

# **Fuel Cell Methanol Reformer System for Submarines**

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# Fuel Cell Methanol Reformer System for Submarines

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## 1 Introduction

After the successful market introduction of Fuel Cell powered submarines, HDW is ahead of the market in the field of conventional submarines equipped with Air-Independent propulsion (AIP) systems. Today HDW offers different types of submarines including fuel cell systems like the classes U212A (Germany, Italy) or the class 214. All these submarines are based on fuel cell systems with metal hydride storage cylinders for the hydrogen.

In the recent decades conventional submarines were based on diesel-electric propulsion with lead batteries for submerged operation. Improvements to these systems have been gradually since WW II, small steps leading to improvements mainly in the field of signatures of the submarine. But still the snorkel operation to recharge the batteries is mandatory at least every few days.

In Comparison submarines equipped with Fuel Cells offer remarkable operational advantages. The AIP-equipped submarines can stay submerged during operation for a much longer time than before at similar performance regarding noise level. This is caused by the fact that fuel cells produce electrical energy without any moving parts, similar to a battery.

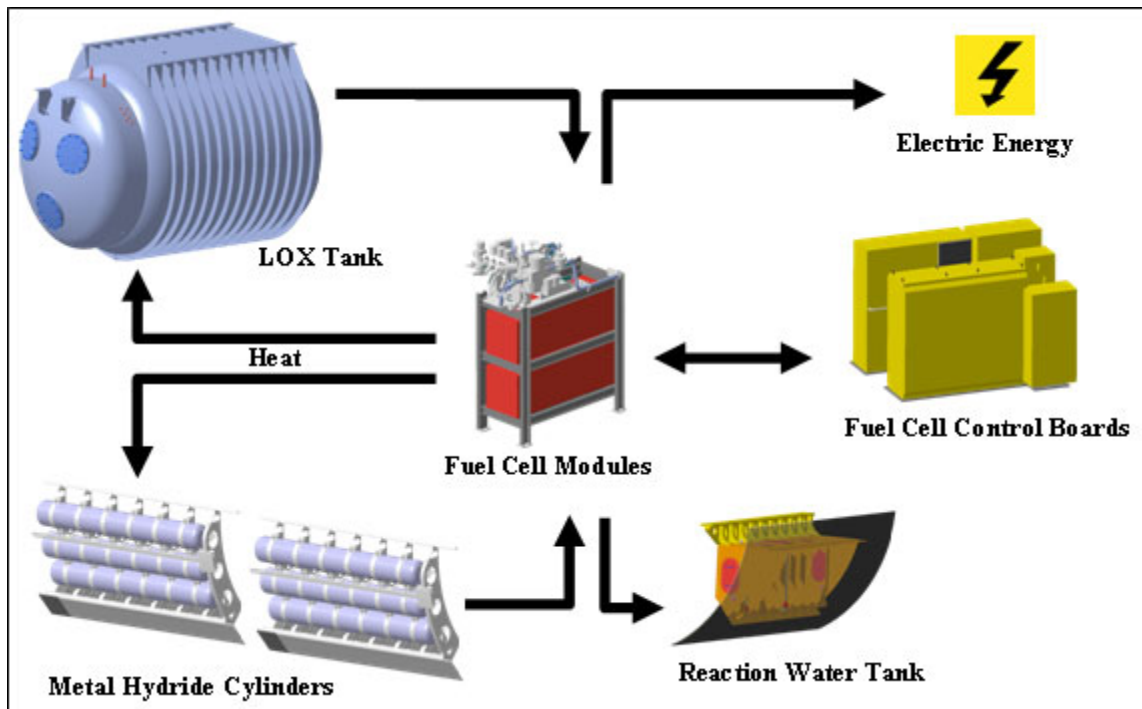
Generally the requirements of the AIP Systems in addition to the enlarged submerged operation period are as follows:

- high efficiency (low heat discharge to sea water)
- low noise level
- low magnetic signature
- small size
- low weight
- low effort for maintenance / no extra crew

Fuel cells have been under development by Howaldtswerke-Deutsche Werft for more than 20 years. In 1988 first sea tests were performed with a fuel cell plant in the submarine U1. Today four submarines of Class U212A are in service at the German Navy. Furthermore several export contracts could be realised, also with some submarines already in operation. Compared to other applications, fuel cells in submarines made its way because of the enormous customer benefit they offer. The development was based on a completely new approach, not on the replacement of any existing system [1].

## 2 Proven Technology

The system installed onboard the HDW submarines today consists of the components shown in Figure 1.



**Figure 1: Overview about Fuel Cell System components.**

The PEM fuel cells deliver the electrical energy for the boats power network system via a DC/DC-converter. The waste heat from the fuel cell is used to release the hydrogen from the metal hydride storage cylinders and to evaporate liquid oxygen for the operation of the  $H_2/O_2$  fuel cells. The reaction water is collected onboard to prevent the need for weight compensation with sea water. In case of Class 209 and 214, two Siemens FCM 120 Fuel Cells are used, with 240 kW maximum system power output [2].

