The question of hydrogen economy and pollution associated with combustion engines using fossil fuel and criteria pollutants have been investigated. Ships, specifically cargo ships and the volume of trade point to alarming findings regarding pollution contribution of criteria emissions by cargo and all ships small and big[1,2]

It is clear that a sustainable shipping economy is the solution for resolving these problems. Hydrogen is cited as the most abundant and clean energy if renewable sources are used for hydrogen generation from water using electrolysis. The question of hydrogen economy, design of hydrogen fuelled cargo ships and specially designed drive system, integrating low power hydrogen fuel cells for large drives are discussed in [3, 4]

This paper will consider a limited horse power cargo ship and compare the same ship equipped with hydrogen storage; hydrogen fuel cell and electric drive and associated electronics. The hydrogen ship design in this paper assumes mobile and stationary hydrogen fuelling stations are available along the shipping routes.

Hydrogen economy is developing in a rapid pace. Hydrogen vehicles are commercialized and soon will be available to consumers. The main problem remaining is to utilize this technology for ships that runs on pure hydrogen. The storage of hydrogen and safety has been investigated and a number of storage devices have been ISO certified. Volumetric data points to a larger volume ratio for hydrogen compare to liquefied hydrocarbons. Here we will consider a number of options available for ships.

2. HIGH-PRESSURE TANKS

The first possibility is to assume that hydrogen is available on shipping routes and the ship is equipped with sufficient storage capacity. Hydrogen tanks for 5,000 psi (35 MPa) and 10,000 psi (70 MPa)have been certified worldwide, however, driving ranges for compressed tanks remain inadequate and the energy consumed to compress the hydrogen reduces the efficiency of this storage media. The weight and size of the tanks are also an impediment commercial vehicle application, but can be used for cargo ships.

Liquefied Hydrogen**,** will improve density however, hydrogen loss is the concern and thermal jackets are required. Liquefying hydrogen requires extra energy. Hydrogen can be stored in metal hydride. This technology is based on the fact that hydrogen atoms can be stored in spaces between atoms of alloys under moderate pressure and temperature, creating hydrides. A metal hydride tank contains a granular metal, which adsorbs hydrogen and releases it with the application of heat. The heat may be supplied as excess heat from a fuel cell. Conventional high capacity metal hydrides require high temperatures (300°-350°C) to liberate hydrogen, but sufficient heat is not generally available in fuel cell for transportation applications.

Carbon Nano-tubes store hydrogen in microscopic pores on the tubes and within the tube structures. Similar to metal hydrides in their mechanism for storing and releasing hydrogen they hold the potential to store a significant volume of hydrogen. However, the amount of storage and the mechanism through which hydrogen is stored in these materials are not yet well-defined. [5]

3. HYDROGEN FUEL CELL

Hydrogen fuel cell is the heart of non- combustion hydrogen drive system. This technology has developed to implementation level. International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), [6] is dedicated to accelerating the development of hydrogen, and fuel cell technologies, the IPHE has established the following overarching priorities:

1. Accelerating the market penetration and early adoption of hydrogen and fuel cell technologies and its supporting infrastructure.
2. Adopting policy and regulatory actions to support widespread deployment.
3. Raising the profile with policy-makers and the public.
4. Monitoring hydrogen, fuel cell and complementary technology developments.

To illustrate the possibility of a hydrogen feeder ship, we will consider limited horse power cargo ships ranging from 6MW to 36MW. Fig.1 depicts the hydrogen storage volume at different pressures, required per hour for ships ranging from 6 to 36 MW. A typical Hydrogenic 100kW fuel cell will consume 1140 liters/minute or 68.4m^3/h at standard pressure and temperature. Thus for a six mega- watt propulsion drive it will require 60x68.4= 4104 m^3 of H_2 per hour equal to 363.19 Kg/hr.

