The Role of Developing Electric Boats in This Era

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Abstract
The need for the reduction of CO_2 levels has been strongly advocated in recent years. The reason for this is mainly to slow the environmental problems related to the green house effect. The reduction of CO_2 also means reducing the consumption of our earth's natural resources represented by fossil fuels. One of the ways to reduce CO_2 levels is to shift ground transportation to the more efficient boat transport. A typical petroleum-based internal combustion engine has a very high accumulated-energy density, however, better fuel consumption/efficiency can be achieved by changing to an electric powered motor. This modal shift will reduce fuel consumption by 75%. The downside for this change is the very low accumulated-energy density and distance compared with petroleum-based fuels The upside is more efficiency, lowered pollution levels and a better, cleaner earth in a long run. Creative solutions to further improve fuel efficiency will be necessary for boat transportation in order to provide comprehensive performance superior to the internal combustion engine. The relationship between energy consumption and speed on boats are proportional to multipliers of 3-6. This means that energy consumption can be reduced effectively by lowering the boats' speed even slightly. However, the other important point is to reduce the boats' hull resistance, which requires the development of a highly efficient boat system. Based on such considerations, our research focused on the development of electric technologies for cruising boats on rivers and lakes. The electric-driven boat is to be 20m in length with a 20-ton displacement, a 100-passenger capacity, and in service for about 5 hours per day. The admirable characteristics of electric powered boats are the quiet operation and reduction of pollutants introduced to the water and air. Electric motors have been used primarily on small boats but the time has come for larger applications. This paper talks about (1) theoretic research in the relationship between the boat design and speed required for high efficiency cruising boats, (2) attributes of a 5m model boat and (3) a future development plan.

Keywords
electric boat, fuel cell, river cruise, CO_2 reduction

1. INTRODUCTION
Until now, researches on electric vehicles have been promoted with a main focus on automobiles and motorcycles. However, the superior characteristics inherent to electric motors, such as quiet operation and high efficiency, provide significant benefits not only for land transportation but also to marine boats. In addition to other involvements, the Asian Electric Vehicle Society should play an important role in improving the awareness of researchers and policy makers to promote a wider application of electric motors.

Unfortunately, the amount of carbon dioxide gas continues to rise even though it has been six years since the Kyoto Protocol (Treaty). Even in 2001, total emission increased by 5.2% compared to the base year. Countermeasures are imminently needed for the transportation/distribution category, which shows the most emission increase, causing over 20% of the entire emission problem.

A possible solution is to deploy a modal shift in transportation utilizing electric boats on rivers and lakes from the ground-oriented transfers of individuals and the long-haul trucking distribution system. It is necessary to suppress greenhouse gases and conserve energy as well as contain disturbances in the neighboring areas caused by noise and river pollutants.

In Japan, rivers were utilized in the past and were considered the most effective method of primary transportation but have faded without a second thought in light of the automobile-oriented distribution/transportation system of the 20th century. Unfortunately this era only pursued speed and time efficiency without considerations for energy conservation, problems associated with unbridled pollution and the world is now facing a turning point.

The efficiency of an electric boat can be expressed in terms of the CO_2 emission level at about 10g/km ton, which is about 10 times better than that of an internal combustion engine at 100g/km ton (assumption: automotive fuel consumption to be 20km/liter). Boat efficiency can be further improved by more than four times by switching the current diesel propulsion system to the more efficient electric propulsion system.

For these reasons, this paper suggests a modal shift of the ground-based transportation of passengers and trucking-based distribution to maritime shipping utilizing rivers and lakes by developing the world's first highly efficient electric boats. Technologies that will lead to a successful development of the electric-driven transportation will heighten the awareness of the public to conserve energy ultimately leading to the reduction of CO_2 levels. Technologies and knowledge accumulated through the development of electric boats for rivers and lakes can be utilized to develop ocean-use boats for adjacent coastlines. Such achievements will guide us to a greater opportunity to further the research of electric vehicles.