In total the system has a very high electrical efficiency of up to 60 %, and offers many benefits regarding submarine specific requirements.

## 3 Reasons for Reforming onboard Submarines

Even if the existing fuel cell system offers many advantages, the tendency in submarine development goes to higher amounts of stored AIP-Energy. The system based on metal hydride storage is relatively heavy, resulting in the fact that the amount of hydrogen stored onboard is limited by the size of the submarine, having in mind the principle of Archimedes.

Generally liquid fuels have high volumetric and gravimetric energy content and are easy to handle. These advantages in combination with the fuel cells performance motivated HDW to start with the development of a reformer system for onboard hydrogen production [3].

#### 4 Choice of Feedstock

The choice of the best fuel for a reformer system for submarines has great influence not only on the system design, but also on the submarines design and performance. Generally the feedstock for a reformer system can be hydrocarbon or alcohol. Compared to the storage of pure hydrogen, this implies the production of  $\text{CO}_2$  onboard. As  $\text{CO}_2$  cannot be stored onboard like e.g. the product water of the fuel cell, it has to be discharged into the surrounding sea. To realize a weight balanced system (principle of Archimedes), the lost weight of the  $\text{CO}_2$  has to be compensated with sea water.

The reformer has to be operated with fuel + oxygen (+ water). The oxygen is stored onboard as a liquid in a cryogenic tank. This LOX-tank is the dominant component regarding system size. Consequently, the oxygen consumption of the AIP-System is very important and should be kept as low as possible. Considering the entire AIP-System, the chemical products are water ( $\text{H}_2\text{O}$ ) and carbon dioxide ( $\text{CO}_2$ ). Therefore, the ratio of H to C in the chemical structure should be high, because the oxidation of C requires more oxygen than the oxidation of H. Furthermore the overall system efficiency is of importance for the oxygen consumption, and of course for the fuel consumption.

Further factors are important for the choice of feedstock are the worldwide availability, the safety (handling etc.), the purity (avoidance of additional adsorbers etc.) and the reforming temperature to keep the reformer easy.

Summarized the requirements for the feedstock are:

- high hydrogen content in the chemical structure
- high efficiency of the reforming process
- worldwide availability
- easy storage onboard
- easy handling for e.g. refuelling
- easy reformation

HDW has considered three feedstocks for submarine reforming: Diesel ( $\text{C}_{13.57}\text{H}_{27.14}$ ) Ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ) and Methanol ( $\text{CH}_3\text{OH}$ ). The final choice was made for Methanol because of the following reasons<sup>4</sup>:

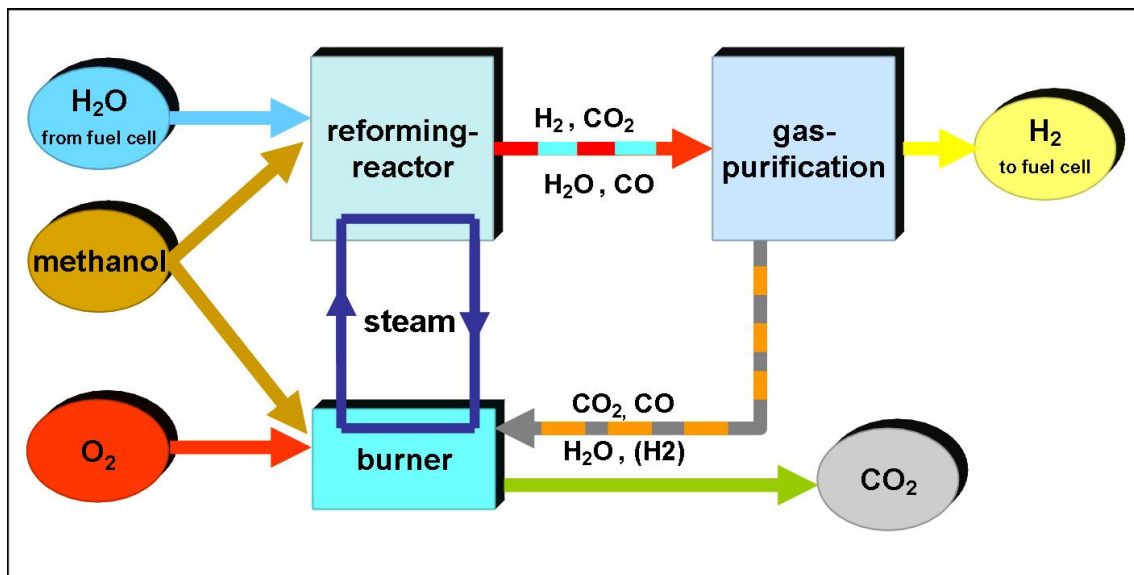
- H/C ratio is highest for Methanol
- highest efficiency of reforming process
- very easy reformation (T app. 250 °C; for Diesel > 850 °C, for Ethanol >700 °C required)
- worldwide availability
- high purity (no sulphur etc.)