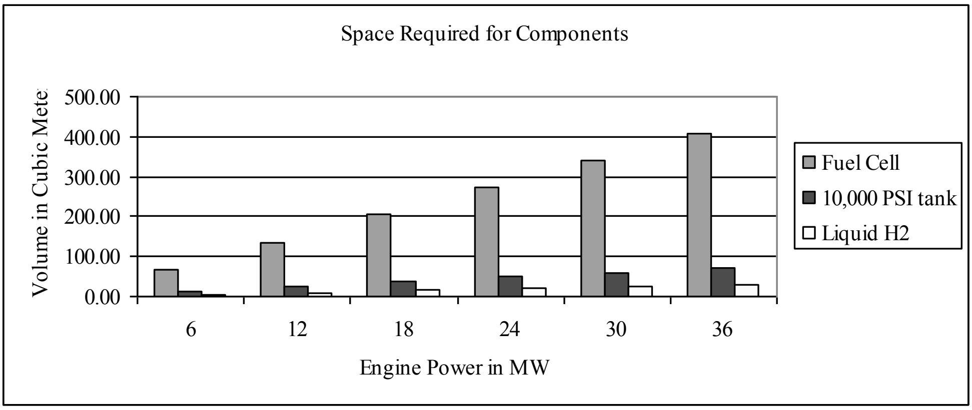

Figure 1.

The relationship between storage weight and fuel cell weight as function of engine power is depicted in Fig.2, We assume 100kW fuel cells each weighing 500Kg and that gravimetric ratio of liquid hydrogen storage, to storage vessel is 0.07

