Proceedings of the 2000 Hydrogen Program Review
NREL/CP-570-28890

# AN INVESTIGATION OF THE INTEGRATION OF HYDROGEN TECHNOLOGY INTO MARITIME APPLICATIONS

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## Abstract

The primary goal of the project was to identify the foundation and beginning steps of a systematically, vertically integrated, approach to the application of hydrogen technology, and precursor technologies, to the maritime transportation sector. The Maritime Hydrogen Technology Development Group (MHTDG), which is an industry working group of uniquely qualified industrial organizations, was formed to carry out the project analysis and future planning efforts. The MHTDG identified the vertically integrated system and the constituent technological and other infrastructure systems issues. The MHTDG members carried out technological and other analysis in their individual fields of expertise which was assembled into a final report. The primary objective in preparing this report was to provide a tool that will support taking the first steps towards developing a working relationship between two groups - those multidisciplinary workers in the new fuel and energy conversion technologies disciplines and those multidisciplinary workers that comprise the maritime transportation sector. A second objective was to provide a reasonable basis to support prudent management decision making by all the multidisciplinary groups with regard to the most appropriate actions that need to be taken next.


## 1. Project description

The use of hydrogen as the energy carrier in the maritime transportation sector is essentially unexplored as a system. Yet hydrogen, in combination with other enabling technologies, has the potential of offering significant emissions and energy consumption reductions in that transportation sector.

The major port and vessel systems impacted by the enabling technologies include hydrogen production, hydrogen storage, shipboard and on-shore; the prime propulsion system; auxiliary and emergency power, shipboard and on-shore; system controls and safety; as well as equipment installation; codes and standards; port operations; and public awareness, safety and protection. All of these aspects must be integrated in the processes of design, construction and operation  Public safety, acceptance, and benefit as well as the interests of port authorities, liability issues, and boat builders needs must all be addressed and unifying interfaces identified and put in place if a transition to lower emissions generating and more energy efficient technologies are to find practical application in the maritime transportation sector.

The primary goal of the project was to identify the foundation and beginning steps of a systematically, vertically integrated, approach to the application of hydrogen technology, and precursor technologies, to the maritime transportation sector. To bring focus and direction to this untapped market, DCH Technology formed the Maritime Hydrogen Technology Development Group (MHTDG), which is an industry working group of uniquely qualified industrial organizations. The companies comprising the MHTDG participated on a significant cost sharing basis

The project focused on identifying the critical technological and other related areas required to be addressed in order to begin the process of constructively and safely introducing hydrogen power to the maritime community.

Support of this project was provided by DOE's Office of Power Technologies under DOE Contract No. DE-FG01-99EE35102. The project specifically relates to the development of Maritime Applications within that Office's Hydrogen Program: System and Process Analysis and Information Dissemination.

## 2. Project objectives and rationale

The long term objective of the project is to reduce the energy consumption and emissions of the maritime transportation sector specifically through the use of hydrogen as an energy carrier and fuel cell and other related technologies as hydrogen energy conversion technologies.

This year’s objectives were to start the process of exploring the path to reducing the energy consumption and emissions produced by the maritime transportation sector through the use of hydrogen. The principal product resulting from this effort is this report.

The rationale comprising our approach to this first phase of the project consisted of the following:

1. Assemble a multidisciplinary team, the Maritime Hydrogen Technology Development Group - the MHTDG - possessing the required knowledge, experience and skills in the constituent technologies.
2. Identify the technologies that would comprise a vertically integrated system.
3. Using the knowledge and experience of the MHTDG members identify the state of the art and identify and develop a plan of approach to implementing the nogoical next steps that could lead to the eventual implementation of an integrated maritime hydrogen system.
4. Identify and start to develop funding support for the implementation of that plan.

## 4. Major work areas and progress

The major work areas comprising the project work plan consisted of the following:

#1 Establish the Maritime Hydrogen Technology Development Group (MHTDG).