2. TECHNOLOGICAL CHALLENGES FOR THE DEVELOPMENT OF ELECTRIC BOATS

Today, there are large-scale boats equipped with hybrid propulsion systems consisting of an electric motor and generator that uses diesel as a fuel. However, there are no mid-class boats in Japan that fully utilize an electric propulsion system. Under such circumstances, we performed a study on mid-class electric boats. Japan is proud of its high technologies in optimizing designs of boats, propellers and motors for maritime use. The combination of these state-of-the-art technologies will lead to the realization of boats propelled entirely by electric. Minami [2003] proposed the development of the first 20-meter electric boat for river cruising in 2003. This paper discusses the specific objectives and research contents for the actual development of the electric boat.

Electric boats are highly efficient but their characteristically low energy density requires technological innovations in storage and supply. A wide variety of choices are available to overcome this challenge of energy storage and supply including the dramatic advancement of capacitors and lithium batteries in recent years. Furthermore, offshore wind power generation, which facilitates zero emission and sustainable energy supply, is now available to develop a comprehensive transportation system.

The goal of the technological development here is to realize the first fully electric, fully advantageous mid-size boat in the world. It is possible to drastically reduce the number of batteries on board and to radically extend the travel distance due to the significant advancements of fuel cells in recent years. This research aims to realize zero emission by switching the boat fuel engines to electric, thus ultimately and automatically suppressing disturbances in the surrounding areas with less water pollution, improved air quality and lower noise levels.

3. TECHNOLOGICAL DEVELOPMENTS

This developmental proposal to promote the modal shift of utilizing electric boats leads to the technological developments to reduce the amount of CO_2 as a synergy effect. In order to achieve this objective, the superior properties of the electric boats must appeal to the vehicle users and promote energy conservation, in addition to the hardware-related contribution reducing CO_2. Thus, the technological developments must be pursued simultaneously considering both industrial and social aspects.

3.1 Developments of industrial technology

The following are identified as elements of technological developments in the industrial aspect. Vehicles with electric motors are more efficient compared to those with internal combustion engines but their accumulated energy density is lower than petroleum-driven vehicles and requires special considerations for development. Boats, in general, increase energy consumption is proportional to the cubic of their speed due to limited propeller efficiency. It is important to consistently maintain efficient performance with vehicles utilizing electric powered motors. To improve the overall performance at lower speeds, unprecedented factors come into consideration for development.

(1) Application of Fluid Theory: Research on low-speed boat design and a proposal on low-speed boat engineering research.
(2) Designing an efficient hull and propeller
(3) Development of a highly efficient and reliable electric motor
(4) Boat electrical charging system
(5) Energy storage system: Lithium battery, capacitor, fuel cell, etc.
(6) Fuel cell

3.2 Specific technological developments and research contents

(1) Development of a boat with reduced resistance
(2) Development of highly efficient propellers (low-loss design for low-speed operation)
(3) Development of a propulsion system (development of a 10kW electric motor with an underwater cooling system (Maximum output 20 kW), designing of an electric controller)
(4) Development of an electric storage system (application of the newest lithium ion battery, designing a charge controller)
(5) Construction of 1/4 and 1/2-size models of the boat and implement a verification test (navigation test on a designated river)
(6) Development and design of a fuel cell generator (rat-

ing 10kW, for boats)
(7) Survey on power requirements for a designated river (survey on the navigation pattern and the charging system infrastructure)
(8) Exterior boat design (for tourism)

3.3 Sociotechnological developments

The bubble's implosion marked the start of a return to a slower-paced society. Interests in the rivers and boat cultures are gradually intensifying. Tokyo is said to have 808 towns, but Osaka on the other hand is said to have 808 bridges indicating a large number of rivers that criss-cross the city. Both the public and private sectors have started local economic promotion activities with themes related to rivers and boats. Through collaboration with municipalities and consultants, this project tries to promote a modal shift toward boat transportation by sociotechnological developments and establishment of an environment suitable for electric boats.