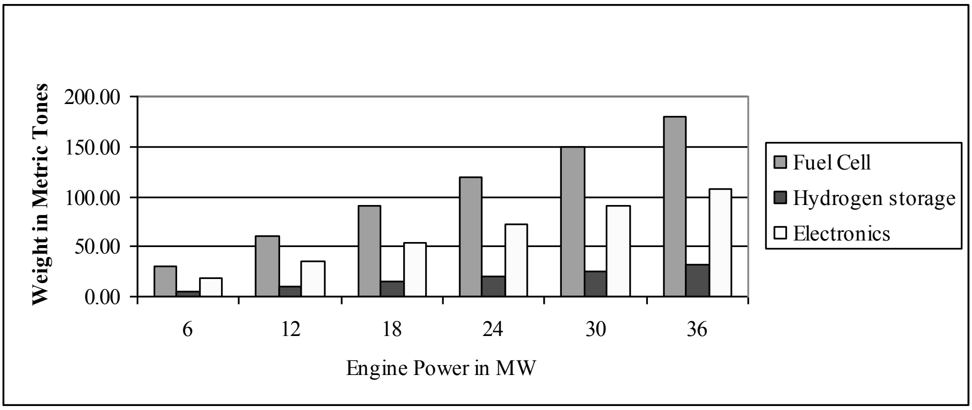

Figure 2. Power System Component Weight

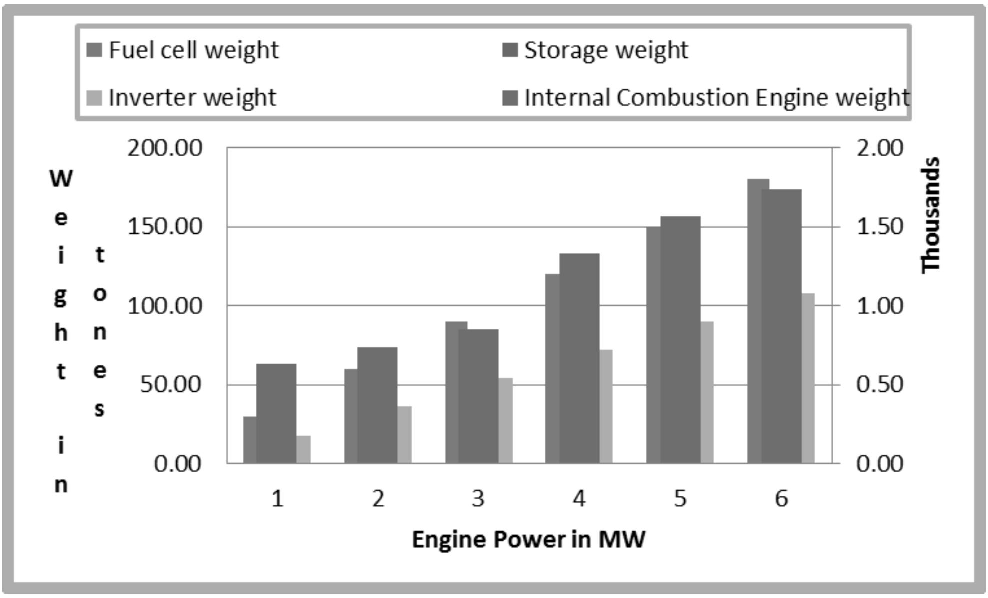

Figure 3. Hydrogen and Internal Combustion Engine Power System Component Weights

Figure 3 shows a comparison of the weight of hydrogen power components to that of similarly powered internal combustion engine. The engines weights displayed are for the Sultzer RTA line of two –stroke marine diesel engines at rated equivalent MW ratings. [7] Obviously engine weights will vary by manufacture and features but there are obvious and substantial differences in weights for the power system components.

To establish the relationship between space required and distance traveled, we assume an 18 MW ship traveling at 18 nautical miles per hour. Fig.4 shows the storage space required for hydrogen as a liquid and hydrogen in 10,000 psi tanks. For reference purposes we have calculated theoretical fuel consumption rates for HFO of a similarly powered motor vessel and plotted the corresponding fuel storage required.

The fuel consumption for the reference internal combustion engine was calculated based on specific fuel consumption (SFC) for an 18 MW slow speed large bore two stroke cycle engine. [8] The SFC was assumed to be 180g/kw h. It is important to note that the SFC figures will vary across the engine loading conditions. The storage of HFO (m3) for the 5000 nautical mile distance represents approx. 30% of the overall storage capacity for fuel oil on this vessel.

Fig. 3 shows that for large distances at this stage of hydrogen storage development, building ships to cover large distances is not practical.

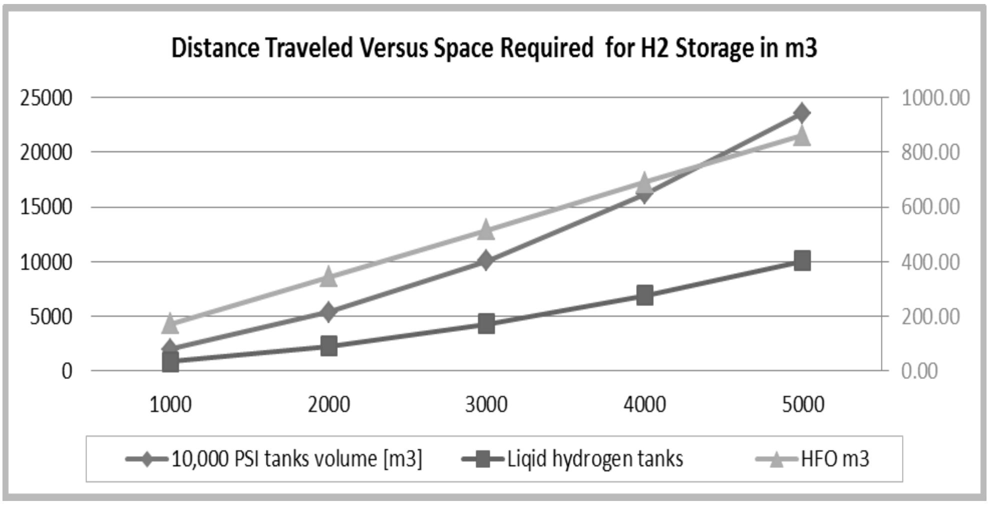

Figure 3.