Agreements were entered into between DCH Technology, Inc. and the following organizations in the technology areas indicated:

ABS Americas – Maritime regulatory requirements and related considerations
Art Anderson Associates – Marine engineering and architectural considerations, Vessel fuel cell conversion specification development
CryoFuel Systems, Inc. – Hydrogen infrastructure
Desert Research Institute – Fuel cell technology
Engineering Technical Associates – Environmental considerations and maritime fuel cell and alternative fuel state-of-the-art
Ergenics, Inc. - Hydride storage technology
Hydrogen Burner Technology, Inc. – Reformer technology
Rode & Associates, LLC – Risk planning
Longitude 122 West – Economic Analysis
Southwest Research Institute – Hydrogen piston engines
Teledyne Brown Engineering – Merchant Marine Academy Fuel Cell Laboratory Design Specification

#2 MHTDG Tasks Definition - Develop specific tasks for each aspect to be addressed by the MHTDG. Each task will be the responsibility of a Working Group within the MHTDG. Working Groups will be multi-disciplinary and each group will be chosen from participating companies. The Working Groups will be managed by DCH.

#3 MHTDG Interfacing - Develop clear interfaces between the Working Groups so each participant knows the requirements of the others. Interfaces and requirements of DoE, DoT, and DoD were included. The organizational structure of the MHTDG that resulted from this work is illustrated in figure 1.

#4 MHTDG Architecture Definition - The MHTDG will develop their technologies and methodologies implementation requirements in a scaleable format. This task will include a design review with DoE, DoT, and DoD participation TBD by the COTR. The results of this work are presented in section 4.0 of this report.

#5 Document the Project Findings – The Multidisciplinary Report

#6 Start the development of Phase II support

## 5. The Multidisciplinary Report

The objective sought in the multidisciplinary report is to provide adequately detailed information of support prudent management decision making with regard to supporting Phase II.

The design, construction, operation and maintenance of any vessel, whether pleasure craft or supertanker, requires both broad and detailed knowledge in a wide range of technological disciplines – it is a multidisciplinary challenge. The approaches to carrying out the broad range of multidisciplinary activities, which are not unique to the maritime transportation sector, have evolved over decades into a body of knowledge. This body of knowledge includes acquired skills, process approaches, management methods and so forth. Specifications and standards, both government and industrial, comprise a critical component of that knowledge base.