3.4 Specific sociotechnological developments and research contents

Establish social conditions necessary to develop and widely penetrate the use of electric boats.
(1) Survey and research to establish social conditions necessary to widely penetrate and heighten the approval of electric boats.
(2) Research laws, regulations, disciplinary rules and investigation on possible policy amendments
(3) Research and propose aids and subsidies necessary to adopt, manage and maintain an electric boat.
(4) Survey electric boat markets that are highly receptive and expandable, and research on expansion policies.
(5) Survey and research boat types, specifications and designs compatible to multiple markets.
(6) Research cost assessment and optimization

3.5 Related technological developments

Related technology for the electric-operated mobility category is the electric vehicle. Thus, development histories for land vehicles such as a motor, controller, charging system is long and a wealth of technologies is available to be utilized. However, electric boats operated on water require new developments and improvements including water resistance, anticorrosive properties and safety assurances since they are operated on such a highly conductive surface. In Japan, the Ministry of Land, Infrastructure and Transport is taking initiatives to establish aids, subsidies and regulations for the further development of LRT. This is a part of the activities to improve environmental issues in the transport/distribution category. The modal shift toward shipping utilizing electric boats is also an important sociotechnological development.

4. BUSINESS GOAL

Development, commercialization and penetration of application-specific electric boats will be attempted. An experimental boat (capacity of about 100 passengers) will be placed in service on the Yodo River in Osaka in 2007 for the purpose of a feasibility study for mass production and commercial penetration.

First Phase (3 years)
First Year
- Survey to determine the specifications of the boat
- Survey, design and production of the model ship and related technologies
- Survey the social system for penetration

Second Year
- Survey, design and prototype of infrastructures
- Construct the experimental boats (10m size), implement the experiment and analyze results
- Design social system to promote penetration
- Improve awareness and educate ship owners and personnel involved

Third Year
- Manufacture the commercial experiment boat (capacity of about 100 passengers)
- Technological development necessary for manufacturing of the commercial experiment boat (capacity of about 100 passengers)
- Design and architect an infrastructure
- Implement a feasibility study and analysis
- Propose policies and enactment for the modal shift to river routes
- Investigate multi-purpose applications for the model boat

5. PROJECT

5.1 Project overview

(1) With a theme of electric boat development, integrate superior technologies of the companies that rarely were involved in the transportation/environment category and expand the involvement of the companies that own environmental improvement technologies.
(2) Establish a social environment to penetrate the developed electric boats with the improvement/elimination of laws/regulations and cooperation from experts in the aid/subsidy field.
(3) By developing a basic boat type, develop a boat compliant for each application to promote the modal shift.
(4) Design a low-speed boat, improve an efficiency of a submergible electric motor and electric controller, and develop fuel cell mounting technology

(5) Clearly demonstrate the possible deployment into transport/distribution means in the Tokyo metropolitan area as well as other areas with rivers through an actual navigation test with the technologies.
(6) Provide a message that the use of the electric boats will contribute in the improvement of the water/air pollution issues associated with vehicle traffic.

5.2 Urgent necessity of this project

There is no absolute cure for global warming in the aspect of the transport and distribution policies. This is why the promotion of the modal shift, which is the most effective policy, is now necessary. Ever since the enforcement and installation of the speed limiters restricting truck speeds, a shift of cargo from vehicles to the railway systems has began. However, looking at the current CO_2 emission levels, a prompt shift to a more energy-efficient boat transport system on rivers/coastal lines is desirable. However, currently all the water-buses used on the Sumida River and Yodo River, cruising boats on Lake Ashino, over 100 cargo boats on the Ara River, ships transferring goods along the coastal lines and leisure/fishing boats discharge airborne microorganisms and nitrogen dioxide. In addition, water pumped as an engine coolant, fuel and engine lubricating oil leaks are causing water pollution of the rivers, lakes and swamps. The electric boats under development for this project is expected to improve energy efficiency by 4 times compared to diesel engine boats and suppress global warming dramatically at its penetration stage. Furthermore, the electric boats require no fuel or pumping of water for cooling and generate no exhaust gases, eliminating all the current pollution sources. Development of the electric boats is needed immediately not only to reduce emissions causing global warming, but also to conserve the comprehensive ecosystems of rivers, lakes and swamps as well as an energy-saving aspect.