4. USING METHANE STEAM REFORMERS

The storage of hydrogen requires space which is practical in liquid hydrogen form as evident from the above graph. But liquid hydrogen requires energy for cooling. To present what is required for onboard hydrogen production we look at two possibilities, MSR and electrolysis. Electrolysis requires an average of 4.5 KWh/Nm^3 of hydrogen produced. This will require specially designed ships that utilizes solar and wind on board. This requires some additional storage to guarantee sufficient supply of hydrogen for short distances and will be practical only for ships traveling along the sunny routes. Fig.4 shows required volume for onboard reformers and liquid natural gas.

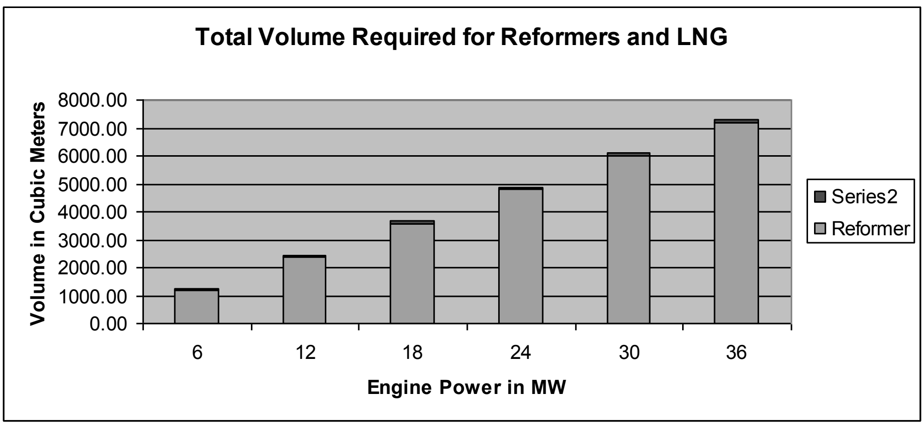

Figure 4.

In Fig. 5, we compare space required verses distance traveled for three different technologies, liquid hydrogen supply, natural gas onboard reformers with limited storage and electrolysis, for hydrogen supply on board of a feeder ship of 18 MW(24120 hp) assuming it travels at an average speed of 18 nautical miles per hour. The volume of electronics control system and the electric drive have not been taken into account. Also it is important to point that hydrogen fuel cells require air flow defined by the manufacturer.

Another important fact to mention is that electrolysis will require an average of 4.5 KWh/ Nm^3 of hydrogen production. This in turn will require solar panels which are addressed by the naval architects.

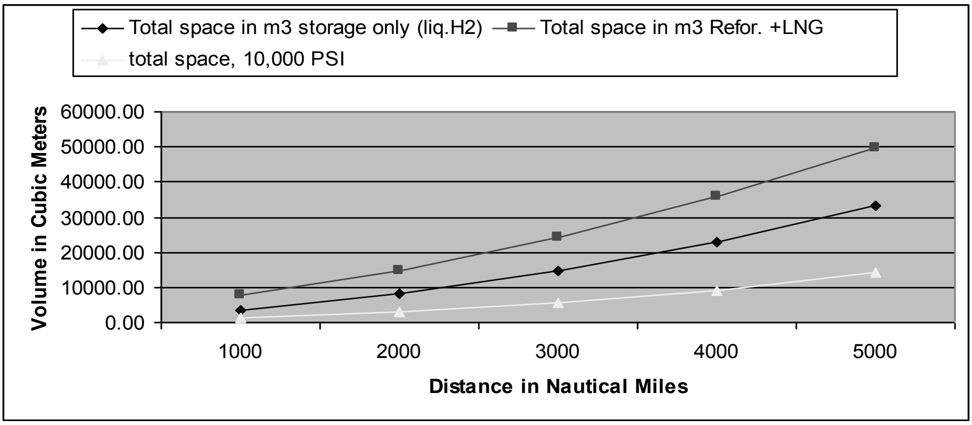

Fig.5

The emission of criteria pollutants from a ship, equipped with 12k90MC, Hitachi MAN B&W 1290mk, built in 1998 and rated at 54,840 Kw, operating at about 90% rated speed produces six grams of CO2 per kWh [7]. We have calculated CO2 emission as function of distance assuming the ship travels at 18 nautical miles per hour for our model feeder ship rated at 18 MW. Fig.6 shows emission for the same engine power using hydrogen produced by solar and other renewable and a methane reformers hydrogen ship.