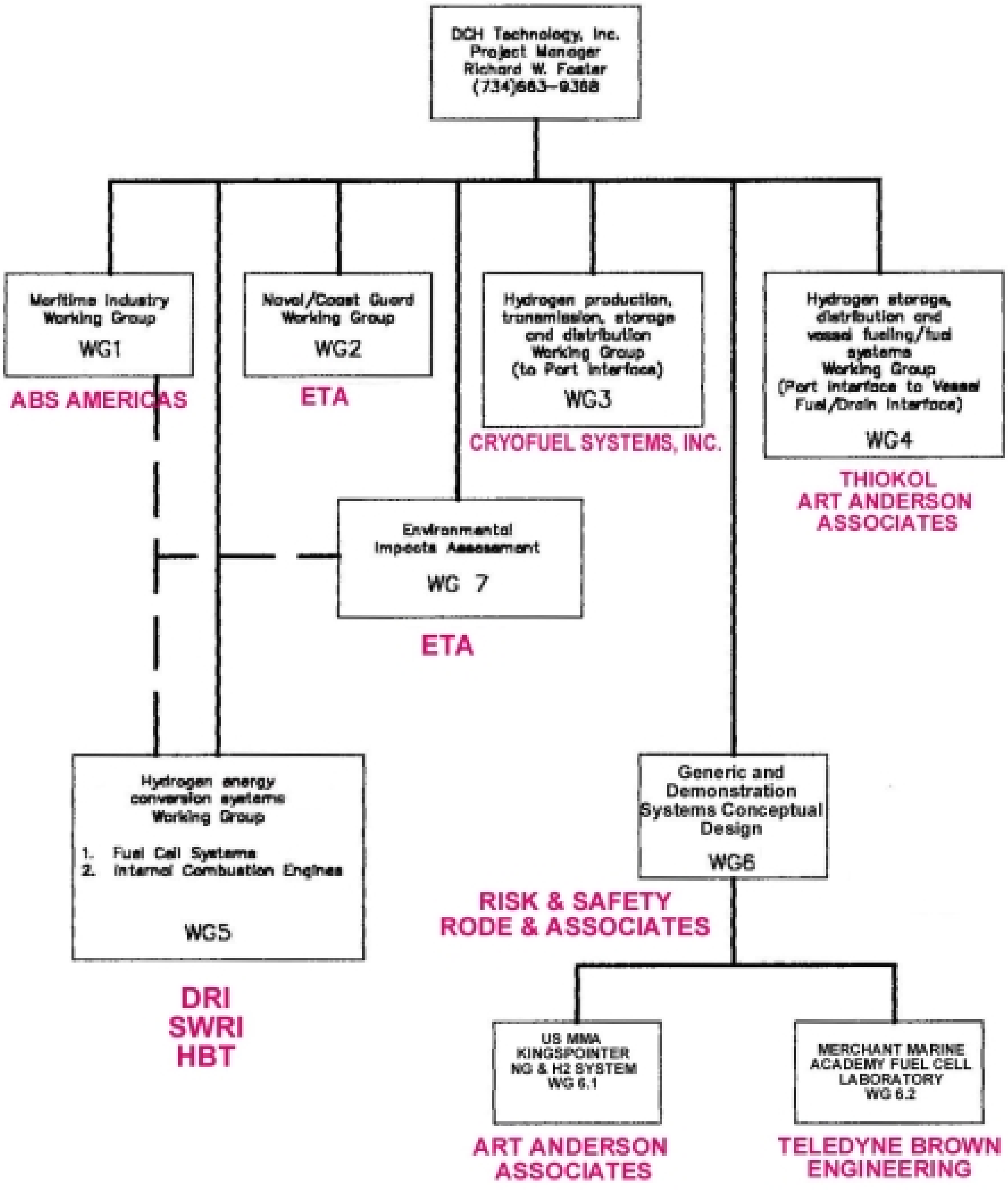


**Figure 1 The Project organization chart with MHTDG members interfaces**

The introduction of a very different set of fuels and propulsion technologies, the case here in terms of natural gas and hydrogen as fuels and fuel cell systems in the role of energy conversion systems for these new fuels, represents a radical departure from past practices. Major parts of that knowledge base discussed in the preceding paragraphs do not exist but must be brought into beings. Doing this presents a significant challenge.

This report brings together, in as detailed a form as practical, a body of information describing the new fuel and energy conversions technologies that must be mastered if these new technologies are to find practical implementation in the maritime transportation sector.

Our primary objective in preparing this report is to provide a tool that will support taking the first steps towards developing a working relationship between two groups - those multidisciplinary workers in the new fuel and energy conversion technologies disciplines and those multidisciplinary workers that comprise the maritime transportation sector.

A second objective is to provide a reasonable basis to support prudent management decision making by all the multidisciplinary groups with regard to the most appropriate actions that need to be taken next.

Our approach to the development of the report was to make it as generic in its treatment of the various subjects as practical. In order to do so we avoided considering design specific approaches or implementations, except by way of example, also to the extent practical.

### *5.1 Technologies treatment*

Figure 2 presents a flow chart that illustrates the fact that there are many alternatives in terms of the specific design approaches that may be taken to implementing low emissions, energy efficient marine main propulsion, auxiliary and emergency power systems. Discussion of these many design approaches was found to be impractical because of their number. Rather the MHTDG approached in terms of the major technologies that can provide the building blocks for specific design approaches.