In urban areas, environmental improvements and a relaxing atmosphere are necessary, where individuals can reacquaint themselves with the water. Osaka City where this project will be carried out was once called the "city of water." However, in recent years, due to the advanced development of ground transportation, water transportation has declined dramatically. As a result, rivers have lost their role as efficient transportation channels. To effectively utilize the rivers while conserving the environment ultimately leads to the public's awareness of rivers as comforting/relaxing places. A new approach to realize such an environment is in desperate need. To start with, based on the development of new technologies, commercialization of the electric cruising boat that is nonpolluting, environmentally friendly and effective in reducing CO_2 levels can show its superiority as an innovative form of water transportation. This will remind the public of the importance of water channels, bring water closer to their lives, and ultimately be effective in promoting the advantages of reduced ground transportation with less CO_2 in the air. Such activities can also lead to city rejuvenation. This action needs to take place quickly because a disastrous future is imminent without the immediate reduction of the CO_2 level. Many people believe that it is necessary to be involved with water and recreate old water-related scenes from the past. What is important is how to recreate such sceneries. Electric boats generate hardly any noise enabling urban residents to enjoy a quiet living by the water as well as tourists enjoying the peaceful scenes of the lakes and rivers.

Modal shift requires incentives but existing waterbuses generate engine noises that disturb tranquil sightseeing excursions on the water. The rivers are narrow and the existing waterbuses also disturb the peacefulness of the neighboring buildings and parks. Electric boat transportation on rivers rather than automobile usage is encouraged because of its highly ecological nature.

Prompt development of electric boats is in need by combining all the currently available resources and technologies in order not only to reduce CO_2 gases creating global warming but also to conserve the ecosystems of lakes and rivers as well as to conserve energy. This project proposes the development of electric boats to be aligned with that objective. Electric boats are far more efficient compared to diesel powered boats and contribute to a dramatic reduction of CO_2. In the past, various hybrid boats using an electric motor powered by a diesel generator were built including an icebreaker; however, there are no commercial mid-size boats that operate using just batteries or fuel cells with an improved efficiency. Most of the conventional electric boats have only been small in size (several meters in length). Thus, this project proposes to solve such issues and develop new technologies that realize realistic advantages by reducing CO_2. The characteristics of this project are outlined below.

(1) By improving the efficiency of vehicle electrification, CO_2 levels can be reduced. The energy consumption is reduced by the boat shape, improved efficiency of the propellers and reduced-speed. An electric cruising boat will be built as a prototype that will run 5 hours per day to prove its operability compared to conventional diesel powered boats. By demonstrating the successful results, the technologies can be applied to a variety of boats used along the coast and a major contribution to the reduction of CO_2 can be expected.
(2) This research will focus on a cruising boat accommodating 80-100 passengers. The unique approach of this project is to demonstrate the feasibility of

running the cruising boat that is highly efficient, quiet (necessary in the urban environment), fuel efficient and non-polluting for both the air and water while overcoming the technological challenges.

6. REDUCTION OF CO_2 BY A MODAL SHIFT TO BOATS

6.1 Reducing CO_2 levels

A heavy fuel oil driven boat with a drainage volume of over 100 tons generates about 10g/km/ton of CO_2 per ton. On the other hand, CO_2 generated by an automobile is about 100g/km/ton.

In addition, compared to an internal combustion engine, an electric motor is 4 times more efficient and emits no CO_2. Additionally, utilizing natural energy such as wind power and biomass completes a sustainable energy supply and mobility system. Use of fuel cells improves CO_2 reduction by 4 times compared to the internal combustion engine.

(1) 100 cruising boats run under 22 knots nationwide. They are operated on diesel fuel. If 100 electric cruising boats are put into service for 10 hours per day at 20 knots per hour instead of the current diesel boats, 12,000 tons of CO_2 can be eliminated annually.

(2) There are 560,000 small boats (less than 5 tons) using petroleum fuel nationwide. Shifting 300,000 small boats that are used along the coastlines of the 560,000 boats to electric reduces 2.7 million tons of CO2 assuming that the boats run 30 km per day.

(3) Shifting 100,000 automobiles that drive 50km per day to electric boats that are quiet, more efficient and free from exhaust will provide a reduction of 350,000 tons of CO_2 annually.

(4) As applications of energy-saving electric boats penetrate into the market, the public awareness for the modal shift will heighten. And such public awareness and a variety of energy-saving activities will result in a multiplier effect further revolutionizing the public perception toward energy conservation. If 1.0% reduction of currently generated CO_2 is achieved, 13 million tons of CO_2 can be eliminated.