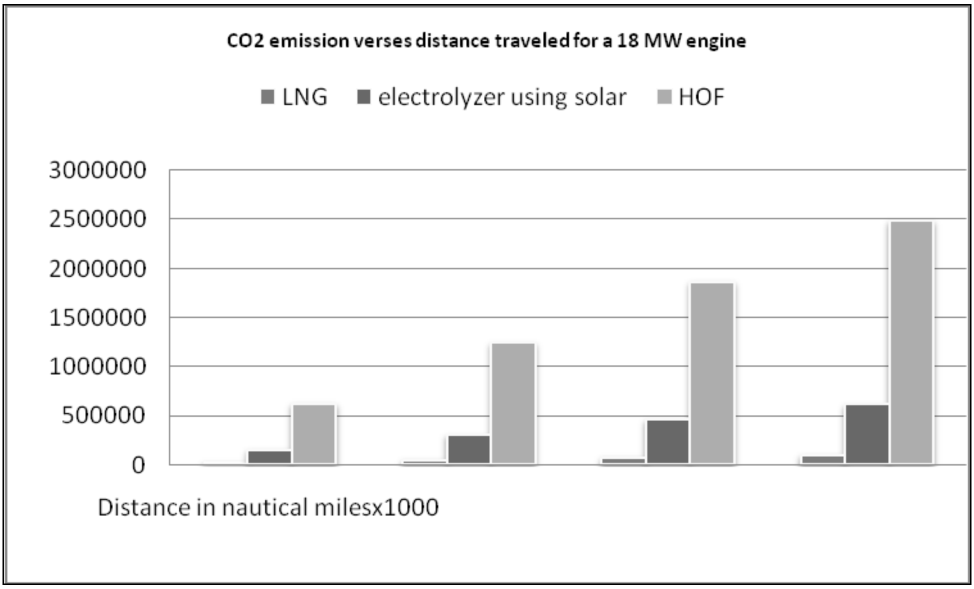

Figure 6.

5. THE HYDROGEN ECONOMY TODAY

The latest "Zemship", which stands for zero emission ship was launched into regular line service on the Alster River in Hamburg, Germany. Zemship use two, 48 kW maritime fuel cells and a lead-gel battery in a hybrid system for propulsion. The ship can transport 100 passengers while demonstrating nearly twice the efficiency of a standard diesel vessel.

The independently conducted studies show that hydrogen and fuel cell technologies are likely to be cost competitive with other alternative technologies and that countries should take a portfolio approach to addressing the world's energy, environmental, and economic issues.

The United States organization Fuel Cells 2000 published "The Business Case for Fuel Cells" in September 2010 which showcases successful use of fuel cells by 38 companies. Research Progress the rising levels of investment in developing transformative energy technologies, coupled with broad international cooperation and innovative research and development (R&D), has produced substantial advances in hydrogen and fuel cell technologies and in the production, storage, and transport infrastructure needed to support their growth. [8]

6. RECOMMENDATIONS

To initiate the building of hydrogen cargo ships, it is necessary to decide which path to follow. There are a number of choices and the possibilities are:

1. Use liquid Methane or Ethanol as source of high density hydrogen and reformers.
2. Use existing 10,000 psi cylinders each containing 175kg of hydrogen

3. Use Elecrolizers, compact batteries used in electric vehicles and solar panels to produce hydrogen with limited storage.
4. Design hybrid ship propulsion systems using a combination of above.

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