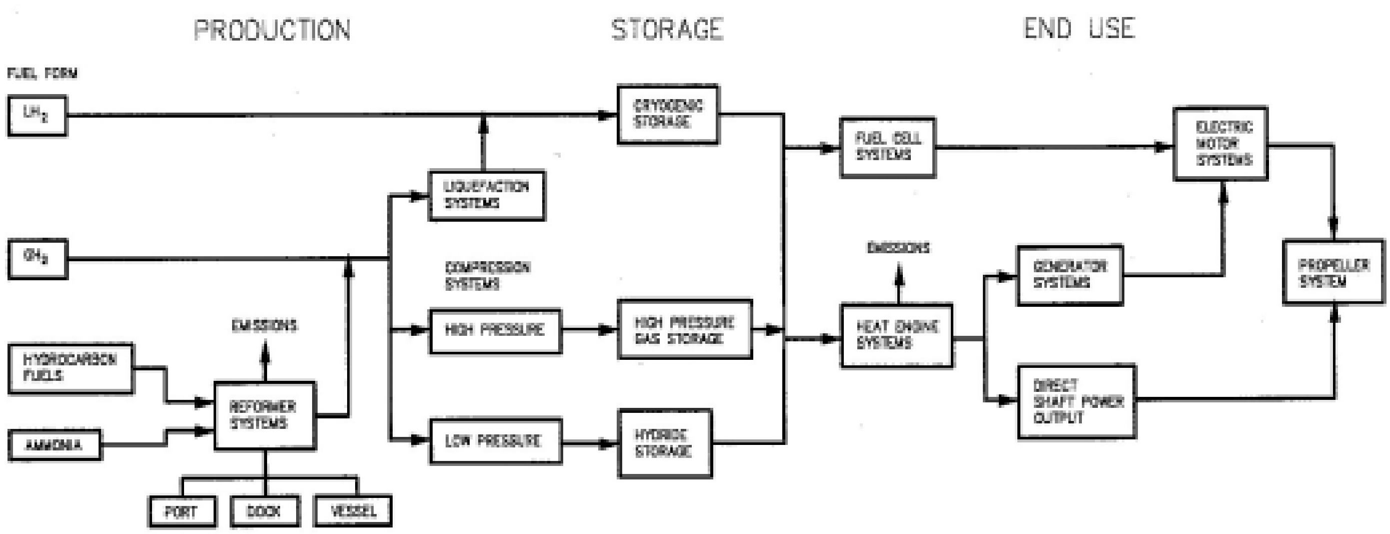


**Figure 2 Breakdown of the constituent technologies considered in the MHTD project**

### 5.2 The vessel types considered

One of the initial tasks undertaken by the MHTDG was the development of a listing of the vessel types and their ROM characteristics to be considered in the course of carrying out the project. The objective sought in doing this was to provide all MHTDG members with a common baseline set of vessels to be considered in the course of carrying out the tasks comprising the project work plan. The baseline list is presented in table 1.

## Table 1 Generic Vessel Characteristics

| TYPE OF SHIP | tons | l, ft | BHP | V, kts |
|---|---|---|---|---|
| Average tank model | 1 | 20 | -- | 4 |
| 6 m Sail boat | 4 | 23 | -- | 6 |
| Pleasure Craft | 5 | 30 | 150 | 15 |
| A Ferry | 30 | 55 | 300 | 14 |
| Small C.G. cutter | 200 | 85 | 500 | 14 |
| Average tug boat | 300 | 100 | 1000 | 10 |
| Coastal Motor Ship | 300 | 100 | 1000 | 10 |
| Average fishing boat | 300 | 100 | 600 | 10 |
| Coastal motorship | 750 | 155 | 400 | 11 |
| Tugboat | 800 | 200 | 2500 | 17 |
| Coast Guard cutter | 2000 | 300 | 5000 | 18 |
| Average destroyer | 3000 | 400 | 70000 | 36 |
| Average cargo ship | 9000 | 400 | 4000 | 14 |
| Old-type cruiser | 9000 | 650 | 80000 | 32 |
| Average tanker | 20000 | 500 | 5000 | 14 |
| Small cargo vessel | 20000 | 600 | 15000 | 20 |
| Modern tanker | 40000 | 600 | 20000 | 17 |