6.2 Initial cost

This is the calculation to derive the cost to change an engine to an electric motor. If driven at 10km/h with higher efficiency, a 20-ton boat can be driven with a 20kW (about 30 horsepower) electric motor. The production costs for the electric motor is equivalent to that of the fuel engine. Once mass production becomes feasible in the future, the cost can be easily reduced to 1/5 of the fuel engine production costs. Another benefit is that electric motors are durable with 50 years of life unlike fuel engines. 5,000 USD/KW is necessary as battery cost. Fuel cells cost about 8,000 USD/KW currently but as the automobile market develops, the cost is expected to drop to 50 USD/KW in about 10 years. The initial cost for electrification doubles for the entire boat. However, cost reduction will be achieved in the long term.

6.3 Running cost

(1) 100 cruising boats cost 500,000 USD in heavy fuel oil annually. Using 20kW electric motors (on average) on 100 boats will cost 300,000USD for 5 hours of service per day. (1KWH=0.1 USD)

(2) Many small-size boats are powered by gasoline. If one liter of gasoline cost 0.5USD with the tax exemption, total cost will be 10 million USD. With electrification, assuming that an electric motor consumes 1kW on average and runs 10km at the speed of 10km/h, the cost will only be 300,000USD. Electrification leads to the effective reduction of fuel costs and CO_2 levels.

(3) 2 billion yen is required for the modal shift of 100,000 automobiles with 10km driving mileage and 0.7USD/liter for fuel price. If 10 automobiles can make a modal shift to a 20-ton electric boat with the capacity for 100 passengers or 10-ton of cargo, it will cost only 700,000USD at the speed of 10km/h for the 20kW motor.

As noted, electrification reduces running costs. If a gasoline-driven automobile drives 100 km, it consumes about 10 liters of fuel costing about 10USD. An electric automobile only consumes 10kWH on average costing 1USD, which is 1/10 of the cost for a gasoline-driven automobile. In the aspect of both energy consumption and cost, electric boats are a superior means of transportation.

7. OBJECTIVES

(1) An electric boat scheduled for a commercial experiment in Osaka for 2006 is expected to be commercialized for service on the old Yodo River after concluding a feasibility test.

(2) In the scope of shifting the internal combustion engine boats used as waterbuses nationwide to electric, establish laws, regulations, finances and a suitable system along with technological developments. Furthermore, create an environment that makes it easy for boat-related business owners to adopt electric boats.

(3) The motor and controller developed for the project boat will demonstrate as a unit of capacity that is interchangeable and equivalent with an internal combustion engine in an automobile.

(4) The power charging/distribution system for boats

has unique land-based infrastructures. The device is also an indispensable key for the use of off shore power generation utilizing the wind.

(5) This project plans to develop a fuel cell system, of which specifications can be modified based on the onboard power volume as a hybrid system with lithium batteries or capacitor. Thus, this system is expected to have a wide range of applications as a multi-purpose power source.

(6) Each unit (engine/control system, power storage system, land-based power charge/distribution system) will be developed as a basic model for a variety of electric boats, which can be modified for a wide range of applications by simply changing specifications for specific purposes.

Example: Small-size special boat: 104000, Fishing boat: 4000, Pleasure motor boat: 290000, Cruising boat: 20800, Other

Figure 1 shows the conceptual image of the completed 20m electric river cruising boat.

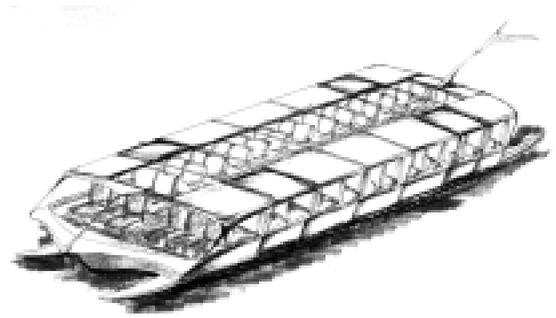

Fig. 1 A conceptual image of a 20m electric river cruising boat

9. CONCLUSION

This paper stated that the development of an electric boat would provide solutions to part of the current issues such as CO_2 reduction, energy conservation and comfortable transportation, and introduced the development project. It also investigated feasibility to promote the modal shift to electric boats with data based on the proven performances and achievements. In the process, construction of a 20m river cruising boat was proposed and the technological developments from both engineering and social aspects were discussed.

References

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