#### 5 System Configuration

At the beginning of the development the requirements for the reformers have been defined. A major requirement was the operation based on the existing and proven Siemens Fuel Cells. Furthermore the exhaust gas ( $\text{CO}_2$ ) pressure should be high, to enable the discharge of exhaust gas into the surrounding seawater without the need for an additional exhaust gas

compressor. Of major importance was the overall system efficiency and the reliability and availability of the system.

Based on these requirements, the choice was a methanol steam reformer system operated at elevated pressure. The hydrogen purification is performed with a membrane purification unit. The required thermal energy is produced in a high-pressure oxygen burner. An overview about the process is shown in Figure 2.



**Figure 2: Overview of Methanol Reformer System.**

The methanol is mixed with water, evaporated and fed to the steam reformer. The reforming reactor is heated by a boiling water cycle. The methanol-water mixture is converted into a hydrogen-rich gas mixture at typical methanol reforming temperatures. This reformat gas is further processed in a gas purification unit. The major fraction of hydrogen is separated and can be fed directly to the Siemens Fuel Cell. The rest of the reformat gas is burned, to provide the required heat for the reforming process. The only product gas from the reformer is CO<sub>2</sub> at elevated pressure, the H<sub>2</sub>O in the exhaust gas is condensed and reused internally. The methanol reformer itself will be operated in an encapsulation comprising several safety features, to prevent the crew from any harmful gases and liquids.

## 6 Status of Development

The reformer development at HDW started many years ago under the assumption that the German Navy would choose reformer technology for their second batch of Class 212 Submarines. After the decision to stay with the metal hydride storage cylinders, the development of reformer systems for submarines has been performed with reduced resources. Today the efforts have been increased again, to have the chance to offer the system to potential costumers worldwide.

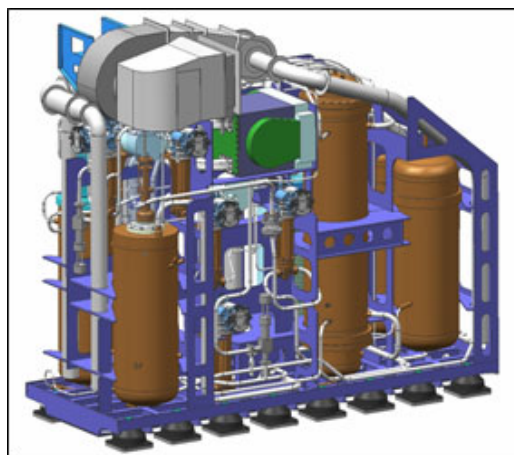
HDW operates a full size functional demonstrator in the test facilities in Kiel. The demonstrator has formerly been built up with COTS components – most of the components used cannot be applied onboard a submarine. Now single components and systems are

developed and installed to achieve a submarine-proven design, and to test them under real process conditions in the functional demonstrator.

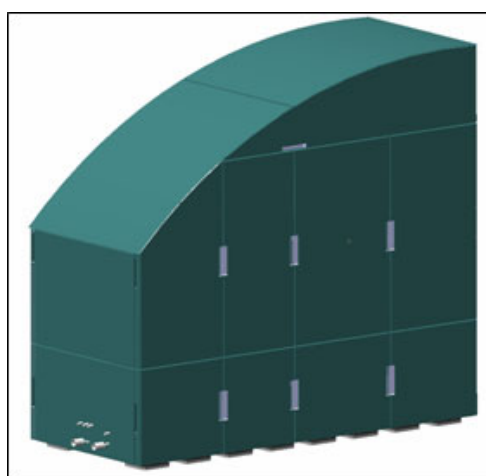
The major milestone in 2009 was the realisation and testing of a new gas purification. The purification unit has passed a shock test under operating conditions (temperature, and pressure difference) as part of military approval of the component. Furthermore the performance of the unit could be verified. The hydrogen is of a very high purity, the requirement of the Siemens Fuel Cell is fulfilled. In February 2010 the Reformer has been coupled with a submarine fuel cell with very good results – no difference in fuel cell performance could be detected compared to Hydrogen from the cryogenic storage tank at HDW.

The test runs with the reformer showed a very high efficiency of the system. The efficiency ( $H_{u\_H_2} / H_{u\_CH_3OH}$ ) was measured to be >90 %.

The system integration has been worked out, a picture of the unit is shown in Figure 3. Another picture including the encapsulation is shown in Figure 4.



**Figure 3: Methanol Reformer System**



**Figure 4: Encapsulation of MRS**

## 7 Outlook

The reformer system will be further developed to meet all demands for onboard operation. During a reconstruction period in this year the heat integration will be further improved, and the valves in the plant will be replaced.

The operation of Reformer with fuel cell will be extended to implement and test a new DC/DC-converter.

Further major steps in the development will be the operation of the reformer system together with an exhaust gas treatment unit, to discharge CO<sub>2</sub> directly into the surrounding seawater.

All these further steps will bring the Fuel Cell Methanol Reformer System closer to application. With this technology HDW offers a second option of Fuel Cell AIP solution, that will confirm the leadership of HDW in AIP-Systems for submarines.

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