### 5.3 Multidisciiplinary report structure

The outline of the multidisciplinary report consists of the following:

Table of Contents

6. Systems and Technologies Assessments
  6.1 Port, dock and vessel fueling systems - AAA
  6.2 Hydrogen Fuel Storage and Reformers Technology
    6.2.1 Cryogenic storage tanks, design and manufacture - Thiokol
    6.2.2 Hydride Hydrogen Storage Systems – DCH/Ergenics
    6.2.3 Pressure Storage - Thiokol
    6.2.4 Reforming of alternative fuels for fuel cell systems - HBT
  6.3 Hydrogen Energy Conversion Technologies
    6.3.1 Fuel Cell Systems - DRI
    6.3.2 Turbines - DCH
    6.3.3 Piston Engines - SwRI
7. Vessel design and construction certification issues and Global and US Maritime industry requirements - ABS Americas
8. Risk Mitigation, Risk Management and Risk Management Planning Requirements - Rode & Associates, LLC
9. A General Level Overview of Financial/Cost Considerations – Latitude 122 West
10. The Development of New Technologies – an Overview
11. Conclusions and Recommendations
    Appendices
      Appendix 1 U.S. Merchant Marine Academy Fuel Cell Laboratory Requirements Specification
      Appendix 2 Fuel Cell Vessel Preliminary Design Requirements Specification
      Appendix 3 Vessel Fueling Infrastructure – Dock and Fuel Barge

## 6. Next steps

A major work product resulting from this effort was the joint development of a CRADA scope of work between MARAD and DCH Technology, Inc./MHTDG. The SOW embodies the summary conclusions of the MHTDG regarding the logical next steps to be carried out.

The tasks comprising this scope of work are listed below and represent the next steps that should be taken as determined by the findings of this project:

"Cooperative research and development activities between MARAD and the recipient may involve the following:

1. Determination of operational and logistic feasibility of utilizing alternative fuels, including hydrogen, aboard one or more specified marine vessels.
2. Determination of regulatory and safety feasibility of performing the above.
3. Determination of operational suitability of alternative fuel power plants such as fuel cells aboard one or more specified marine vessels, including regulatory and safety criteria.
4. Research and development of shipboard interface to above items, including power conditioning, control systems, sensing systems and ancillary systems.
5. Research and development of a marine fuel cell laboratory at the United States Merchant Marine Academy, including such items as hydrogen generation, hydrogen storage, fuel cell installation, safety systems, fuel cell controls, fuel cell power generation/conditioning, load controls, and transient load testing.
6. Design, installation and evaluation operation of actual shipboard alternative fuel and non-standard power plants.

7. Design, installation and operational testing of a hydrogen fuel cell powered vessel. The vessel may be provided by the Maritime Administration and may operate in the San Francisco Bay area.
8. Determination of other national and international partnership activities that could be formed in support of all the above."

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## 7. Summary of accomplishments - Future plans

In summary:

1. The MHTDG has been established.

2. The vertically integrated system has been defined.

3. The state-of-the-art of the constituent systems and subsystems technologies has been established and problems and issues identified. The findings resulting from this work are presented in this report.

4. The next logical steps have been identified.

5. To the extent permitted by available resources, the MHTD project participants will work to identify and develop a source of funding support for a cooperative approach to the tasks specified in the MARAD CRADA.

5. To the extent permitted by the supporting resources that might be developed, our next year's goal will be to initiate the activities defined in the MARAD CRADA. Our objective will be to move the state of the art of the constituent technological and supporting infrastructure systems forward from that first demonstrated by the U.S. Navy over 2 decades ago.

**Figure 3 USN gaseous hydrogen fueled turbine powered workboat – late 60’s**